American College of Radiology
ACR Appropriateness Criteria®
Thoracic Outlet Syndrome

Variant 1: **Neurogenic thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI chest without and with IV contrast	Usually Appropriate	O
MRI chest without IV contrast	Usually Appropriate	O
Radiography chest	Usually Appropriate	☢
CT chest with IV contrast	May Be Appropriate	☢☢☢
CTA chest with IV contrast	May Be Appropriate	☢☢☢
US duplex Doppler subclavian artery and vein	May Be Appropriate	O
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without IV contrast	Usually Not Appropriate	☢☢☢
CTV chest with IV contrast	Usually Not Appropriate	☢☢☢☢
MRA chest without and with IV contrast	Usually Not Appropriate	O
MRA chest without IV contrast	Usually Not Appropriate	O
Catheter venography upper extremity	Usually Not Appropriate	☢☢☢
MRV chest without and with IV contrast	Usually Not Appropriate	O
MRV chest without IV contrast	Usually Not Appropriate	O
Arteriography upper extremity	Usually Not Appropriate	☢

Variant 2: **Venous thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.**

Procedure	Appropriateness Category	Relative Radiation Level
Catheter venography upper extremity	Usually Appropriate	☢☢☢
US duplex Doppler subclavian artery and vein	Usually Appropriate	O
CT chest with IV contrast	Usually Appropriate	☢☢☢
Radiography chest	Usually Appropriate	☢
CTV chest with IV contrast	May Be Appropriate	☢☢☢☢
MRI chest without and with IV contrast	May Be Appropriate	O
MRV chest without and with IV contrast	May Be Appropriate	O
MRA chest without and with IV contrast	May Be Appropriate	O
MRA chest without IV contrast	May Be Appropriate (Disagreement)	O
MRI chest without IV contrast	May Be Appropriate	O
MRV chest without IV contrast	May Be Appropriate	O
CT chest without IV contrast	May Be Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
Arteriography upper extremity	Usually Not Appropriate	☢
CTA chest with IV contrast	Usually Not Appropriate	☢☢☢

Variant 3: **Arterial thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA chest with IV contrast	Usually Appropriate	☢☢☢
MRA chest without and with IV contrast	Usually Appropriate	O
Radiography chest	Usually Appropriate	☢
US duplex Doppler subclavian artery and vein	Usually Appropriate	O
Arteriography upper extremity	Usually Appropriate	☢
CT chest with IV contrast	May Be Appropriate	☢☢☢
MRI chest without and with IV contrast	May Be Appropriate	O
MRA chest without IV contrast	May Be Appropriate	O
MRI chest without IV contrast	May Be Appropriate	O
CT chest without IV contrast	May Be Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
Catheter venography upper extremity	Usually Not Appropriate	☢☢☢
CTV chest with IV contrast	Usually Not Appropriate	☢☢☢☢
MRV chest without and with IV contrast	Usually Not Appropriate	O
MRV chest without IV contrast	Usually Not Appropriate	O

THORACIC OUTLET SYNDROME

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Summary of Literature Review

Introduction/Background

Thoracic outlet syndrome (TOS) denotes the clinical entity that occurs with compression of the brachial plexus, subclavian artery, and/or subclavian vein at the superior thoracic outlet. There are three distinct spaces that can be implicated in TOS. Narrowing of each space results in slightly different presentations because of differing severity of impingement on the transiting neurovascular structures [1,2]. The costoclavicular triangle consists of the clavicle superiorly, the anterior scalene muscle posteriorly, and the first rib inferiorly. All three neurovascular structures pass through this space. Narrowing of this space tends to cause venous symptoms, frequently denoted venous TOS (vTOS), with varying degrees of additional symptoms due to arterial or brachial plexus compression. The interscalene triangle consists of the anterior scalene muscle, middle scalene muscle, and first rib. Trunks of the brachial plexus and the subclavian artery pass through this space; narrowing here causes neurological dominant TOS (nTOS), arterial dominant (aTOS), or combinations of both. The pectoralis minor space, defined by the pectoralis minor muscle anteriorly and chest wall posteriorly, is essentially an extension of the thoracic outlet and can result in varying degrees of compression similar to the costoclavicular space.

During extreme shoulder abduction, the costoclavicular space is naturally narrowed. Anatomical variants such as a cervical rib can cause narrowing of the scalene triangle. Other possible sources of compression include anomalous first rib, C7 transverse process, or post-traumatic changes from prior clavicular or rib fractures. In patients who perform activities that require repetitive upper-extremity movement, such as swimming or throwing, or in patients who are not involved in excessive overhand motion but who have an anatomic predisposition to TOS, repetitive stress can lead to symptoms of TOS [3]. The subclavius muscle may hypertrophy, further narrowing the costoclavicular space, and the repetitive stress leads to thickening and fibrosis, notably in the subclavian vein wall, with restrictive fibrotic tissue surrounding the vein. Eventually, there is damage of the intima, resulting in luminal narrowing and a scarred, thrombogenic surface within the vein. Arterial changes in TOS similarly include intimal damage and thrombosis, with additional concerns of distal embolization and aneurysm formation. Neurological symptoms include chronic arm and hand paresthesia, numbness, or weakness.

Although the exact prevalence of TOS is unknown, symptomatic TOS has been estimated to be 10 per 100,000 [4]. The current management of TOS is variable [5-11]. Understanding the various anatomic spaces, causes of narrowing, and resulting neurovascular changes are important in choosing and interpreting radiological imaging, which may be performed to help diagnose TOS and plan for intervention.

This document has separated imaging appropriateness based on neurogenic, arterial, or venous symptoms, acknowledging that some patients may present with combined symptoms that may require more than one study to fully resolve. Additionally, in the postoperative setting, a new symptom may indicate a complication. Consultation

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with a radiologist may be useful at the time of examination ordering to optimize the study for the prevailing clinical symptom.

Special Imaging Considerations

CT

Imaging of the thoracic outlet often requires specific protocols and positioning that is not inherent in standard CT or MRI neck, cervical spine, or chest protocols. CT evaluation of TOS is typically performed in "neutral" and "stressed" positions. Images are obtained from the elbow to aortic arch with the arms adducted (neutral), followed by abduction (stressed) and repeat imaging.

When contrast is indicated, scan acquisition is typically performed with a contralateral antecubital intravenous (IV) injection, with either an empiric scan delay of 15 to 20 seconds or bolus tracking over the ascending aorta [12,13]. Some centers add the additional step of placing the contralateral arm in abduction (with the symptomatic ipsilateral arm in the neutral position) in order to minimize streak artifact [14].

For the purposes of distinguishing between CT and CT angiography (CTA), ACR Appropriateness Criteria topics use the definition in the ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA) [15]:

> *"CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial or venous enhancement. The resultant volumetric dataset is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3-D renderings."*

All elements are essential: 1) timing, 2) reconstructions/reformats, and 3) 3-D renderings. Standard CTs with contrast also include timing issues and recons/reformats. Only in CTA, however, is 3-D rendering a required element. This corresponds to the definitions that the CMS has applied to the Current Procedural Terminology codes.

CT venography (CTV) is obtained separately for each arm position 120 to 180 seconds after IV injection of iodinated contrast [6] in order to obtain venous opacification. The contrast injection should be performed in either the contralateral arm or other location. Multiplanar reformations are then produced to evaluate the thoracic space and true axial compression of the vessel. Center-line and volume-rendered images may also be produced to aid in visualization.

CTA chest and CTV chest specifically denote studies tailored to evaluating the chest and thoracic outlet. These include evaluation of central vessels as well as subclavian and axillary arteries and veins, respectively. This is distinct from CTA upper extremity and CTV upper-extremity protocols, which are designed to evaluate the entire limb peripherally to the level of the wrist.

MRI

MRI is typically performed with high-resolution T1-weighted and T2-weighted sequences in sagittal and axial planes to delineate anatomy and evaluate cervical radiculopathy, the brachial plexus, muscular attachments, and sites of compression [16,17]. Evaluation of the anatomic spaces is performed in both neutral and arms-abducted positions. Sagittal T1-weighted imaging performed with the patient's arms in abduction typically demonstrates effacement of fat adjacent to the brachial plexus roots, trunks, or cords within the interscalene triangle or costoclavicular space. T1-weighted imaging performed in sagittal and axial planes can also demonstrate causative lesions of nTOS, including the cervical ribs, congenital fibromuscular anomalies, and muscular hypertrophy. Imaging with turbo spin-echo T2-weighted or short tau inversion recovery sequences, as well as contrast-enhanced MRI, can be useful in cases in which spinal cord lesions or primary disorders of the brachial plexus (eg, brachial plexitis) are considered an alternative diagnoses to nTOS [18].

Contrast-enhanced 3-D MR angiography (MRA) techniques have been described at both 1.5T and 3T to assess for TOS [19]. Breath-hold arterial phase contrast-enhanced 3-D MRA and equilibrium phase imaging is obtained using a 3-D gradient-echo pulse sequence with fat suppression. These can be obtained in both neutral and stressed positions with the exact protocol customized to institutional needs. A coronal oblique 3-D slab of the MRA is often obtained covering bilateral subclavian and axillary vessels. Unenhanced mask imaging is followed by multiphase contrast-enhanced dynamic acquisition in the same orientation. Noncontrast time-of-flight MRA may be considered, particularly in patients with contraindications to gadolinium-based contrast; however, these techniques suffer from flow artifacts, which could lead to false diagnosis of stenosis or thrombosis [19]. Noncontrast MRA

also requires long acquisition times when combined with postural maneuvers that may be difficult to achieve for patients with severe clinical symptoms.

Contrast-enhanced 3-D MR venography (MRV) techniques have been described at both 1.5T and 3T to assess for vTOS [19]. Breath-hold venous phase contrast-enhanced 3-D MRV and equilibrium phase imaging is obtained using a 3-D gradient-echo pulse sequence with fat suppression. These can be obtained in both neutral and stressed positions with the exact protocol customized to institutional needs. A coronal oblique 3-D slab is often obtained covering bilateral subclavian and axillary vessels. Unenhanced mask imaging is followed by multiphase contrast-enhanced dynamic acquisition in the same orientation. Noncontrast time-of-flight MRV may be considered, particularly in patients with contraindications to gadolinium-based contrast; however, these techniques suffer from flow artifacts that could lead to false diagnosis of stenosis or thrombosis [19]. Noncontrast MRV also requires long acquisition times when combined with postural maneuvers that may be difficult to achieve for patients with severe clinical symptoms.

CTA chest and CTV chest specifically denote studies tailored to evaluate the chest and thoracic outlet. These include evaluation of central vessels as well as subclavian and axillary arteries and veins, respectively. This is distinct from CTA upper extremity and CTV upper-extremity protocols, which are designed to evaluate the entire limb peripherally to the level of the wrist.

Discussion of Procedures by Variant

Variant 1: Neurogenic thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.

Arteriography Upper Extremity
Selective upper-extremity arteriography is unable to directly image neurologic structures. This procedure is therefore not considered a first-line test for nTOS pre- or postoperatively.

Catheter Venography Upper Extremity
Dedicated endovascular catheter venography is unable to directly image neurologic structures. This procedure is therefore not considered a first-line test for nTOS pre- or postoperatively.

CT Chest
CT for the evaluation of nTOS is limited by the lack of resolution of neural structures, although evaluation of the space sizes gives secondary indicators that may aid in diagnosis [13]. The goal is to demonstrate anatomical narrowing that could cause neurovascular compression. Findings include effacement of fat within the respective space and distortion or narrowing of the space with provocative or stress positioning.

To also define adjacent vascular structures, a CT with IV contrast is sufficient for evaluation of nTOS [12,13].

CT allows quantification of the change in costoclavicular or interscalene spaces with provocative maneuvers [12,13], the presence of bony abnormalities [20,21], or superior sulcus pathology [22].

CT without IV contrast may be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and assess adequate decompression. If there is a clinical concern for arterial or venous compromise, postintervention for patients with nTOS, imaging should be guided by those Variants.

CTA Chest
CTA does not provide further evaluation of the neurologic structures as compared with chest CT. If there are overlapping symptoms with aTOS or vTOS, review of the other Variants in this document may help with protocol optimization.

CTV Chest
CTV does not provide further evaluation of the neurologic structures as compared with chest CT. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

MRI Chest
MRI has inherent advantages over ultrasound (US) in its ability to delineate extravascular anatomy, particularly in anatomic sites with poor sonographic windows, and MRI has advantages over CT in its characterization and differentiation of soft tissues.

For evaluation of patients with nTOS, definition of the brachial plexus and cervical spine and dynamic evaluation of neurovascular bundles in the costoclavicular, interscalene, and pectoralis minor spaces are required. Noncontrast MRI can be sufficient to diagnose nTOS.

In one study, for patients with nTOS, the neurovascular bundle was most commonly compressed in the costoclavicular space, mostly secondary to position, and very rarely compressed in the pectoralis minor space [16]. The cause of TOS was congenital bone variations in 36%, congenital fibromuscular anomalies in 11%, and positional in 53%. In 5%, there was unilateral brachial plexitis in addition to compression of the neurovascular bundle. Severe cervical spondylosis was noted in 14%, contributing to TOS symptoms [16].

MRI without IV contrast may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and assess adequate decompression. Postcontrast imaging may additionally be useful to assess the soft tissues for inflammatory or neoplastic conditions.

MRA Chest
Contrast-enhanced 3-D MRA techniques do not provide evaluation of the neurologic structures. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

MRV Chest
Contrast-enhanced 3-D MRV techniques do not provide adequate evaluation of the neurologic structures. This procedure is therefore not considered a first-line test for nTOS pre- or postoperatively.

Radiography Chest
Chest radiography is frequently used as an initial imaging modality in suspected TOS. Osseous abnormalities associated with TOS are frequently easily diagnosed by chest radiographs. These include first rib anomalies [20], cervical ribs [23], congenital osseous malformations [24,25], and focal bone lesions [26]. Soft-tissue lesions, such as lung neoplasms [27], may also be evaluated, although the negative predictive value of chest radiographs is low, such that cross-sectional imaging is a necessary part of a complete TOS workup. In the postoperative setting, radiographs may be useful to confirm osseous changes and evaluate for postoperative complications, such as pneumothorax.

US Duplex Doppler Subclavian Artery and Vein
US is widely used as an imaging modality in the initial evaluation of patients with suspected arterial or venous pathology. Although many patients with nTOS have additional symptoms due to arterial or venous compression, US is not as valuable in assessing direct neurological involvement. Real-time duplex US can be used to evaluate the cross-sectional area of the costocervical space with and without provocative maneuvers [28]. Diagnosis of compressive effects upon the brachial plexus is a challenge [29], and symptoms of TOS may unmask a deeper regional pathology such as a Pancoast tumor or cervical spondylopathy, requiring further imaging. If there is reason to believe that symptoms could be related to hypertrophy of the anterior scalene muscles, US could be used for guidance to inject anesthetic in an attempt to confirm nTOS [30]. The procedure is considered diagnostic of nTOS if the patient experiences relief of symptoms after the injection. In the postoperative setting, US can be useful to evaluate vessel patency and complications such as postoperative hematoma or fluid collection.

Variant 2: Venous thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.

Arteriography Upper Extremity
Selective upper-extremity arteriography may be used to evaluate extrinsic compression of the subclavian artery; however, it does not provide diagnostic assessment of the subclavian vein. This procedure is therefore not considered a first-line test for vTOS. In the postprocedure setting, catheter arteriography may be performed to evaluate and intervene on suspected or confirmed arterial complications.

Catheter Venography Upper Extremity
Diagnostic venography may be performed for suspected vTOS in which the veins of the affected extremity are catheterized, and contrast injection is performed via the catheter during digital subtraction acquisition in both neutral and stressed positions. Typical findings include narrowing of the subclavian vein with appearance of venous collateral vessels. These are generally seen projecting over the thorax or across the neck. Total occlusion of the subclavian vein may be present in chronic or acute TOS, and all findings may be present on only stressed position venography or at stress and neutral positions.

As part of the evaluation for surgical decompression, patients may also undergo contralateral venography as well as catheter-directed thrombolysis. Angioplasty is not typically performed in the chronic setting, and at some centers, it is generally avoided prior to surgical decompression. In patients with total or near-total subclavian vein occlusion, endovascular recanalization of the subclavian vein may be attempted, and, if successful, a peripherally inserted central venous catheter is occasionally inserted and positioned so that it courses across the newly recanalized venous segment. It is then left indwelling until after surgical decompression is performed so as to preserve a route of intraluminal access across the diseased subclavian vein segment.

One advantage of venography as a diagnostic tool is that other presurgery interventions may be performed, including intravascular thrombolysis, thrombectomy, and angioplasty. For postsurgical decompression, catheter venography is often indicated for evaluation of residual narrowing and possible US angioplasty of the diseased or stenosed segment with the external compression [31,32]. Intravascular US (IVUS) may be used as an adjunct in the postoperative setting to evaluate residual lumen size and presence of webs and has been shown to detect a higher degree of stenosis compared with venography alone [33].

CT Chest

For noncontrast chest CT, the goal is to demonstrate anatomical narrowing that could cause vascular compression. Findings include effacement of fat within the respective space and distortion or narrowing of the space with provocative or stress positioning.

Given the enhanced visualization of vascular structures with contrast, chest CT with IV contrast is preferred for evaluation of vTOS, and the acquisition is typically performed with a contralateral antecubital injection of contrast material.

Chest CT without IV contrast may be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and assess adequate decompression. However, chest CT with IV contrast has the advantage of providing assessment of vascular patency, which is a potential complication in the postintervention setting for patients with vTOS.

CTA Chest

CTA is performed to evaluate arterial compression and is therefore of limited use in the evaluation of vTOS. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

CTV Chest

CTV is performed to evaluate venous compression in neutral and elevated arm positions. Venous compression is often present with abduction in asymptomatic patients, and therefore this finding alone may be insufficient to diagnose vTOS. Venous thrombosis and presence of collateral venous circulation essentially bypassing the thoracic outlet confirms the existence of hemodynamically significant vTOS [1].

Multiple studies have demonstrated the utility of CTV with IV contrast in evaluation of the upper-limb veins; however, reliance on axial slices alone can lead to misrepresentation of the degree of any stenosis, with one study showing underestimation of stenosis found in 43% of transverse CT scans but only in 10% of sagittal reformations. Overestimation of stenosis was also more frequent on surface displays with 3-D shading (16%) than on volume-rendered images (7%) [12], thus advancing the case for evaluation of these studies using these multiplanar tools in addition to standard reformations.

CTV may be performed in the postintervention setting to evaluate interval changes in the thoracic outlet, assess adequate decompression, and follow-up on vessel patency or complications. Recurrent or persistent venous thrombosis may require reintervention.

MRI Chest

MRI for vTOS is performed to delineate anatomy and evaluate the pertinent anatomic spaces in both neutral and arms-abducted positions. Noncontrast MRI findings include effacement of fat adjacent to the subclavian vein. T1-weighted imaging performed in sagittal and axial planes can also demonstrate causative lesions, including cervical ribs, congenital fibromuscular anomalies, and muscular hypertrophy.

Venous compression has been routinely demonstrated in all 3 compartments of the thoracic outlet in both asymptomatic and symptomatic populations when the arms were abducted [17]. Therefore, a finding of compression on abduction must be interpreted carefully. In symptomatic patients, venous thrombosis and collateral circulation

are detected in both neutral and stressed arm positions, suggesting these findings are more reliably diagnostic of vTOS. They represent an objective, but likely chronic, finding of clinically significant venous compression.

Given the need to assess the subclavian vein as well as venous collaterals in vTOS, noncontrast MRI is insufficient alone; the addition of IV contrast, particularly when an MRV protocol is performed, provides optimal assessment. The combination of soft-tissue and vascular assessment provided by MRI with IV contrast makes it an excellent modality when compared with US and CT; however, the longer acquisition times may prove difficult for highly symptomatic patients.

MRI with IV contrast may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and assess adequate decompression.

MRA Chest
MRA is not optimized for evaluation of the venous structures. If there are overlapping symptoms, review of the other variants in this document may help with protocol optimization. Interestingly, in one study [19], all patients with arterial compression were found to have venous compression during arm abduction. In patients with venous compression on one side, 71% had significant bilateral venous compression. Of these patients with bilateral imaging findings, only 21% had bilateral clinical symptoms or findings suggestive of TOS. Therefore, MRA has the potential to overdiagnose vTOS, and clinical symptoms must be taken into account.

MRA may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet, assess adequate decompression, and confirm arterial patency.

MRV Chest
MRV is commonly performed in conjunction with MRI chest [34-36]. The primary MRV finding is narrowing of the subclavian vein; however, other findings, such as complete occlusion, collateral vessel formation, and visualization of thrombus, aid in the diagnosis of vTOS. Interestingly, in one study [19], all patients with arterial compression were found to have venous compression during arm abduction. In patients with venous compression on one side, 71% had significant bilateral venous compression. Of these patients with bilateral imaging findings, only 21% had bilateral clinical symptoms or findings suggestive of TOS. Therefore, MRV has the potential to overdiagnose vTOS, and clinical symptoms must be taken into account.

MRV may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet, assess adequate decompression, and confirm arterial patency.

Radiography Chest
Because of the importance of identifying osseous structures that may impinge on the spaces of the thoracic outlet, chest radiography is useful in performing a robust evaluation for all types of TOS. As opposed to directly evaluating vascular structures, osseous abnormalities associated with TOS are frequently easily diagnosed by chest radiographs. These include first rib anomalies [20], cervical ribs [23], congenital osseous malformations [24,25], and focal bone lesions [26]. In the postoperative setting, radiographs may be useful to confirm osseous changes and evaluate for postoperative complications such as pneumothorax.

US Duplex Doppler Subclavian Artery and Vein
US excels at evaluating arterial or venous pathology throughout the body. Real-time duplex US is noninvasive and can be easily performed during dynamic maneuvers. The technique involves B-mode US and Doppler study of the subclavian vessels and is typically performed at rest (neutral position) and with provocative maneuvers such as Adson, Eden, and 90° Wright tests. These tests were considered positive if they produced flow acceleration followed by turbulence and, finally, by an arrest in signal propagation [37,38]. These methods apply to both arterial and venous assessment. Evaluation of the cross-sectional area of the costocervical space may also be performed [28].

US has a longstanding and well-documented role in the diagnosis of upper-extremity DVT [5,39], a common presentation of vTOS in the acute setting. Although the main advantage of US is the ability to directly compare between provocatively induced symptoms and concurrent direct vessel visualization, there is debate in the literature as to the significance of imaging findings, particularly with respect to maneuvers to minimize the thoracic outlet and associated spaces [28,37,40].

It is important to consider that certain etiologies of vTOS due to deeper pathology, such as Pancoast tumor or cervical spondylopathy, may require further investigation with cross-sectional imaging.

In the postoperative setting, US can be useful to evaluate vessel patency and complications, such as postoperative hematoma or fluid collection.

Variant 3: Arterial thoracic outlet syndrome. Initial imaging and follow-up imaging after surgery or intervention.

Arteriography Upper Extremity
Conventional catheter-based arteriography is effective at locating the exact point of vascular compression. In order to perform complete arteriography, catheter injection of contrast must be made from the aortic arch or the proximal subclavian artery. Injections and digital subtraction angiographic acquisitions are performed in both the neutral and abducted positions to assess dynamic changes. Vascular access is typically obtained from the femoral artery, although a radial artery approach can be considered. Even as a diagnostic tool alone, arteriography carries some risk. Because of its invasive nature and lack of information regarding surrounding structures, catheter-based angiography is largely only pursued if an endovascular intervention is envisioned.

In the postintervention setting, catheter arteriography can provide definitive evaluation of arterial compression, occlusion, or other complication, such as dissection or aneurysm formation. This modality has the added advantage of possible immediate endovascular intervention.

Catheter Venography Upper Extremity
Diagnostic venography is not optimized for arterial evaluation. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

CT Chest
For noncontrast CT, the goal is to demonstrate anatomical narrowing that could cause vascular compression. Findings include effacement of fat within the respective space and distortion or narrowing of the space with provocative or stress positioning.

In a comprehensive study [13], a statistically significant difference was found between the distribution of the distances measured in the neutral and abducted positions in patients with arterial stenosis versus those without arterial stenosis.

CT without IV contrast may be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and assess adequate decompression. However, CT with IV contrast has the advantage of providing assessment of vascular patency, which is a potential complication in postintervention setting for patients with aTOS.

CTA Chest
CTA is performed to evaluate arterial compression in neutral and elevated arm positions. An indentation of the anterior wall of the subclavian artery as it passes around the anterior scalene muscle may be observed [13] as well as displacement of the subclavian vessels. Arterial compression is assessed by using arterial cross-sections produced by sagittal reformation of data. Sagittal reformation can show the location and severity of the arterial compression, and volume-rendered images allow simultaneous analysis of bones and subclavian artery. Arterial stenosis is expressed as the percentage of reduction of the cross-sectional area or the diameter of the artery [1].

Multiple studies have demonstrated the utility of CT in evaluation of the upper-limb arteries and veins; however, reliance on axial slices alone can lead to misrepresentation of the degree of any stenosis, with one study showing underestimation of stenosis found in 43% of transverse CT scans but only 10% of sagittal reformations. Overestimation of stenosis was also more frequent on surface displays with 3-D shading (16%) than on volume rendered images (7%) [12], advancing the case for evaluation of these studies on vascular workstations. For arterial compression, there is evidence of good correlation of CT findings with operative findings and results of decompression [41].

CTA may be performed in the postintervention setting to evaluate interval changes in the thoracic outlet, assess adequate decompression, and follow-up vessel patency or complications. Recurrent or persistent venous thrombosis may require reintervention.

CTV Chest
CTV is performed for evaluation of venous compression. This specific modality is therefore of limited use in aTOS. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

MRI Chest
MRI for aTOS is performed to delineate anatomy and evaluate the pertinent anatomic spaces in both neutral and arms-abducted positions. Noncontrast MRI findings include effacement of fat adjacent to the subclavian vein. T1-weighted imaging performed in sagittal and axial planes can also demonstrate causative lesions, including cervical ribs, congenital fibromuscular anomalies, and muscular hypertrophy.

Given the need to assess the subclavian artery in aTOS, noncontrast MRI would be insufficient, with contrast-enhanced MR arteriography providing optimal assessment. The combination of soft-tissue and vascular assessment provided by MRI with contrast makes it an excellent modality when compared with US and CT; however, the longer acquisition times may prove difficult for highly symptomatic patients.

MRI with IV contrast may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet and to assess adequate decompression.

MRA Chest
The primary MRA finding is narrowing of the subclavian artery; however, other findings, such as complete occlusion, collateral vessel formation, and visualization of thrombus, aid in the diagnosis of aTOS. MRA may help identify the severity of TOS and guide surgical or endovascular management [36]. If there is no evidence of compression on the abducted images, then imaging in the neutral position may be deferred. In the evaluation of TOS, if there is compression of the subclavian artery depicted on both sagittal T1-weighted and MRA, it may be denoted as aTOS. Further findings of aTOS that may be present include fixed or dynamic stenosis, aneurysm, mural thrombus, or distal emboli. Numerous MRA techniques have been described including noncontrast MRA, including inversion recovery methods for patients unable or unwilling to have contrast [42], simultaneous bilateral MRA [34], and dual-gadolinium injection protocols [35].

Ancillary findings include possible etiologies of aTOS, frequently cervical or anomalous first rib, scalene muscle, fibromuscular bands, or pectoralis minor tendon, and anomalous course of the subclavian artery within the scalene muscle.

MRA may also be performed in the postintervention setting to evaluate interval changes in the thoracic outlet, assess adequate decompression, and confirm arterial patency.

MRV Chest
MRV is not needed in patients with aTOS. If there are overlapping symptoms, review of the other Variants in this document may help with protocol optimization.

Radiography Chest
Because of the importance of identifying osseous structures that may impinge on the spaces of the thoracic outlet, chest radiography is useful in performing a robust evaluation for all types of TOS. As opposed to directly evaluating vascular structures, osseous abnormalities associated with TOS are frequently easily diagnosed by chest radiographs. These include first rib anomalies [20], cervical ribs [23], congenital osseous malformations [24,25], and focal bone lesions [26]. In the postoperative setting, radiographs may be useful to confirm osseous changes and evaluate for postoperative complications such as pneumothorax.

US Duplex Doppler Subclavian Artery and Vein
As with vTOS, US is an excellent initial study in the evaluation of aTOS. The subclavian and axillary arteries can be directly visualized and assessed for aneurysmal change, arterial stenosis, and thrombosis. Dynamic arterial blood flow can be assessed during abduction. Findings include decrease in arterial diameter, changes in peak velocity, or reproducible symptoms considered to be diagnostic of aTOS. Evaluation of the cross-sectional area of the costocervical space may also be performed [28]. It is important to consider that although aTOS may be identified by US, certain etiologies due to deeper pathology, such as cervical spondylopathy, require further imaging.

In the postoperative setting, US can be useful to evaluate vessel patency and complications, such as postoperative hematoma or fluid collection.

Summary of Recommendations

- **Variant 1:** Radiography of the chest and either MRI without and with IV contrast of the chest or MRI without IV contrast of the chest are usually appropriate for the initial and follow-up imaging after surgery or intervention for patients with nTOS. MRI without IV contrast is an acceptable alternative to MRI without and with IV

contrast (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

- **Variant 2:** Radiography of the chest and US duplex Doppler of the subclavian artery and vein, CT with IV contrast of the chest, or catheter venography of the upper extremity are usually appropriate for the initial and follow-up imaging after surgery or intervention for patients with vTOS. US duplex Doppler, CT with IV contrast, and catheter venography are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). The panel did not agree on recommending MRA without IV contrast of the chest for the initial and follow-up imaging after surgery or intervention for patients with venous thoracic outlet syndrome. There is insufficient medical literature to conclude whether or not these patients would benefit from MRA without IV contrast of the chest for this clinical scenario. Imaging in this patient population is controversial but may be appropriate.
- **Variant 3:** Radiography of the chest and CTA with IV contrast of the chest, MRA without and with IV contrast of the chest, US duplex Doppler of the subclavian artery and vein, or arteriography of the upper extremity are usually appropriate for the initial and follow-up imaging after surgery or intervention for patients with aTOS. CTA with IV contrast, MRA without and with IV contrast, US duplex Doppler, and arteriography of the upper extremity are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the

long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document [43].

Relative Radiation Level Designations		
Relative Radiation Level*	**Adult Effective Dose Estimate Range**	**Pediatric Effective Dose Estimate Range**
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv
*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."		

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The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.