ORIGINAL ARTICLE

Evaluation of the Cross-Sectional Area of the Median Nerve by Ultrasonography in Patients With Carpal Tunnel Syndrome

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Abstract- The use of ultrasonography (US) as a non-invasive method to evaluate and diagnose musculoskeletal disorders has increased in recent years. This cross-sectional study assessed the cross-sectional area (CSA) of the median nerve using US in patients with carpal tunnel syndrome (CTS). Clinical and demographic data of patients were recorded. Nerve conduction studies (NCS), US, and needle electromyography (EMG) were performed. In addition, US evaluated the flattening ratio (FR) and CSA of the median nerve. This study assessed 600 wrists of 300 patients with CTS referred to Golestan Hospital (Ahvaz, Iran) for nine months. There were 102 males and 198 females, with a mean age of 46.83±9.50 years. Many patients were aged 40-59 years old. Furthermore, 240 patients had bilateral CTS. The hands affected by CTS were categorized into three groups based on the severity of CTS: mild (298 hands, 49.7%), moderate (164 hands, 27.3%), and severe (138 hands, 23%). Substantial differences were detected in the average age, CSA of the median nerve, body mass index (BMI), ring-finger method (RF), FR, and outcomes in Tinel's sign and Phalen's test based on the severity of CTS (P<0.05). The increase in CSA of the median nerve was related to the severity of CTS. In addition, the US could effectively evaluate the severity of CTS. Utilizing US to measure the CSA of the median nerve was beneficial for identifying and assessing the severity of CTS. However, it should not be regarded as a substitute for NCS. Integrating NCS, US, and needle EMG can enhance diagnostic accuracy and provide more comprehensive insights into severity and underlying causes of CTS. These findings may help healthcare professionals prioritize and improve the quality of diagnosis, treatment, and care for patients with CTS.

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Keywords: Ultrasonography; Carpal tunnel syndrome; Electrodiagnostic; Median nerve; Nerve conduction study

Introduction

Carpal tunnel syndrome (CTS) is a prevalent entrapment neuropathy characterized by numbness, pain, and tingling sensations in the fingers of the affected individual (1,2). This condition occurs when the median nerve becomes compressed or constricted as it passes through the wrist (1). Factors that increase the likelihood of developing CTS include obesity, repetitive wrist movements, genetic predisposition, pregnancy, and inflammation associated with rheumatoid arthritis (3). Individuals with CTS often experience symptoms that worsen at night and with repetitive tasks, possibly leading to persistent discomfort (4). CTS is often associated with careers that involve prolonged computer usage or repetitive movements (4). Diagnosis typically involves a clinical evaluation and electromyographic results, along with sonographic signs such as swelling of the median nerve, reduced echogenicity, and vascular alterations (5). The treatment options range from non-invasive approaches, such as ergonomic adjustments and splinting, to surgical interventions when conservative approaches fail or in cases of severe CTS (1). The diagnosis of CTS traditionally relied on needle electromyography (EMG) and nerve conduction studies (NCS) (6). However, recent studies have highlighted the effectiveness of ultrasound

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sonography (US) and magnetic resonance imaging (MRI) as complementary diagnostic tools (7,8).

NCS is commonly used to diagnose CTS and it is considered the standard method with a sensitivity of 85% and specificity of 95% (9). However, it is invasive, intricate, and costly, leading to higher expenses and longer diagnosis times (10). In contrast, the US is a non-invasive and rapid diagnostic tool that is becoming more widely available to healthcare professionals (11-14). It was indicated that the US has an overall diagnostic accuracy of 86.8% (15). Furthermore, the US offers superior visualization of anatomical structures and nerve configurations, thereby enhancing patient comfort during the diagnostic process (16). The US may provide a beneficial alternative to NCS for diagnosing CTS, presenting advantages in terms of convenience and accessibility (17).

Needle EMG serves a significant role in the diagnosis and management of CTS (6). While it is not essential for establishing a CTS diagnosis, it can provide valuable insights, particularly in cases where NCS yields ambiguous results (6). In cases of early and mild CTS, conventional NCS may appear normal, but needle EMG can reveal subclinical motor involvement, highlighting its diagnostic value (18). In addition, Needle EMG can detect axonal loss, which aids in determining treatment strategies, including surgical intervention (19).

Assessment of the cross-sectional area (CSA) of the median nerve using US offers distinct advantages over alternative diagnostic methods for CTS (17). Ultrasound-based predictive models have shown the capability to diagnose CTS accurately without the requirement for CSA measurement (17). It was reported that US is a reliable method with high sensitivity (90.6%) and specificity (82.52%) in detecting CTS, comparable to NCS (10,20). It is a valuable diagnostic tool for identifying severe cases of CTS. However, its efficacy in determining the severity of the condition in cases ranging from minimal to moderate is limited compared to electrophysiological tests (21). In practice, the majority of physicians diagnose CTS through clinical assessment and only use supplementary examinations, such as NCS or US, for confirmation when necessary (22).

In recent years, there has been ongoing discussion regarding the effectiveness and precision of NCS and US in diagnosing CTS (23). Various studies have reported different levels of diagnostic accuracy for these assessments (23) with a lack of definitive conclusions (23). In addition, NCS are frequently used for diagnosing CTS, while the use of US is increasingly gaining acceptance (24). This study evaluated the capability of US in assessing the CSA of the median nerve and the severity of CTS.

Materials and Methods

A cross-sectional study was performed among 300 CTS patients (600 hands) who were referred to the neurology departments of Golestan Hospital (Ahvaz, Iran), between July 2023 and March 2024. The study was approved by the Medical Ethics Committee at Ahvaz Jundishapur University of Medical Sciences (IR.AJUMS.HGOLESTAN.REC.1402.022), and all patients signed an informed consent at the commencement of the study. All participants underwent NCS, needle EMG, and US examinations conducted by the same neurologist and radiologist, respectively. A checklist form was created to encompass a range of demographic and clinical details, including gender, age, body mass index (BMI), the hand impacted by CTS, CSA of median nerve, flattening ratio (FR), ring-finger method (RF), as well as Tinel's sign and Phalen's test.

The FR is calculated by measuring the CSA of the median nerve at the carpal tunnel in relation to its width, providing insights into nerve deformation (25). A higher FR indicates more severe compression of the median nerve or greater flattening, which is critical for diagnosing CTS (25-27). The sensory latencies of the ring finger were measured using antidromic stimulation that involved comparing the median nerve responses to the ulnar nerve responses above the wrist and recording sensory nerve action potentials (SNAPs) from the ring finger. It was indicated that this method can be highly sensitive (28,29). The FR is a measure that evaluates the severity of median nerve compression, while the RF method utilizes sensory NCS to compare latencies between the ulnar and median nerves at the ring finger, providing insights into nerve function (28).

The diagnosis of CTS in this study was determined using the CTS-6 evaluation tool (30,31), with a score ≥12 points required for all participants. Exclusion criteria included individuals with a history of wrist surgery for fractures or lacerations, underlying conditions such as inflammatory polyneuropathy, diabetes mellitus, autoimmune, metabolic disorders, rheumatoid arthritis, pregnancy, or other carpal tunnel-related lesions.

Electrodiagnostic tests were performed using the Nihon Kohden 4 ME 8 electrode entrance 4 record channel device following the guidelines recommended by the American Association of Neuromuscular and electrodiagnostic medicine (AANEM) (32). All participants underwent sensory and motor NCS for the ulnar and median nerves. The NCS tests were conducted by a neurologist. Patients with positive NCS results were categorized into three subgroups based on the severity of electrophysiological findings (33). These subgroups were defined as follows: mild neuropathy was characterized by a reduction in median sensory nerve conduction velocity (SNCV) (<44 m/s) and normal distal motor latency (<4.4 m/s). Moderate neuropathy was indicated by a decreased median SNCV (<44 m/s) and prolonged distal motor latency (≥4.4 m/s). Severe neuropathy was identified by the absence of sensory response and prolonged distal motor latency of 4.4 milliseconds or more (23).

Ring electrodes were employed to assess SNCV in an orthodromic manner (23). The electrodes were strategically placed over the fifth finger for the ulnar nerve and the second finger for the median nerve (23). Stimulation of the ulnar and median nerves was conducted at the elbow and wrist. For the median nerve, the active electrode was attached to the proximal interphalangeal joint of the second finger, while the reference electrode was placed 4 cm distal to the active electrode (23). A ground electrode was located between the active electrode and the stimulus. The median sensory nerve was stimulated at 14 cm proximal to the active electrode. Subsequently, measurements of baseline-to-peak amplitudes, latencies, and SNCV were calculated. In addition, the difference in sensory latencies between the ulnar and median nerves was analysed using the RF, with values exceeding 0.5 suggesting a potential diagnosis of CTS (23). Furthermore, needle EMG was conducted on the abductor pollicis brevis muscle to exclude the possibility of cervical radiculopathy (32).

Ultrasonography of the carpal tunnel was conducted by a radiologist, who was not informed about the physical and electrophysiological characteristics of the patients. The examination was performed using a Philips IU22 ultrasound system equipped with a 5-17 MHz linear transducer. The circumference and CSA of the median nerve were measured at the entrance of the carpal tunnel, just below the proximal edge of the flexor retinaculum, with the pisiform bone as a reference point (23).

The tracing method was employed to assess the circumference and CSA of the median nerve at the carpal tunnel inlet, specifically at the site just beneath the proximal edge of the flexor retinaculum, using the pisiform bone as a reference point. This technique involved outlining a continuous line within the hyperechoic boundary of the nerve. The ellipsoid area formula (D1×D2×3.14/4) was applied for these measurements. Each measurement was taken three times, and the average value was subsequently applied for statistical analysis. In addition, the mean FR, which is the ratio of the median nerve's major axis to its minor axis, was calculated at the carpal tunnel inlet (23).

Statistical analysis

The statistical data analysis was carried out using the SPSS software (version 22). The Kolmogorov-Smirnov test was employed to evaluate the normal distribution of data. In addition, quantitative variables were presented as mean and standard deviations (SD), whereas categorical variables were represented as frequencies and percentages. Furthermore, chi-square and one-way analysis of variance (ANOVA) tests were used.

Results

This study evaluated 600 wrists of 300 patients with CTS. There were 102 males and 198 females, with a mean age of 46.83±9.50 years (mean±SD), ranging from 30 to 75 years. The majority of patients were aged 40-59 years old. Furthermore, 240 patients had bilateral CTS. The hands affected by CTS were categorized into three groups based on the severity of CTS: mild (298 hands, 49.7%), moderate (164 hands, 27.3%), and severe (138 hands, 23%). Positive Tinel's sign and Phalen's test were observed in 65% and 77 % of the affected hands, respectively. Additionally, the majority of the patients exhibited an overweight BMI. The clinical and demographic data of the CTS patients are detailed in Table 1.

Substantial differences were detected in the average age, CSA of the median nerve, BMI, RF, FR, and outcomes in Tinel's sign and Phalen's test based on the severity of CTS ($P<0.05$) (Table 2). The increase in CSA of the median nerve was related to the severity of CTS.

Table 1. Demographic and clinical characteristics of CTS patients (n=300)

Variables		Mean±SD
Age (years)		46.83 ±9.50
BMI (kg/m^2)		25.39±1.94
CSA of median nerve (mm^2)		13.35±2.41
RF		1.28±0.24
FR		3.75±0.37
Age Group		**n (%)**
30-39		26 (8.7)
40-59		241 (80.3)
60-75		33 (11)
Gender	Male	102(34)
	Female	198 (66)
Severity of CTS	Mild	298 (49.7)
	Moderate	164(27.3)
	Severe	138 (23)
Tinel's sign (600 wrists)	Negative	213(35.5)
	Positive	387(64.5)
Phalen's test (600 wrists)	Negative	140(23.3)
	Positive	460(76.7)

CSA, cross sectional area; BMI, body mass index; CTS, carpal tunnel syndrome; RF, ring-finger method; FR, flattening ratio

Table 2. Characteristics of CTS patients based on the severity of CTS (n=300)

Severity of CTS		Mild (n=298)	Moderate (n=164)	Severe (n=138)	*P*
Variables			**Mean±SD**		
Age (years)		47.03 ±8.57	44.20 ±7.85	49.54 ±12.15	$P<0.05$
CSA of median nerve (mm^2)		11.26±0.59	14.03±0.47	17.07±0.77	$P<0.05$
BMI (kg/m^2)		24.02±0.82	25.29±0.45	28.44±1.11	$P<0.05$
RF		1.04±0.21	1.46±0.32	1.61±0.41	$P<0.05$
FR		3.17±0.25	4.25±0.41	4.43±0.33	$P<0.05$
			n (%)		
Tinel's sign (600 wrists)	Negative	82 (27.5)	65(39.7)	66(47.8)	$P<0.05$
	Positive	216 (72.5)	99(60.3)	72(52.2)	
Phalen's test (600 wrists)	Negative	76(25.5)	44(26.8)	20(14.5)	$P<0.05$
	Positive	222(74.5)	120(73.2)	118 (85.5)	

$P<0.05$ was statistically significant. CSA, cross-sectional area; BMI, body mass index; CTS, carpal tunnel syndrome RF, ring-finger method; FR, flattening ratio

Discussion

This study examined 600 wrists of 300 patients with CTS, with a mean age of 46.83±9.50 years (ranged 30-75 years). The majority of patients belonged to the 40-59 age group. Moreover, most patients were overweight. In this study, 66% of patients with CTS were female, while 34% were male. Similar findings were reported in other studies among CTS patients in Iran (34-38), where women constituted the majority of participants diagnosed with CTS. The average age of the patients in the current study was consistent with the mean age reported in comparable studies conducted in Iran (34-36,38-40). It was reported that CTS is more prevalent among women and older individuals (41) and is typically observed in individuals in the middle to older age range (5). The probability of experiencing CTS increases with advancing age, primarily due to age-related degenerative changes in the wrist, decreased tissue flexibility, and the cumulative effect of strain on the median nerve (5,42). Obesity is a significant contributing factor to the development of CTS (5,43). Individuals with obesity are at a 1.5 times higher risk of developing CTS, for each incremental increase of one point in BMI, there is an associated 8% increase in the risk of developing CTS (5,43).

In this study, 240 patients had bilateral CTS. The hands affected by CTS were categorized into three groups based on the severity of CTS: mild (298 hands, 49.7%), moderate (164 hands, 27.3%), and severe (138 hands, 23%). Positive Tinel's sign and Phalen's test were observed in 65% and 77% of the affected hands, respectively. It has been reported that as the severity of

CTS increases, the reliability of Tinel's sign as a diagnostic tool may decrease. Tinel's sign demonstrated a low sensitivity of 46% in diagnosing CTS, particularly in moderate cases (44). Substantial differences were detected in the average age, CSA of the median nerve, BMI, RF method, FR, and outcomes in Tinel's sign and Phalen's test based on the severity of CTS (P<0.05). The increase in CSA of the median nerve was related to the severity of CTS. Similar results were reported in a study among 65 patients with CTS in Greece (23). They concluded that combining the US of the median nerve with NCS substantially improves the sensitivity and reliability of diagnosing patients with CTS (23). This approach can also be utilized to evaluate the severity of CTS, serving as a viable alternative to NCS due to its notable advantages, including cost-effectiveness, non-invasiveness, efficiency in terms of time, and improved patient convenience (23). In contrast, a study conducted in Iran investigated 70 wrists with CTS and found that using US to measure the CSA of the median nerve can be beneficial in identifying and assessing the severity of CTS (34). However, it was noted that the US should not be considered a substitute for NCS (34). Implementing US as the primary diagnostic tool may prove advantageous in reducing the need for NCS (34). A meta-analysis of 13 studies indicated that sonography using the CSA measurement of the median nerve is not a replacement for electrodiagnostic testing (EDX) in diagnosing CTS. However, it can provide additional findings in the diagnostic process (45).

NCS is commonly used to approve the presence of CTS, while US is a well-established non-invasive method that provides insights into wrist anatomy and variations in the median nerve and surrounding structures (22). In addition, NCS provides details on the location of the lesion and the function of larger-diameter nerve fibers; however, it is associated with disadvantages such as increased costs, time demands, and patient discomfort (24). In contrast, the US method is described as a straightforward, cost-effective, non-invasive, and painless diagnostic technique (22,46); real-time imaging enables the observation of tissue dynamics (22), and it also allows for the identification of secondary causes such as space-occupying lesions (16). However, a notable limitation is the inability to assess nerve function, which may lead to lower sensitivity to variability compared to NCS (47).

Median nerve enlargement, specifically the CSA at various carpal tunnel levels, is the most commonly employed parameter for diagnosing CTS using US (46). The swelling of the median nerve, as determined by CSA, reflects the severity of nerve damage (48). It has been indicated that CTS patients have substantially larger CSAs of the median nerve compared to healthy controls (49,50). The CSA of the median nerve has been identified as the most sensitive method for diagnosing early-stage CTS (48). The primary method for diagnosing CTS is through clinical assessment (33). The CTS-6 assessment tool had a sensitivity of 95% and a specificity of 91% (46). In cases where the clinical evaluation is inconclusive, US and NCS are commonly employed for diagnosis (6). In addition, US and NCS serve to confirm CTS (46) and are not standalone diagnostic methods but rather supplementary tools to clinical examination, enhancing diagnostic precision (23).

NCS and needle EMG are both utilized in assessing the severity of CTS (19). The invasive nature of needle EMG can lead to discomfort for patients, making it less desirable compared to non-invasive NCS (19). In patients with prolonged median motor distal latencies but normal compound muscle action potential (CMAP) amplitudes, needle EMG may reveal subtle abnormalities, indicating potential axonal loss (51). It has been indicated that axonal loss is associated with reduced median nerve amplitude and conduction velocity, complicating the diagnosis (52). CMAP amplitudes are strong predictors of spontaneous EMG activity, with a significant odds ratio, indicating their importance in clinical assessments (19). The presence of spontaneous activity in needle EMG can influence treatment strategies, such as the decision to proceed with surgical intervention (19).

Ultrasonography is playing an increasingly significant role in the assessment and diagnosis of musculoskeletal system disorders (23). Several sonographic criteria have been suggested for evaluation and diagnosis of CTS, with the CSA imaging of the nerve at the carpal tunnel entrance and exit demonstrating superior efficacy (53). It has been documented that a significant proportion of patients diagnosed with clinically evident CTS who present with normal NCS exhibit abnormal findings on neuromuscular ultrasound (54). Therefore, the importance of US is underscored in this context, particularly for cases of mild CTS that may not be detectable through NCS (54). Despite the cost-effectiveness, accessibility, and minimally invasive nature of US, its utilization is contingent upon the expertise of the radiologist, which is heavily influenced by experience and environmental factors. The absence of a universally accepted and standardized criterion agreed upon by researchers has led to the continued popularity of electrodiagnostics in clinical practice (40,53,55).

Evaluation of the CSA of median nerve through the

US has significant implications for clinical practice in managing CTS. This non-invasive technique enhances diagnostic accuracy, allowing for better differentiation between primary and secondary causes of CTS (56). US has shown a sensitivity of 90.6% and specificity of 82.52% in diagnosing CTS, making it a reliable alternative to NCS (10). The CSA measurements correlate positively with symptom severity and functional status, providing a quantitative basis for assessing disease progression (57). It also facilitates pre- and post-operative evaluations, allowing clinicians to monitor nerve recovery and adjust treatment plans accordingly (58). While ultrasonography is valuable, it may not capture all cases of CTS, as some patients may show positive findings only in NCS (59). NCS tests offer functional insights, confirming the severity of nerve compression and correlating with ultrasound findings (56,60). Reliance solely on US without considering clinical symptoms and NCS may lead to misdiagnosis or inappropriate treatment. Integrating these modalities is essential for optimal patient care (59,60). Combining clinical evaluation, ultrasound, and NCS improves sensitivity and specificity for CTS diagnosis (8,60).

This study suggests that using US to measure the CSA of the median nerve can assist in diagnosing and classifying the severity of CTS. Clinical observations play a substantial role in the identification of CTS. Enhanced precision in clinical assessments is essential for improving diagnostic accuracy. To enhance the accuracy and precision of diagnostic evaluations, it is recommended to use a combination of different clinical assessments simultaneously. Integrating US with electrodiagnostic tests significantly enhances the reliability of diagnostic evaluations for patients with CTS (23). NCS remains a critical component in CTS diagnosis, providing objective data on nerve function. When used alongside needle EMG and US, it can confirm findings and enhance diagnostic confidence, particularly in ambiguous cases, indicating a need for a balanced approach in diagnostic practices (61).

The study is subject to several limitations. Firstly, it did not incorporate a control group consisting of healthy individuals, thereby preventing a comparative analysis between wrists affected by CTS and those unaffected. Secondly, it had a single-center design. The study focused solely on two parameters in the US, which restricted the scope of its findings. Understanding the interplay between nerve morphology and functional impairment remains crucial for effective management. Further studies are recommended to span a longer duration, encompass a larger statistical sample, and involve multiple research centers to yield more robust and well-documented outcomes. To facilitate more comprehensive investigations, a prospective study design should be adopted. This design systematically categorizes patients from the outset, and relevant data is meticulously recorded. Subsequent studies should also explore the cost-effectiveness of US techniques and aim to generate evidence-based algorithms applicable in clinical settings.

This study revealed that the increase in CSA of the median nerve measured by US was directly related to CTS severity. Ultrasonography can effectively assess the severity of CTS; it is cost-effective, non-invasive, and convenient for patients. Utilizing US to measure the CSA of the median nerve proved to be beneficial for identifying and classifying the severity of CTS. It is suggested to use the US as a screening method to detect CTS in individuals at high risk. However, it should not be regarded as a substitute for NCS. Integrating NCS, US, and needle EMG can enhance diagnostic accuracy and provide more comprehensive insights into the severity and underlying causes of CTS. The findings of this study have the potential to improve the quality of diagnosis, treatment, and care for patients with CTS.

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LB and GS developed the study concept and the study protocol. SM generated the first draft of the manuscript and conducted data analysis. All authors thoroughly assessed the manuscript draft and endorsed the final version.

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