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Added Value of Ultrasonography in the Diagnosis, Management, and Follow-up of Carpal Tunnel Syndrome

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Abstract

Background: Carpal tunnel syndrome (CTS) remains one of the most common compression neuropathies affecting the upper extremity. Despite electrophysiological (EP) testing being considered an important diagnostic tool, it has notable limitations.

Aim of Study: This study aimed to evaluate ultrasonography (US) and nerve conduction studies (NCS) as complementary tools for CTS diagnosis, treatment planning, and monitoring.

Patients and Methods: This retrospective study included 60 patients of both sexes diagnosed with CTS. Patients underwent comprehensive clinical assessment, NCS, and high-resolution US before and three months after surgical intervention. Parameters assessed included distal motor latency, cross-sectional area, flattening ratio, and anteroposterior dimension of the carpal tunnel.

Results: The US demonstrated 90.4% sensitivity and 87.5% specificity for CTS diagnosis, while NCS showed 86.5% sensitivity and 75% specificity. Post-surgical evaluations revealed significant improvements in all measured parameters (p<0.001). Additionally, the US identified anatomical variations that influenced management decisions, including aberrant median artery (13.33%) and lipomas (3.33%).

Conclusions: The US provides valuable complementary information to EP testing in CTS assessment, offering superior diagnostic accuracy and the ability to detect structural abnormalities that may influence treatment planning. The combination of clinical examination, electrodiagnostic testing, and US optimizes patient care in CTS management.

Key Words: Carpal Tunnel Syndrome – Ultrasonography – Nerve Conduction Studies – Cross-Sectional Area – Median Nerve.

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Introduction

CARPAL tunnel syndrome (CTS) represents one of the most common compression neuropathies affecting the upper extremity, characterized by median nerve (MN) compression at the wrist **[1]**. The condition may also manifest with compression at other locations throughout the arm **[2]**. CTS predominantly affects individuals over 40 years of age, with a marked female predominance **[3]**.

Despite extensive research, consensus regarding optimal diagnostic criteria remains elusive. Current diagnostic approaches incorporate patient history, physical examination, and electrophysiological (EP) testing **[4]**. Many authorities consider EP evaluation an important diagnostic tool, offering high sensitivity and specificity **[5]**. However, these tests present notable limitations, including patient discomfort, specialized equipment requirements, time-intensive procedures, and considerable false-positive and false-negative rates **[6]**.

Furthermore, EP findings do not consistently correlate with neuropathic pain severity in CTS patients **[7]**. In straight forward cases, clinical assessment alone may suffice for accurate diagnosis, with EP testing providing additional value primarily in atypical presentations or when potential diagnostic confounders exist **[8]**.

While EP studies often identify the lesion level, they fail to provide spatial information about the nerve and surrounding structures that might illuminate underlying etiology **[9,10]**. In recent years, growing interest in advanced imaging modalities, particularly ultrasonography (US), has been demonstrated to have significant diagnostic value **[11,12]**.

The US offers several advantages: Widespread availability, non-invasive methodology, and efficient examination time **[13]**. This modality enables the assessment of multiple MN parameters, includ-

ing cross-sectional area (CSA), vascularity, and mobility **[14]**. Additionally, the US provides valuable insights regarding anatomical variations potentially contributing to CTS pathogenesis **[15]**.

This study aims to comprehensively evaluate US and nerve conduction studies (NCS) as complementary tools for diagnosis, treatment planning, and longitudinal monitoring in patients with CTS.

Patients and Methods

This retrospective study involved 60 cases, aged 18 years or older, of both sexes, who were diagnosed with CTSat Kafr Elsheikh University Hospitals, Egypt, between February and May 2025. Ethical approval was obtained from the institutional Ethical Committee (ID: KFSIRB200-513), and the study was registered at ClinicalTrials.gov (ID: NCT06834061). Written informed consent was obtained from all participants.

Exclusion criteria included prior wrist surgery/injection/fracture; clinical/EP evidence of CTS-mimicking conditions (cervical radiculopathy, polyneuropathy, proximal median neuropathy); history of CTS-associated disorders (acromegaly, diabetes, hypothyroidism, pregnancy, rheumatoid arthritis); electrodiagnostic findings of other neurological disorders; and subclinical sensory polyneuropathy.

A detailed medical history was recorded for each patient, including pain, numbness, weakness, and duration. Clinical examination was performed, including evaluation of blood pressure, pulse, cardiovascular, neurological, and respiratory signs. Local examinations included sensory assessment. The Hoffmann-Tinel sign was considered positive when a light tap on the MN in the carpal tunnel area caused tingling in the nerve distribution. Phalen's sign was deemed positive when tingling in the MN distribution was elicited by fully flexing the wrists for up to 60 seconds. Laboratory tests were conducted for all participants, including fasting blood glucose, glycated hemoglobin, liver and kidney function tests, thyroid function, and lipid profile.

The US and NCS examinations were performed before surgery and repeated three months postoperatively.

Electromyography (EMG):

EMG examinations were conducted in an identical room with comparable ambient temperature conditions. When routine tests, such as median sensory nerve conduction velocity in the two-digit/wrist segments and median distal motor latency (DML) from the wrist to the thenar eminence, yielded results within expected norms, supplementary tests were conducted, including segmental evaluations over a short 7–8cm span or comparative studies of the median and ulnar nerves. All patients underwent F-wave testing as part of the protocol.

Measurements obtained included the distal sensory latency of the MN (upper normal limit 3.6ms), the differential between distal sensory latencies of the median and ulnar nerves (upper normal limit 0.4ms), DML to the thenar eminence (upper normal limit 4.3ms), median motor nerve conduction velocity (lower normal limit 49m/s), and median sensory nerve conduction velocity (lower normal limit 49m/s). The severity of EP impairment in CTS was determined based on the classification proposed by Padua et al. **[16]**. CTS-affected hands were stratified into six groups according to neurophysiological findings: negative (no abnormalities in any test), minimal (abnormalities limited to segmental or comparative tests), mild (abnormal sensory nerve conduction velocity in digit/wrist with normal DML), moderate (abnormal sensory nerve conduction velocity in digit/wrist and abnormal DML), severe (no sensory response and abnormal DML), and extreme (complete absence of motor and sensory responses).

Ultrasonography:

High-resolution real-time US of the carpal tunnel (both hands) was performed using a US machine with a 12 MHz linear array transducer. The US examination was conducted on the same day or within three days of the EP study. During the examination, patients were seated facing the sonographer with the forearm resting on the table and the palm facing up in the neutral position. The volar wrist crease was used as an initial external reference point, with subsequent modifications during scanning using carpal bony landmarks and internal reference points. Fig. (1).

A comprehensive assessment of the MN was conducted throughout its course within the carpal tunnel, utilizing both transverse and longitudinal planes. Located superficial to the echogenic flexor tendons, the nerve's size, shape, echogenic properties, and spatial relationship with surrounding anatomical structures and the flexor retinaculum were carefully recorded. The presence or absence of synovial fluid and any masses were noted, alongside evaluations of the MN's continuity and any areas of constriction observed in both transverse and longitudinal perspectives. Fig. (1).

Measurements of the MN were obtained at the carpal tunnel's proximal inlet and distal outlet. The nerve's mean CSA was calculated by outlining its boundaries with electronic calipers (direct tracing method). The flattening ratio, defined as the ratio between the major and minor axes of the MN was determined at both the inlet and outlet of the tunnel. The flexor retinaculum's thickness was gauged as

close to the midline as feasible in the midsection of the carpal tunnel. The anteroposterior dimension (APD) of the carpal tunnel was measured at its central point, corresponding to the distal margin of the pisiform bone. Additional abnormalities, such as lipomas, were detected using the US. Doppler imaging was performed to detect vascular abnormalities such as an aberrant median artery (AMA). Fig. (1).

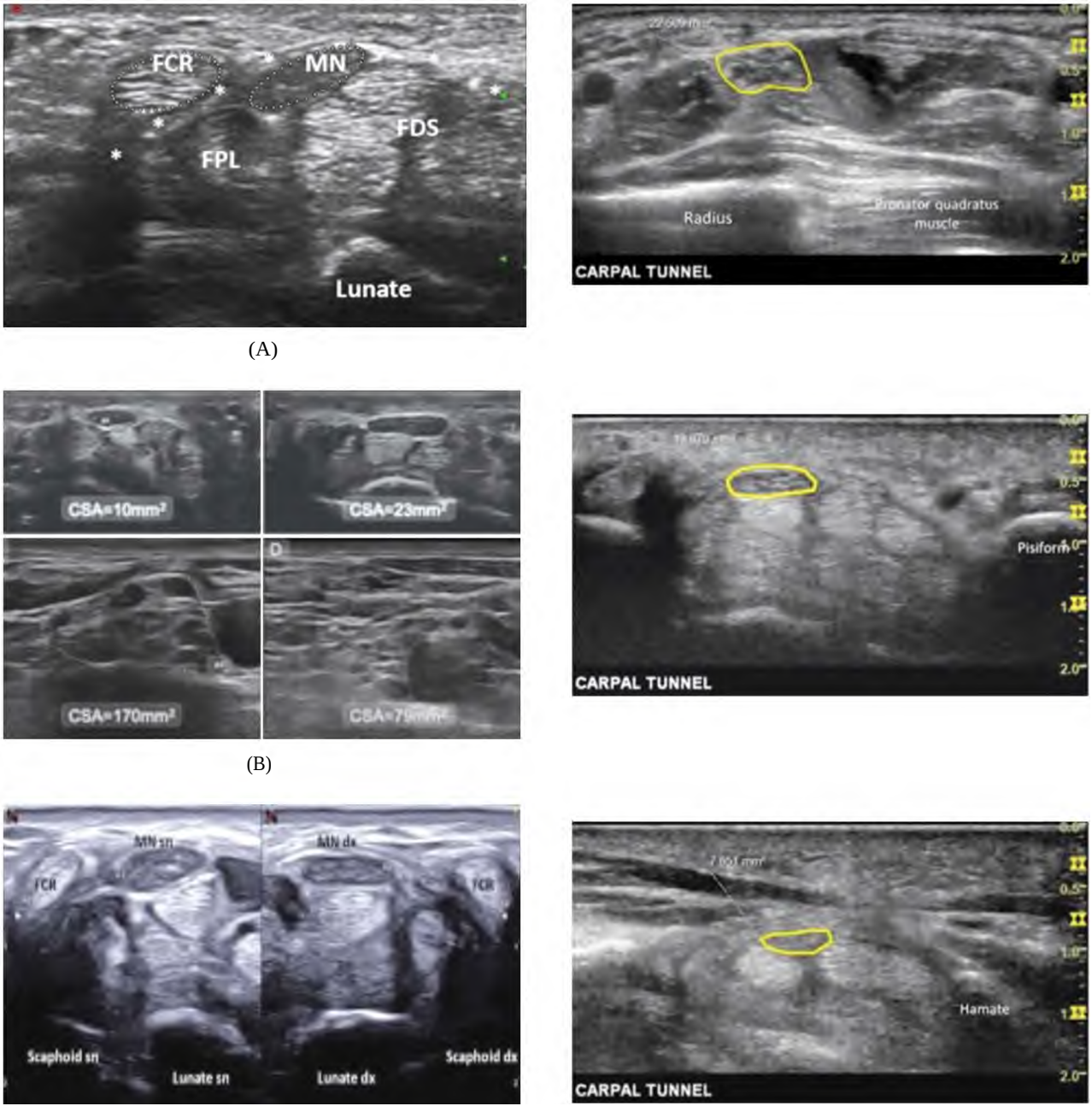

Fig. (1): (A) Median nerve,flexor carpiradialus,flexor polious longus. (B) Cross-section area. (C) Compressed median nerve. (D) Median nerve compression in carpal tunnel syndrome.

The surgical procedure:

The surgical procedure was performed under local anesthesia. The anesthetic needle was placed subcutaneously between the thenar and hypothenar masses proximal to the distal wrist. A 2-3cm incision was made through the skin and the most superficial subcutaneous tissue. A self-locking retractor was placed in the incision with sufficient tension to allow proper exposure and tissue retraction. A reverse blade technique was employed, where the blade was turned upward, and tissues were pushed down with the back of the blade as the tip was lifted and gently pushed forward. Surgical sutures were made with Prolene 3/0.

Postoperative analgesia was provided with intravenous paracetamol, NSAIDs, or nalbuphine 10mg, which could be repeated every 6 hours as needed. Sutures were removed after 14-21 days. Patients were followed up with repeat US at onemonth post-intervention.

The primary outcome was that the US's sensitivity to the diagnosis of CTS was recorded intraoperatively.

Sample size calculation:

The sample size was calculated using the Epi Info 2002 statistical software package. The calculation was based on a 95% confidence level and a previously reported sensitivity of US in the diagnosis of CTS **[17]** of 84.6%, ±10% confidence limit. An additional nine cases were included to account for potential dropouts. Accordingly, a total of 60 cases were planned for recruitment.

Statistical analysis:

Data analysis was performed utlizing SPSS version 26 (IBMInc., Chicago, IL, USA). Continuous variables were expressed as means accompanied by standard deviations (SD) and evaluated for differences between measurements through an unpaired Student's *t*-test. Categorical variables were reported in frequency and percentage and analyzed for differences using the McNemar test. Kappa was used to measure agreement between the surgery and US or NCS to detect CTS. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were used to evaluate diagnostic performance. A two-tailed *p*-value <0.05 was considered statistically significant.

Results

The mean age was 47.3±16.04 years. Sex was male in 22 (36.67%) patients and female in 38 (63.33%). The mean weight was 81.7±13.91Kg. The mean height was 1.67±0.07m. The mean BMI was 29.31±5.59Kg/m^2. Side was right in 29 (48.33%) patients, left in 20 (33.33%) patients and both in 11 (18.33%) patients. The mean duration of symptoms was 7.8±3.06 months.Tinel's test was positive in 53 (88.33%) patients. Phalen's test was positive in 58 (96.67%) patients. Table (1).

Table (1): Demographic data, duration of symptoms, Tinel's and Phalen's test of the studied patients.

	(n=60)
Age (years)	47.3±16.04
Sex:	
Male	22 (36.67%)
Female	38 (63.33%)
Weight (kg)	81.7±13.91
Height (m)	1.67±0.07
Body mass index (kg/m^2)	29.31±5.59
Side:	
Right	29 (48.33%)
Left	20 (33.33%)
Both	11 (18.33%)
Duration of symptoms (months)	7.8±3.06
Tinel's test (Positive)	53 (88.33%)
Phalen's test (Positive)	58 (96.67%)

Data are presented as mean ± SD or frequency (%).

DML and CSA wrist and flattening ratio were significantly lower postoperative than preoperative (p<0.001). APD wrist, flexor retinaculum, motor conduction velocity, and sensory conduction velocity were significantly higher postoperative than preoperative (p<0.001). Table (2).

Table (2): Anteroposterior dimension wrist, cross-sectional area wrist, flexor retinaculum, flattening ratio, distal motor latency, motor conduction velocity, and sensory conduction velocity of the studied patients.

	Pre-operative	Post-operative	*p*-value
Ultrasound measurements:			
Anteroposterior dimension Wrist (mm)	1.9±0.49	2.2±0.48	<0.001
Cross-sectional area Wrist (mm^2)	17.7±4.3	9.4±4.64	<0.001
Flexor retinaculum	0.9±0.4	1.1±0.4	<0.001
Flattening ratio	2.1±0.18	1.9±0.2	<0.001
Nerve conduction studies:			
Distal motor latency	5.7±0.95	4.6±0.99	<0.001
Motor conduction velocity	47.8±5.2	50.7±5.33	<0.001
Sensory conduction velocity	32.9±2.9	41.6±3.01	<0.001

Data are presented as mean ± SD.

CTS was minimal in 17 (28.33%) patients, mild in 15 (25%) patients, moderate in 12 (20%) patients, severe in 6 (10%) patients and extreme in 2 (3.33%) patients. Lipoma was present in 2 (3.33%) patients. AMA was present in 8 (13.33%) patients. Table (3).

Table (3): Carpal tunnel syndrome severity, lipoma, and aberrant median artery of the studied patients.

	(n=60)
Carpal tunnel syndrome severity:	
Negative	8 (13.33%)
Minimal	17 (28.33%)
Mild	15 (25%)
Moderate	12 (20%)
Severe	6 (10%)
Extreme	2 (3.33%)
Lipoma	2 (3.33%)
Aberrant median artery	8 (13.33%)

Data are presented as frequency (%).

The US can significantly predict CTS with 90.4% sensitivity, 87.5% specificity, 97.9% PPV and 58.3% NPV. There was an insignificant difference between surgery and US findings (p=0.219, Kappa=0.643). Table (4).

Table (4): Role of the ultrasound in the prediction of carpal tunnel syndrome.

	Surgery			*p*-value
	Yes	No	Total	
Nerve conduction studies:				
Yes	47	1	48	0.219
No	5	7	12	McNemar test
Total	56	8	60	Kappa
Sensitivity	Specificity	PPV	NPV	0.643
90.4%	87.5%	97.9%	58.3%	

PPV: Positive predictive value.
NPV: Negative predictive value.

The NCS can significantly predict CTS with 86.5% sensitivity, 75% specificity, 95.7% PPV and 46.2% NPV. There was an insignificant difference between surgery and NCS findings (p=0.180, Kappa=0.487). Table (5).

Table (5): Role of nerve conduction studies in the prediction of carpal tunnel syndrome.

	Surgery			*p*-value
	Yes	No	Total	
Ultrasound:				
Yes	45	2	47	0.180
No	7	6	13	McNemar test
Total	56	8	60	Kappa
Sensitivity	Specificity	PPV	NPV	0.487
86.5%	75%	95.7%	46.2%	

PPV: Positive predictive value. NPV: Negative predictive value.

Discussion

US measurement of the MNCSA offers significant diagnostic value, particularly for identifying mild and severe CTS, and is a non-invasive complement to traditional diagnostic techniques **[18].**

The study population exhibited a predominance of overweight individuals with unilateral right-sided CTS in subacute to chronic phases Matching Drakopoulos et al. **[19]**, who observed similar laterality trends in their cohort. In contrast, Braham et al. **[4]** reported 90.9% bilateral CTS in occupational cases, suggesting that occupational repetitive motions may predispose to bilateral involvement. The unilateral predominance could reflect non-occupational etiologies or laterality in daily hand use. The association between overweight status and CTS aligns with pathophysiological mechanisms, as increased adiposity elevates carpal tunnel pressure, exacerbating nerve compression **[20]**. However, Grujoska-Veta et al. **[21]** noted a mean age of 55.4 years in their cohort, which may correlate with chronicity due to prolonged nerve insult.

Our evaluation of clinical provocative tests demonstrated that Phalen's test exhibited superior sensitivity (96.67%) than Tinel's sign (88.33%). These findings were consistent with Braham et al. **[4],** who reported a significant association between positive Phalen's test results and increased CSA (p=0.005) and retinacular bulging (p=0.02). Similarly, Grujoska-Veta et al. **[21]** observed that clinical provocative tests correlated significantly with US-parameters. However, as observed by Kumar et al. **[22],** provocative tests alone may be insufficient for definitive diagnosis or therapeutic decision-making without complementary electrodiagnostic or US assessment.

Significant postoperative improvements were evident in both US and EP parameters (p<0.001), confirming the efficacy of the therapeutic intervention. US assessments revealed a marked reduction in the MN-CSA, aligning with Allam et al. **[23],** who

reported a decreased CSA in healthy individuals compared to CTS patients (p<0.001). Additionally, the increase in APD and the improved nerve flattening ratio areconsistent with findings by Asadov et al. [24] on reduced MN compression post-treatment. EP measurements also demonstrated significant functional recovery, increased motor conduction velocity, in line with Drakopoulos et al. [19], and improved sensory conduction velocity, indicating enhanced neural transmission [4]. Furthermore, the decreased DML corroborates the improvements observed by Yoshii et al. [25] following carpal tunnel release.

The cohort exhibited heterogeneous severity, predominantly minimal (28.33%) and mild (25%) cases, contrasting with Ratasvuori et al. [26], where moderate-severe cases dominated. This discrepancy may arise from earlier detection via the US in our study, as the US detects nerve compression before EP changes manifest [21]. The higher proportion of minimal and mild cases in our cohort may reflect earlier presentations or different referral patterns. Notably, our US evaluation identified anatomical variants potentially contributing to CTS, with AMA detected in 13.33% of patients and lipoma present in 3.33% of cases, aligning with Allam et al. [23], who associated such variants with surgical complexity. These findings underscore the value of the US in identifying structural contributors to CTS, as emphasized by Drakopoulos et al. [19], who similarly reported coexisting pathologies such as tenosynovitis, space-occupying lesions, and supplementary muscles or vessels that may indirectly increase carpal tunnel pressure.

The US demonstrated superior diagnostic performance in our study, with a sensitivity of 90.4%, specificity of 87.5%, PPV of 97.9%, and NPV of 58.3%. These results compare favorably with those reported by Shaukat et al. [27], who documented a sensitivity of 92.8%, specificity of 75%, PPV of 98.1%, NPV of 42.8%, and diagnostic accuracy of 91.6%. Similarly, Dixit et al. [28] reported a USsensitivity of approximately 98.6% with a specificity of 60% when using CSAat the carpal tunnel as the diagnostic criterion. The insignificant difference between surgical and US findings in our study (p=0.219, Kappa=0.643) further validates the US as a reliable preoperative assessment tool. However, our findings diverge some what from those of Erickson et al. [20], whose systematic review concluded that there was insufficient evidence to support routine diagnostic use of US in suspected CTS cases or to replace electrodiagnostic testing.

NCS in our investigation demonstrated robust diagnostic capability with 86.5% sensitivity, 75% specificity, 95.7% PPV, and 46.2% NPV. The insignificant difference between surgical and NCS findings (p=0.180, Kappa=0.487) underscores the complementary nature of EP assessment in CTS diagnosis. These findings align with Grujoska-Veta et al. [21], who reported statistically significant correlations between CSA and electroneuromyography (ENMG) severity (p=0.000003 to p<0.0001). Similarly, Omar et al. [29] documented significant negative correlations between CSA at the carpal tunnel inlet and sensory nerve conduction (r= –0.59, p=0.001), though the correlation with motor nerve conduction was weaker (r=–0.23, p=0.01). Ratasvuori et al. [26] likewise found strong agreement between US, ENMG, and clinical diagnosis (p<0.005), though they noted that 43% of non-CTS patients had false-positive ENMG results. This highlights the importance of integrated multimodal assessment for accurate diagnosis and therapeutic planning [4].

This study's retrospective design, single-center setting, and small sample size limit generalizability. Excluding comorbidities (e.g., diabetes) reduces applicability to broader CTS populations. Short-term follow-up precludes assessing long-term outcomes. Operator dependency on US and EP tests may introduce bias. The absence of blinding during postoperative assessments could affect objectivity.

Conclusions:

US demonstrated superior sensitivity and specificity to NCS in diagnosing CTS, with significant postoperative improvements in MN parameters. Both modalities showed strong agreement with surgical findings. Moreover, the US is valuable in detecting false-negative cases that appear normal on NCS, identifying anatomical anomalies such as an AMA or lipoma that NCS may not detect, and preventing potential surgical complications. The US also facilitates early postoperative follow-up. US enhances overall diagnostic accuracy by providing anatomical information complementary to EP data.

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Conflict of Interest: Nil.

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القيمة المضافة لاستخدام السونار
فى تشخيص وعلاج متلازمة النفق الرسغى

بالرغم من شيوع وقدم المعرفه بمتلازمه النفق الرسغى الا ان التشخيص الاكلينيكى واستخدام رسم العصب وتخطيط العضلات احيانا يكونا غير كافيين.

باضافه استخدام السونار فى التشخيص والمتابعه فوائد عده خصوصاً فى وجود عيوب خلقيه او اورام شحميه او مضاعفات.

لقد أجريت دراستنا على ستين مريضاً يعانون من سمات متلازمه النفق الرسغى.

خضع المرضى للتقييم الإكلينيكى و ورسم العصب وتخطيط العضلت والتصويرى بالموجات الصوتيه السونار قبل إجراء الجراحة وتم متابعتهم لمدة ستة أشهر.

ضمت الدراسة ستين مريضاً كان منهم اثنين وعشرين ذكراً و ثمانية وثلاثين من الإناث وتراوح عمرهم بين عشرين وخمس وستين عاماً بمتوسط عمر ٤٧,٢ عاماً.

ولقد تطابقت نتائجنا مع من سبقنا من الباحثين المستخدمين لنفس الطريقة فى التشخيص والمتابعه باضافه دقه اكبر للتشخيص والمتابعه والعلاج .

الإستنتاج: اضاف استخدام الموجات الصوتيه فى تشخيص متلازمه النفق الروسغى دقه اكثر فى التشخيص خصوا فى الحلات السلبيه الكاذبه فى رسم العصب بالرغم من وجود تشخيص اكلينكى قوى كما ساعد فى تجنب النزيف الشديد اثناء العمليه لوجود الشيريان الاوسط الخلقى كما ساعد فى تشخيص وجود اساباب اخرى مثل الاورام الشحميه كما تميز السونار بسرع تشخيص التحسن او المضاعفات لذلك يوصى باستخدام السونار مع التشخيص الاكلينيكى ورسم العصب لدقه اكبر ونتائج افضل.