Al-Azhar International Medical Journal

Volume 4 | Issue 2 Article 30

2-2023

Nerve conduction study and ultrasonography of median nerve in predicting outcome after surgical release in carpal tunnel syndrome

Mahmoud Mohamad Hasan
Department of Neurology, Al-Azhar University – Assuit

Ali Farrag El Hadad
Department of Neurology, Al-Azhar University – Assuit

Maysra Abdelhalim Ali
Department of Orthopedic Surgery, Al-Azhar University – Assuit

Tarek Mohammed Mansour
Department of Neurology, Al-Azhar University – Assuit

Mohammed Fouad Mehanny
Department of Neurology, Al-Azhar University - Assuit, Egypt, mohammedmehanny20@gmail.com

How to Cite This Article

Hasan, Mahmoud Mohamad; El Hadad, Ali Farrag; Ali, Maysra Abdelhalim; Mansour, Tarek Mohammed; and Mehanny, Mohammed Fouad (2023) "Nerve conduction study and ultrasonography of median nerve in predicting outcome after surgical release in carpal tunnel syndrome," *Al-Azhar International Medical Journal*: Vol. 4: Iss. 2, Article 30.
DOI: https://doi.org/10.58675/2682-339X.1674

ORIGINAL ARTICLE

Nerve Conduction Study and Ultrasonography of Median Nerve in Predicting Outcome After Surgical Release in Carpal Tunnel Syndrome

Mahmoud Mohamad Hasan [a], Ali Farrag El Hadad [a], Maysra Abdelhalim Ali [b], Tarek Mohammed Mansour [c], Mohammed Fouad Mehanny [a,*]

[a] Department of Neurology, Al-Azhar University, Assiut, Egypt
[b] Department of Orthopedic Surgery, Al-Azhar University, Assiut, Egypt
[c] Department of Radiology, Al-Azhar University, Assiut, Egypt

Abstract

Background: **Carpal tunnel syndrome (CTS) is a peripheral entrapment neuropathy in which compression of the median nerve at the wrist occurs.**

Objective: **The aim was to evaluate and study ultrasound (US) and nerve conduction of median nerve in predicting outcome after open surgical release in carpel tunnel syndrome.**

Patients and methods: **This prospective observational study included 30 patients from outpatient neurology and orthopedic clinics of Al-Azhar Assiut University Hospitals. The duration of the study ranged from 6 to 12 months.**

Results: **US findings were significantly decreased postoperatively. Regarding receiver operating characteristic curve of US findings in predicting outcome after open surgical release in carpel tunnel syndrome, regarding Cross-sectional area at tunnel inlet, its sensitivity was 40%, specificity was 82%, area under the curve (AUC) was 0.615 and cutoff point was less than or equal to 13.5. Regarding cross-sectional area at tunnel outlet, its sensitivity was 32%, specificity was 86%, AUC was 0.523, and cutoff point was less than or equal to 14. Regarding maximal cross-sectional area along the tunnel, its sensitivity was 34%, specificity was 78%, AUC was 0.586, and cutoff point was less than or equal to 16. Regarding receiver operating characteristic curve of distal motor latency (DML), sensitivity was 87.1%, specificity was 89.7%, AUC was 0.813, and cutoff point was less than or equal to 4.9.**

Conclusion: **Ultrasonography is a good sensitive tool in diagnosis of CTS as compared with the clinical examination and electrophysiological findings. Open carpal tunnel release was effective in improving CTS clinical, electrophysiological, and functional parameters. Most of the patients were satisfied with the results of open carpal tunnel release (OCTR).**

Keywords: Abductor digiti minimi, Carpal tunnel syndrome, Ultrasound

1. Introduction

Peripheral neuropathies are disorders of the peripheral nervous system characterized by damage and pressure on the nerve when passing through a narrow space.[1] Carpal tunnel syndrome (CTS) is one of the most common upper extremity-compression neuropathies and is caused by compression of the median nerve in the carpal tunnel at the wrist. The median nerve may also be limited to other locations in the arm and forearm. The incidence of CTS is ~1 in 1000 people in the general population.[2]

Pathogenesis of CSC are mechanical stress, microvascular insufficiency, and oscillometric theories. Although the precise etiology of CTS is believed to be idiopathic or multifactorial, probable risk factors for CTS include obesity, diabetes,

Accepted 24 August 2022.
Available online 23 May 2023

* Corresponding author at: Department of Neurology, Al-Azhar University, Assiut, 71611, Egypt. Fax: 20225065986.
E-mail address: mohammedmehanny20@gmail.com (M.F. Mehanny).

https://doi.org/10.58675/2682-339X.1674

hypothyroidism, menopause, arthritis, old age, and pregnancy.[3]

The cause of this type of polyneuropathy is increased pressure in the carpal tunnel on the median nerve, which leads to significant changes in intraneural microcirculation and the structure of nerve fibers, impaired axonal transmission, and a change in vascular permeability, with edema and impaired nerve.[4]

Histologically, noninflammatory fibrosis of the subpolyp connective tissue, particularly in the area around the flexor tendons, is the hallmark of the development and progression of CTS. Ultrasound (US) is a follow-up option as a diagnostic tool in CTS. In addition, the US provides information on anatomical differences in the median nerve and surrounding structures that may be a causative factor in CTS. In the United States, a transverse section of the median nerve has been used to classify the severity of CTS as normal, mild, moderate, and severe.[5]

An electrodiagnostic test (EDX) often confirms the diagnosis, but limitations include patient discomfort and a variable rate of false-negative results. In addition, EDX provides physiological information about slow nerve conduction and axon loss but does not provide anatomical details that reflect the underlying cause.[6]

Management for CTS varies and depends on the severity of the syndrome. Nonimperfect squamous cell carcinomas are traditionally treated conservatively with fixation or injections. Surgical management can continue. Standard open surgery is a basic procedure that involves a 3–5-cm incision that allows for successful release of the carpal tunnel.[7]

This study aims to evaluate US and nerve conduction study of median nerve in predicting outcome after an open surgical release in carpel tunnel syndrome.

2. Patients and methods

This is a prospective observational study conducted over a period of 6–12 months on 30 patients randomly selected from participants in the Neurology and Orthopedics Clinic at Al-Azhar Assiut University Hospital.

Patients diagnosed with CTS and positive on Tinel and Phalen challenge tests were included. Medical history, clinical signs, or electrodiagnostic findings suggestive of co-existing neurological disorders; subclinical sensory polyneuropathy; rheumatologic disease; systemic clinical disease affecting mineral metabolism; surgical history; or trauma to the upper limbs and/or neck were the exclusion criteria.

All patients had detailed medical history and clinical examination, which included evaluation of blood pressure, pulse, and cardiovascular, neurological, and respiratory signs. Local examination included sensory research. Engine test was done. Hoffmann–Tinel sign positivity was as follows: a light tap on the median nerve in the area of the carpal tunnel causes tingling in the nerve distribution. Phalen's sign was positive as follows: tingling of the median nerve distribution is caused by fully flexing the wrists for up to 60 s. Laboratory tests included fasting blood glucose, glycated hemoglobin, liver and kidney function tests, thyroid function, and lipid profile. Nerve conduction studies were performed before and 3 months after surgery. Median sensorimotor conduction studies for all patients and assessment of median nerve F-wave response were done (Fig. 1).

The electrophysiological examination was classified as follows: normal: normal range, light: plane of the wrist segment with restricted distal motor deceleration, moderate: abnormal wrist segment height and distal motor response, and severe: lack of sensory response and abnormal distal motor response with little or no amplitude.

Surgical technique: preoperative: the surgery was performed under local anesthesia with a pneumatic tourniquet around the arms. The needle was placed subcutaneously between the thenar and hypotenary masses just proximal to the distal wrist. Intraoperative: A 2–3-cm incision was made through the skin and the most superficial subcutaneous tissue. A

Fig. 1. Nihon Kohden Corporation, Model: MEB2003k, Serial no 00051, Japan 2012.

self-locking retractor was placed in the incision with sufficient tension to allow proper exposure and retraction of the tissue. Then, using a reverse blade technique where the blade is turned upward, the tissues are pushed down with the back of the blade as the tip is lifted and gently pushed forward with the uterus securing the tissues in preparation for. The surgical sutures are made with Prolene 3/0. Postoperative: analgesia was provided with intravenous paracetamol or NSAIDs or even nalbuphine 10 mg, which can be repeated every 6 h. The sutures were removed after 10 days in the OPC. High-resolution US examination of the median nerve was performed before and 3 months after surgery (Fig. 2).

US technique was used to measure median nerve cross-section. The participants sat with arm supported to keep wrist and fingers extended, forearm supinated, elbow fully flexed, and shoulder flexed at 60°. The distal wrist crease was taken as the starting point for the US. At each site, the median nerve CSA was obtained using the trace function by tracing directly within the hyperechoic rim of the nerve. The transducer was held perpendicular to the nerve to obtain an accurate cross section. The area was surveyed at both locations. Results were compared before and after surgery (Fig. 3).

Median nerve elastography measurement technique: the transducer was rotated 90° from the transverse image plane to the sagittal plane. Sonoelastographic images were obtained by repeated palmar compressions with the probe. The median nerve was examined longitudinally and transversely. 4 cm above the distal end of the radius and at the entrance of the carpal tunnel. The elastogram appeared in a rectangular study area as a translucent color-coded live image overlaid on the B-mode image. Color coding indicated the relative stiffness of the tissue in the area of interest and ranged from red (soft) to blue (hard). Green and yellow indicate medium elasticity (Fig. 4).

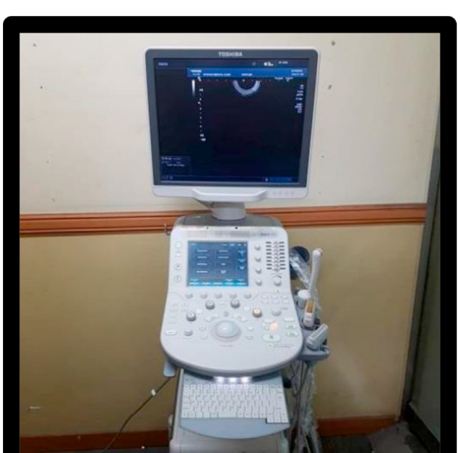

Fig. 2. Xario 200 Ultrasound System Toshiba Medical Systems Corporation, Tokyo, Japan 2014 with a 5–13 MHz linear array transducer.

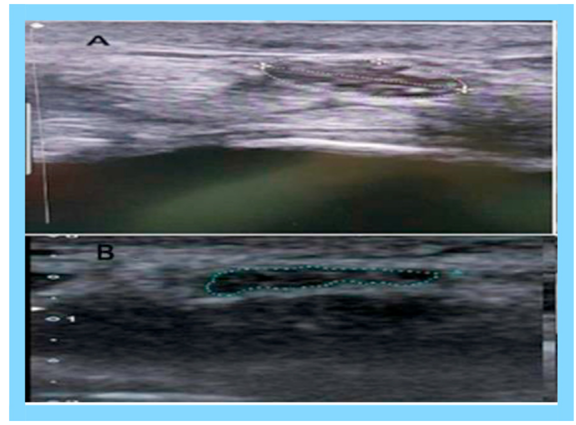

Fig. 3. Ultrasound examination of median nerve diameter in a 39-year-old woman diagnosed as having carpal tunnel syndrome (the dotted area). (a) Preoperative. (b) At 3 months.

Official Ethics Committee approval was obtained from Al-Azhar Assiuit University Hospitals and the Department of Orthopedic Surgery. Informed consent was obtained from all participants after being informed.

Statistical analysis was performed using IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp. (Statistical Package for the Social Sciences). Data were presented according to the type of data (parametric and nonparametric) obtained for each variable. *P* values less than 0.05 (5%) were considered statistically significant, *P* greater than 0.05 as not significant (NS), and *P* less than 0.01 as highly significant (HS). The Kruskal–Wallis test was used to assess the statistical significance of the difference in a

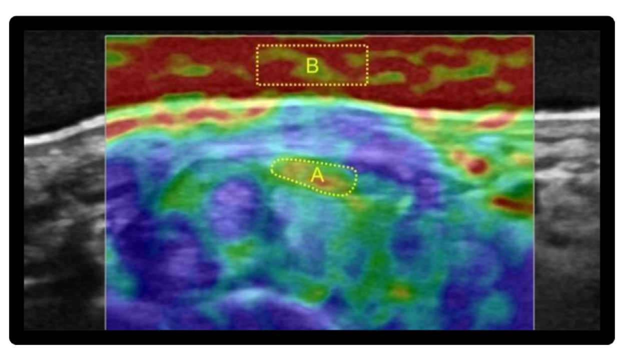

Fig. 4. Transverse images of a 57-year-old female. (a) Conventional B-mode ultrasound image shows sonoelastographic. The color represents the elasticity of the tissue. The strain ratio of the AC (b) to the MN (a) was 2.9. AC, acoustic coupler; MN, median nerve.

nonparametric variable between more than two study groups. One-way analysis of variance was used for normal continuous variables. Post-hoc analysis by analysis of variance was performed using Tukey's test with post-hoc analysis using Mann–Whitney *U*-test.

3. Results

A total of 30 patients were examined in this study clinically and by nerve conduction study. Their mean age was 52.07 ± 10.74 years and ranged from 27 to 61 years. The mean BMI was 25.65 ± 3.62 kg/m^2. Among the 30 studied patients with CTS, 26 patients (86.66%) had unilateral CTS (17 of them were females and nine of them were males), whereas four patients (13.33%) had bilateral CTS (all of them were females). A total of 34 hands were affected (Tables 1–11, Figs. 5 and 6).

Table 4. Frequencies of special tests among the affected hands (34).

Variables	Total [*N* (%)]	Right hand [*N* (%)]	Left hand [*N* (%)]
Positive Phalen's	24 (70)	14 (41.2)	10 (29.4)
Positive Tinel's	19 (55.8)	11 (32.3)	8 (23.5)
Thenar atrophy	3 (8.8)	1 (3)	2 (5.8)

Variables	AUC	SE	95% confidence interval	Cutoff	Sensitivity (%)	Specificity (%)
Cross-sectional area at tunnel inlet	0.615	0.074	0.471–0.760	≤13.5	40	82
Cross-sectional area at tunnel outlet	0.523	0.075	0.375–0.671	≤14	32	86
Maximal cross-sectional area along the tunnel	0.586	0.076	0.438–0.734	≤16	34	78
DML	0.813	0.059	0.723–0.953	≤4.9	87.1	89.7

AUC, area under the curve; DML, distal motor latency.

Table 1. Demographic and clinical data of patients.

Variables	Patients (*n* = 30)
Age (years)	
Mean ± SD	52.07 ± 10.74
Range	27–61
Sex [*n* (%)]	
Female	21 (70)
Male	9 (30)
BMI (kg/m^2)	
Mean ± SD	25.65 ± 3.62
Range	25.6–29.3
Residence [*n* (%)]	
Rural	12 (40)
Urban	18 (60)

Table 2. Symptom distribution among the affected hands.

	Affected hands (*n* = 34) [*N* (%)]
Swelling	8 (23.5)
Nocturnal pain	16 (47)
Sensory symptoms	34 (100)
Motor symptoms	2 (5.9)

Table 3. Types and numbers of the affected hands (34).

Variables	CTS affected hands (*n* = 34) [*N* (%)]
Right hand	19 (55.9)
Left hand	7 (20.5)
Bilateral	8 (23.6)

CTS, carpal tunnel syndrome.

Table 5. Nerve conduction study grades among the affected CTS hands.

Variables	CTS hands (*n* = 34) [*N* (%)]
Normal	4 (11.7)
Mild	9 (26.5)
Moderate	12 (35.3)
Severe	9 (26.5)

CTS, carpal tunnel syndrome.

Table 6. Ultrasound findings preoperatively and postoperatively among the patients with CTS.

Variables	Preoperative	Postoperative	p_t	*P*
Cross-sectional area at tunnel inlet (mm^2)				
Mean ± SD	14.32 ± 4.25	11.57 ± 3.81	2.64	0.011
Range	11.2–16.5	8–14.1		
Cross-sectional area at tunnel outlet (mm^2)				
Mean ± SD	15.27 ± 4.86	12.42 ± 4.55	2.34	0.025
Range	12.6–18.1	8.3–15		
Maximal cross-sectional area along the tunnel (mm^2)				
Mean ± SD	15.96 ± 5.22	13.12 ± 4.86	2.18	0.033
Range	12.5–19.2	10–16.5		

CTS, carpal tunnel syndrome.

Table 7. Strain ratio measurements of the median nerve preoperatively and postoperatively among the CTS.

Variables	Preoperative	Postoperative	p_t	*P*
Strain ratio at tunnel inlet				
Mean ± SD	1.83 ± 0.878	1.19 ± 0.212	2.13	0.035
Range	1.9–2.8	3–3.2		
Strain ratio at proximal forearm				
Mean ± SD	2.36 ± 0.817	1.98 ± 0.457	2.33	0.031
Range	1.8–3.2	1.5–2.5		

CTS, carpal tunnel syndrome.

Table 8. Comparison of strain elastography findings preoperatively and postoperatively among the CTS.

Strain elastography	Preoperative [*n* (%)]	Postoperative [*n* (%)]	$\chi 2$	*P*
Blue (hardest)	8 (26.7)	1 (3.3)	**5.4**	**0.012**
Mixed (moderate)	13 (43.3)	8 (26.7)	1.83	0.176
Green (mild)	6 (20)	12 (40)	2.86	0.091
Red (softest)	3 (10)	9 (30)	3.75	0.051

CTS, carpal tunnel syndrome. Bold values are significant.

Table 9. Nerve conduction studies of median nerve preoperatively and postoperatively among the CTS.

Variables	Preoperative	Postoperative	p_t	P
DML (ms)				
Mean ± SD	6.65 ± 1.73	4.32 ± 0.715	**6.82**	**0.000**
Range	4–8.5	3.5–5.2		
CMAP (mV)				
Mean ± SD	9.51 ± 5.24	12.19 ± 4.71	**2.08**	**0.042**
Range	5.4–12.8	9.2–16		
MCV (m/s)				
Mean ± SD	47.56 ± 8.61	51.97 ± 5.11	**2.41**	**0.019**
Range	40–56	46–58		
PL (ms)				
Mean ± SD	4.87 ± 0.747	4.06 ± 0.66	**4.45**	**0.000**
Range	4–5.8	3.2–5.1		
SNAP (μV)				
Mean ± SD	19.15 ± 9.88	14.26 ± 9.47	1.96	0.055
Range	11.5–27.7	6.6–26.2		
SCV (m/s)				
Mean ± SD	32.12 ± 5.86	42.23 ± 5.2	**7.07**	**0.000**
Range	27.6–38.2	38.1–48.5		

CMAP, compound motor action potential; CTS, carpal tunnel syndrome; DML, distal motor latency; MCV, motor conduction velocity; PL, peak latency; SCV, sensory conduction velocity; SNAP, sensory nerve action poteintal. Bold values are significant.

Table 10. Nerve conduction studies of median nerve and US among the CTS according to recurrence.

Variables	Nonrecurrent ($n = 25$)	Recurrent ($n = 5$)	*t*	*P*
DML (ms)				
Mean ± SD	4.11 ± 0.624	6.72 ± 1.88	5.82	0.000
CMAP (mV)				
Mean ± SD	12.21 ± 4.19	8.89 ± 5.3	2.47	0.034
MCV (m/s)				
Mean ± SD	52.26 ± 4.57	46.82 ± 6.29	2.29	0.028
PL (ms)				
Mean ± SD	3.94 ± 0.691	4.9 ± 0.768	2.79	0.009
SNAP (μV)				
Mean ± SD	14.1 ± 5.43	19.65 ± 4.93	2.11	.044
SCV (m/s)				
Mean ± SD	42.25 ± 5.31	32.1 ± 5.92	3.84	0.001
Cross-sectional area at tunnel inlet (mm^2)				
Mean ± SD	11.13 ± 3.27	14.86 ± 3.82	2.27	0.031
Cross-sectional area at tunnel outlet (mm^2)				
Mean ± SD	12.03 ± 3.42	15.65 ± 3.38	2.16	0.039
Maximum cross-sectional area along the tunnel (mm^2)				
Mean ± SD	12.89 ± 2.78	15.94 ± 2.99	2.21	0.035

CMAP, compound motor action potential; CTS, carpal tunnel syndrome; DML, distal motor latency; MCV, motor conduction velocity; PL, peak latency; SCV, sensory conduction velocity; SNAP, sensory nerve action poteintal; US, ultrasound.

Table 11. Correlation between nerve conduction studies of median nerve and US among the CTS postoperatively.

Variables	Cross-sectional area at tunnel inlet		Cross-sectional area at tunnel outlet		Maximum cross-sectional area along the tunnel	
	r	*P*	*r*	*P*	*r*	*P*
DML (ms)	0.391	0.002	0.417	0.004	0.318	0.008
CMAP (mV)	−0.315	0.012	−0.309	0.027	−0.288	0.089
MCV (m/s)	−0.421	0.001	−0.378	0.006	−0.347	0.015
PL (ms)	0.371	0.002	0.382	0.005	0.356	0.012
SNAP (μV)	0.332	0.005	0.402	0.002	0.270	0.152
SCV (m/s)	−0.409	0.001	−0.391	0.013	−0.412	0.009

CMAP, compound motor action potential; CTS, carpal tunnel syndrome; DML, distal motor latency; MCV, motor conduction velocity; PL, PL, peak latency; SCV, sensory conduction velocity; SNAP, SNAP, sensory nerve action poteintal; US, ultrasound. Bold values are significant.

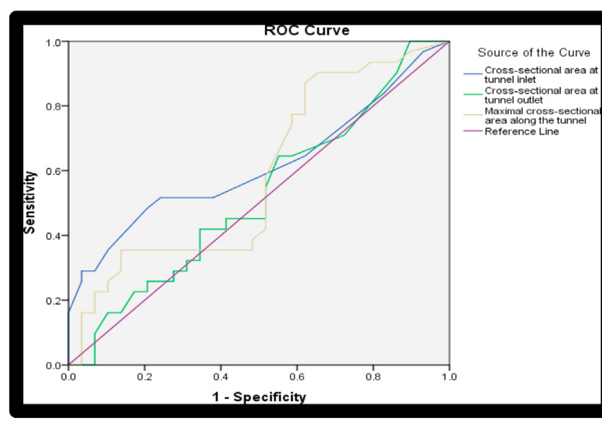

Fig. 5. Receiver operating characteristic (ROC) curve of ultrasound findings after open surgical release in carpal tunnel syndrome.

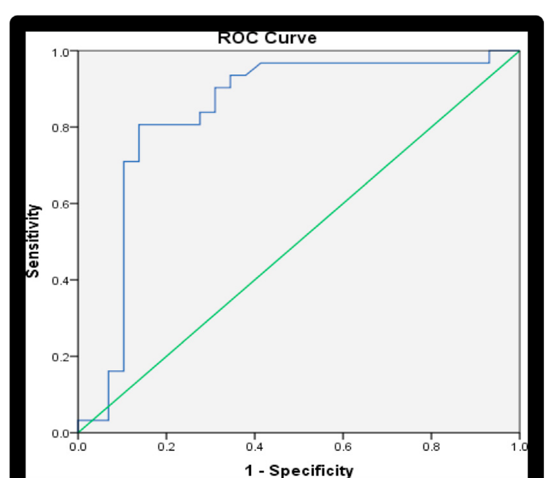

Fig. 6. Receiver operating characteristic (ROC) curve of DML findings in after open surgical release in CTS. DML, distal motor latency.

4. Discussion

The prevalence of CTS in the general population is ~8%, higher in those who do manual labor. Force, repetition, awkward posture, and vibration are important risk factors for SCC.[8]

This prospective observational study included 30 patients selected from participants in the neurological and orthopedic outpatient departments of Al-Azhar Assiut Teaching Hospitals. The duration of the study ranged from 6 to 12 months to evaluate the US and median nerve conduction study to predict the outcome after open surgery for surgical release in CTS.

This number of patients in our study is considered relatively small compared with other studies such as El Miedany and colleagues, who included 233 patients with CTS in their study. El Miedany et al.[9] included 200 patients with carpal tunnel syndrome.[10] In the same context, Kim et al.[11] included 264 symptomatic hands with CTS.

Regarding patient demographics, our study showed that mean ± SD age was 52.07 ± 10.74 years, and mean ± SD BMI was 25.34 ± 2.62. Regarding the distribution by sex, nine cases (30%) were male and 21 cases (70%) were female.

Our results showed that mean preoperative distal motor latency in patients was 6.65 ± 1.73, which significantly reduced to 4.32 ± 0.715 postoperatively ($P = 0.000$), and this is consistent with the results from Yoshii *et al.*[12] who reported that there were significant decreases in distal motor and sensory nerve conduction latencies after carpal tunnel release ($P < 0.01$).

Our results showed that the mean preoperative compound motor action potential (CMAP) was 9.51 ± 5.24, which increased significantly postoperatively to 12.19 ± 4.71 ($P = 0.042$) in patients.

A study by Miyamoto et al.[13] showed that after carpal tunnel exposure in 20 cases, the mean motor conduction velocity (MCV) was 38.34 preoperatively and increased to 55.3 postoperatively. The mean LMD was 5.8 preoperatively and decreased to 4.8 postoperatively. The mean SL was 6.9 preoperatively and decreased to 4.9 postoperatively, which is consistent with our results.

Farias Zuniga et al.[14] found that after carpal tunnel release, distal motor latency improved overall in 63% of participants, from 5.02 to 4.47 ms at follow-up. Mean motor amplitude also improved from a group mean of 9.21 mV to a mean of 9.64 mV at follow-up.

In the present study, the lack of improvement in sensory nerve action poteintal (SNAP) amplitude 3 months after surgery can be attributed to the possibility of degeneration of sensory nerve fibers that took longer to regenerate (>3 months). It should be noted that the SNAP amplitude reflects the supramaximal stimulation of all available nerve fibers, as reported by Preston and Shapiro.[15] Therefore, reducing any fiber type affects the SNAP amplitude. It is also known that sensory fibers are more sensitive to compression than motor fibers in patients with CTS, as reported by Schmid et al.[16] Therefore, it is possible that sensory fibers that are ischemic while degenerating may contribute to SNAP amplitude with no improvement after 3 months.

Regarding the US results of our study, there was a significant decrease in median nerve CSA at the entrance of the tunnel in patients, with a mean preoperative value of 14.32 ± 4.25 to 11.57 ± 3.81 three months after the procedure ($P = 0.011$). In terms of strain ratio, our results showed a significant increase in entry into the carpal tunnel in patients, with a mean preoperative value of 2.83 ± 0.878 ($P = 0.035$).

Consistent with our results, Roquelaure et al.[17] found that after carpal tunnel release, the CSA area decreased significantly and tension increased significantly compared with before carpal tunnel release.

Orman et al.[18] reported that mean tissue strain was lower in patients with SCC than in controls, which is similar to our results.

Mean CSA, total blue pixels, and blue indices differed significantly between cases of varying severity and controls. They concluded that sonoelastography could be used to diagnose and assess the severity of SCC cases.

4.1. Conclusion

US is a sensitive tool in the diagnosis of CTS in relation to clinical examination and electrophysiological findings. Open carpal tunnel clearance was effective in improving the clinical, electrophysiological, and functional parameters of CTS.

Conflict of interest

Authors declare that there is no conflict of interest, no financial issues to be declared.

References

1. Eroğlu A, Sarõ E, Topuz AK, Şimşek H, Pusat S. Recurrent carpal tunnel syndrome. *World J Clin Cases*. 2018;6:365.
2. Hassan MM, Al-Hawary MA. Body mass index and motor distal latency as independent. *Egypt J Neurol Psychiat Neurosurg*. 2013;50:13−14.
3. Wang L. Guiding treatment for carpal tunnel syndrome. *Phys Med Rehabil Clin*. 2018;29:751−760.

4. Gillig JD, White SD, Rachel JN. Acute carpal tunnel syndrome. *Orthop Clin N Am*. 2016;47:599−607.
5. Sharma D, Jaggi AS, Bali A. Clinical evidence and mechanisms of growth factors in idiopathic and diabetes-induced carpal tunnel syndrome. *Eur J Pharmacol*. 2018;837:156−163.
6. Aboonq M. Pathophysiology of carpal tunnel syndrome. *Neurosciences (Riyadh)*. 2015;20:4−9.
7. Festen-Schrier VJMM, Amadio PC. The biomechanics of subsynovial connective tissue in carpal tunnel syndrome. *J Electromyogr Kinesiol*. 2018;38:232−239.
8. Roquelaure Y, Garlantézec R, Evanoff BA, Descatha A, Fassier JB, Bodin J. Personal, biomechanical, psychosocial, and organizational risk factors for carpal tunnel syndrome. *Pain*. 2020;161:749−757.
9. El Miedany Y, El Gaafary M, Youssef S, Ahmed I, Nasr A. Ultrasound assessment of the median nerve. *SpringerPlus*. 2015;4:1−10.
10. Castro ADA, Skare TL, Pan Nassif, Sakuma AK, Barros WH. Sonographic diagnosis of carpal tunnel syndrome. *Radiol Bras*. 2015;48:287−291.
11. Kim DH, Marquardt TL, Gabra JN, et al. Pressure-morphology relationship of a released carpal tunnel. *J Orthop Res*. 2013;31:616−620.
12. Yoshii Y, Tung WL, Yuine H, Ishii T. Postoperative diagnostic potentials of median nerve strain after carpal tunnel release. *BMC Muscoskel Disord*. 2020;21:1−9.
13. Miyamoto H, Halpern EJ, Kastlunger M, et al. Carpal tunnel syndrome. *Radiology*. 2014;270:481−486.
14. Farias Zuniga A, Ghavanini AA, Israelian G, Keir PJ. Ultrasound examination predicts 6-month progression in carpal tunnel syndrome patients. *J Orthop Res*. 2020;3:321−330.
15. Preston DC, Shapiro BE. *Electromyography and neuromuscular disorders. Clinical-electrophysiological correlation*. 2nd ed. 32. Philadelphia, PA: Elsevier, Butterworth-Heinemann; 2007: 33−40.
16. Schmid AB, Bland JD, Bhat MA, Bennett DL. The relationship of nerve fiber pathology to sensory function in entrapment neuropathy. *Brain*. 2014;137:3186−3199.
17. Roquelaure Y, Chazelle E, Gautier L. Time trends in incidence and prevalence of carpal tunnel syndrome over eight years according to multiple data sources. *Scand J Work Environ Health*. 2017;43:75−85.
18. Orman G, Ozben S, Huseyinoglu N, Duymus M, Orman KG. Ultrasound elastographic evaluation in the diagnosis of carpal tunnel syndrome: initial findings. *Ultrasound Med Biol*. 2014;39: 1184−1189.