Baz *Egyptian Journal of Radiology and Nuclear Medicine* (2019) 50:76
https://doi.org/10.1186/s43055-019-0100-1

Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH Open Access

An overview of the findings of dynamic upper limbs' arterial and venous duplex in cases of vascular thoracic outlet syndrome

Ahmed A. Baz

Abstract

Background: To describe the findings of the dynamic upper limb arterial and venous duplex in the assessment of vascular compression in cases of VTOS. This study was conducted on 58 patients with VTOS; they were evaluated by dynamic duplex examination.

Results: Vascular compression was subdivided into a venous compression that was detected in (84.4%, $n = 49$), arterial compression that was seen in (1.7%, $n = 1$), and combined arterial and venous compression that was present in (13.7%, $n = 8$); bilateral compression was existing in (94.4%, $n = 55$), compression at the scalene triangle was seen in (1.7%, $n = 1$), at the costo-clavicular space was seen in (91.3%, $n = 53$), and at the retro-pectoral space was depicted in (8.6%, $n = 5$).

Complicated arterial compression was detected in (1.7%, $n = 1$), whereas venous complications were seen in (6.8%, $n = 4$).

Conclusion: Dynamic duplex ultrasound offered a simple, noninvasive, and quick technique that can help in the evaluation of the vascular thoracic outlet syndrome without exposure to ionizing radiation or contrast media administration like that in CT; nevertheless, it is done with the patient in the upright position, thus avoiding the high false-negative results associated with the supine position that is used in the CT and MRI studies.

Keywords: Dynamic, Upper limb arterial, Venous duplex, Vascular, Thoracic outlet syndrome

Background

Thoracic outlet syndrome (TOS) encompasses a group of clinical compression syndromes where there is a dynamic impingement of the neurovascular structures at the thoracic outlet; this compression can occur at three anatomical confinements including the scalene triangle, the costo-clavicular space, and the retro-pectoral space [1–4]. From a clinical aspect, it could be classified into a neurogenic thoracic outlet syndrome (NTOS) which is-by far-more common being observed in more than 90% of cases and a vascular thoracic outlet syndrome (VTOS) which is less common being only observed in less than 10% of cases and includes the arterial and the venous subtypes; however, the NTOS and the VTOS can coexist in the same patient [1, 5, 6].

TOS is a frequently overlooked or under diagnosed problem with controversies about its definition, incidence, diagnosis, and management; moreover, its clinical diagnosis may be challenging as it could be mimicked by other conditions where the vascular and neurogenic manifestations are interrelated [7, 8]. The presence of vascular symptoms and signs may greatly help in diagnosing TOS but unfortunately the incidence of VTOS is by far too much less than NTOS [7].

TOS diagnosis is usually done on clinical basis; thus, the clinical presentation depends on the structure being compressed; hence, the investigations are implemented as the confirmatory tests for the condition including electrodiagnostic tests, brachial plexus neurography in cases of NTOS, and the imaging studies are usually considered if there is a suspicion about the presence of vascular compression VTOS [4, 9].

Imaging plays an important role in the diagnosis of VTOS as the diagnosis is usually established by clinical

Correspondence: ahmedbaz2012@yahoo.com; ahmedbaz2012@Gmail.com; ahmedbaz2012@cu.edu.eg
Diagnostic and interventional radiology departement, Kasr Aliny school of medicine, Cairo University, Cairo, Egypt

examination that often needs confirmatory tests [4]. Many imaging studies may share in this regard including the plain X-ray of the cervical spine and the chest for exclusion of osseous abnormalities that may narrow the spaces, dynamic duplex ultrasound, computed tomography (CT) angiography, and magnetic resonance imaging (MRI) with dynamic maneuvers which can be used to determine the degree and the location of the vascular compression [4, 9–11].

Dynamic duplex ultrasound is considered as an important supplementary tool for assessment of the vascular compression at the thoracic outlet while performing the provocative maneuvers especially when the clinical examination is supporting the presence of VTOS and the other imaging modalities (like CT and MRI) did not give satisfactory results [4]. Color duplex examination is considered as a noninvasive and simple test when compared with digital subtraction angiography [12]; it can be used as a real-time examination that assesses the subclavian vessels compression in both arms in a similar way as the clinical tests; moreover, it can detect any superadded complications in the compressed vessels in addition to the screening of the rest of the limb vessels [3].

Aim of the work

The purpose of this study is to describe the findings of the dynamic upper limbs' arterial and venous color duplex ultrasound in cases diagnosed clinically as vascular thoracic outlet syndrome and to detect if there is any complication of long-standing compression.

Methods

The study was conducted on 58 patients with a clinical presentation of vascular thoracic outlet syndrome; (8 males and 50 females) from May 2015 till December 2017. The patients were referred to our department from the vascular surgery department after their clinical assessment for confirmation of the clinical findings and for the exclusion of complications.

The patients' ages ranged from 21 to 54 years with a mean age ± SD (34.25 ± 7.97 years).

Inclusion criteria

Patients that had clinical symptoms and signs of vascular thoracic outlet compression syndrome and those who had the willingness to participate in the study were included.

Patients with venous TOS may have edema, cyanosis, or sudden onset of thrombosis occurring after varying degrees of effort.

Patients with an arterial TOS may be presented by ischemia occurring after effort or positional vasomotor disorders.

Exclusion criteria

Patients were excluded when they had NTOS only by clinical examination or if they had other causes of upper limb pain that could limit the full range of movement of the upper extremity during the dynamic duplex examination like shoulder impingement syndrome, frozen shoulder, or any contracture deformity of the proximal segment of the upper limb.

The local ethics committee approved the study and all participants gave their informed consent before being included.

Imaging technique and diagnostic criteria in sonography

All patients were examined basically by routine arterial and venous duplex examination for both upper limbs in the neutral arm position (with arms alongside the body) while the patients were seated in the upright position as a baseline study and to detect any unrelated vascular abnormality and to exclude any complications of vascular compression in cases of longstanding VTOS including arterial thromboembolism, aneurisms or stenosis, and the venous complications which include thrombosis or persistent stenosis.

The examination was performed with a 7.5-MHz linear high-frequency probe (Toshiba Xario 200 and GE vivid S5 and GE logic P5) that might be complemented by low-frequency 3.5-MHz probes in cases with relatively deep vessels and thick chest walls. All patients were evaluated by a single operator who is considered as an expert one.

The dynamic duplex examination was directed mainly to detect the vascular compression rather than to elicit the symptoms of NTOS; thus, we selected the maneuvers that are associated mainly with vascular impingement.

Adson's test was performed by turning the head to a side with neck extension, and the patient was asked to take a deep breath, then the axillary artery through an infraclavicular window was assessed by color and spectral Doppler then compared with the baseline examination that was performed in the neutral position (Fig. 1) to detect any significant change in the form of dampening of the flow velocity and prolongation of the acceleration time in the interrogated arterial spectral waveform; this might be correlated clinically with the weak or obliterated pulse. Then the subclavian artery was assessed in the neutral neck position and with Adson's test to detect any significant postural-related stenosis. This test was performed to detect the arterial compression at the scalene triangle. If there was a concern about the compression at the scalene triangle by clinical examination, an X-ray of the cervical spine and the upper chest was performed for the exclusion of an osseous abnormality like a cervical rib [5].

Arm abduction and external rotation (ABER) was performed by abducting the arm and in external rotation

Fig. 1 Photographic images for the patient positioning and exposure in neutral arm position (**a**) in arm abduction and external rotation (ABER) (**b**) and in arm abduction with turning the face to the contra-lateral side (Adson's test) (**c**)

with assessment of the degree of the arterial compression at the costo-clavicular space (Fig. 1) by visualizing the B-mode changes (diameter reduction) and by color Doppler for detection of color aliasing for vascular stenosis; then by spectral waveform analysis, the velocity ratios associated with each degree of arm abduction at the site of compression were assessed, and the downstream effect in the distal arteries including the degree of velocity dampening, prolongation of the acceleration time, and in some cases, a complete cessation of the arterial flow were also seen. A rebound hyperemia in the distal arteries was seen on return to the neutral arm position in cases of vascular compressions [5, 12].

According to Longley et al. and Wadhwani et al. studies, the velocity in the subclavian artery is 50–100 cm/sec and any rise in the velocity ratio > 2 folds is considered as significant compression and corresponds to > 50% stenosis which is considered as hemodynamically significant [3, 12].

In a similar way, the veins were examined with the same degrees of arm abduction to detect the vein compression by the B-mode that may appear as a tapered narrowing pointed to the costo-clavicular space giving a pattern of "peak-like" configuration; then by turning on the color duplex, an aliasing from the high velocity would be seen and confirmed through the spectral Doppler interrogation to detect the rise in the velocity ratios measured during the abduction and compared to the measurements taken in the neutral position or as compared to the preceding non compressed vein segment.

It worth mentioning that arm abduction had been reported as the postural maneuver for VTOS diagnosis especially when combined with the imaging techniques like duplex, CTV, or MRV [10, 13–19]; thus, it was considered the main postural maneuver in this study.

The retro-pectoral space (subcoracoid) is the most lateral space that lies underneath the pectoralis minor muscle and overlying the chest wall; thus, for the neurovascular structures passing through this space, arm hyperabduction would induce the compression. In a similar way, the artery and the vein were evaluated by B-mode, color Doppler, and spectral waveform analysis for the presence of any significant stenosis on dynamic examination [5, 12].

Statistical methods

Data were coded and entered using the statistical package SPSS version 25. Data was summarized using frequencies (number of cases) and relative frequencies (percentages) for categorical variables.

Results

Fifty eight patients were included in this study. Their primary diagnosis was established on the clinical basis, and then they were evaluated by dynamic upper limb's arterial and venous duplex for assessment of the proximal upper limb vessels compression and for detection of any complication of this compression.

In this study, patients were subdivided according to the type of vascular compression into a pure venous compression that was detected in 49 patients (84.4%), pure arterial compression that was found in one patient (1.7%), and combined arterial and venous compression that was seen in 8 patients (13.7%) (Table 1).

For the side of affection, a bilateral compression was encountered in 55 patients [(94.4%) (46 patients with pure venous compression, one patient with pure arterial compression, and 8 patients with combined arterial and venous compression) (Table 1)].

Table 1 Demonstrating the type of vascular compression at the thoracic outlet as well as the side of affection, and the number and the percent of cases

Type of vascular compression		Number	Percent (%)
Pure venous compression		49 patients	84.4
	Unilateral affection	3 patients	5.1
	Bilateral affection	46 patients	79.3
Pure arterial compression		1 patient	1.7
	Unilateral affection	0 patient	0
	Bilateral affection	1 patient	1.7
Combined arterial and venous compression		8 patients	13.7
	Unilateral affection	0 patient	0
	Bilateral affection	8 patients	13.7

Regarding the site of the compression, it was subdivided into the scalene space with one patient having arterial compression (1.7%) (Fig. 2), and 53 patients (91.3%) were having compression at the costo-clavicular space (venous compression in 45 patients and combined arterial and venous compression in 8 patients) (Figs 3, 4 and 5), and the compression in the retro-pectoral space was depicted in 5 patients (8.6%) and it was of venous type (Fig. 6) (Table 2).

Coexistence of more than one site of compressions in the same patient was noticed in one case (1.7%) at two levels (costo-clavicular and retro-pectoral spaces) and it was also of venous type.

A complicated compression was subdivided into arterial and venous complications.

The arterial complications were including aneurysmal dilatation that was detected in one case (1.7%) at the distal subclavian artery; distal arterial embolism was detected in the same patient (1.7%) at the radial artery (Fig. 7); the arterial thrombosis and the persistent arterial stenosis at the thoracic outlet as well as the pseudoaneurysms were not seen as complications of VTOS in this study (Table 3).

The venous complications were including the axillary and subclavian vein thrombosis (ASVT); it was reported in 3 patients (5.1%) (Fig. 8), and persistent venous stenosis at the site of compression was identified on the right side in one patient (1.7%) (Table 3).

Discussion

TOS is a compression syndrome that could be classified as the VTOS which is considered less frequent than the NTOS; VTOS had been further subdivided anatomically into three compartments where the compression could

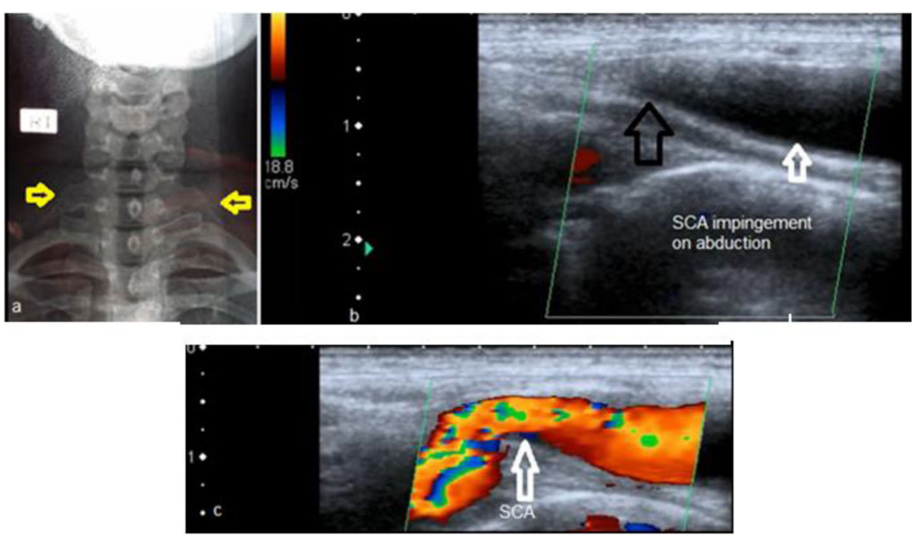

Fig. 2 a Plain X-ray image (AP view) showing bilateral cervical ribs (transverse yellow arrows). **b** Color Doppler image showing the left subclavian artery being impinged by 180° of arm abduction with no detectable flow in the distal segment (open white arrow) and severe narrowing "peak configuration" of the compressed segment (open black arrow). **c** Color Doppler image for the same artery but with 120° of arm abduction showing less significant stenosis of the artery denoted by the color aliasing (open white arrow) with filling of the distal segment

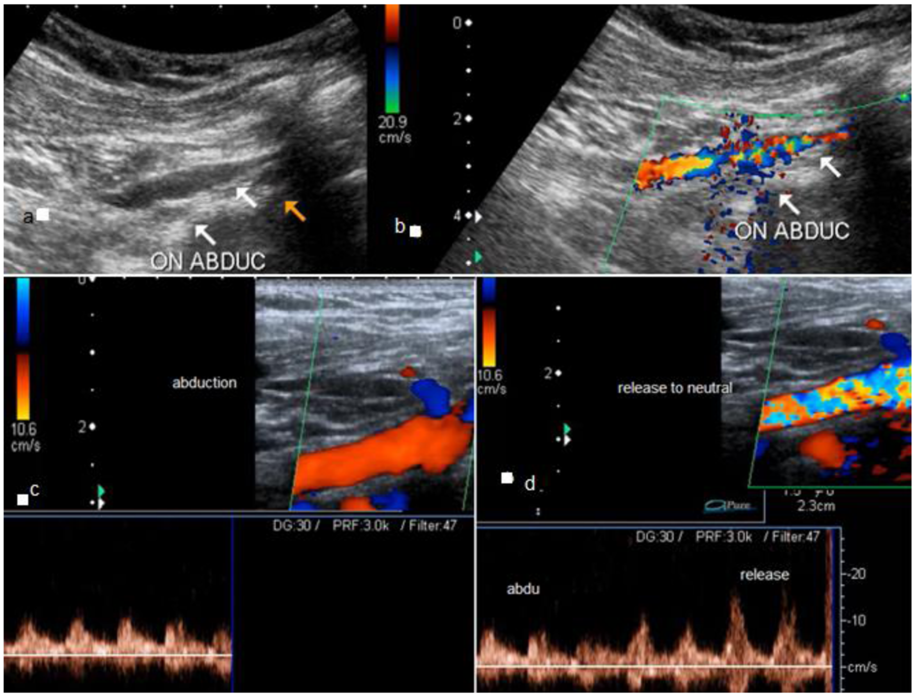

Fig. 3 a B-mode image of the axillary-subclavian artery junction showing tapered significant narrowing of the axillary artery on arm abduction (white arrows) at the outlet of the costo-clavicular space (yellow arrow). **b** Color image for the same arterial segment in (**a**) showing marked color aliasing with a visible bruit due to high velocity jet of the arterial stenosis (white arrows). **c** Spectral and color Doppler image for the downstream brachial artery showing significant dampening of the flow on arm abduction. **d** Spectral and color Doppler image showing rebound hyperemia (color aliasing) with increased velocity on release of the impingement of the artery by return to the neutral arm position

take place, and those are the scalene triangle, the costo-clavicular space, and the retro-pectoral space [1–3].

The present study was concerned with the description of the ultrasound findings in cases of VTOS by dynamic duplex examination and detection of the complication of long-standing compression.

By dynamic duplex examination, venous compression was the predominating type of VTOS in this study being found in (84.4%) of the patients; bilateral affection was also a predominating feature being observed in (94.4%) of the patients; nevertheless, most of the compressions took place at the costo-clavicular space (91.3%); this greatly matched the studies done by Ersoy et al. and Raptis et al. [9, 19].

Multi-level compression in the same extremity was seen in one patient (1.7%), and it was of the venous type, the compression was at the costo-clavicular space in addition to the retro-pectoral space as detected by dynamic duplex scanning, and this was considered as an uncommon finding.

Combined arterial and venous compression was the second type of compression being seen in 8 patients (13.7%) and occurred at the costo-clavicular space (Figs. 3, 4, and 5) and this also went with the Demondion et al. and Ersoy et al. studies [4, 9].

Pure arterial compression without venous compression was seen only in one patient in this study (1.7%) and occurred in the scalene triangle where the artery and the vein are anatomically separated from each other, and only the arteries are located in the scalene triangle alongside the brachial plexus; this could explain why the arterial TOS was being observed in conjugation with NTOS in some cases; thus, pure arterial compression is considered as a rare type of TOS and usually associated with an underlying osseous abnormality; thus, its presence necessitates an X-ray examination; nevertheless, the distal arterial embolism is considered as a feature complication of the condition [20–22], and this was also manifested in the present study, where the only case of pure arterial compression was at the scalene triangle and was associated with a bony cervical rib and distal subclavian artery aneurysm; moreover, a distal arterial embolism to the ipsilateral radial artery was present as well (Fig. 7).

Complicated venous compression occurred in two forms, the first one was the ASVT and this was detectable in (5.1%) of patients (Fig. 8), and this could be attributed to the repeated strenuous and overhead activities with frequent vein crushing between the osseous structures, namely the first rib and the clavicle-inducing endothelial injuries promoting venous thrombosis, and this condition could be termed Paget-Schroetter syndrome or effort-induced thrombosis [2, 21]. Actually, the affected patients with thrombosis in our study gave histories of

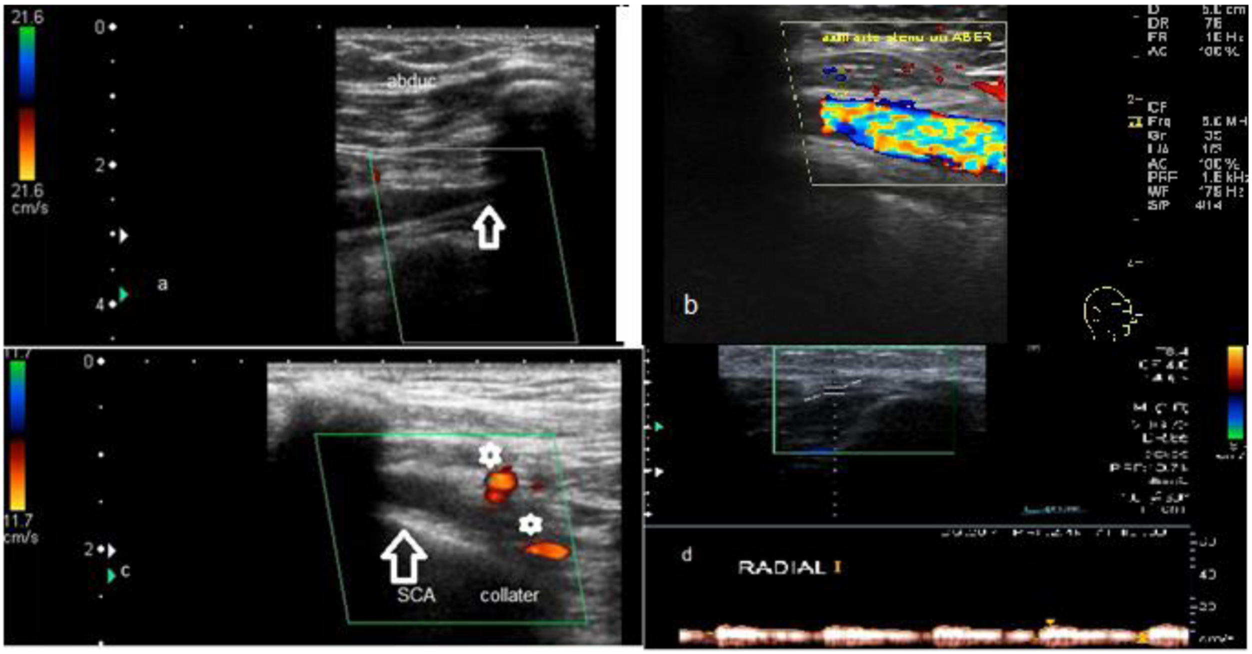

Fig. 4 a Color image of the axillary-subclavian artery junction showing tapered significant narrowing of the artery on arm abduction with a peaking of the artery toward the costo-clavicular space (white open arrow). Note the flow cessation in the examined artery. **b** Color image for the same arterial segment in another patient showing marked color aliasing due to high-velocity jet of the arterial stenosis at the outlet of the costo-clavicular space. **c** Color Doppler image showing complete cessation of the arterial flow on arm abduction (open white arrow) and the presence of regional arterial collaterals (white asterisks) circumventing the obstruction. **d** Spectral Doppler image showing tardus parvus waveform that was interrogated in the distal radial artery on arm abduction. This was correlated clinically with an obliterated or a weak radial pulse

occupational and sport-related overhead activities. The second form was a persistent venous stenosis at the site of compression and this was seen in one patient (1.7%); this greatly matched Ersoy et al. [6] and could be due to either endothelial injury from repeated trauma by extrinsic compression or perivenular fibrosis and adhesions [2].

Actually, we need to clarify that the present study was a description of US findings among patients referred with a clinical presentation of VTOS, but the spectrum of radiological observations overestimated the prevalence of disease, since most had only positional compression as a radiological finding, but the vascular injury that might support the clinical diagnosis had been described as a complication of long standing compression but at the same time, it should be clear that, whatever the imaging modality used for assessment of positional compression, this overestimation can occur as the imaging modalities mainly assess the degree of diameter or cross area reduction of the vessel lumen on the provocative maneuvers [4, 10, 11, 19, 22].

However, it is important to know that the cornerstones of the VTOS diagnosis are the clinical aspects through the meticulous history taking and the physical examination, and the role of imaging is to confirm the clinical diagnosis, detection of the site, and the cause of vascular impingement; delineate the abnormal anatomical structures; and to help in the classification of the VTOS into an arterial, venous, or both types and finally in detection of the superadded complications [22].

Imaging of VTOS had been implemented by multiple diagnostic modalities including plain radiography, conventional angiography (arteriography and venography), CT, MRI, and sonography; plain radiography of the cervical spine and the chest was obtained symmetrically and usually used to exclude an osseous abnormality of the thoracic outlet region that might impinge the neurovascular structures; those could be an osseous cervical rib (Fig. 1), elongated transverse process of C7, exostosis, callus of old clavicular, or first rib fractures [4, 21].

Conventional angiography including the arteriography and venography was considered as an invasive modality that could display the extrinsic vascular compression at certain anatomical location and may give an idea about the collateral vessels that circumvent the obstruction level but definitely missing the depiction of the impinging structure; thus, it may be better replaced by the less invasive imaging modalities [4]. Conventional angiography has an important role in the management of VTOS in cases of the ASVT through the catheter-directed thrombolysis therapy as a prior procedure for surgical decompression of the VTOS; moreover, the arteriography may be employed for angioplasty and/or

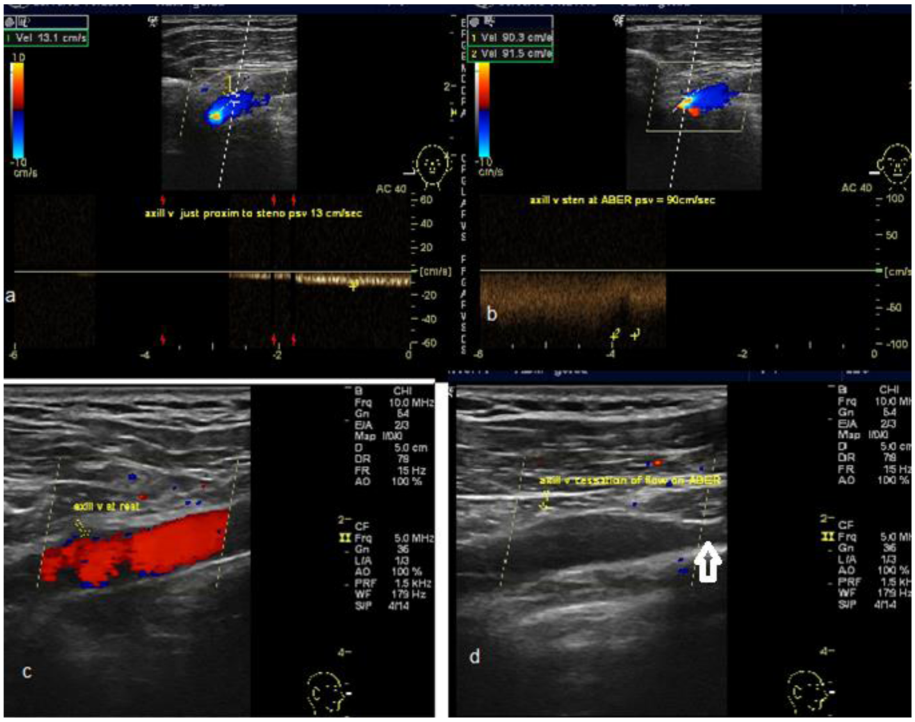

Fig. 5 a–**d** Ultrasound images showing significant stenosis of the compressed vein segment at the costo-clavicular tunnel as evidenced by significant rise in the velocity ratio > 6.5 (13 cm/sec in neutral position seen in **a** reaching (90cm/sec in arm abduction and external rotation seen in **b**. **c** Color image for the axillary vein in the resting position but with abduction and external rotation (ABER) almost total cessation of flow was noted in **d** with peaked narrowing at the costo-clavicular outlet (white arrow)

stent deployment in cases of residual stenosis after surgical decompression of arterial TOS [22].

CT angiography (CTA)

CTA examination with the arms beside the body (neutral position) and then with arm elevation (abduction position), then a comparison of the images obtained with the neutral arm position to those obtained with the abduction arm position were done to detect the degree of vascular narrowing by the postural changes [10]. CTA gives valuable vascular anatomical details in the assessment of VTOS; however, there are many limitations including technical aspects regarding the arm elevation that could be hindered by the CT tunnel (especially if more than 120°) [22], the supine position of the CT examination which may be associated with high false-negative results [23], and the CTA examination is done is associated with exposure to ionizing radiation as well as the side effects of contrast media.

MR imaging (MRI)

MRI and especially the magnetic resonance angiography (MRA) examinations are noninvasive, cross-sectional imaging modalities that have multiplanar capabilities with no exposure to ionizing radiation; they exhibit a better spatial and temporal resolution of the anatomical details; again, multiple positions are required for evaluation of the vascular narrowing with the postural changes. Certain planes are considered especially important like the sagittal planes in T1-weighted sequences as well as the coronal planes, and then the degree of the vascular compression is assessed by comparing the diameter reductions of the vessels in the arm abduction with that in the neutral position [4, 11, 19, 22].

Like CTA, the MRI has some limitations regarding the arm abduction as well as the supine position which is associated with high false-negative results as previously mentioned.

Raptis et al. described the use of contrast-enhanced MRI in VTOS with a special recommendation to the use of blood pool contrast agent (gadofosveset trisodium) in order to do a single injection for the two arm positions [19]. Again, the use of the contrast agents is contraindicated in cases with renal impairment.

The relatively high cost of the MRI compared to the other modalities in addition to its contraindications like claustrophobia and metallic implants (like pacemakers) may limit its use in certain circumstances.

Duplex ultrasound

Thanks to its availability, simplicity, noninvasive nature as well as being inexpensive modality, the ultrasound had gained a wide popularity; moreover, there is no

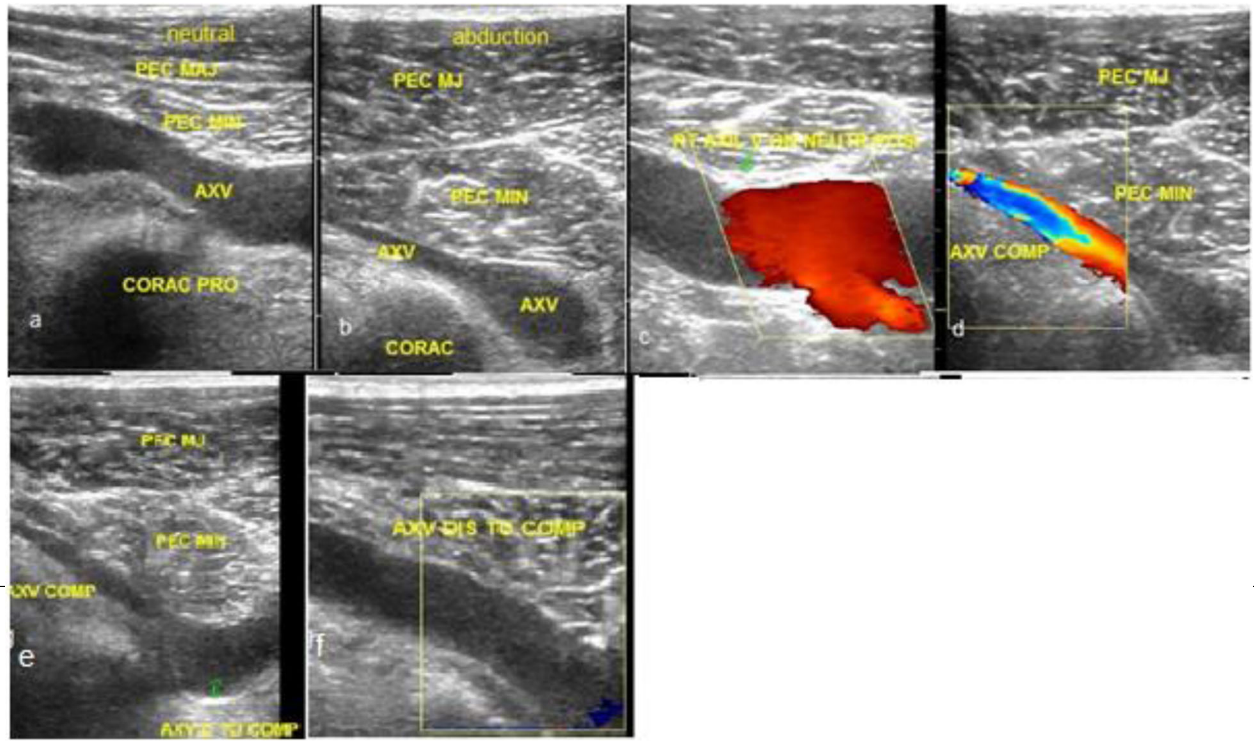

Fig. 6 B-mode ultrasound images for the axillary vein in the retro-pectoral\sub-coracoid space with the arm in the neutral position (**a**) and in arm abduction (**b**) showing marked compression of the vein by the overlying pectoralis minor muscle. Color Doppler images with the arm in the neutral (**c**) and in the abduction (**d**) positions showing significant stenosis with color aliasing in the compressed vein segment by the overlying pectoralis minor muscle. B-mode and color Doppler images of the axillary vein distal to the compression level showing the vein distension (**e**) with almost total cessation of the venous flow with the hyper-abduction (**f**)

hazardous exposure to ionizing radiations or use of contrast material.

In contrast to CT and MRI, the duplex ultrasound can be done in the upright position, thus avoiding the high false-negative results associated with the supine position.

The dynamic duplex ultrasound gives the chance for a direct correlation between the dynamically provoked symptoms and the associated vascular compression at the same time. Additionally, the determination of the degree of arm abductions associated with symptoms could be easily done.

Table 2 Demonstrating the site of vascular compression in the study as well as the patients' number and percent

	Number	%
Scalene triangle (arterial)	1 patient	1.7
Costo-clavicular space		
Venous compression	45 patients	77.5
Arterial compression	0 patient	0
Arterial and venous compression	8 patients	13.7
Retro-pectoral space		
Venous compression	5 patients	8.6
Arterial compression	0 patient	0
Arterial and venous compression	0 patient	0

The postural induced hemodynamic changes like blunting of the arterial waveform, flow cessation, and high-velocity jets of stenosis could be easily performed by the dynamic duplex ultrasound.

The arteries and the veins of both upper extremities could be examined at the same session by dynamic duplex ultrasound.

Butros et al. had special consideration for the use of duplex ultrasound in the venous TOS which is to be limited for diagnosis of the associated venous thrombosis with a limited value in the detection of thrombosis that extended to the central veins in the thorax; in addition, they considered that its use in cases of venous TOS—in the absence of thrombosis—is still equivocal when compared to CT or MRI [24].

Raptis et al. preferred the use of the duplex ultrasound in the clinical setting to prove the patency of the vessels and to detect abnormalities like thrombosis, aneurysms, or pseudo-aneurysms but not to use it in exclusion of the venous TOS when there is a clinical suspicion; they justified this by the limited visualization of the central

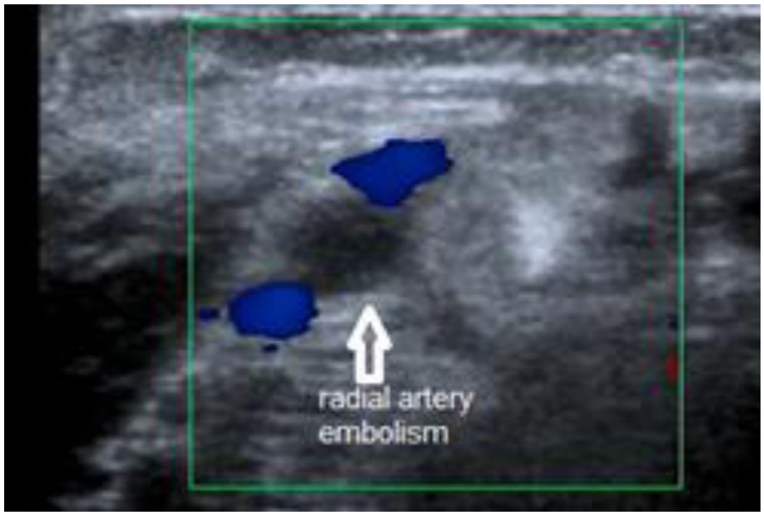

Fig. 7 Color image of the occluded distal radial artery (open white arrow) by embolism from proximal long-standing VTOS; note the blue-coded radial vena comitants denoting their patency

subclavian vein due to the acoustic shadow of the clavicle [19]. We disagree with this point because the assessment of the compression of the veins took place at the axillary-subclavian vein junction which is present in the outlet of the costo-clavicular tunnel (distal to the lower edge of the clavicle); then, by the postural maneuvers, the compressed vein displayed a peak-like configuration with a tapering end toward the costo-clavicular tunnel outlet, and the associated color Doppler and spectral Doppler changes would be apparent just distal to this level, thus giving the chance for the assessment of the degree of vascular compression (Figs. 3, 4, and 5); moreover, the indirect signs like vein distension, flow cessation, and lack of the respiratory phasicity of the flow in the venous segment downstream, this compression level would be helpful.

Table 3 Demonstrating the complications of vascular compression in thoracic outlet compression syndrome as well as the number and the percent of the affected cases

Complicated compression	Number	%
Arterial		
Aneurisms	1 patient	1.7
Pseudo-aneurysms	0 patient	0
Thrombosis	0 patient	0
Distal embolism	1 patient	1.7
Persistent stenosis	0 patient	0
Venous		
Thrombosis	3 patients	5.1
Persistent stenosis	1 patient	1.7

Demondion et al. went for the use of ultrasound as a supplementary technique for the CT and the MRI in diagnosis of VTOS especially in cases that had positive clinical findings but the CT and the MRI findings were negative, they also explained this by the limitation of the ultrasound in detecting other pathologies that could affect the lung apex (like tumors) and might give a clinical picture mimicking the TOS [4].

As a general rule, it should always be kept in mind that the diagnosis of VTOS is clinically based, and the diagnosis could not be established based only on the vascular compression by any imaging modality; thus, the interpretation of the images should be done in parallelism with the clinical diagnosis [1, 3, 4, 19].

Longley et al. suggested the use of color Doppler ultrasound in the workup of cases with venous TOS as a promising technique through evaluation of the subclavian vein, but its use in cases of arterial TOS was still questionable in their limited study [3].

Literally, the imaging findings of vascular compression with postural changes may be detectable even in asymptomatic subjects; thus, the clinician and the radiologist should be aware of such bias so as not to do unnecessary surgical interventions [19].

We had an explanation for the absence of the symptoms in some individuals who might have imaging evidence of vascular compression; in fact, these individuals had a narrow space for passage of the neurovascular structures but actually the overuse and the repeated micro-trauma to the vessels may precipitate the symptoms especially on the long-run scales; this could be noticed in persons who had certain occupations and even gymnastics with overhead activities; moreover, some individuals might have unilateral

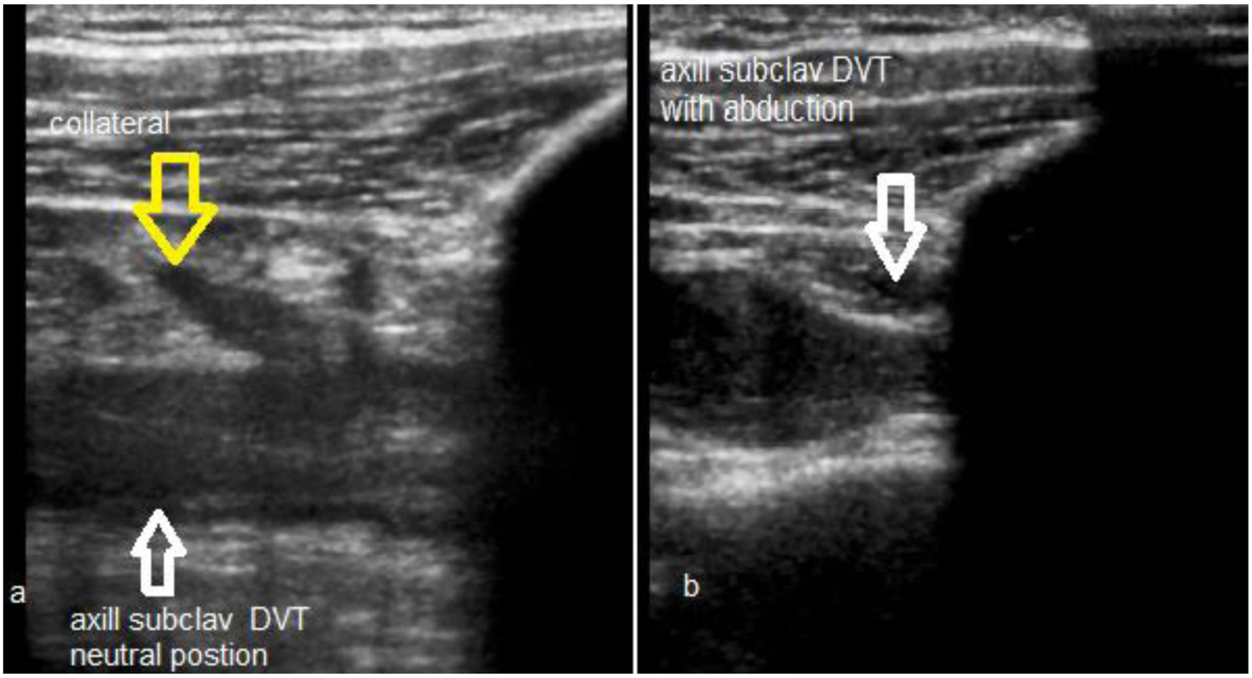

Fig. 8 a B-mode image of the axillary-subclavian vein junction showing thrombus filled vein segment (ASVT) (open white arrow) with venous collaterals arising at this level (yellow open arrow) in the neutral position. **b** B-mode image with arm abduction, a peaking of the vein segment with marked compression of the thrombus filled vein at the costo-clavicular space were seen (open white arrow)

symptoms in spite of the presence of bilateral vascular compression by the imaging but usually the symptoms were seen in the dominant side, then by a meticulous history taking some patients reported the presence of occasional symptoms in the asymptotic side but to a much lesser degree than the symptomatic side.

As we discussed, some authors suggested the use of the dynamic duplex for evaluation of the presence of the VTOS and put the criteria for the diagnosis [3, 4, 12, 24], and some limited its use for the clinical setting and for detection of complications or even as a supplementary modality when there are positive clinical findings and negative imaging findings by CT or MRI; in addition, it had proved usefulness in the follow-up assessment of the post-surgical decompression cases [1, 4, 19]. In our experience, the dynamic duplex examination is a good diagnostic modality for assessment of the vascular compression in VTOS and for detection of any superadded complications of vascular compression, unlike plain radiography and CT, it may be of limited use in the demonstration of the osseous abnormalities. Both dynamic duplex and the other noninvasive imaging modalities (CT or MRI) can reveal vascular compression in VTOS but the image interpretation and the planning for surgical interventions should be first done in the light of the clinical diagnosis for all modalities.

Considering the availability, cost-effectiveness, and noninvasive nature of the duplex ultrasound as well as the wide range of the postural changes given by dynamic duplex examination, this modality is warranted for assessment VTOS and might be complemented by other modalities like plain radiography, CT, or MRI if there is a clinical indication.

A novel ultrasound finding called wedge-sickle sign has been recently described in the identification of the fibromuscular bands that may exert a compression on the brachial plexus in the interscalene triangle, thus helping for establishing an early diagnosis before a neurologic deficit could supervene [25]; this sign had greatly helped for ultrasound diagnosis of cases with NTOS; however, this was not our main concern in the present study where we targeted the cases of VTOS.

Some limitations were met in this work; the first one was regarding the technique of examination, being deficient in demonstrating the osseous abnormalities like cervical ribs as well as the pulmonary apex region; however, it was further complemented by other modalities if there was a clinical indication; the second one, also, there was no reference imaging standard for the diagnosis (like catheter angiography, CTA, or MRA), apart from the clinical examination, and all the cases were diagnosed clinically, and the main imaging study was the dynamic duplex examination; thus, all other imaging studies were done upon the clinical need.

Conclusion

Dynamic duplex ultrasound offered a simple, noninvasive, and quick technique that can help in the evaluation of the vascular thoracic outlet syndrome in conjugation with the clinical findings without exposure to ionizing radiation or contrast media administration like that in CT; nevertheless, it is done with the patient in the upright position, thus avoiding the high false-negative results associated with the supine position that is used in the CT and MRI. Moreover, it was useful in the detection of any complications of long-standing compression. Bilateral dynamic examination of the upper extremities with the assessment of both arterial and venous systems was readily feasible and could be done in the same session by a relatively low-cost study.

Abbreviations

CTA: Computed tomography angiography; MRA: Magnetic resonance angiography; NTOS: Neurogenic thoracic outlet syndrome; VTOS: Vascular thoracic outlet syndrome

Acknowledgements

Not applicable.

Author's contributions

AAB: the corresponding author had contributed by doing ultrasound examinations and the interpretation of the corresponding correlative image studies if available in the research work. He also had introduced the idea of the current study and helped in the image selection and in the editing of the manuscript and reference collection. The author of this paper have read and approved the final version submitted.

Funding

The author had no fund for this research and had no competing interests.

Availability of data and materials

All data are available on a software system owned by each of the authors and the corresponding author has the authority to respond if there is any query.

Ethics approval and consent to participate

The protocol was reviewed and approved by the local ethics committee of the radiology department, Kasr Aliny hospital, Cairo University.
The reference number was not applicable
All patients had given their written consents to participate in this work

Consent for publication

All patients had given their written consents for publication of this work.

Competing interests

The authors declare that they have no competing interests.

Received: 27 November 2019 Accepted: 2 December 2019
Published online: 11 December 2019

References

1. Povlsen S, Povlsen B (2018) Diagnosing thoracic outlet syndrome: current approaches and future directions. Diagnostics 8(1):21
2. Venkata M. Alla, C. (2018). Paget-Schroetter syndrome: review of pathogenesis and treatment of effort thrombosis. [online] PubMed Central (PMC). Available at:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2967689/. Accessed 13 Apr. 2018
3. Longley D et al (1992) Thoracic outlet syndrome: evaluation of the subclavian vessels by color duplex sonography. J Diagnostic Med Sonography 8(3):168–168
4. Demondion X, Herbinet P, Van Sint Jan S, Boutry N, Chantelot C, Cotten A (2006) Imaging assessment of thoracic outlet syndrome. RadioGraphics 26(6):1735–1750
5. Sanders R, Hammond S, Rao N (2007) Diagnosis of thoracic outlet syndrome. J Vasc Surg 46(3):601–604
6. Hussain M, Aljabri B, Al-Omran M (2016) Vascular thoracic outlet syndrome. Semin Thorac Cardiovasc Surg 28(1):151–157
7. Laulan J, Fouquet B, Rodaix C, Jauffret P, Roquelaure Y, Descatha A (2010) Thoracic outlet syndrome: definition, aetiological factors, diagnosis, management and occupational impact. J Occup Rehabil 21(3):366–373
8. Hooper T, Denton J, McGalliard M, Brismée J, Sizer P (2010) Thoracic outlet syndrome: a controversial clinical condition. Part 1: anatomy, and clinical examination/diagnosis. J Man Manipulative Ther 18(2):74–83
9. Ersoy H et al (2012) Vascular thoracic outlet syndrome: protocol design and diagnostic value of contrast-enhanced 3D MR angiography and equilibrium phase imaging on 1.5- and 3-T MRI scanners. Am J Roentgenol 198(5):1180–1187
10. Remy-Jardin M, Remy J, Masson P, Bonnel F, Debatselier P, Vinckier L, Duhamel A (2000) Helical CT angiography of thoracic outlet syndrome. Am J Roentgenol 174(6):1667–1674
11. Stepansky F et al (2008) Dynamic MR angiography of upper extremity vascular disease: pictorial review. RadioGraphics 28(1):e28
12. Wadhawani R et al (2001) Color Doppler and duplex sonography in 5 patients with thoracic outlet syndrome. J Ultrasound Med 20(7):795–801
13. Leffert RD (1992) Thoracic outlet syndromes. Hand Clin 8:285–297
14. Novak CB, Mackinnon SE (1996) Thoracic outlet syndrome. Orthop Clin North Am 27:747–762
15. Oates SD, Daley RA (1996) Thoracic outlet syndrome. Hand Clin 12:705–718
16. Roos DB (1979) New concepts of TOS that explain etiology, symptoms, diagnosis and treatment. Vasc Surg 13:313–321
17. Demondion X, Boutry N, Drizenko A, Paul C, Francke JP, Cotten A (2000) Thoracic outlet: anatomic, correlation with MR imaging. AJR Am J Roentgenol 175:417–422
18. Smedby O, Rostad H, Klaastad O, Lilleas F, Tillung T, Fosse E (2000) Functional imaging of the thoracic outlet syndrome in an open MR scanner. EurRadiol 10:597–600
19. Raptis C, Sridhar S, Thompson R, Fowler K, Bhalla S (2016) Imaging of the patient with thoracic outlet syndrome. RadioGraphics 36(4):984–1000
20. Illig KA, Thompson RW, Freischlag JA, Donahue DM, Jordan SE, Edgelow PI (eds) (2013) Thoracic outlet syndrome. Springer, New York
21. Sanders RJ, Hammond SL, Rao NM (2008) Thoracic outlet syndrome: a review. Neurologist 14(6):365–373
22. Cormier JM, Amrane M, Ward A, Laurian C, Gigou F (1989) Arterial complications of the thoracic outlet syndrome: fifty-five operative cases. J Vasc Surg 9(6):778–787
23. Scherrer A, Roy P, Fontaine A (1979) Syndrome d'emergence du membre superieur: une reevaluation del'interet de l'angiographie posturale. J Radiol 60:417–428
24. Butros SR, Liu R, Oliveira GR, Ganguli S, Kalva S (2013) Venous compression syndromes: clinical features, imaging findings and management. Br J Radiol 86:20130284
25. Arányi Z, Csillik A, Böhm J, Schelle T (2016) Ultrasonographic identification of fibromuscular bands associated with neurogenic thoracic outlet syndrome: the "wedge-sickle" sign. Ultrasound Med Biol 42(10):2357–2366