The value of neuromuscular ultrasound in relation to clinical and electrophysiological testing in the diagnosis of thoracic outlet syndrome

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Background

Thoracic outlet syndrome (TOS) diagnosis has long been challenging and controversial with no available golden standard diagnostic test.
Objectives To assess the value of NMUS as a new diagnostic tool for TOS and compare it with other clinical and electrophysiological studies.

Patients and Methods

This study was conducted on 20 patients with clinical TOS and 10 healthy controls. They were subjected to history taking, clinical examination, provocative tests, functional assessment using shoulder pain and disability index, electrophysiological and imaging studies including x-ray and NMUS. Pectoralis minor muscle deformation and brachial plexus compression was detected using NMUS by measuring the pectoral bowing ratio (PBR), PBR is significant if >10% on provocation with arm abduction.

Results

In this case control study, mean age of 20 patients was 34.20±9.52. Female:male ratio was 13:7 without significant difference between patients and controls regarding age or sex. Mean pain and disability scores were 73±13.42 and 55.30±15.68 respectively. Compound medial antebrachial cutaneous (MAC) nerve conduction and F-wave studies was positive in 85% of patients and none of the controls. Similarly, NMUS positive finding was detected in 75% of patients and none of the controls with highly significant difference between two groups, $P<0.01$. Diagnostic accuracy (DA) of NMUS for TOS was 83.3% comparable to x-ray and compound MAC, F-wave studies (DA=93.3%, 90% respectively).

Conclusion

Neuromuscular ultrasonography is an important, painless, sensitive tool for assessment of TOS. It is complementary to other imaging and electrophysiological studies and their combination could help in objective diagnosis of TOS.

Introduction

Thoracic outlet syndrome (TOS) was described in 1956 by Peet *et al.* [1] and refers to a group of disorders affecting the brachial plexus, the subclavian vessels, or both, at any point between the base of the neck and the axilla, with several anatomical sites for compression including the interscalene triangle, costoclavicular space, and coracopectoral tunnel [2].

For the diagnosis of TOS, a number of clinical, radiographic, and electrodiagnostic tests have been described. However, many tests are considered unreliable and there is not a single test that is regarded as the 'gold standard' diagnostic test.

Roos [3] stated that the diagnosis must rely on a thorough history and clinical TOS provocation tests findings. Multiple provocative tests were implemented

for the diagnosis of TOS such as Adson's test, hyperabduction test, elevated arm stress test (EAST), and costoclavicular test. The sensitivity and specificity mostly improved when several provocative tests were used in combination [4].

Medial antebrachial cutaneous (MAC) sensory nerve conduction study is an objective tool for confirming true neurological TOS diagnosis. However, standard motor and sensory nerve conduction studies were mainly used for excluding other differential diagnosis of TOS [5,6]. Also F-wave studies add to the weight of TOS diagnosis especially if done with provocative

manoeuvers, which may help to uncover the subtle electrodiagnostic (EDS) abnormalities related to TOS.

Neuromuscular ultrasound (NMUS) is a new imaging modality for examining nerve structures within the thoracic outlet area [7]. In postural TOS, NMUS shows an indentation in the posterior edge of the pectoralis minor by the neurovascular bundle and simultaneous triggering of symptoms of TOS with arm abduction [8]. Thus, we need to evaluate NMUS as a new modality that could aid in the objective diagnosis of TOS.

Aim

The aim of this study was to assess the value of NMUS as a new diagnostic tool for TOS with positive clinical provocative tests and to compare NMUS study with clinical and electrophysiological studies.

Patients and methods

This study was conducted on 20 patients with clinical signs and symptoms of TOS. Ten healthy participants who were matched for age and sex served as a control group. The patients were recruited from Physical Medicine, Rheumatology and Rehabilitation Department outpatient clinic. All patients gave their informed consent to participate in the study. The procedures of the study were in accordance with the Declaration of Helsinki and approved by our institutional ethics committee. The patients included are those having positive vascular and/or neurological findings with clinical provocative tests suggestive of TOS. Excluded were those showing shoulder pathology, cervical radiculopathy, brachial plexus neuritis or injury, peripheral nerve entrapment, or neuropathic affection due to other pathologies.

All patients and controls were subjected to the following:

(1) Full medical history taking stressing on occupation and disease duration.
(2) Thorough clinical examination including four clinical provocative tests such Adson's test, costoclavicular, hyperabduction, and EASTs to detect the different sites of compression and to be more cumulative for sensitivity and specificity of the diagnosis [4].
(3) Functional assessment:
    Functional assessment using shoulder pain and disability index [9].
(4) Electrodiagnostic testing:

Nerve conduction studies were done using Toennies Neuroscreen (Toennies Neuroscreen Plus; Toennis, Hoechberg, Germany) electrodiagnostic device. In motor studies, responses were recorded at a sweep speed of 5 ms/division and gain of 4 mV. In sensory studies, sweep was adjusted at 2 ms and gain at 20 uV. Temperature was kept constant through all the tests at 33–34°C. Studies included sensory and motor nerve conduction studies for ulnar and median nerves to exclude other causes of peripheral neuropathies and/or cervical radiculopathies, MAC nerve conduction studies to provide an objective evidence of neurogenic thoracic outlet syndrome (nTOS) as well as F-wave studies which may help to uncover the subtle electrodiagnostic studies abnormalities related to TOS [10]. F-wave studies were done for both median and ulnar nerves in neutral position and with arm abduction provocation.

(5) Imaging modalities:
    (a) Radiograph of the chest and cervical region:
        Anteroposterior and lateral plains for diagnosing the causes of TOS and excluding other shoulder and upper limb causes of pain.
   (b) NMUS:
        We used the General Electric logic P5 and P6 7–13 MHz system with linear probe (11 l). The imaging time was 5–10 min per side studied. NMUS positive finding was the presence of significant bowing ratio of the neurovascular bundle while being impinged under the pectoralis minor muscle (PMM) posterior edge during arm abduction 'pectoral bowing ratio (PBR).'

PBR measures the deformation of the PMM during arm abduction. This ratio reflects the amount of indentation by the neurovascular bundle as it is tethered under the shortened muscle as the arm abducts above 90°. The PBR is calculated by first obtaining the linear distance (line A-A) across the posterior edges of the PMM under the apex of indentation, then obtaining the vertical distance (line B-B) from line A-A to the apex of the PMM, finally dividing B-B by A-A and is considered abnormal if more than 10% as shown in [8] Fig. 1.

Statistical analysis

The clinical, electrophysiological, and imaging data were recorded on an investigative report form. These data were transferred to an IBM card using IBM-PC with statistical program SPSS, Windows, version 22 (IBM Corp., Armonk, NY, USA), to obtain descriptive statistics including mean, SD, range (minimum–maximum), and number and percent (for qualitative data) and analytical statistics including

Figure 1
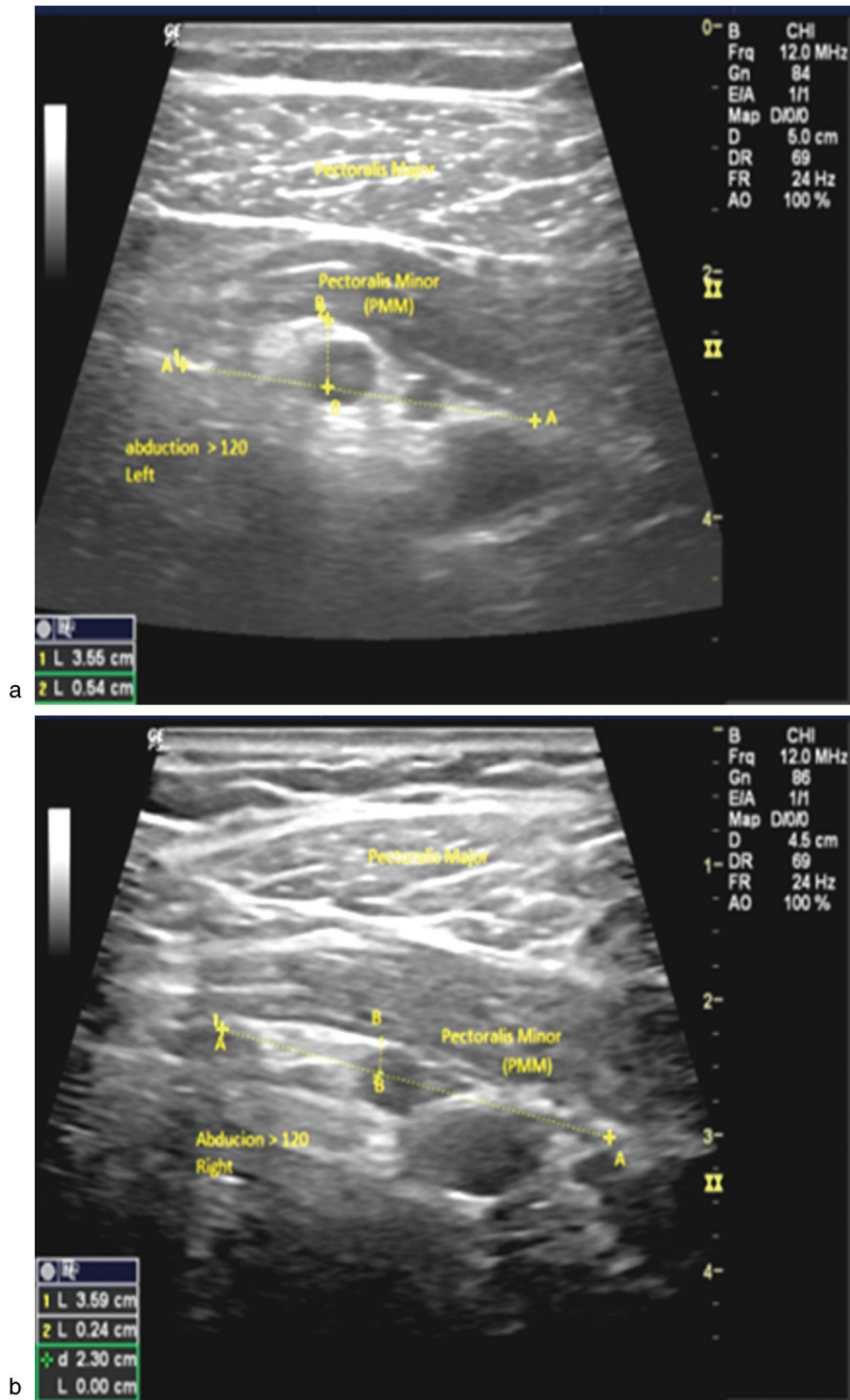
(a) Image showing neuromuscular ultrasound assessment of patients with left thoracic outlet syndrome; the left arm was abducted more than 120 with impingement of neurovascular bundle 'pectoral bowing ratio' (line B-B) under the pectoralis minor muscle (PMM) posterior edge (line A-A) with (B-B)/(A-A) exceeding 15%. (b) Normal right side of the same patient was assessed during arm abduction more than 120 with no significant impingement and the same ratio was not exceeding 10%.

Student's t test comparing between two independent means, χ^2 test used for qualitative data, and P value describing the level of significance which could be nonsignificant if P value more than 0.05, significant if P value less than 0.05, and highly significant if P value less than 0.01.

Evaluation of diagnostic methods

$$\text{Sensitivity} = \frac{\text{true positive}}{\text{true positive} + \text{false negative}} \times 100.$$

Table 1 Comparison between the control group and patient's group regarding demographic data

	Control group (N=10)	Patients group (N=20)	*t* test value	*P* value	Significance
Sex [*n* (%)]					
Females	7 (70.0)	13 (65.0)	0.075[a]	>0.05	NS
Males	3 (30.0)	7 (35.0)			
Age					
Mean±SD	35.40±9.17	34.20±9.52	0.329[b]	>0.05	NS
Range	21–49	21–49			

[a]χ^2 test. [b]Independent *t* test. *P* value more than 0.05, nonsignificant.

Table 2 Comparison between patients and control groups as regards sensory nerve conduction studies

	Control group (N=10)	Patients group (N=20)	*t* test	*P* value	Significance
MSL (ms)					
Mean±SD	2.74±0.19	2.68±0.26	0.651	>0.05	NS
Range	2.5–3	2.1–3			
USL (ms)					
Mean±SD	2.69±0.20	3.00±0.89	1.074	>0.05	NS
Range	2.4–3	2.4–6.3			
DCL (ms)					
Mean±SD	2.77±0.17	2.68±0.22	1.151	>0.05	NS
Range	2.5–3	2.2–3			
MAC L (ms)					
Mean±SD	2.77±0.17	3.44±1.05	1.971	>0.05	NS
Range	2.5–3	2.1–5.9			
MAC A (uV)					
Mean±SD	11.54±2.64	10.95±6.33	0.281	>0.05	NS
Range	7–15	2.5–34			
MAC sensory [*n* (%)]					
Negative	10 (100.0)	10 (50.0)	7.500	<0.01	HS
Positive	0 (0.0)	10 (50.0)			
MAC+F-wave [*n* (%)]					
Positive	0 (0.0)	17 (85.0)	19.615	<0.01	HS
Negative	10 (100.0)	3 (15.0)			

DCL, dorsal cutaneous nerve latency; HS, highly significant; MAC L/A, medial antebrachial cutaneous nerve latency, amplitude; MAC+F-wave, summation of medial antebrachial cutaneous and F-wave studies positive cases; MSL, median nerve sensory latency; USL, ulnar nerve sensory latency, MAC sensory represents the number of cases with abnormal latency and/or amplitude. *P* value more than 0.05, nonsignificant; *P* value less than 0.01, highly significant.

(1) Specificity=true negative/true negative+false positive×100.
(2) Positive predictive value=true positive/true positive+false positive×100.
(3) Negative predictive value=true negative/true negative+false negative ×100.
(4) Test accuracy=true positive+true negative/total number.

Results

This study was conducted on 20 patients with clinical signs and symptoms suggesting of TOS. There were 13 (65.0%) women and seven (35.0%) men with age ranged between 21and 49 years. Ten healthy matched controls were included. There were seven (70.0%) women and three (30.0%) men as shown in Table 1.

History taking and thorough clinical examination revealed that most of the patients gave history and showed clinical symptoms and signs suggestive of nTOS in the form of pain and paresthesia with only one patient showing weakness symptoms and signs. One patient gave history and showed clinical symptoms and signs suggestive of vascular TOS.

Clinical provocative tests revealed Adson test positive in 10 (50%) patients, costoclavicular test: this showed positive findings in two (10%) patients, EAST: this showed positive in all patients (100%) while hyperabduction test was positive in 16 (80%) patients.

Electrophysiological studies revealed positive findings regarding F-wave studies with loss of persistence in

Figure 2
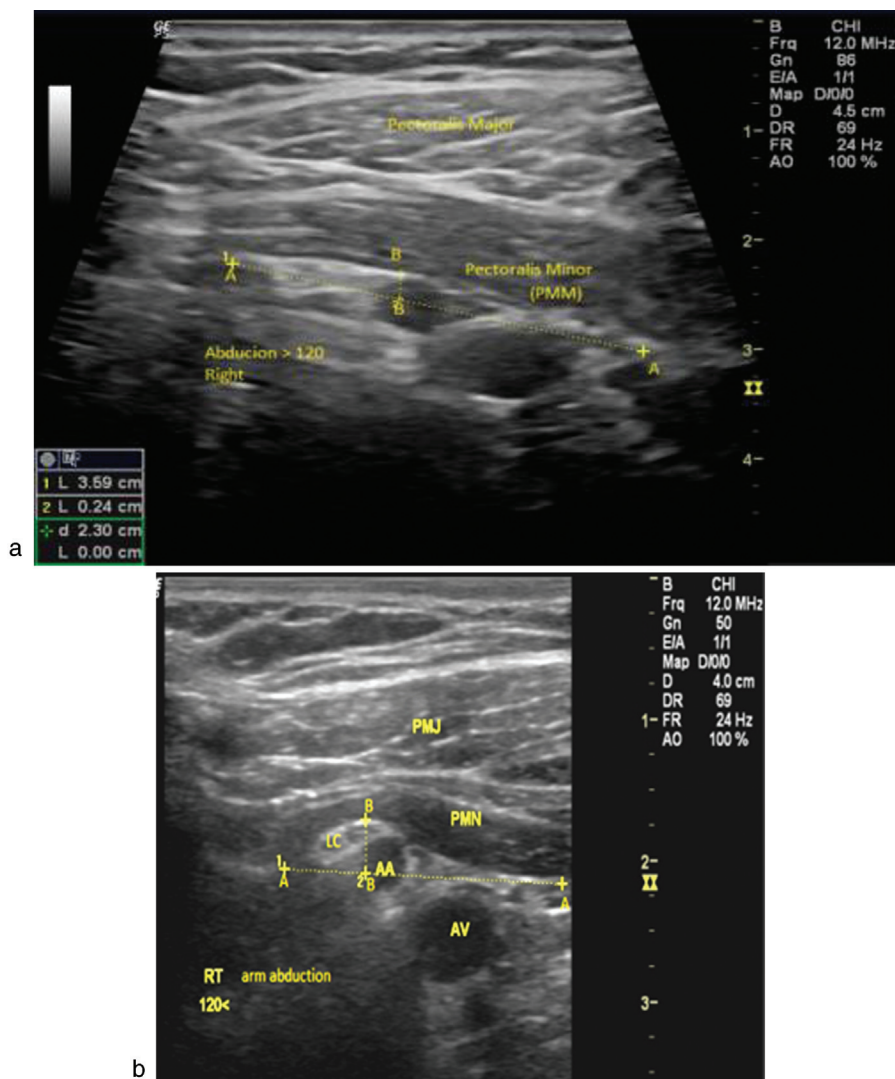
(a) Image showing a neuromuscular ultrasound assessment of one of our patients with right thoracic (RT) outlet syndrome. The right arm was assessed at rested position '0' with the normal position of neurovascular bundle (lateral cord 'LC,' axillary artery 'AA,' axillary vein 'AV,' and other cords) under the pectoralis minor muscle (PMN) posterior edge without impingement. (b) The same right arm of the patient with right side thoracic outlet syndrome was assessed at the abducted position more than 120 showing impingement of the same neurovascular bundle (line B-B) under the pectoralis minor muscle posterior edge (line A-A) with the pectoral bowing ratio exceeding 14%.

Table 3 Comparison between patients and controls regarding radiography and neuromuscular ultrasound findings

Imaging	Control group [n (%)]	Patients group [n (%)]	χ^2	P value	Significance
Radiography					
Negative	10 (100.0)	2 (10.0)	22.500	<0.01	HS
Elongated C7 transverse process	0 (0.0)	10 (50.0)			
Cervical rib	0 (0.0)	7 (35.0)			
Fracture clavicle	0 (0.0)	1 (5.0)			
NMUS					
Negative	10 (100.0)	5 (25.0)	15.000	<0.01	HS
Positive	0 (0.0)	15 (75.0)			

HS, highly significant; NMUS, neuromuscular ultrasound. P value less than 0.01, highly significant.

eight cases while performing test at rest (40%), increased to be 12 (75%) cases while performing it with provocation. MAC sensory nerve conduction studies also were positive in 10 (50%) patients.

Summation of positive cases having positive F-wave and MAC studies 'compound MAC and F-wave studies' resulted in 17 (85%) positive patients and three (15%) negative patients as shown in Table 2.

Table 4 Comparison between neuromuscular ultrasound subgroups (positive and negative cases) regarding clinical provocative test findings

Clinical test	Negative US (*N*=5) [*n* (%)]	Positive US (*N*=15) [*n* (%)]	Test value	*P* value	Significance
Adson					
Negative	3 (60.0)	7 (46.7)	0.267	>0.05	NS
Positive	2 (40.0)	8 (53.3)			
Costoclavicular					
Negative	5 (100.0)	13 (86.7)	0.741	>0.05	NS
Positive	0 (0.0)	2 (13.3)			
EAST					
Negative	0 (0.0)	0 (0.0)	NA	NA	NA
Positive	5 (100.0)	15 (100.0)			
Hyperabduction					
Negative	3 (60.0)	1 (6.7)	6.667	<0.05	S
Positive	2 (40.0)	14 (93.3)			

EAST, elevated arm stress test; NA, not applicable; S, significant; US, ultrasound. *P* value more than 0.05, nonsignificant; *P* value less than 0.05, significant.

Table 5 Diagnostic accuracy of neuromuscular ultrasound, radiography, and medial antebrachial sensory nerve conduction studies

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Neuromuscular ultrasound	75.0	100.0	100.0	66.7	83.3
Radiography	90.0	100.0	100.0	83.3	93.3
MAC	50.0	100.0	100.0	50.0	66.7
Compound MAC+F-wave studies	85.0	100.0	100.0	76.9	90.0

MAC, medial antebrachial cutaneous sensory nerve conduction; MAC+F-wave studies, summation of medial antebrachial cutaneous and F-wave studies positive cases; NPV, negative predictive value; PPV, positive predictive value.

Comparison between the number of patients and control groups with abnormal values regarding the results of compound MAC and F-wave studies showed highly significant statistical difference.

NMUS was positive in 15 (75%) patients who showed PBR more than 10%, while five (25%) patients showed negative ultrasound findings. Radiological findings are seen in Figs 1 and 2, Table 3.

Comparison between patients and controls regarding the radiograph and NMUS findings showed that there was a highly significant statistical difference between both groups.

Comparison between NMUS subgroups regarding different clinical provocative tests including Adson's, costoclavicular, EAST, and hyperabduction tests showed no statistical significance except for hyperabduction test as shown in Table 4.

Comparison between NMUS subgroups regarding other imaging and electrophysiological studies revealed no statistical significance difference.

Summation of the clinical provocative tests was used as the gold standard test to evaluate the diagnostic accuracy of the NMUS, radiograph, and electrophysiological studies for TOS (Table 5).

Discussion

TOS is not the name of a single entity but rather a collective title for a variety of conditions attributed to the compression of neurovascular structures as they traverse the thoracic outlet. Through decades TOS remained one of the most controversial clinical entities in medicine as proved with many research studies [11]. This is because the objective diagnosis of TOS has been problematic due to lack of presence of gold standard diagnostic test, presence of variable manifestations as well as presence of a list of differential diagnosis that may mimic the disease [12].

To overcome these diagnostic obstacles, thorough clinical examination and various investigation tools have been used for objective TOS diagnosis. Thorough clinical examination should include a general inspection of the patient with attention to the affected limb in comparison to the contralateral limb, postural assessment, an examination of the cervical spine and neck including the scalene triangle, an examination of the shoulder, a full neurological examination of the upper limbs,

peripheral vascular examination, and the performance of provocative maneuvers [13].

Investigations play an important role in the diagnosis of TOS; they include imaging and electrodiagnostic studies. Imaging could assist in giving an anatomical cause of compression specially if done dynamically (with provocative maneuvers) as this could help in the assessment of thoracic outlet by stressing its contents and thus increase the weight of TOS diagnosis as well as to rule out other neck and shoulder pathologies that may mimic TOS. Electrodiagnostic studies also serve to increase the weight of TOS diagnosis through functional assessment of the nerves as well as ruling out other neurologic etiologies as contributors to a patient's symptomatology [14].

Moore and Wei [15] stated that a combination of clinical presentation, electrodiagnostic studies, and imaging findings is adequate for the diagnosis of various types of TOS. This made the Consortium for Outcomes Research and Education of TOS to develop a preliminary set of diagnostic criteria for proper TOS diagnosis depending on such combination [16].

This research work was conducted to assess the value of NMUS as a new diagnostic tool for TOS in patients with positive clinical provocative tests and to compare the NMUS study with clinical and electrophysiological studies.

Our study was designed as a case–control study including patients with TOS having positive vascular and/or neurological findings with clinical provocative tests and excluded any patient with other causes of peripheral nerve entrapment, shoulder pathology, cervical radiculopathy, and/or tumor pathology.

Gillard et al. [4] showed that a cluster of two provocative tests displayed the highest sensitivity (90%), while a cluster of five positive provocative tests increased the specificity for TOS to 84%. In this study, among the four provocative tests used, the most sensitive was the EAST as it examines the result of loading the plexus throughout the TOS container 'all sites' [17].

In this work, functional assessment using shoulder pain and disability index revealed pain score ranges were more than disability score ranges because only one patient experienced weakness symptoms.

In our study, standard peripheral nerve conduction tests were done to exclude other additional lesions. Novak et al. [18] implied that the minimal number of TOS patients usually have positive findings with nerve conduction studies at the brachial plexus level. However, other research studies stated that these standard electrical studies may identify other diagnoses that produce overlapping symptoms [5].

Seror [5] reported that abnormal conduction in the MAC nerve, associated with the medial cord of the brachial plexus, may suggest TOS. Furthermore, MAC nerve conduction studies may help to provide objective evidence of nTOS [19].

Also, F-wave studies add to the weight of TOS diagnosis especially if done with provocative maneuvers which may help to uncover the subtle EDS abnormalities related to TOS [20]. Thus our study included all EDS parameters on patients and control groups either to increase the weight of TOS diagnosis through performing MAC nerve conduction studies and F-wave studies with and without provocation or to exclude TOS differential diagnosis through performing the standard sensory and motor nerve conduction studies.

NMUS was used to measure the PBR in TOS patients. The PBR objectively measures deformation of the PMM during arm abduction and is considered abnormal if greater than 10%. This ratio reflects the amount of indentation by the neurovascular bundle as it is tethered under the shortened muscle as the arm abducts above 90° [9].

Positive ultrasound findings were detected in 75% of the patients and NMUS diagnostic accuracy was 83% comparable to that of the radiographic findings and compound MAC and F-wave findings. However, ultrasonography is cheap, quick, painless, no hazard of radiation (safe), and allows for real time and dynamic assessment of thoracic outlet.

Division of the patients' group into positive and negative subgroups based on the NMUS findings was done with subsequent comparison between subgroups and all patient findings, including demographic data (age and sex), shoulder pain and disability scores, clinical, EDS, and clinical provocative tests, revealed no statistically significant difference, but on comparison regarding MAC sensory nerve conduction studies, there was a statistically significant difference between values.

The fact that 66.7% of patients who were negative by MAC nerve study were positive by NMUS denotes the significance of ultrasonography for diagnosis of symptomatic TOS cases which could be missed by nerve conduction.

Comparing patients with positive and negative NMUS findings as regards hyperabduction clinical provocative test findings revealed a significant difference between the two groups as this test is conducted for examination of neural tissue compromise through the thoracopectoral gate [21], which is the same area examined by NMUS using the same provocative maneuver (pectoral bowing while hyperabducting the arm).

The previous findings confirm that radiography and nerve conduction studies especially combining MAC nerve conduction studies with F-wave studies (with and without provocation) are complementary tests to NMUS and a combination of these tests could help in the objective diagnosis of TOS.

Limitations of the study
Ultrasound study was done only on the pectoral gate, which is affected mainly with the postural type of TOS. It did not include NMUS assessment of scalene and supraclavicular areas due to some technical limitation to visualize these anatomical sites. In spite of the fact that posture may be affected with any type of TOS, future studies are recommended to extend ultrasonographic assessment of scalene and supraclavicular areas which could help in the objective diagnosis of TOS. Also, the role of treatment modalities for these types of compression neuropathy also needs to be investigated to know which of these vast batteries of tests could better reflect the improvement of the patient's condition by physical therapy since it is considered the cornerstone for the management of these cases.

Conclusion
NMUS is an important, safe, painless, and sensitive anatomical tool for the assessment of TOS. Electrodiagnosis gives an idea about the functional status of nTOS. Radiography, electrodiagnosis, and NMUS are complementary to each other for confirmation of the diagnosis of TOS.

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