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Thoracic outlet syndrome: a review

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Thoracic outlet syndrome (TOS) is a rare condition (1-3 per 100,000) caused by neurovascular compression at the thoracic outlet and presents with arm pain and swelling, arm fatigue, paresthesias, weakness, and discoloration of the hand. TOS can be classified as neurogenic, arterial, or venous based on the compressed structure(s). Patients develop TOS secondary to congenital abnormalities such as cervical ribs or fibrous bands originating from a cervical rib leading to an objectively verifiable form of TOS. However, the diagnosis of TOS is often made in the presence of symptoms with physical examination findings (disputed TOS). TOS is not a diagnosis of exclusion, and there should be evidence for a physical anomaly that can be corrected. In patients with an identifiable narrowing of the thoracic outlet and/or symptoms with a high probability of thoracic outlet neurovascular compression, diagnosis of TOS can be established through history, a physical examination maneuvers, and imaging. Neck trauma or repeated work stress can cause scalene muscle scaring or dislodging of a congenital cervical rib that can compress the brachial plexus. Nonsurgical treatment includes anti-inflammatory medication, weight loss, physical therapy/strengthening exercises, and botulinum toxin injections. The most common surgical treatments include brachial plexus decompression, neurolysis, and scalenotomy with or without first rib resection. Patients undergoing surgical treatment for TOS should be seen postoperatively to begin passive/assisted mobilization of the shoulder. By 8 weeks postoperatively, patients can begin resistance strength training. Surgical treatment complications include injury to the subclavian vessels potentially leading to exsanguination and death, brachial plexus injury, hemothorax, and pneumothorax. In this review, we outline the diagnostic tests and treatment options for TOS to better guide clinicians in recognizing and treating vascular TOS and objectively verifiable forms of neurogenic TOS.

Level of evidence: Narrative Review

Keywords: Neurogenic; vascular; arterial; venous; diagnostic exams; management

Thoracic outlet syndrome (TOS) was first described by Peet et al[79] in 1956 as a heterogeneous characterization of symptoms associated with neurovascular compression at the thoracic outlet. This can lead to pain, numbness, and paresthesias of the neck, upper back, and upper extremity.[51,106] TOS is a relatively rare syndrome (1-3 per 100,000) and is classified according to the structure being constricted: neurogenic (nTOS), arterial (aTOS), and venous (vTOS). Common etiologies of TOS include trauma, repetitive upper extremity movement, and anatomic abnormalities.[53,62] Diagnosing TOS can be difficult due to poorly defined diagnostic criteria, shared symptoms with other conditions, and rarity of the syndrome. Oftentimes, generalized arm pain is incorrectly ''diagnosed'' as nTOS, leading to useless and potentially harmful treatments. However, awareness of the constellation of symptoms and physical examination findings characteristic of TOS can improve the clinician's likelihood of accurately diagnosing

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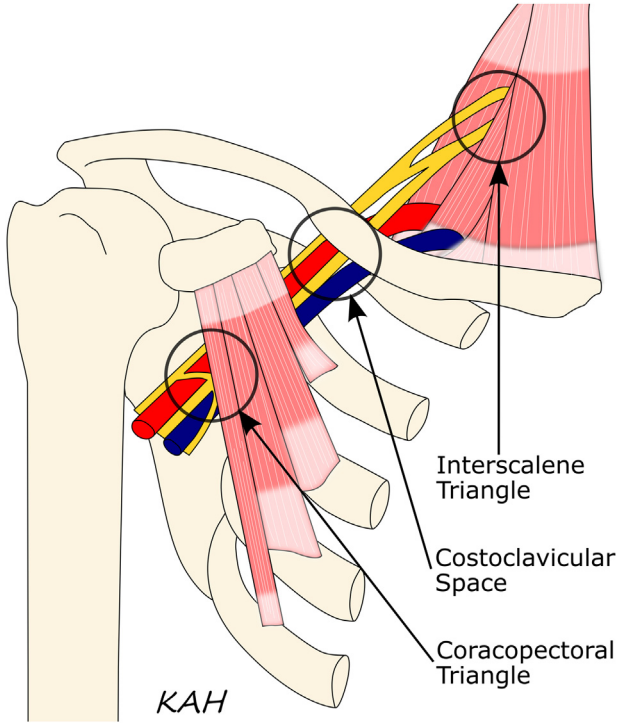

Figure 1 Thoracic outlet syndrome can occur at the interscalene triangle, costoclavicular space, and the coracopectoral triangle.

and treating the condition when objective identifiable narrowing of the thoracic outlet is present.

Anatomy

The thoracic outlet is the space from the supraclavicular fossa medial to the axilla that traverses inferior to the clavicle and pectoralis minor laterally and superior to the first rib. Key neurovascular structures that pass through the thoracic outlet include the brachial plexus, subclavian artery, and subclavian vein. Neurovascular compression can occur at 3 anatomic locations: the interscalene triangle, costoclavicular space, and coracopectoral tunnel (Fig. 1).[46] The interscalene triangle borders include the anterior scalene muscle, middle scalene muscle, and the first rib, which encompasses the subclavian artery and brachial plexus. The costoclavicular space is the area between the first rib and clavicle and includes the brachial plexus, subclavian artery, and subclavian vein. which runs medially to the anterior scalene muscle. The coracopectoral tunnel is the area that is between the ribs and the pectoralis minor muscle and contains the cords of the brachial plexus and the axillary artery. Clinicians should be aware of anatomic variations that can cause TOS such as the presence of cervical ribs, which originate from the seventh cervical vertebrae, vary in length, and can fuse to the first rib.[15,62]

Etiology

TOS is caused by a reduction in the space within the thoracic outlet and is classified according to the neurovascular structures being compressed. nTOS is characterized by constriction of the cords of the brachial plexus (90%-95% of all cases), vTOS is characterized by constriction of the axillary or subclavian vein (3%-5%), and aTOS is characterized by constriction of the axillary or subclavian artery (<1%).[72,93] nTOS may further be divided into true (presence of objective findings) and disputed (absence of objective findings) nTOS. It has been cited that disputed nTOS makes up 95%-99% of all nTOS diagnoses.[94,103] The cause of TOS can be anatomic narrowing due to soft-tissue (70%) or osseous abnormalities (30%).[6] In a metanalysis of 357 patients with cervical ribs, 51.3% (35%-68%) of patients exhibited vascular TOS.[44] Soft-tissue abnormalities that have been implicated in the compression of structures in the thoracic outlet include scalene muscle hypertrophy,[27,81] crossing of the anterior and medial scalene insertions,[58,68,121] anomalous presence of the scalenus minimus,[58] soft-tissue tumor,[26,113] and abnormal insertion of the costoclavicular ligament near the subclavian vein.[40] The osseous abnormalities associated with compression of structures in the thoracic outlet include the presence of cervical ribs,[91] elongated C7 transverse process,[4] first rib abnormality,[13,91] clavicular enlargement or callous formation,[13] first rib fracture,[13] clavicle fracture,[16] acromioclavicular or sternoclavicular joint disturbance,[74] and osseus tumor.[70]

Constriction or injury to one of the neurovascular structures in the thoracic outlet may be induced by trauma either directly through fracture fragments, vessel hemorrhage, or dislocation of the humeral head or medial end of the clavicle,[57,84,122] or indirectly through associated swelling. TOS may also be caused by chronic repetitive activity of the subclavius and anterior scalene muscles which may lead to muscle hypertrophy and subsequent impingement of neurovascular structures or microvascular damage leading to fibrosis.[53] Soft-tissue and osseous abnormalities can also cause TOS when combined with overuse or neck trauma.

Epidemiology

TOS is most commonly diagnosed in patients between the ages of 20-30 years for vascular forms and between 20-40 years for the neurogenic form.[39] nTOS is more common in women, vTOS is more common in men, and men and women are affected equally by aTOS.[39] Most cases of TOS arise from either acute trauma causing cervical rib impingement or repeat injuries to the scalene muscles leading to muscle fibrosis and thoracic outlet narrowing.[93] The possible pathogenesis of the cycle of tissue injury and repair can be elicited by repetitive harmful movements of the arm, shoulder, and/or neck typically in the setting of

work. Patients who perform repeated arm and shoulder movements through work, weightlifting, and athletics are at an increased risk for developing TOS.[12,24]

Patient history/complaints

The clinical presentation of TOS is variable and depends on the anatomic features being compressed. aTOS most often presents with symptoms consistent with intermittent ischemia of the hand including pain, pallor, claudication, paresthesias, and coldness.[93] Symptoms of aTOS may extend throughout the upper extremity consistent with subclavian artery compression. In contrast, the most indicative sign of vTOS is arm swelling with possible cyanosis that is not found in aTOS or nTOS. vTOS caused by subclavian vein thrombosis is known as Paget-Schroetter syndrome. Other symptoms consistent with venous obstruction can also present in vTOS including pain and feelings of heaviness.[93] Patients with nTOS may present with neck pain, trapezius pain, supraclavicular pain, shoulder pain, arm pain, paresthesias, hand weakness, arm weakness, and/or shoulder weakness.[93] The variety in presentation further points to the fact that nTOS could be harmfully used as a ''catch-all'' diagnosis. Diagnosing a patient with nTOS to ascertain a diagnosis could lead to high-risk treatments and physicians should use this diagnosis with caution when an anatomic anomaly is not present—such as a bony anomaly present on x-ray or a fibrous band extending from a cervical rib or elongated transverse process on magnetic resonance neurography.[8]

Physical examination

The diagnosis of TOS is difficult to establish because there are few objective findings that confirm the diagnosis.[59] When performing a physical examination on a patient with suspected TOS, the clinician should focus on the cervical spine, shoulder, and upper extremity with particular emphasis on the posture of the head and neck.[53,59] The appearance of the limbs and chest should be noted for color, temperature, swelling, and atrophy.[59] Based on the presentation of the patient, the clinician should tailor the physical examination accordingly (Table I).

Suspected neurogenic TOS and/or idiopathic arm pain

nTOS is often diagnosed by process of elimination due to the difficulty in imaging and localization of neurologic dysfunction. nTOS should only be diagnosed in the presence of verifiable pathology such as brachial plexus incasing fibrous bands visible on imaging. An nTOS diagnosis is often made without any measurable pathology, and the diagnosis should be made sparingly to avoid potentially high-risk treatments leading to no symptomatic relief. Patients typically present with pain, paresthesias in the fingers, and weakness of the upper extremity.[69] A hallmark feature of nTOS is pain with pressure on the supraclavicular or infraclavicular brachial plexus[69,77]; this can be used to differentiate nTOS from pathology of the cervical spine, shoulder, and carpal/cubital tunnel.[59] Pain is often provoked when the arm is used overhead.[77] The physical examination maneuvers used to support an nTOS diagnosis are not consistently reliable and can lead the clinician to make an incorrect nTOS diagnosis prematurely, so they should be used with caution.

Another common finding in patients with nTOS is the ''Gilliat-Sumner Hand'' sign with thumb abductor pollicis brevis atrophy.[53,59,64,105] Rarely, the hypothenar musculature and the interossei muscles are also atrophied.[53,59] Additionally, median nerve distribution sensation is normal in these cases.

Idiopathic arm pain refers to pain of the upper extremity that cannot be attributed to any identifiable pathology. Clinicians may mistakenly diagnose idiopathic arm pain as nTOS in the context of vague arm pain with possible involvement of the brachial plexus even when there is no verifiable abnormality. However, the diagnostic maneuvers, treatments, and/or diagnosis itself may cause harm. This should be avoided. Patients with idiopathic arm pain often have diffuse, vague, and difficult to describe symptoms.[73] Idiopathic arm pain is correlated with symptom amplification overtime where previously ignored symptoms are now being relabeled as additional evidence of pathologic arm pain.[118,119] Catastrophizing symptoms may be a physical presentation of contributing psychosocial factors.[73] Such factors may include dissatisfaction with support systems, poor interpersonal relationships, and little decision-making power in the workplace.[10,41,66,100] Nonsurgical management for patients with symptoms consistent with nTOS is less successful in patients with depression, obesity, workers' compensation cases, and any concomitant history of carpal or cubital tunnel syndrome.[76] This suggests that, in some patients with underlying psychosocial factors, physical symptoms may manifest from an amplification of psychological symptoms rather than a ''curable'' pathology.

Suspected venous TOS

Patients present with severe upper extremity edema and deep upper extremity pain.[48,59,77] When any form of vascular TOS is suspected, it is important to compare the skin color, temperature, and atrophy of the affected arm to the contralateral arm.[59] A clinician should suspect vTOS when a young, active patient presents with sudden onset upper extremity edema and cyanosis.[69,77] A thorough history can reveal potential risk factors involving repeated

Table I Thoracic outlet syndrome (TOS) physical examination maneuvers

Test	Type of TOS	Description	Positive test result	Sensitivity	Specificity
Adson's Test (Fig. 2)	aTOS vTOS nTOS	Arm extended in 30° abduction. Patient takes deep breath and clinician feeling for pulse disappearance	Distal radial pulse disappearance (aTOS); Paresthesias/Pain (nTOS)	79%-92%	76%
Elevated Arm Stress Test/ Roos (Fig. 3)	nTOS	Sitting patient abducts arms to 90° with shoulders in full external rotation and elbows flexed to 90°. Patient opens and closes hands for 30s.	Pain, numbness, or tingling in the affected extremity	84%-98%	30%
Upper Limb Tension Test/ Elevey's Test (Fig. 4)	nTOS	Pos 1: Patient abducts shoulders to 90° with elbows extended Pos 2: Hold position 1 with wrists in full flexion Pos 3: Laterally flex head away from affected limb	Paresthesias and pain	72%-97%	11%-33%
Hyperabduction/Wright's Test (Fig. 5)	aTOS vTOS	Sitting patient abducts arm to 90° with shoulder in full external rotation. While clinician is feeling distal radial pulse, patient abducts to 180°	Diminished or complete disappearance of radial pulse	70%	53%
Cyriax Release Test (Fig. 6)	nTOS	Seated patient crosses their arms holding the elbows at 80° flexion. The clinician grasps under the forearms and elevates the patient	Paresthesias and pain relief (release phenomenon)	-	88%
Costoclavicular Pressure/ Eden's Test (Fig. 7)	nTOS aTOS vTOS	Seated patient abducts arms to 30° and fully extends both arms while clinician palpates distal radial pulses.	Diminished or disappearance of distal radial pulse; paresthesias or extremity pain	84%	52%
Brachial Plexus Compression/Morley's Compression Test	nTOS	Patient is seated in relaxed position while clinician compresses the supraclavicular fossa for 30s	Paresthesias, pain, and aching	-	-

aTOS, arterial TOS; *vTOS*, venous TOS; *nTOS*, neurogenic TOS.

overhead activities and weightlifting.[77] Paget-Schroetter syndrome is a form of vTOS that is caused by thrombosis of the subclavian vein rather than mechanical compression.

Patients with suspected vTOS will not have brachial plexus tenderness, but will present with severe edema and cyanosis.[48,69,77] Additionally, superficial veins of the arm, neck, and chest can become engorged due to increased venous pressure.[48,69] Patients with this symptomology should be sent for duplex ultrasound, computed tomography (CT), or magnetic resonance imaging (MRI) to confirm diagnosis. It is important to note that vTOS is rare and easily diagnosed.

Suspected arterial TOS

This rare clinical presentation is severe and warrants immediate treatment. Patients typically present with unilateral

hand ischemia.[77] aTOS is accompanied by persistent pain and numbness in the affected extremity, impaired temperature sensation, and limb pallor and coldness.[69,77] Pain typically worsens with exercise and especially with overhead movements.[53] While vTOS presents with edematous chest and upper extremity, aTOS is often accompanied with a pale or cyanotic chest.[53] Additionally, the ulnar, radial, and brachial pulses may be absent on the affected limb due to proximal subclavian artery compression.[77] Another physical examination finding common in aTOS is a difference in systolic blood pressure between symptomatic and asymptomatic sides as high as 20 mm Hg.[48,53,59] Finally, narrowing of the subclavian artery can cause bruits or pulsating masses in the supraclavicular region.[48] Duplex ultrasound, CT, or MRI should be done in patients with these findings. Again, aTOS is rare and presents with clear signs, symptoms, and imaging.

The following diagnostic physical examinations can be used to narrow in on a TOS diagnosis.

Diagnostic maneuvers

The diagnostic maneuvers presented in this section have reported sensitivity and specificity values, and the reference standard reported in these studies is based on the holistic review of all assessment methods (ie, history, physical examination, and imaging) and not 1 single parameter.[37,88]

Adson's test

Adson's test (Adson Maneuver) is performed by having a seated patient fully extend their elbow with the shoulder in 30° of abduction. With a patient's head rotated toward the involved limb, the clinician instructs the patient to take a deep breath (Fig. 2).[53,59,69] The examination is positive if the radial pulse is decreased or absent or if neurologic symptoms such as pain or paresthesias of the hand or arm manifest. Adson's test is primarily used to diagnose vTOS and aTOS but is positive for nTOS if pain and paresthesias are present with the maneuver.[45] The examination has a sensitivity of 79%-92% and a specificity of 76% for vascular forms of TOS.[37,59,88] In fact, 40% of asymptomatic patients will have pulse disappearance by performing this maneuver.[69]

Elevated Arm Stress Test

The Elevated Arm Stress Test, or Roos test, is specific for nTOS and is performed by having a seated patient abduct the affected shoulder 90° with full shoulder external rotation and elbows flexed to 90°. The patient then opens and closes their hands rapidly for 3 minutes (Fig. 3).[53,69,77] Patients with nTOS will have rapid onset of upper extremity pain within 20-30 seconds of beginning the test.[77] Patients will experience heaviness, weakness, pain, and/or paresthesias in the affected extremity.[53] The sensitivity and specificity for the Elevated Arm Stress Test is 84%-98% and 30%, respectively. However, when done in conjunction with Adson's test, the specificity increases to 82%.[37,59,88]

Upper Limb Tension Test

The Upper Limb Tension Test, also known as Elvey's test, is specific to nTOS and is performed through a series of 3 consecutive positions, with each position increasing pressure on the brachial plexus. The first position is performed by abducting both the patient's shoulders to 90° with elbows extended (Fig. 4*A*). The second position adds dorsiflexion at the wrists (Fig. 4*B*). The third position adds lateral flexion of the head to the contralateral side (Fig. 4*C*).[93] A positive sign for this examination is paresthesias and pain caused by the compression of the brachial plexus nerves in any of the 3 positions.[53,69] Typically, patients positive for nTOS will have pain during wrist extension and minor relief during wrist flexion.[77] Sensitivity and specificity for the Upper Limb Tension Test ranges from 72% to 97% and 11% to 33%, respectively.[82,87,120]

Wright's test

Wright's test (hyperabduction test) is specific for vascular TOS and is performed with the patient seated. The patient abducts the affected arm to 90° with the shoulder in full external rotation and the clinician palpates the distal radial pulse. The patient then raises their arm to 180° abduction while the clinician continues to palpate the distal radial pulse (Fig. 5). A positive sign for this maneuver is a diminished or complete disappearance of the distal radial pulse upon arm extension. This test is specific for TOS and is more sensitive to vascular forms of TOS.[45] This maneuver has a value of 70% and 53% for sensitivity and specificity, respectively.[37]

Cyriax Release Test

The Cyriax Release Test is performed with the patient seated with their arms crossed. The test is specific for nTOS and is indicated particularly with night pain. The patient's elbows should be in 80° flexion. The clinician, from behind, places their hands on the patient's elbows and lifts the shoulders upwards (Fig. 6). A positive Cyriax test is unique in that it displays a release phenomenon—symptoms are relieved by the maneuver and relapse when the clinician releases the patient.[46] The specificity of the Cyriax release test for nTOS is 88%; the sensitivity has not been reported.[114]

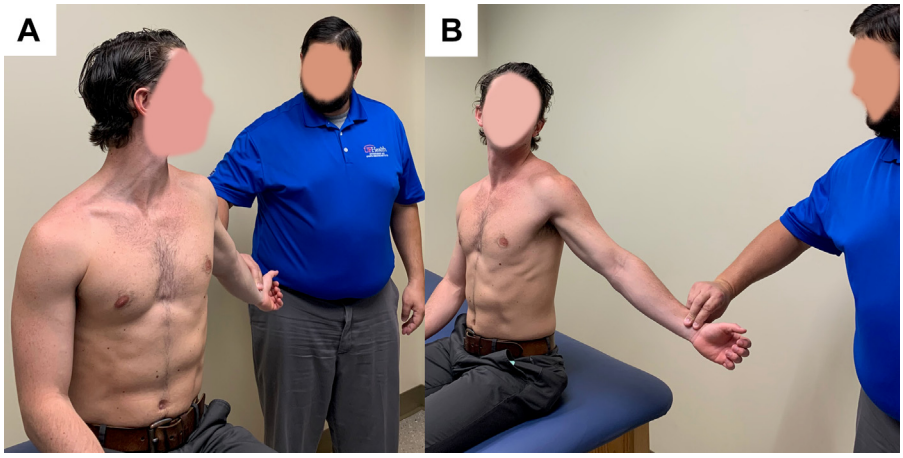

Figure 2 In Adson's test, the clinician palpates the distal radial pulse and instructs the patient to abduct the arm to 30° with the arm in full extension (A and B). The patient turns their head toward the involved side and takes a deep breath. A positive sign is radial pulse diminishment or disappearance and/or sudden onset pain.

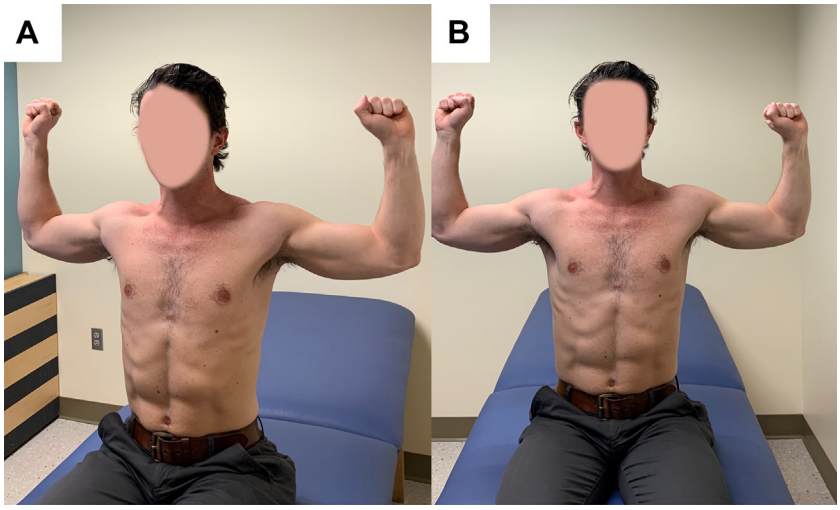

Figure 3 In the Elevated Arm Stress Test (EAST), the seated patient abducts the shoulders to 90° with full shoulder external rotation and the elbows flexed to 90° (A and B). The patient opens and closes their fists for 30 seconds to 3 minutes. A positive sign for this test is rapid onset of pain throughout the affected extremity.

Costoclavicular pressure test

The costoclavicular pressure test, or Eden's test, is performed with the patient seated. The clinician palpates the distal radial pulses and instructs the patient to abduct their arms to 30° and fully extend their shoulders. The patient then fully flexes their neck to compress the neurovascular bundle (Fig. 7). A positive test result is diminished or complete disappearance of distal radial pulse or onset of paresthesias and pain. This diagnostic maneuver can be used for diagnosis of all forms of TOS. Sensitivity for the costoclavicular pressure test is 84% and specificity is 52%.[75] These values are not widely reported, and further work is needed before the costoclavicular pressure test can provide clinically useful information.

Brachial plexus compression test

The brachial plexus compression test, or Morley's compression test, is specific for nTOS and is performed with the patient seated in a relaxed position. The clinician then compresses the supraclavicular fossa, compressing the neurovascular bundle affected in TOS. A positive sign in this maneuver is onset of pain, paresthesias, and aching.

Imaging

Imaging is an important step in evaluating for suspected TOS after physical examination.[53,69] Imaging can also aid in identifying anatomic abnormalities that can lead to

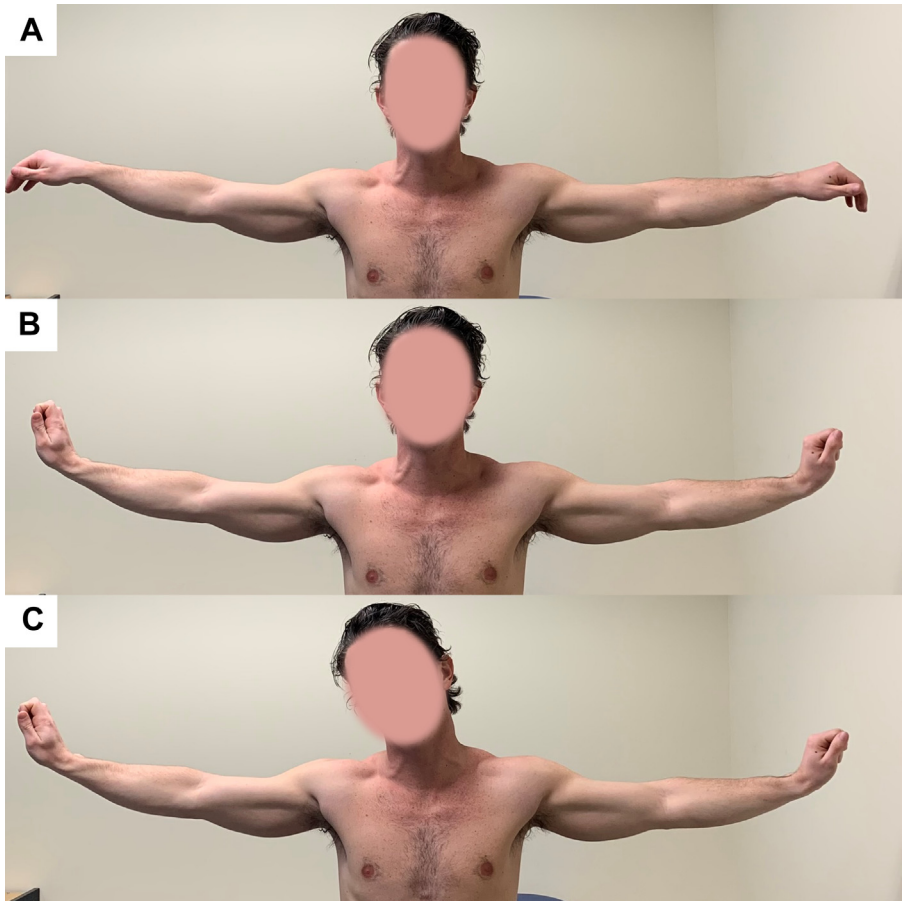

Figure 4 The Upper Limb Tension Test (ULTT), is done in 3 separate maneuvers placing more tension on the brachial plexus with each step. (**A**) The patient abducts their arms to 90° with elbows extended and wrists relaxed. (**B**) The patient fully flexes their wrists. (**C**) The patient laterally flexes their neck (ear to shoulder) to the unaffected side.

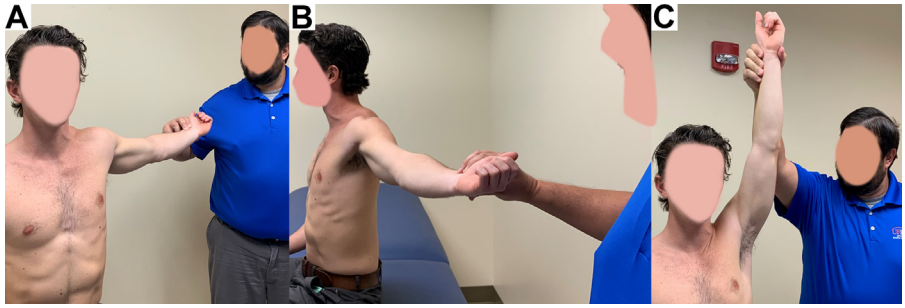

Figure 5 In Wright's test, or the hyperabduction test, (**A, B**) the clinician palpates the distal radial pulse with the patients affected arm at 90° abduction and the shoulder in full external rotation. (**C**) The patient then abducts the arm to 180° with the clinician still palpating the distal radial pulse. A positive sign for this test is diminishment or complete disappearance of the radial pulse.

decreased space in the thoracic outlet. A combination of duplex ultrasonography (DUS), CT, MRI, and angiography/venography can be used.[48]

Duplex ultrasound examination

If vascular TOS is suspected, DUS is the first-choice imaging modality because it is inexpensive, readily available, and noninvasive.[48,53,69,77] DUS can detect subclavian aneurysms, arterial stenosis, and thrombosis in the subclavian vasculature.[48] DUS can also be concurrently performed during physical examination tests such as the Adson maneuver, Elevated Arm Stress Test, Upper Limb Tension Test, and Roos examination to measure the changes in blood flow during the maneuver.[48] The sensitivity of Doppler ultrasonography ranges from 87% to 100% and specificity is 82%-100% when diagnosing vascular TOS.[31,37,50,59,63,80,83]

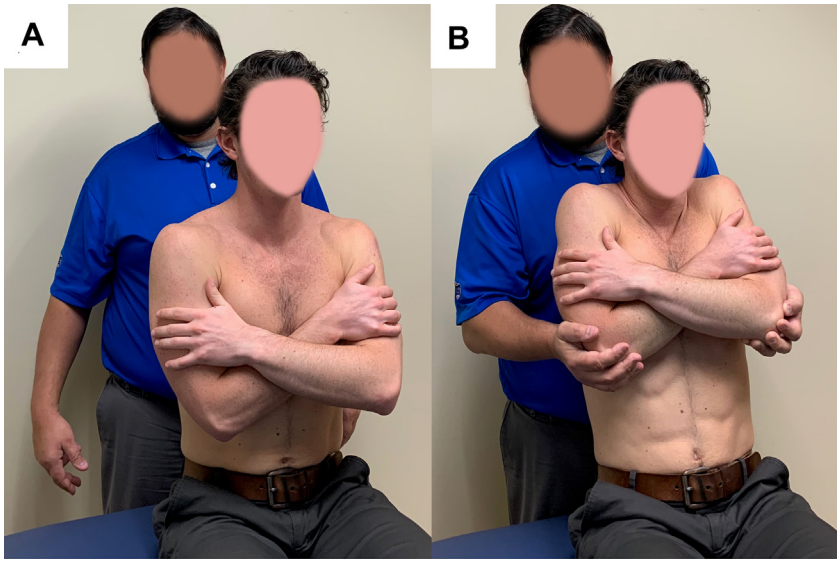

Figure 6 In the Cyriax Release Test, (**A**) the patient crosses their arms to put their elbows in 80° flexion. (**B**) The clinician grabs underneath the elbows and lifts the patients shoulders up, releasing tension on the brachial plexus. A positive sign for this exam is reestablishment of pain upon release of the position.

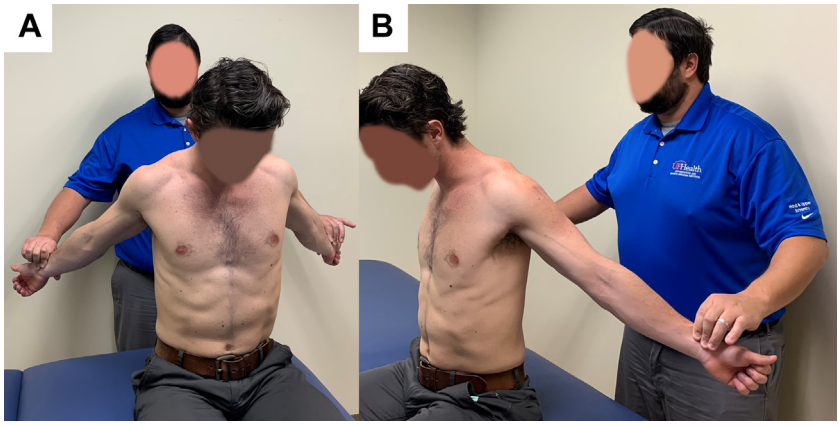

Figure 7 In the Costoclavicular Pressure Test, (**A, B**) the clinician palpates the distal radial pulse while the patient has both arms at 30° abduction with the shoulders in full external rotation. A positive sign for this maneuver is diminished or complete disappearance of the distal radial pulse.

DUS is a useful modality, but there are limitations. The clavicle and other bony structures can cause acoustic shadowing to the area of interest and can make it difficult to compress the subclavian vein.[59,77] If the vasculature appears occluded, a different imaging modality should also be utilized.

Radiography

TOS is often caused by congenital osteologic abnormalities such as the presence of cervical ribs, elongated C7 transverse processes, low-lying shoulder girdles, and elongated first ribs.[48,59] Chest and cervical spine radiography is useful in identifying bony anomalies.[48,59] These bony abnormalities can lead to vascular and/or nTOS. When a bony abnormality is suspected, radiography would be beneficial to confirm this finding. Chang et al[15] reviewed 20 patients who underwent cervical rib resection identified through chest and cervical radiography. Thirty-five percent presented with subclavian vein thrombosis, 25% presented with an ischemic upper extremity without thrombosis, 25% presented with nTOS, and 15% presented with subclavian vein thrombosis. If an osseous abnormality is not identified using radiography, CT or MRI can be used to image the underlying soft-tissue structures directly.

CT and MRI

CT and MRI are also useful in detecting soft-tissue abnormalities such as metastatic disease, a tumor in the region, or malunited rib or clavicle fractures.[59] If a radiograph does not

Table II Summary of presentation, diagnosis, treatment, and outcomes for neurogenic, venous, and arterial thoracic outlet syndrome (TOS).

TOS type	Neurogenic TOS	Venous TOS	Arterial TOS
Etiology	Constriction of the chords of the brachial plexus	Constriction of axillary vein	Constriction of the axillary artery
Presentation	• Pain, paresthesias in the fingers, and weakness in the upper extremities • More common in females • Most commonly diagnosed in patients ages 20-40 yr • Most common form (90%-95%)	• Severe upper extremity edema, deep upper extremity pain, and cyanosis • More common in males • Most commonly diagnosed in patients ages 20-30 • Less common form (3%-5%)	• Persistent pain and numbness in the affected extremity, impaired temperature sensation, and limb pallor and coldness • Affected equally in males and females • Most commonly diagnosed in patients ages 20-30 yr • Least common form (<1 %)
Physical examination	• Pain during palpation of the brachial plexus • Gilliat-Sumner Hand • Maneuvers: ◦ Adson's Maneuver ◦ EAST/Roos Test ◦ ULTT/Elvey's Test ◦ Cyriax ◦ Costoclavicular Compression/Eden's Test ◦ Brachial Plexus Compression/Morley's Compression Test	• A thorough history of the patient can reveal potential risk factors involving repeated overhead activities and weightlifting • Suspicion confirmed with imaging • Maneuvers: ◦ Adson's Maneuver ◦ Costoclavicular Compression/Eden's Test ◦ Hyperabduction/ Wright's Test	• The ulnar, radial, and brachial pulses may be occluded on the affected limb due to proximal pinching of the subclavian artery • Differences in blood pressure between symptomatic and asymptomatic sides • Suspicion confirmed with imaging • Maneuvers: ◦ Adson's Maneuver ◦ Costoclavicular Compression/Eden's Test ◦ Hyperabduction/ Wright's Test
Imaging	• Radiography can identify congenital abnormalities in the osteology • CT and MRI are useful in detecting soft tissue abnormalities; MRI can be used to directly image the brachial plexus	• Duplex ultrasonography (DUS) is the first-choice imaging modality • Venography is a definitive way in diagnosing venous TOS • Radiography can identify congenital abnormalities in the osteology • CT and MRI are useful in detecting soft tissue abnormalities	
Treatment	• Medication: Anti-Inflammatories, muscle relaxants • Weight loss • PT for periscapular muscle strengthening • Interscalene botulinum toxin type A injections	• Catheter-directed thrombolysis of subclavian vein • Thoracic outlet decompression surgery – first rib resection, removal/ division of anterior scalene muscle	• Antiplatelet and anticoagulant therapy • Scalenectomy • First rib resection • Arterial bypass

(*continued on next page*)

Table II Summary of presentation, diagnosis, treatment, and outcomes for neurogenic, venous, and arterial thoracic outlet syndrome (TOS). (*continued*)

TOS type	Neurogenic TOS	Venous TOS	Arterial TOS
Outcomes	Initial success rate of 91%-93% with regression to 64%-71% 10 yr postoperatively	• 90% improvement in symptoms after thoracic decompression and thrombolysis • Excellent clinic outcomes	
Complications	• Injury to the subclavian vessels (0%-3%), brachial plexus or terminal nerves (0.5%-11%), hemothorax (0%-4%), and pneumothorax (2.1%-34%) • First rib regrowth leading to recurrent TOS		

CT, computed tomography; *EAST*, Elevated Arm Stress Test; *MRI*, magnetic resonance imaging; *PT*, physical therapy; *ULTT*, Upper Limb Tension Test.

reveal a bony abnormality, a CT or MRI would be beneficial to detect if there is an objectively verifiable soft-tissue abnormality. CT and MRI can be performed with the affected shoulder fully abducted and externally rotated as well as in the adducted position for comparison.[83]

The improved soft-tissue visualization afforded by MRI compared to CT can better identify lower plexus abnormalities such as loss of fat around brachial plexus or brachial plexus edema.[28,83] Additionally, newer MRI techniques are being studied that will allow the clinician to image the fibrous bands.[28] Magnetic resonance neurography can also be used to image brachial plexus compression directly, helping confirm the diagnosis of nTOS.[69] In fact, a diagnosis of nTOS can be confirmed using T2-weighted MRI to image the suspected brachial plexus compression or lesion.[8,29]

Catheter-directed venography/angiography

Catheter-directed venography/angiography is useful in confirming the diagnosis and treating of vascular TOS (Paget-Schroetter syndrome and aTOS). This modality is beneficial when duplex ultrasound revealed subclavian vessel thrombosis and/or when the clinical signs and symptoms are strongly indicative of vascular TOS. The vessels are visualized by injecting contrast into the affected vessel with the patient's arm in hyperabduction and observing the blood flow.[36,102] In the presence of an acute venous thrombus, endovascular catheter-directed thrombolysis or angioplasty is effective for treatment, followed subacutely, within 1 to 2 months, by surgical decompression of the thoracic outlet.[69,77] Acute endovascular intervention for an intraluminal thrombus preserves the long-term patency of the subclavian and other veins.

Treatment

Treatment approach for TOS depends on whether the patient has an objectively verifiable form of TOS or "disputed TOS." Surgery is initially indicated only for symptomatic patients with objectively verifiable forms of TOS (fibrous band nTOS and vascular TOS).[93] Surgery is indicated for all types of TOS in patients who have progressive symptoms despite nonoperative measures with muscle atrophy or a progressive deficit.[11,14] Treatment does vary by type of TOS or symptomology (Table II).

Nonsurgical management

Nonsurgical treatment is first line for nTOS. This includes medication (anti-inflammatories, muscle relaxants), weight loss, and disease-specific physical therapy (PT). PT typically lasts for a period of at least 6 months, and 1 study reported that 25 of 42 patients with symptoms consistent with nTOS had symptomatic relief with therapy.[76] However, the accuracy of an nTOS diagnosis should be considered when evaluating the efficacy of various interventions. PT includes periscapular muscle strengthening (all scalene and pectoralis minor muscles), biofeedback, tendon and nerve gliding techniques, and postural exercises to reduce the pressure on the involved neurovascular structures.[2,21,76,117] Although there are no studies comparing the efficacy of pharmaceutical interventions for TOS to PT, a combined approach can successfully relieve symptoms in approximately 60%-70% of patients with nTOS.[9] If patients remain symptomatic after an appropriate period of observation and PT, then interscalene injections of anesthetics, botulinum toxin type A, or steroids have been used with relatively high success in patients with nTOS.[17,22,30,54,108] Christo et al[17] demonstrated a 29% reduction in subjective pain scores at 3 months after a botulinum toxin injection in 27 patients with symptomatic nTOS despite PT. Furthermore, relief after anterior scalene blocks can be predictive of a successful surgical outcome if decompression is eventually performed.[65] Overall, nonsurgical management for nTOS has been found to be less successful in patients with depression, obesity, workers' compensation cases, and any concomitant history of carpal or cubital tunnel syndrome.[76] Patients diagnosed with verifiable nTOS who do not respond to an appropriate

trial of conservative management or have progressive neurologic symptoms despite treatment may be candidates for surgical decompression. In patients where there is no identifiable pathology causing symptoms consistent with nTOS, surgical decompression is an option, but comes with significant risks. The outcomes in patients with disputed nTOS should be compared to disputed nTOS patients who underwent simulated surgical treatment since all of the outcomes in this group are subjective; however, no such study has been conducted at present.

Surgical management

Historically, vTOS with an acute or subacute thrombus was managed only with systemic anticoagulation and extremity elevation; however, this approach resulted in long-term morbidity such as pulmonary embolism, venous distension, and superficial thrombophlebitis in up to 75% of patients.[107,112] More modern techniques include catheter-directed thrombolysis with success rates of subclavian vein patency near 100% when thrombolysis is performed within 2 weeks of symptom onset.[60,71,99] This treatment is typically combined with definitive thoracic outlet decompression surgery which may either be delayed 1-3 months with anticoagulation to allow endothelial healing and resolution of the acute inflammatory response or as soon as 4 hours after thrombolysis depending on clinician preference.[67,110] Decompression of the thoracic outlet is commonly performed by vascular and thoracic surgeons, but orthopedic surgeons are often involved in the diagnosis and sometimes may be trained to perform the surgery. Decompression is accomplished by first rib resection, release of the anterior scalene muscle, subclavius muscle, and perivenous scar[71,99,112] and is often combined with intraoperative or postoperative venography with or without balloon angioplasty.[99] Anticoagulation is typically continued for 3 months postoperatively. Stenting in this area is contraindicated given the high rate of mechanical failure without surgical decompression.[109] Patients with Paget-Schroetter syndrome may require late vein reconstruction for chronic occlusion.[92]

aTOS may present with a subclavian artery aneurysm from prolonged arterial compression by rib anomalies. Antiplatelet and anticoagulant therapy is initiated to help stabilize the mural thrombus and prevent further embolization. A supraclavicular approach is often selected to perform a scalenotomy, first rib resection if needed, and arterial reconstruction or bypass.[115] A single-institution series of 40 patients who underwent surgical decompression and subclavian arterial reconstruction (70%) demonstrated 4.5-year patency of 72%, and no patients experienced further embolization.[115]

The first described surgical management for TOS was for a subclavian artery aneurysm in patients with cervical ribs.[19] Surgical goals include interscalene space decompression with or without first rib resection.[95] Anterior scalenotomy and subsequent additional operative techniques for cervical rib resection were created including transaxillary, posterior thoracotomy, supraclavicular, and infraclavicular approaches.[1,38,85] Decision for which procedure and approach to utilize depends primarily on the specific anatomic anomaly and surgeon preference. The posterior thoracotomy approach, originally described by Clagett et al[18] in 1962, allows for exposure of the proximal brachial plexus for neurolysis; however, it has been largely substituted for more contemporary approaches due to the degree of soft-tissue dissection, decreased shoulder function, and possible injury to the long thoracic, dorsal scapular, and accessory nerves.[86,104]

Current surgical approaches for treatment of TOS include an anterior supraclavicular approach,[25,58] transaxillary approach,[56,111] and video-assisted thoracoscopic approach.[35,49]

The supraclavicular approach for TOS provides a wide exposure, adequate visualization of the brachial plexus and other sites of compression, and enables arterial reconstruction when indicated (Fig. 8).[6,25,58,104] The anterior and middle scalene muscles can be completely resected and/or released off their attachments on the first rib. In addition, the brachial plexus is well visualized to allow for safe neurolysis. Removal of the first rib has not been shown to positively influence surgical outcomes, with a high complication rate compared to supraclavicular neurolysis and scalenotomy alone.[124] The supraclavicular approach is also favored in muscular or obese patients or in recurrent TOS following first rib resection.[3,6]

The transaxillary approach, first described by Roos[85] in 1966, is performed through a transverse incision at the inferior margin of the axilla from the pectoralis major anteriorly to the latissimus dorsi posteriorly. The shoulder is abducted with the elbow flexed. Deeper dissection to the lateral chest wall and ultimately to the first rib requires identification of the long thoracic, thoracodorsal, and second intercostobrachial nerves.[56,111] The rib is then freed from muscular attachments and removed. The transaxillary approach has the advantage of allowing for a more limited amount of dissection and external scarring with increased visualization of the ribs during resection, fibrous adhesion removal and does not require retraction of the neurovascular structures.[42] The major disadvantage is that it does not allow for vascular reconstruction when necessary.

The video-assisted thoracoscopic approach involves stripping the parietal pleura and periosteum over the first rib. The intercostal muscles and scalene muscles are dissected from the first rib. While visualizing and retracting the neurovascular bundle carefully, the rib is subsequently cut and resected through one of the ports.[35,49] This procedure can be performed through supraclavicular or transaxillary incisions.[49]

Although less commonly performed than the transaxillary or supraclavicular approaches, an additional infraclavicular incision may be needed to fully expose the

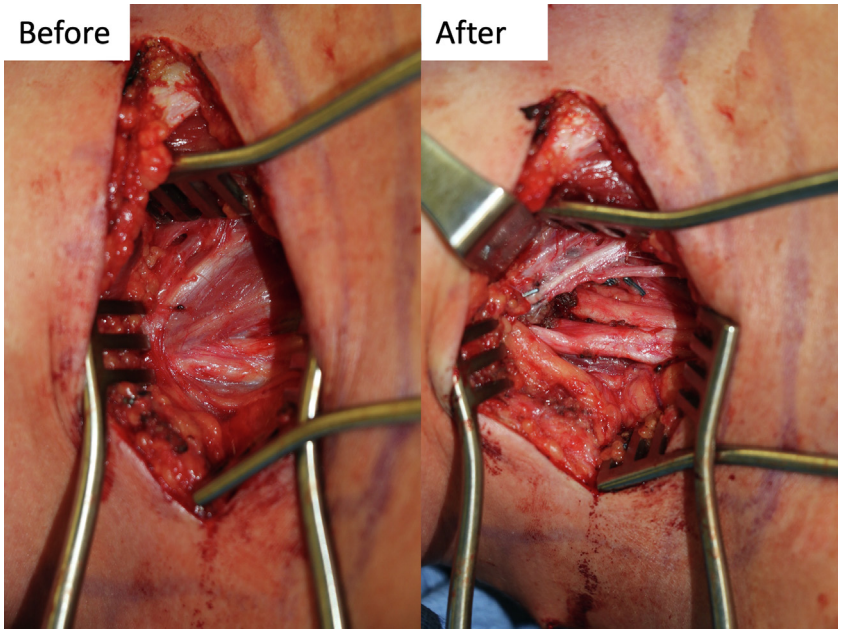

Figure 8 Supraclavicular approach for thoracic outlet syndrome surgical management.

venous structures particularly in cases which require extensive venous reconstruction (Fig. 9). A transverse incision is made from the medial portion of the clavicle to the manubrium. To minimize injury, the pectoralis major muscle is split in-line with its fibers exposing the subclavius muscle and vein. Once the subclavius muscle is divided and the vein is mobilized, the phrenic nerve is isolated and protected. The anterior scalene muscle insertion is then exposed. This allows resection of the first rib and excellent exposure of the subclavian artery and vein.[23] Additionally, exposure of the central veins can be achieved by medial extension of the incision and performing a transverse sternotomy.

In patients with pectoralis minor syndrome, a pectoralis minor tenotomy performed via the deltopectoral interval can reduce subcoracoid compression.[116]

Minimally invasive approaches such as extrapleural thorascopic decompression have been described to minimize soft-tissue disruption; however, these minimally invasive techniques have not demonstrated any superiority over standard surgical approaches.[49]

Anomalous insertion of the pectoralis minor (PMi) tendon has been associated with TOS.[5] In fact, the PMi has been reported to be involved in 75% of patients with TOS.[90] Anomalous insertion of the PMi occurs when parts of the tendon or the entire PMi muscle bypass insertion to the coracoid process and insert on the coracohumeral or coracoacromial ligament.[5] PMi tenotomy can be used as a low-risk procedure for symptomatic relief of TOS.[90,98,116] Arthroscopic PMi release has shown symptomatic relief in TOS patients with the only complication being rare surgical site infection (3 of 100 operations).[90,98] To perform a PMi tenotomy, standard posterior and anterior portals are placed along with a mid-coracoid portal. The rotator interval is opened, and the base of the coracoid is exposed. The coracohumeral ligament is released to expose the subcoracoid region. The PMi tendon can be seen inserting to the superomedial aspect of the coracoid. Once the PMi tendon is visualized, an electrocautery device can be used to release the tendon. Care should be taken not to damage the musculocutaneous nerve.[43] Outcomes rates for PMi tenotomy were 69%-90% excellent, 2%-20% fair, and 8%-22% failed.[90,98]

Rehabilitation

Postoperative care after TOS decompression focuses on pain control, minimization of swelling, maximizing neck/shoulder range of motion, wound healing, and appropriate graduated PT. During the first 3-4 weeks, strength training should be avoided. Passive and assisted exercises for shoulder range of motion and ''nerve gliding'' for neural mobilization are used. Improving posture, muscle mechanics, and diaphragm conditioning is emphasized. By 8 weeks, resistive strength training for the periscapular muscles is initiated with the goal of maintaining full range of motion and physiologic movement patterns.[2] If return to athletic competition is a postoperative goal, then rehabilitation is transferred to an athletic trainer at the 12-week mark to begin sport-specific programs. Full return to high-level athletic competition can take up to 9-12 months after surgical decompression.

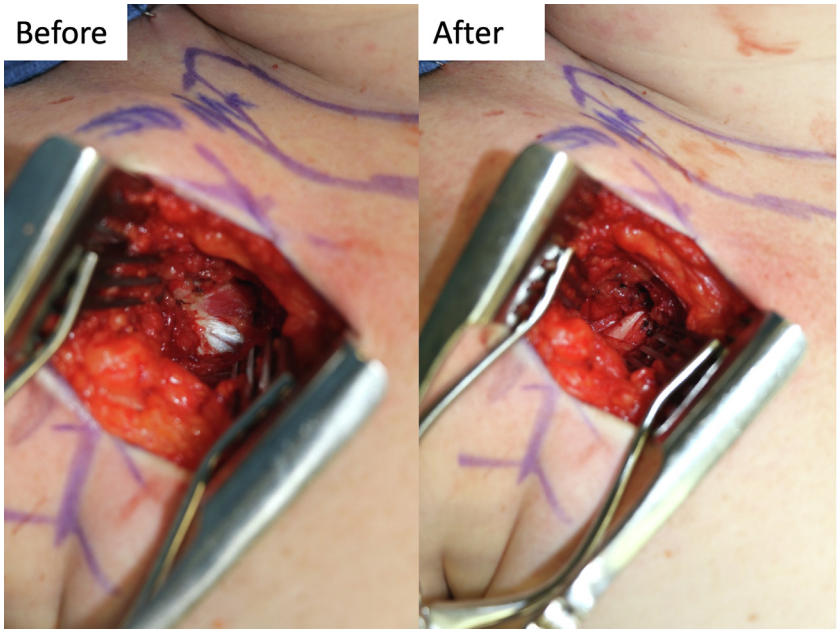

Figure 9 Infraclavicular surgical approach for thoracic outlet syndrome.

Outcomes

Derkash's classification is commonly used to determine outcomes after surgical TOS decompression, and prognosis is dependent on the clinical type.[78,123]

- Excellent result: No pain, easy return to preoperative profession and leisure daily activities.
- Good result: Intermittent pain that is well tolerated, possible return to preoperative professional and leisure daily activities.
- Fair result: Intermittent pain that is not well tolerated, difficult return to preoperative professional and leisure daily activities.
- Poor result: Symptoms not improved or aggravated.

A comprehensive review of surgical outcomes for nTOS found that surgical approach does not appear to influence postoperative outcomes and initial success rates approach 91%-93%.[89,96,97] This improvement in symptoms appears to wane over time, with the proportion of excellent Derkash results decreasing to 64%-71% around 10 years postoperatively.[7,32,55] Inferior outcomes are associated with workers compensation cases.[33] In the presence of a preoperative psychosocial limitation such as depression or decreased education level, patients were less likely to have resolution of symptoms postoperatively.[7]

Positive outcomes following aTOS and vTOS are dependent on resolution of ischemic or thrombotic symptoms if present, vessel patency, and improvements in subjective quality of life measures. Multiple studies of patients surgically treated for aTOS demonstrated over 90% improvement of Derkash's classification to the category of excellent/good.[7,20] For vTOS, patients who receive successful thrombolysis in the acute phase followed by decompression achieve greater than 90% Derkash's classification of excellent/good, 95% vein patency rates, and excellent clinical outcomes.[14,60,71,78,99,112]

Complications

Due to the nature of the surgical procedure and numerous adjacent anatomic structures, the potential complications from TOS can be severe. Complications include injury to the subclavian vessels or thoracic duct (0%-3%), brachial plexus or terminal nerves (0.5%-11%) hemothorax (0%-4%), and pneumothorax (2.1%-34%).[3,7,47,56,101] Wound complications and injury to nerves or lymphatics occurs much less often at 3% and $<1\%$, respectively.

In a major systematic review of 5008 procedures, there was no report of major vascular injury. Recurrent TOS was the most common complication, comprising 32% of all complications.[111] Recurrent TOS is treated similarly to primary TOS; nonsurgical treatment is recommended with surgery reserved for recalcitrant cases. Although rare, the first rib may regrow, leading to recurrent TOS symptoms that are treated with additional resection.[34] Likes et al[61] found that the most etiology for recurrent TOS is a residual first rib after decompression and removal led to improvement in all 15 patients in their series. Likewise, Jammeh et al[52] showed a greater rate of residual scalene muscle and/or first rib presence in patient presenting with recurrent TOS. The authors reported substantial improvements in the QuickDASH and other patient-reported

outcome measures after revision thoracic outlet decompression.[54]

Conclusions

TOS is a complicated and controversial diagnosis. TOS can broadly be classified as ''disputed'' or objectively verifiable. Vascular forms of TOS and nTOS in the presence of verifiable, anatomic abnormalities are considered objectively verifiable. ''Disputed'' TOS is when patients present with arm pain that cannot be attributed to any anatomic abnormalities such as cervical ribs, soft-tissue abnormalities, or scalene muscle fibrosis. Making a diagnosis of TOS in patients who present with idiopathic arm pain can lead to many potentially harmful and useless treatments. However, using the diagnostic maneuvers, imaging modalities, and treatment options presented in this manuscript, objectively verifiable TOS can be appropriately recognized, diagnosed, and treated.

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