The Egyptian Journal of Hospital Medicine (October 2025) Vol. 101, Page 4643-4649

Correlation between Ultrasound Findings and Nerve Conduction Studies in Evaluation of Upper Limb Neuropathy

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ABSTRACT
Background: Entrapment neuropathy (EN), also termed impingement or compression neuropathy, refers to a clinical condition resulting from peripheral nerve compression within narrow anatomical spaces or tunnels, secondary to causes such as trauma, congenital anomalies, tumors, or metabolic disorders.
Objective: This work assessed the correlation between high-resolution ultrasound (US) findings and nerve conduction studies (NCS) in upper-limb EN.
Patients and Methods: This prospective study involved 54 patients attending the neurology outpatient clinic with suspected unilateral or bilateral upper-limb nerve entrapment underwent US, Doppler sonography, and NCS.
Results: There was significant association between patients' nerve conduction results and ultrasonography doppler activity. The ultrasonography doppler activity outcomes were statistically significantly related to nerve conduction outcomes (p-value<0.001) with Substantial agreement as kappa co-efficient = 0.653.
Conclusion: High-resolution US is a powerful adjunct to NCS in diagnosing upper-limb EN. Marked Doppler hyper-vascularity and enlargement of the nerve cross-sectional area (CSA) were strongly associated with abnormal electrophysiologic results,
Keywords: Ultrasound Findings, Nerve Conduction Studies, Upper Limb Neuropathy.

INTRODUCTION

Entrapment neuropathy (EN), also termed *impingement syndrome* or *compression neuropathy*, refers to peripheral nerve compression within narrow anatomical passages or tunnels along its course, secondary to trauma, congenital anomalies, tumors, or metabolic disorders [1]. The terms *entrapment* and *compression* indicate that the pathology arises from external mechanical factors rather than intrinsic neural disease. The prevalence of EN varies, with some neuropathies being common and others rare[2].

EN can involve both upper and lower limbs; however, upper-limb EN is more frequent. The most prevalent is carpal tunnel syndrome (CTS), followed by cubital tunnel syndrome (CuTS) and other ulnar neuropathies [3, 4]. Despite differences in anatomical distribution, these neuropathies share similar pathophysiology and therapeutic principles [5]. The upper limb is innervated by branches of the brachial plexus (BP), which forms in the posterior cervical triangle and extends into the axilla, where peripheral nerves destined for the upper extremity originate [6].

After exiting the BP, these nerves traverse the arm and forearm, passing through relatively fixed anatomical tunnels, particularly near the elbow joint. Pathological conditions, such as chronic kidney disease (CKD), diabetes mellitus (DM), thyroid dysfunction, or local fractures, can cause swelling within these confined spaces, resulting in nerve compression. This compression compromises microvascular perfusion, producing focal ischemia and subsequent symptoms including pain, paresis, sensory deficits, and muscle weakness within the nerve's distribution [5].

Nerve conduction studies (NCS) remain the primary confirmatory test for EN diagnosis, though they have limitations. NCS may fail to detect early or mild neuropathy, yield false negatives, and are more effective for large, myelinated fibers without precisely localizing entrapment sites. They may also be uncomfortable, costly, and yield variable results [7].

Ultrasound (US) is an effective first-line imaging modality for EN, offering affordability, speed, high spatial resolution, and dynamic nerve assessment. The ultrasonographic Tinel's sign, paresthesia elicited by probe pressure at the entrapment site, can provide supportive diagnostic evidence. US also facilitates real-time clinical correlation and history-taking [8].

High-resolution US enables evaluation of nerve echotexture and cross-sectional area (CSA), while Doppler imaging can assess intraneural hyperemia, inflammation, and vascular compromise [7].

This work aimed to assess the correlation between US findings and NCS in the evaluation of upper-limb EN.

PATIENTS AND METHODS

This current prospective study was carried out on 54 patients from the Neurology outpatient clinic with a provisional diagnosis of unilateral or bilateral upper limb nerve entrapment at the Radiology Department in National Institute of Neuromotor System.

The study was conducted after approval of the Research Ethics Committee and was adhered to the Helsinki Declaration. Informed written consent was obtained from each patient.

Inclusion criteria were adult patients with clinical symptoms and signs of upper limb nerve entrapment and underwent nerve conduction study (NCS).

Received: 11/07/2025
Accepted: 11/09/2025

Exclusion criteria were patients with provisional diagnosis of cervical radiculopathy and with history of surgery in the upper limb.

All patients underwent a standardized diagnostic protocol that included complete history taking, covering personal history, presenting complaint and its duration, present illness, history of drug sensitivities, past medical history, and past surgical history. Physical examination involved the assessment of vital signs and inspection for signs of pallor, cyanosis, jaundice, and lymph node enlargement. Radiological investigations consisted of US examination and Doppler sonography.

Ultrasound Examination: Ultrasound imaging was performed using a Toshiba HD6 machine equipped with a 3–12 MHz linear probe. B-mode (gray-scale) imaging was used for anatomical assessment, while color Doppler was employed for vascular evaluation. During the examination, the patient was positioned seated in front of the radiologist with the arm positioned according to the nerve being assessed, ensuring the limb remained relaxed to avoid compression artifacts. The cross-sectional area (CSA) of each nerve was measured three times at each site, and the mean of the three measurements was recorded as the final value. The nerve margin was identified as the interface between hypoechoic nerve fascicles and the hyperechoic nerve sheath and was traced using the ultrasound caliper.

For detection of the median nerve at the wrist (carpal tunnel), the probe was placed on the distal forearm in a transverse orientation. Anatomical and sonographic landmarks of the carpal tunnel included the lunate and capitate bones forming the floor, with four bony structures defining the sides: proximally the pisiform and scaphoid tubercle, and distally the hook of hamate and trapezium tubercle.

For identification of the ulnar nerve at the wrist (Guyon canal), the probe was positioned over the canal, which lies lateral to the pisiform bone. The ulnar nerve was visualized as a hypoechoic fascicular structure located lateral to the ulnar artery in a transverse orientation.

For assessment of the ulnar nerve at the elbow (cubital tunnel), the probe was placed posterior to the medial epicondyle. Anatomical landmarks included the medial epicondyle anteriorly, the olecranon posteriorly, and Osborne’s ligament together with the flexor carpi ulnaris (FCU) forming the roof.

For evaluation of the radial nerve at the spiral groove, the probe was positioned over the mid-humerus and moved proximally and distally to locate the humeral shaft as the main bony landmark. The radial nerve was identified as a hypoechoic fascicular structure adjacent to the humerus.

For brachial plexus assessment, probe positioning varied according to the part examined. To visualize the roots (interscalene part), the probe was placed in a transverse orientation opposite the level of the cricoid cartilage (approximately C6), between the scalene muscles. For the trunks and divisions (supraclavicular part), the probe was positioned transversely superior to the clavicle, lateral and posterior to the subclavian artery. For the cords and branches (infraclavicular part), the probe was positioned transversely inferior to the clavicle, medial to the coracoid process, surrounding the axillary artery.

Doppler Sonography Examination Technique

Doppler sonography was performed using gray-scale and color Doppler with a linear 7–15 MHz transducer (HDI 5000, Advanced Technology Laboratories). The patient’s position was adjusted according to the nerve being assessed. The color Doppler box was minimized to include only the nerve, and Doppler gain together with the pulse repetition frequency (PRF) were adjusted for optimal sensitivity. PRF was set at 800 Hz, and Doppler gain was increased to the maximum level that avoided clutter artifacts. The examination focused on detecting increased intraneural vascularity, as normal nerves typically show minimal or no detectable blood flow. Color Doppler settings were optimized for low-flow vessel detection. All sonograms were digitally stored using a picture archiving and communication system (PACS).

Ethical considerations

The study was conducted after obtaining approval from the Research Ethics Committee of the Faculty of Medicine, Menoufia University. Written informed consent was obtained from all participants prior to enrolment. The consent form clearly stated their voluntary agreement to participate in the research and to allow publication of anonymized data, with full assurance of confidentiality and privacy protection. All procedures were carried out in accordance with the ethical principles of the World Medical Association’s Declaration of Helsinki for research involving human subjects.

Statistical analysis

Statistical analysis was performed using SPSS, Statistical Package. Qualitative data were represented as frequency and percentage. Quantitative data were presented as Mean Standard Deviations, Median, and Range. A two tailed P value < 0.05 was considered significant. ROC curve was performed for prediction of upper limb neuropathy.

RESULTS

Table 1: Demographic and Clinical Characteristics of the Study Participants

Parameter		**N**	**%**
Age (Year)		36.41 ± 12.17	
Age groups			
18-29		14	25.9
30-39		18	33.3
40-49		13	24.1
>50		9	16.7
Gender			
Male		28	51.9
Female		26	48.1
Parameter		**N**	**%**
Side	Right	28	51.9
	Left	26	48.1
Cause	Entrapment	21	38.9
	Trauma	33	61.1
Nerve conduction	Negative	7	13.0
	Positive	47	87.0
Ultrasound findings			
Doppler activity		44	81.5
Muscle atrophy		31	57.4
Cross section area		0.269 ± 0.19	
Nerve affected			
Brachial plexuses		6	11.1
Median Nerve		26	48.1
Radial Nerve		8	14.8
Ulnar Nerve		14	25.9
Clinical Data		**N**	**%**
Pain		28	51.9
Numbness		3	5.6
Weakness		31	57.4
Paresthesia		11	20.4

Data is expressed as the mean ±SD. **N**= Number, **%= percentage.**

Demographic data of the patients and Clinical features of the patients with upper limb neuropathy, ultrasound findings and nerve conduction studies were shown in **Table 1**.

Table 2: Association between patients' nerve conduction results and ultrasonography muscle atrophy

Muscle atrophy	**Nerve conduction**						χ^2	**P-value**
	Negative (n = 7)		**Positive (n= 47)**		**Total (n= 54)**			
	No.	**%**	**No.**	**%**	**No.**	**%**		
No	1	14.3%	22	46.8%	23	42.6%	2.636	0.104
Yes	6	85.7%	25	53.2%	31	57.4%		
Total	7	100.0%	47	100.0%	54	100.0%		

There was no significant association between patients' nerve conduction results and ultrasonography muscle atrophy (**Table 2)**.

Table 3: Association between patients' nerve conduction results and ultrasonography doppler activity

Ultrasonography doppler activity	**Nerve conduction**				**Total**		χ^2	**P-value**
	Negative (n = 7)		**Positive (n= 47)**					
	No.	**%**	**No.**	**%**				
No	6	85.7%	4	8.5%	10	18.5%	24.06	<0.001*
Yes	1	14.3%	43	91.5%	44	81.5%		
Total	7	100.0%	47	100.0%	54	100.0%		

There was significant association between patients' nerve conduction results and ultrasonography doppler activity (**Table 3)**.

Table 4: Agreement (sensitivity, specificity and accuracy) for ultrasonography doppler activity

Ultrasonography doppler activity	Nerve conduction				Sensitivity (%)	Specificity (%)	PPV	NPV	Accuracy (%)
	Negative (n = 7)		Positive (n= 47)						
	No.	%	No.	%					
No (n=10)	6	85.7%	4	8.5%	91.5	85.7	97.7	60.0	90.7
Yes (n=44)	1	14.3%	43	91.5%					
(PV)	0.653 (<0.001*)								
Level of agreement	Substantial agreement								

K: Kappa test **PPV**: Positive predictive value **NPV**: Negative predictive value, *: significant p value <0.05. PV: ?

The ultrasonography doppler activity outcomes were statistically significantly related to nerve conduction outcomes (p-value<0.001) with Substantial agreement as kappa co-efficient = 0.653 (**Table 4)**.

Table 5: comparison between patients' nerve conduction results as regards cross section area

Cross section area	Nerve conduction						Mann-Whitney U Test	
	Negative (n = 7)			Positive (n= 47)			U	P-value
Range	0.04	-	0.38	0.01	-	0.93	44.00	<0.001*
Mean ±SD	0.12	±	0.116	0.29	±	0.196		
Median (IQR)	0.09(0.06-0.09)			0.25(0.13-0.40)				

*: significant p value <0.05.

Comparison between nerve conduction results showed that the median (IQR) of cross section area in negative patients was 0.09(0.06-0.09) statistically significantly lower than the median (IQR) in positive patients which was 0.25(0.13-0.40) (P-value<0.001) (**Table 5)**.

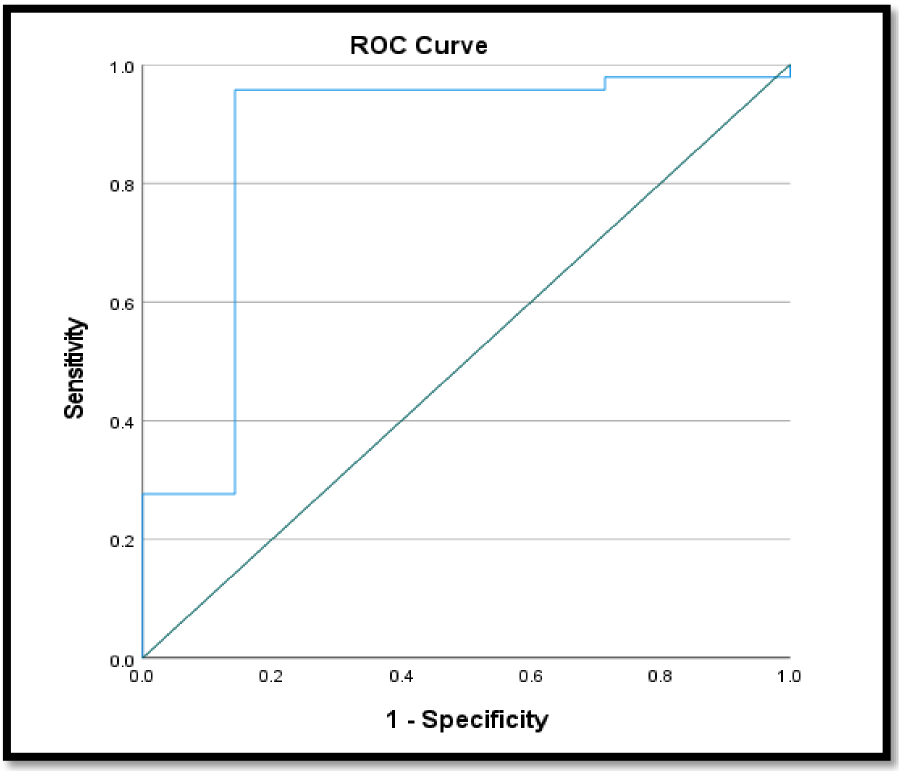

Figure 1: ROC curve for cross section area for prediction of upper limb neuropathy.

ROC results revealed that the cross-section area cutoff value is equal or more than 0.10 cm^2 and the area under the ROC curve is equal to 0.866 which indicate that it is an excellent predictor for prediction of upper limb entrapment neuropathy. The sensitivity, specificity, positive predictive, negative predictive, accuracy values of cross section area for prediction of upper limb entrapment neuropathy were 95.7%, 85.7%, 97.8%, 75% and 94.4% respectively (**Figure 1).**

A female patient 45 years old reported Erb's palsy, complaining of left hand tingling , pain and weakness (**Figure 2).**

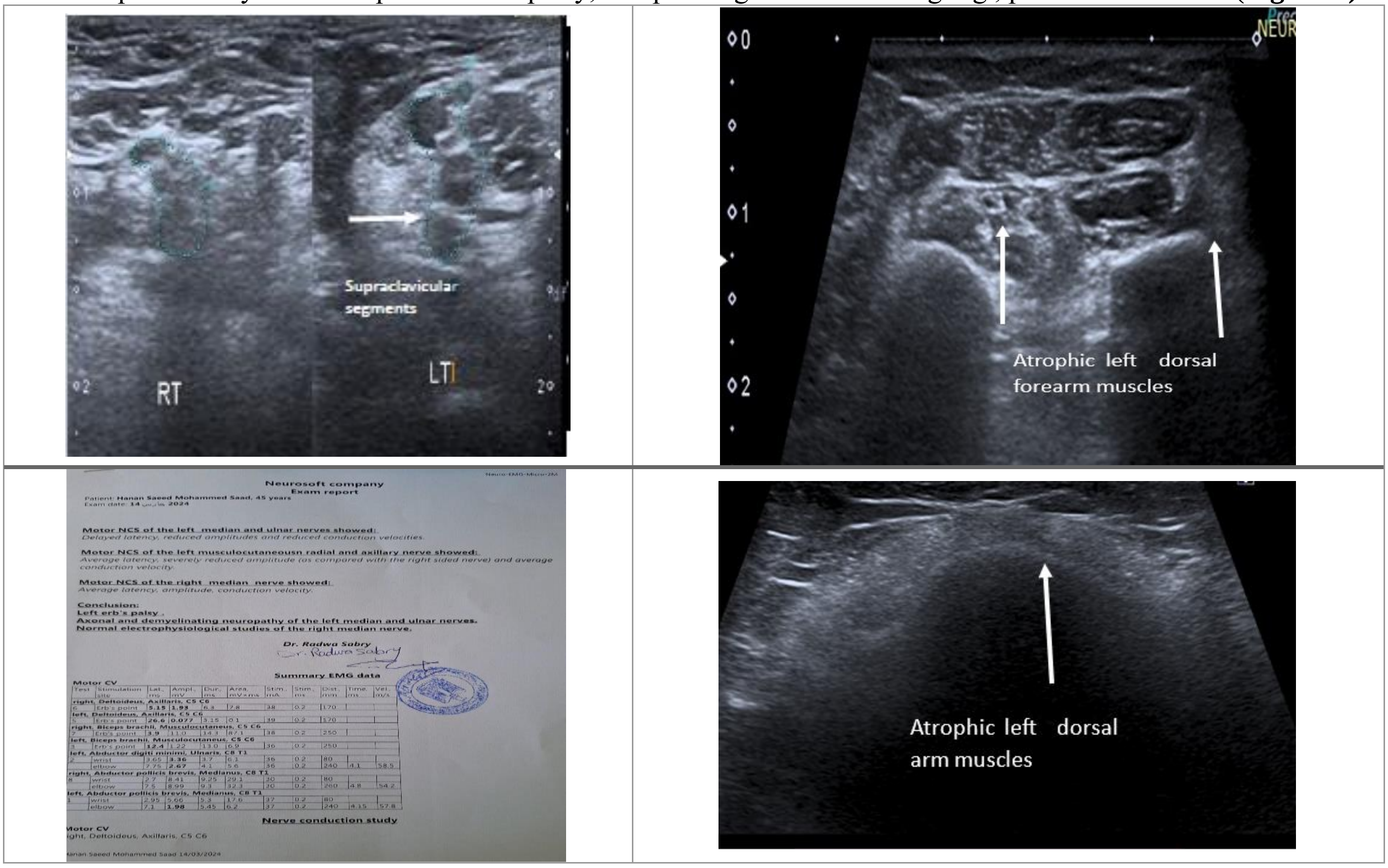

Figure 2: Real time U/S showing : diffuse swelling of the supraclavicular segments of the left brachial plexus more along C6 down C8 levels with no transaction . Variable atrophic changes along the arm and the forearm of the left upper limb muscles more along the shoulder girdle, posterior arm and volar forearm . The nerve conduction studies showing : Axonal and demyelinating neuropathy of the left median and ulnar nerve.

DISCUSSION

High-resolution US has emerged as a valuable complement to NCS in the evaluation of upper limb neuropathies. Entrapment neuropathies like CTS (median nerve compression at the wrist) and cubital tunnel syndrome (ulnar nerve at the elbow) are common, often presenting with pain, paraesthesia, and numbness in the affected hand [9]**.**

This study showed a mean patients' age of 36.4 ± 12.2 years ranging from 17 to 65 years with nearly equal gender distribution. This concurs with the typical demographic for idiopathic entrapment neuropathies like CTS, which often affect middle-aged individuals as described by **Zaki *et al*.** [10]. However, the equal gender split in the study (approximately 1:1) is noteworthy, since CTS alone usually shows a female predominance (three to ten times more common in women).

The side of involvement was almost even (right side 51.9%, left 48.1%), suggesting no strong laterality bias in this cohort. This near-equal side distribution aligns with some clinical observations as described by **Mohammadi *et al*.** [11] and **Vo *et al*.** [12] and **Rayegani *et al*.** [9] who, in alignment with our findings, studied 96 cases of nerve entrapment without emphasizing a side predilection, implying both hands were commonly affected (often bilaterally).

In this study, NCS were positive in 87% of patients with suspected neuropathy, meaning 13% had normal or inconclusive electrodiagnostic results despite clinical signs. Electrodiagnostic tests can miss mild or early cases of entrapment, the sensitivity of NCS was described to be 73.4% by a meta-analysis conducted by Demino and Fowler., [13] that was based on 19 studies with a total of 2927 limbs, so false negatives are not uncommon.

Ultrasound, on the other hand, was abnormal in a high proportion of the study patients: 81.5% showed Doppler-detected intraneural blood flow increase and 57.4% showed muscle atrophy in the US. In fact, some recent studies have found ultrasound can detect nerve abnormalities when NCS cannot such as reported by **Catanzaro *et al*.**, [14] who found positive ultrasound evidence of nerve in 81.2% confirmed cases, whereas NCS was positive in only 71.8%. Similar data were reported by **Yoon *et al*.** [15] and **Kutlar *et al*.** [16] who advocated ultrasound as an adjunct or even alternative in difficult cases.

The distribution of nerves affected in the study was: median nerve 48.1%, ulnar nerve 25.9%, radial nerve 14.8%, and brachial plexus 11.1%. Median nerve entrapment is well-known to be the single most frequent upper limb entrapment neuropathy, often quoted to constitute about 90% of all entrapment neuropathies as found by **Mohammadi *et al*.** [11]and **Ghasemi *et al*.** [17].

The next most common in the cohort was the ulnar nerve (about 26%), which aligns with ulnar nerve at the elbow being frequently encountered in clinical practice after median nerve as described by **Mezian *et al*.** causing [18] numbness in the ring and little fingers and hand weakness.

Patients in the current study presented with various chief complaints: 51.9% reported pain, 57.4% weakness, 20.4% paraesthesia, and only 5.6% numbness (some patients clearly had multiple symptoms). This is consistent with typical neuropathies symptoms described in previous studies such as **Rayegani *et al*.** [9] and **Yi *et al*.** [18].

As for the ultrasound-detected muscle atrophy versus NCS findings, over half of the patients (57.4%) had muscle atrophy evident on ultrasound, meaning the muscles innervated by the affected nerve had reduced bulk or increased echogenicity (fatty replacement) indicative of chronic denervation. Surprisingly, the study found no significant association between the presence of muscle atrophy on US and the NCS results. Indeed**, Kim *et al*.** [19] noted that thenar muscle atrophy is a sign of severe, long-term median nerve compression, and it correlates with the severity of CTS on electrodiagnostic grading. They described that thenar atrophy and impaired sensation are indicators of advanced median neuropathy.

Regarding Doppler ultrasound hypervascularity and its correlation with NCS, a key finding of this study was a significant association between Doppler-detected intraneural blood flow (hypervascularity) on ultrasound and the NCS results. They reported a $p<0.001$ for this association with a kappa coefficient of 0.653, indicating substantial agreement. This finding is strongly supported by recent literature. **Kutlar *et al*.** [16] found that Doppler results "strongly correlate with CTS severity". They observed a significant positive correlation between the presence/intensity of intraneural hypervascularity and the electrophysiologic grading of CTS (with $p<0.005$ across severity stages). More recently, **Rayegani *et al*.** [9] in their CTS severity study noted that hypervascularity tends to accompany higher ultrasound cross-sectional area in severe cases, implicitly tying to worse NCS grades (though their focus was CSA).

The present study performed an ROC curve analysis and determined that a nerve cross-sectional area ≥0.10 cm² (≥10 mm²) was an excellent predictor of entrapment neuropathy with an area under the curve (AUC) of 0.866 for this cutoff, with sensitivity 95.7%, specificity 85.7%, positive predictive value (PPV) 97.8%, negative predictive value 75%, and overall accuracy 94.4%. This finding is very much in line with recent studies, particularly for carpal tunnel syndrome. Multiple investigations have hovered around the 9–10 mm² cutoff for median nerve CSA at the wrist as optimal. For instance, **Zaki *et al*.** [10] found that a pisiform-level CSA >9.5 mm² yielded a sensitivity of 95.2% and specificity of 97.4% for diagnosing CTS. **Ghasemi *et al*.** [17] similarly reported that a CSA >0.10 cm² was the best cutoff in an Iranian population. The convergence of evidence around 10 mm² is notable: it appears to be a universal benchmark above which the probability of true entrapment is very high.

CONCLUSION

High-resolution ultrasound is a powerful adjunct to nerve-conduction studies (NCS) in diagnosing upper-limb neuropathies. Marked Doppler hyper-vascularity and enlargement of the nerve cross-sectional area (CSA) were strongly associated with abnormal electrophysiologic results. In contrast, ultrasound-detected muscle atrophy did not correlate significantly with NCS, suggesting that structural denervation changes lag behind functional impairment. Median-nerve entrapment and trauma-related injuries comprised the majority of cases, and the right-to-left distribution was nearly equal, highlighting the need for bilateral evaluation.

Financial support and sponsorship: Nil.
Conflict of Interest: Nil.

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