Imaging in the Diagnosis of Thoracic Outlet Syndrome
EVIDENCE TABLE

Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
1. Atasoy E. Thoracic outlet compression syndrome. *Orthop Clin North Am* 1996; 27(2):265-303.	Review/Other-Tx	N/A	Review thoracic outlet compression syndrome.	No results stated in abstract.	4
2. LaBan MM, Zierenberg AT, Yadavalli S, Zaidan S. Clavicle-induced narrowing of the thoracic outlet during shoulder abduction as imaged by computed tomographic angiography and enhanced by three-dimensional reformation. *Am J Phys Med Rehabil* 2011; 90(7):572-578.	Review/Other-Dx	17 patients	To confirm the location and degree of compromise of the subclavian vessels within the thoracic outlet during ipsilateral arm abduction in patients with clinical evidence of TOS and to identify both the physical and physiologic source of neurovascular compromise that induces the symptoms of TOS.	The level of vessel occlusion varied in the costoclavicular space as well as in demonstrating the alterations in the diameter of both the subclavian artery and vein both in the neutral and the abducted to 90 degrees with external rotation positions. The possible levels of occlusions included the costoclavicular space, the interscalene triangle, and the retropectoralis minor space. The narrowing of the subclavian vessel was considered significant if the percentage change of the vessel's diameter between the neutral and the abducted to 90 degrees with external rotation positions was 30% or greater for the subclavian artery and 50% or greater for the subclavian vein.	4
3. Sanders RJ, Rao NM. Pectoralis minor obstruction of the axillary vein: report of six patients. *J Vasc Surg* 2007; 45(6):1206-1211.	Review/Other-Tx	6 patients	To describe the diagnosis and treatment of 6 patients with partial axillary vein obstruction by the pectoralis minor muscle, a condition that can mimic subclavian vein obstruction.	Venography demonstrated axillary vein compression under the pectoralis minor, which was more significant than the minor degree of subclavian vein compression seen on the same venogram. Follow-up was 1.5 years to 10 years in 3 patients and 3 months in the other 3 patients. All 6 patients experienced good-to-excellent relief of all symptoms. There were no surgical complications.	4
4. Ranney D. Thoracic outlet: an anatomical redefinition that makes clinical sense. *Clin Anat* 1996; 9(1):50-52.	Review/Other-Dx	N/A	A review on thoracic outlet.	The diagnosis of TOS is intrinsically difficult, and the literature about it is full of confusing terminology.	4
5. Urschel HC, Patel A. Thoracic Outlet Syndromes. *Curr Treat Options Cardiovasc Med* 2003; 5(2):163-168.	Review/Other-Tx	N/A	To review various TOSs in their clinical order of frequency.	For severe nerve compression, whether upper or lower brachial plexus, the best surgical procedure is the transaxillary first rib resection, anterior scalenectomy, and neurovascular decompression. Axillary-subclavian vein occlusion (ie, Paget-Schroetter syndrome) is best treated with early diagnosis, intravenous thrombolysis of the clot, transaxillary first rib resection anterior scalenectomy, and resection of the costoclavicular ligament.	4

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6. Ciampi P, Scotti C, Gerevini S, et al. Surgical treatment of thoracic outlet syndrome in young adults: single centre experience with minimum three-year follow-up. *Int Orthop* 2011; 35(8):1179-1186.	Review/Other-Tx	48 patients	To report surgical treatment of TOS in young adults with a minimum follow-up of 3 years.	No standard surgical procedure has been identified; however, in literature the largest series have been treated with transaxillary first rib resection.	4
7. Gharagozloo F, Meyer M, Tempesta B, Strother E, Margolis M, Neville R. Proposed pathogenesis of Paget-Schroetter disease: impingement of the subclavian vein by a congenitally malformed bony tubercle on the first rib. *J Clin Pathol* 2012; 65(3):262-266.	Review/Other-Dx	15 patients with Paget-Schroetter Disease	To study and compare the anatomical and clinical pathology of first ribs in patients with Paget-Schroetter Disease with first ribs in patients without the disease.	15 first ribs were from patients with Paget-Schroetter Disease and 7 normal first ribs were from human cadavers. In all patients (100%) with Paget-Schroetter Disease there was a bony tubercle that corresponded to the area of the subclavian vein groove in the normal ribs. In all controls (100%), there was a normal subclavian groove without the presence of a tubercle. On preoperative venograms in patients with Paget-Schroetter Disease, the tubercle accounted for an extrinsic protuberance that compressed the subclavian vein (100%). Intraoperatively, the abnormal bony tubercle accounted for the extrinsic compression of the subclavian vein in all (100%) patients with Paget-Schroetter Disease Venograms of the upper extremity obtained after first rib resection showed the disappearance of the extrinsic compression on the subclavian vein (100%) and a patent subclavian vein with elevation of the arm in all patients.	4
8. Rayan GM, Jensen C. Thoracic outlet syndrome: provocative examination maneuvers in a typical population. *J Shoulder Elbow Surg* 1995; 4(2):113-117.	Review/Other-Dx	200 upper extremities of 100 volunteers	To assess provocative examination maneuvers in upper extremities of volunteers to determine the prevalence of positive responses in the typical population.	15 (7.5%) extremities had a Tinel's sign. The vascular response was present in 27 (13.5%) extremities for the Adson maneuver, 94 (47%) extremities for the costoclavicular maneuver, and 114 (57%) extremities for the hyperabduction maneuver. The neurologic response was present in 4 (2%) extremities for the Adson maneuver, 20 (10%) extremities for the costoclavicular maneuver, and 33 (16.5%) extremities for the hyperabduction maneuver. The vascular response is more common than the neurologic response in the typical population.	4

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9. Dale WA, Lewis MR. Management of thoracic outlet syndrome. *Ann Surg* 1975; 181(5):575-585.	Review/Other-Tx	153 extremities in 149 patients	To review management of TOS.	1) Diagnosis is based chiefly upon history; physical signs are inconstant and often absent. 2) Major vascular problems are unusual; angiography is not always necessary. 3) Electromyography is not always critical but does aid in diagnosis of carpal tunnel syndrome. 4) Nonoperative treatment relieves most patients; operative decompression is indicated for a minority. 5) Transaxillary first rib resection, with removal of cervical rib is the best operation. 6) Carpal tunnel decompression should be done concomitantly when needed. 7) Operation is relatively safe.	4
10. Thompson JF, Jannsen F. Thoracic outlet syndromes. *Br J Surg* 1996; 83(4):435-436.	Review/Other	Evaluate 110 patients and operated on 35	To review diagnosis and management of TOS.	Successful treatment of TOS depends on accurate diagnosis, patient selection and meticulous surgery. Duplex scanning, MRI and a careful neurophysiological assessment may improve objectivity, and lead to a more widespread appreciation of the different guises of this challenging condition.	4
11. Torriani M, Gupta R, Donahue DM. Sonographically guided anesthetic injection of anterior scalene muscle for investigation of neurogenic thoracic outlet syndrome. *Skeletal Radiol* 2009; 38(11):1083-1087.	Review/Other-Tx	26 subjects	To describe the technique and complications of sonographically guided anesthetic injection of the anterior scalene muscle in patients being investigated for neurogenic TOS.	26 subjects with suspected neurogenic TOS underwent 29 injections (3 subjects received bilateral injections). Technical success was achieved in all procedures. The mean duration of the procedure was 30 minutes, and there were no cases of intravascular needle placement or neurogenic pain during the injection. No major complications occurred. Temporary symptoms of partial brachial plexus block occurred after 9 injections (9/29, 31%), and a temporary complete brachial plexus block occurred after one injection (1/29, 3%).	4
12. Ersoy H, Steigner ML, Coyner KB, et al. Vascular thoracic outlet syndrome: protocol design and diagnostic value of contrast-enhanced 3D MR angiography and equilibrium phase imaging on 1.5- and 3-T MRI scanners. *AJR* 2012; 198(5):1180-1187.	Observational-Dx	78 patients	To evaluate the efficiency and reproducibility of a contrast-enhanced 3D MRA protocol, using the provocative arm position on 1.5- and 3-T MRI scanners, and to determine the frequency and distribution of vascular compression and vascular complications in the thoracic outlet.	A venous component, which presented with mainly venous symptoms and findings, was confirmed in 85% of the subjects. An arterial component, which presented with clinical symptoms and findings of vascular TOS syndrome, was seen in 82% of the subjects. The vascular component of TOS, which presented with mainly neurogenic or indeterminate symptoms or findings, was excluded in 61% of the subjects.	3

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
13. Levy MM, Bach C, Fisher-Snowden R, Pfeifer JD. Upper extremity deep venous thrombosis: reassessing the risk for subsequent pulmonary embolism. *Ann Vasc Surg* 2011; 25(4):442-447.	Review/Other-Tx	200 patients	To analyze an institution's current treatment practices for UEDVT and assess the risk for subsequent PE.	Among the 200 patients with UEDVT, 156 (78%) had UEDVTs identified as clearly acute or acute on chronic, based on sonographic appearance. In all, 85% of the patients were symptomatic (n = 171). Among the patients, 71 (36%) had documented malignancy, 58 (29%) were postoperative or suffering from trauma, and 52 (26%) were obese (body mass index: >30). In addition, 153 (76%) had associated current or previous indwelling lines or leads. A total of 73 patients (36%) were put on anticoagulation therapy for variable periods. Younger age of the patient, duplex evidence of an acute deep venous thrombosis, and involvement of multiple named upper extremity venous segments were independent predictors of the decision to initiate anticoagulation therapy for patients with UEDVT. Two patients (1%) suffered PE, most likely the consequence of their UEDVTs. An additional 2 patients with UEDVT treated with coumadin died months after hospital discharge from intracranial bleedings after minor falls.	4
14. Lee JA, Zierler BK, Zierler RE. The risk factors and clinical outcomes of upper extremity deep vein thrombosis. *Vasc Endovascular Surg* 2012; 46(2):139-144.	Review/Other-Dx	373 consecutive patients	To identify risk factors and clinical outcomes in patients diagnosed with UEDVT at an academic medical center over a 1-year period.	A quarter of the patients screened by venous duplex US (94/373) had acute UEDVT; 63% presented with arm swelling or arm pain; 48% had cancer; and 93% had indwelling central venous catheters. Cancer patients with central venous catheters were more likely to develop UEDVT (48%). Of the 94 UEDVTs, 16% had concurrent lower extremity DVT. The incidence of objectively confirmed PE was 9% (8/94 patients), and the 1-month mortality rate was 6.4%. The majority of patients (80%) with UEDVT received anticoagulation therapy and 20% were not treated. The most common risk factors for UEDVT were indwelling central venous catheters and a diagnosis of cancer. The incidence rate of PE and mortality rate from UEDVT were not insignificant at 9% and 6%, respectively.	4

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
15. Gelabert HA, Jimenez JC, Rigberg DA. Comparison of retavase and urokinase for management of spontaneous subclavian vein thrombosis. *Ann Vasc Surg* 2007; 21(2):149-154.	Review/Other-Tx	30 consecutive patients	To compare thrombolytic agents in the management of acute Paget-Schroetter syndrome. This study is based on a retrospective review of patients (15 Urokinase, 15 r-TPA) who underwent thrombolysis and surgery for Paget-Schroetter syndrome. The hypothesis is that thrombolysis with Urokinase and r-TPA is equally safe and effective in management of acute axillo-subclavian vein thrombosis.	Primary outcome measures include success of lysis, hemorrhagic complications, subclavian vein patency at completion of treatment, resolution of presenting symptoms, and restitution of normal arm function. There were no significant differences in the primary outcome measures: success of lysis, hemorrhagic complication, perioperative bleeding, and subclavian vein patency. Time to completion of lysis was slightly shorter with r-TPA (but this did not achieve statistical significance). One patient in each group suffered incomplete lysis of thrombus. One patient in the r-TPA group required transfusion due to surgical bleeding. No patient received transfusion due to thrombolysis-related bleeding. All patients experienced resolution of symptoms and return of arm function. The findings support the hypothesis that Urokinase and r-TPA are similarly safe and successful for management of spontaneous axillo-subclavian vein thrombosis.	4
16. Skalicka L, Lubanda JC, Jirat S, et al. Endovascular treatment combined with stratified surgery is effective in the management of venous thoracic outlet syndrome complications: a long term ultrasound follow-up study in patients with thrombotic events due to venous thoracic outlet syndrome. *Heart Vessels* 2011; 26(6):616-621.	Observational-Tx	73 consecutive patients	To analyze clinical characteristics and US follow-up findings in patients with venous TOS treated over a 7-year period.	Endovascular treatment was attempted in all highly symptomatic patients and in those with conservative treatment failure (n = 53), of which 12 required acute surgical intervention. Elective surgical treatment was indicated in 30 other patients because of persistent symptoms. Surgery was associated with a significantly lower rate of the US-detected signs of persisting vascular compression. However, the rate of persisting clinical symptoms was comparable to those treated only by endovascular or conservative therapy. The data demonstrate that initial endovascular treatment proposed as first line therapy to highly symptomatic subjects and in those with conservative treatment failure improves the symptoms in 77% of patients avoiding the need of acute surgery.	2

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
17. Thompson JF, Winterborn RJ, Bays S, White H, Kinsella DC, Watkinson AF. Venous thoracic outlet compression and the Paget-Schroetter syndrome: a review and recommendations for management. *Cardiovasc Intervent Radiol* 2011; 34(5):903-910.	Review/Other-Tx	N/A	To review literature and present the Exeter Protocol along with practical recommendations for management of Paget-Schroetter syndrome.	No results stated in abstract.	4
18. Angle N, Gelabert HA, Farooq MM, et al. Safety and efficacy of early surgical decompression of the thoracic outlet for Paget-Schroetter syndrome. *Ann Vasc Surg* 2001; 15(1):37-42.	Review/Other-Tx	18 consecutive patients	To compare early surgical decompression with the standard management protocol to determine safety and efficacy of the early treatment algorithm.	Symptoms on presentation were similar in both groups. Each patient in both groups had upper extremity swelling, and 5/9 (56%) in the staged treatment group and 3/9 (33%) in the early treatment group presented with pain. Paresthesias were present in 2/9 patients in the staged treatment group and in none of the patients in the early treatment group. Results showed that thrombolysis followed by early operation does not result in increased perioperative morbidity or mortality. Early surgical decompression of the thoracic outlet during the same admission as lysis is as safe and efficacious as the traditional (staged decompression) approach to Paget-Schroetter syndrome. Lysis followed by early surgical decompression should be considered a new standard of care in the management of Paget-Schroetter syndrome.	4

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
19. Melby SJ, Vedantham S, Narra VR, et al. Comprehensive surgical management of the competitive athlete with effort thrombosis of the subclavian vein (Paget-Schroetter syndrome). *J Vasc Surg* 2008; 47(4):809-820; discussion 821.	Observational-Tx	32 competitive athletes	To assess the results of treatment for subclavian vein effort thrombosis in a series of competitive athletes.	Venous duplex US examination in 21 patients had a diagnostic sensitivity of 71%, and the mean interval between symptoms and definitive venographic diagnosis was 20.2 +/- 5.6 days (range, 1-120 days). Catheter-directed subclavian vein thrombolysis was performed in 26 (81%), with balloon angioplasty in 12 and stent placement in one. Paraclavicular thoracic outlet decompression was performed with circumferential external venolysis alone (56%) or direct axillary-subclavian vein reconstruction (44%), using saphenous vein panel graft bypass (n = 8), reversed saphenous vein graft bypass (n = 3), and saphenous vein patch angioplasty (n = 3). In 19 patients (59%), simultaneous creation of a temporary (12 weeks) adjunctive radiocephalic arteriovenous fistula was done. The mean hospital stay was 5.2 +/- 0.4 days (range, 2-11 days). Seven patients required secondary procedures. Anticoagulation was maintained for 12 weeks. All 32 patients resumed unrestricted use of the upper extremity, with a median interval of 3.5 months between operation and the return to participation in competitive athletics (range, 2-10 months). The overall duration of management from symptoms to full athletic activity was significantly correlated with the time interval from venographic diagnosis to operation ($r = 0.820$, $P<.001$) and was longer in patients with persistent symptoms ($P<.05$) or rethrombosis before referral ($P<.01$).	2

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20. Christo PJ, Christo DK, Carinci AJ, Freischlag JA. Single CT-guided chemodenervation of the anterior scalene muscle with botulinum toxin for neurogenic thoracic outlet syndrome. *Pain Med* 2010; 11(4):504-511.	Observational-Tx	29 procedures on 27 participants	To examine pain relief in patients with neurogenic TOS after a single, low dose injection of botulinum toxin A into the anterior scalene muscle under CT guidance.	There was a decline in pain during the 3 months subsequent to botulinum toxin A injection as noted by the following components of the short-form McGill Pain Questionnaire: sensory (P=0.02), total (P=0.05), visual analog scale (P=0.04), and present pain intensity score (P=0.06). The proportion of patients reporting more intense pain scores did not return to the pre-intervention level at 3 months post-botulinum toxin A injection.	2
21. Demondion X, Bacqueville E, Paul C, Duquesnoy B, Hachulla E, Cotten A. Thoracic outlet: assessment with MR imaging in asymptomatic and symptomatic populations. *Radiology* 2003; 227(2):461-468.	Observational-Dx	35 healthy volunteers and 54 patients	To compare the dynamic modifications of the thoracic outlet in asymptomatic volunteers and symptomatic patients and assess the presence and location of vasculonervous compressions in these two populations.	Patients with TOS had a smaller costoclavicular distance after the postural maneuver (P<.001), a thicker subclavius muscle in both arm positions (P<.001), and a wider retropectoralis minor space after the postural maneuver (P<.001) than did volunteers. Venous compressions after the postural maneuver were observed in 47% of volunteers and 63% of patients at the prescalene space, in 54% of volunteers and 61% of patients at the costoclavicular space, and in 27% of volunteers and 30% of patients at the retropectoralis minor space. Arterial and nervous compressions, respectively, were seen in 72% and 7% of patients. No arterial or nervous compression was seen in volunteers. Except for venous thrombosis, vasculonervous compressions were demonstrated only with arm elevation. Only three thoracic outlet measurements differed significantly in both populations.	3

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22. Remy-Jardin M, Doyen J, Remy J, Artaud D, Fribourg M, Duhamel A. Functional anatomy of the thoracic outlet: evaluation with spiral CT. *Radiology* 1997; 205(3):843-851.	Review/Other-Dx	52 volunteers	To determine the anatomic characteristics of the thoracic outlet before and after dynamically induced modifications.	After elevation of the dominant arm, (a) no statistically significant difference was found in median value of the costosubclavian and costoclavicular distances; (b) the median distance between the posterior border of the smaller pectoral muscle and the anterosuperior chest wall was 12 mm in all subjects; (c) the subclavian artery in 18 (75%) women and in 20 (71%) men and/or the subclavian vein in 3 (12%) women and in 3 (11%) men were identified in the costoclavicular space. The median angles of rotation, retraction, and upward displacement of the clavicle were 22 degrees, 32 degrees, and 7 degrees, respectively, in women and 25 degrees, 31 degrees, and 11 degrees, respectively, in men.	4
23. Smedby O, Rostad H, Klaastad O, Lilleas F, Tillung T, Fosse E. Functional imaging of the thoracic outlet syndrome in an open MR scanner. *Eur Radiol* 2000; 10(4):597-600.	Review/Other-Dx	10 volunteers and 7 patients	To test MRI in an open magnet as a method for diagnosis of TOS.	In the neutral position, no significant difference was found between patients and controls. In 90 degrees abduction, the patients had significantly smaller distance between rib and clavicle than the controls (14 vs 29 mm; $P<0.01$). On coronal reformatted images, the compression of the brachial plexus could often be visualized in abduction. Functional MRI seems to be a useful diagnostic tool in TOS. Examination in abduction, which is feasible in an open scanner, is essential for the diagnosis.	4

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24. Chang KZ, Likes K, Davis K, Demos J, Freischlag JA. The significance of cervical ribs in thoracic outlet syndrome. *J Vasc Surg.* 2013;57(3):771-775.	Review/Other-Tx	20 patients	To review operative experience in patients with TOS resulting from cervical ribs causing clinical symptoms.	23 cervical rib resections were performed on 20 patients, 3 of whom had bilateral cervical ribs resected during separate operations. 7 patients presented with subclavian artery thrombosis. 3/7 patients had subclavian artery aneurysms and underwent cervical rib resection through a supraclavicular approach to facilitate subclavian artery bypass. 5 patients presented with an ischemic upper extremity without thrombosis and underwent transaxillary first rib and cervical rib resection. 3 patients presented with subclavian vein thrombosis; 2/3 patients underwent balloon dilation 2 weeks postoperatively for stenosis. Additionally, 5 patients presented with neurogenic TOS evidenced by pain, numbness, and weakness without vascular compromise in the affected arm. Cervical ribs with bony fusion to the first rib were found in 17/23 cases (74%).	4
25. Balakrishnan A, Coates P, Parry CA. Thoracic outlet syndrome caused by pseudoarticulation of a cervical rib with the scalene tubercle of the first rib. *J Vasc Surg.* 2012;55(5):1495.	Review/Other-Dx	1 patient	A 20-year-old man presented with a bony lump above the left clavicle associated with upper limb pain, numbness, and tingling is reported.	A lateral neck radiograph identified an unusual bony contour anteriorly at C7/T1 suggesting a cervical rib (A). Duplex US scan showed widely patent left axillary and subclavian arteries with the arm adducted but severe compression of the subclavian artery on abducting the arm to 90°. A subsequent CTA confirmed bilateral cervical ribs; the left articulating with an extended left transverse process of the seventh cervical vertebra, extending inferiorly to fuse with the first rib (B and C/Cover).	4
26. Kirschbaum A, Palade E, Csatari Z, Passlick B. Venous thoracic outlet syndrome caused by a congenital rib malformation. *Interact Cardiovasc Thorac Surg.* 2012;15(2):328-329.	Review/Other-Tx	1 patient	To describe the first reported case worldwide of a venous compression syndrome caused by a congenital malformation of the 1st and 2nd ribs.	Treatment by transaxillary partial rib resection was necessary and a very good postoperative result was achieved.	4
27. O'Brien PJ, Ramasunder S, Cox MW. Venous thoracic outlet syndrome secondary to first rib osteochondroma in a pediatric patient. *J Vasc Surg.* 2011;53(3):811-813.	Review/Other-Dx	1 patient	To report the very rare case of a pediatric patient with venous TOS due to an osteochondroma of the first rib.	No results stated in abstract.	4

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28. Davis GA, Knight SR. Pancoast tumors. *Neurosurg Clin N Am.* 2008;19(4):545-557, v-vi.	Review/Other-Tx	N/A	To examine a protocol that incorporates induction chemoradiation, surgical resection of the lung tumor by a thoracic surgeon, and neurolysis and preservation of the brachial plexus by a neurosurgeon.	Improved survival outcome, especially in patients demonstrating a pathologic complete response, with preservation of hand function, supports the authors' hypothesis that involved brachial plexus does not need resection in these patients.	4
29. Gillard J, Perez-Cousin M, Hachulla E, et al. Diagnosing thoracic outlet syndrome: contribution of provocative tests, ultrasonography, electrophysiology, and helical computed tomography in 48 patients. *Joint Bone Spine* 2001; 68(5):416-424.	Observational-Dx	48 patients	To evaluate the diagnostic usefulness of provocative tests, Doppler US, electrophysiological investigations, and helical CTA in TOS.	Provocative tests had mean sensitivity and specificity values of 72% and 53%, respectively, with better values for the Adson test ([PPV, 85%), the hyperabduction test (PPV, 92%), and the Wright test. Using several tests in combination improved specificity. Doppler US visualized vascular parietal abnormalities and confirmed the diagnosis in patients with at least 5 positive provocative tests. Electrophysiological studies were useful mainly for the differential diagnosis or for detecting concomitant abnormalities. Although helical CTA provided accurate information on the location and mechanism of vascular compression, the usefulness of this investigation for establishing the diagnosis of TOS and for obtaining pre-therapeutic information remains unclear.	3

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30. Stapleton C, Herrington L, George K. Sonographic evaluation of the subclavian artery during thoracic outlet syndrome shoulder manoeuvres. *Man Ther* 2009; 14(1):19-27.	Review/Other-Dx	10 male and 21 female healthy volunteers	To establish normative vascular responses in the subclavian artery (i.e., arterial diameter and peak systolic blood flow velocity to various arm positions, and determine the incidence of abnormal physiological responses.	Alpha level was set at P=0.01. Significant decreases (P=0.008) in peak systolic blood flow velocity were recorded from 120 degrees, 90 degrees, and 45 degrees abduction (92+/-10, 89+/-11 and 88+/-14 cm s(-1), respectively) to 180 degrees abduction (mean+/-95% CI: 52+/-16 cm s(-1)). Similarly, post-hoc comparisons revealed a significant decrease (P=0.008) in peak systolic blood flow velocity from 120 degrees abduction (94+/-14 cm s(-1)) to 120 degrees abduction with 30 degrees horizontal extension and 90 degrees ER (69+/-12 cm s(-1)). Complete lack of blood flow was demonstrated by 6 subjects and 2 subjects at end of range abduction and combined end of range external rotation and horizontal extension, respectively. The heterogeneous response of asymptomatic individuals with no past history of TOS symptoms raises uncertainty of the validity of positive test responses from extreme arm positions.	4
31. Demondion X, Vidal C, Herbinet P, Gautier C, Duquesnoy B, Cotten A. Ultrasonographic assessment of arterial cross-sectional area in the thoracic outlet on postural maneuvers measured with power Doppler ultrasonography in both asymptomatic and symptomatic populations. *J Ultrasound Med* 2006; 25(2):217-224.	Observational-Dx	44 volunteers and 28 patients	To evaluate the feasibility and potential usefulness of power Doppler US in the assessment of changes in arterial cross-sectional area in the thoracic outlet during upper limb elevation.	No significant arterial stenosis was shown in the interscalene triangle and in the retropectoralis minor space of the volunteers and patients. A significant difference (P<.01) in stenosis between volunteers and patients was seen for all degrees of abduction in the costoclavicular space. The 130 degrees hyperabduction maneuver appeared to be the most discriminating postural maneuver. Seven patients assessed with MRI did not have any arterial stenosis on MRIs, whereas an appreciable degree of arterial stenosis was shown with US.	3
32. Molina JE, Hunter DW, Dietz CA. Protocols for Paget-Schroetter syndrome and late treatment of chronic subclavian vein obstruction. *Ann Thorac Surg* 2009; 87(2):416-422.	Observational-Tx	126 Paget-Schroetter syndrome patients (group I) 81 patients (group II)	To examine protocols for Paget-Schroetter syndrome and late treatment of chronic subclavian vein obstruction.	The acute emergency care resulted in a 100% long-term patency rate in group I, with no sequelae. The patency rate in group II was 100% as well, but in 74% a long vein patch, endovascular stents, or homograft implants were used.	3

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33. Wadhwani R, Chaubal N, Sukthankar R, Shroff M, Agarwala S. Color Doppler and duplex sonography in 5 patients with thoracic outlet syndrome. *J Ultrasound Med* 2001; 20(7):795-801.	Review/Other-Dx	5 patients	To evaluate the use of color Doppler US in the diagnosis of TOS.	Significant changes, (i.e., stages of increased velocities, preocclusion, and occlusion) in the subclavian artery in varying degrees of abduction, were noted in 4/5 cases. Blunted flow in the axillary artery (4 patients) and a rebound increase in velocities on release of abduction were noted in 3 patients. These changes suggested that significant narrowing was causing symptoms.	4
34. Demondion X, Herbinet P, Boutry N, Fontaine C, Francke JP, Cotten A. Sonographic mapping of the normal brachial plexus. *AJNR Am J Neuroradiol* 2003; 24(7):1303-1309.	Review/Other-Dx	12 healthy adult volunteers	To demonstrate that mapping of the brachial plexus may be performed by means of US.	A satisfactory US examination was performed in 10/12 volunteers, leading to a good association with anatomic sections. Two volunteers were excluded from the study because a clear depiction of the brachial plexus was difficult owing to a short neck and low echogenicity at examination. The association between US images and anatomic sections allowed the authors to map the brachial plexus. The subclavian and deep cervical arteries were useful landmarks for this mapping. The eighth cervical nerve root and the first thoracic nerve root were the most difficult part of the brachial plexus to depict because of their deep location.	4
35. Rubin GD, Rofsky NM. *CT and MR Angiography: Comprehensive Vascular Assessment* Philadelphia, PA: Lippincott, Williams & Wilkins; 2009.	Review/Other-Dx	N/A	Book chapter.	N/A	4

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36. Remy-Jardin M, Remy J, Masson P, et al. CT angiography of thoracic outlet syndrome: evaluation of imaging protocols for the detection of arterial stenosis. *J Comput Assist Tomogr* 2000; 24(3):349-361.	Observational-Dx	82 patients	To evaluate the results of cross-sectional imaging and multiplanar and 3D reconstructions for the detection of thoracic outlet arterial stenosis on CT angiograms.	The number of examinations coded with an excellent degree of arterial enhancement was significantly higher in Group 2 than in Group 1 [68 (71%) vs 35 (51%); P<0.001]. The sensitivity and specificity for detection of arterial stenosis were 67% and 96% for transverse CT scans, 69% and 94% for sagittal reformations, 71% and 99% for 3D-shaded surface displays, and 95% and 100% for volume-rendered images. Compared with the standard of reference, a concordant scoring of arterial stenosis severity was found in 54% of transverse CT scans, 84% of sagittal reformations, 78% of 3D-shaded surface displays, and 91% of volume-rendered images. Underestimation of stenosis was found in 43% of transverse CT scans and 10% of sagittal reformations; overestimation of stenosis was more frequent on 3D-shaded surface displays (16%) than on volume-rendered images (7%). The reader's experience was marked for the interpretation of cross-sectional images but did not influence the interpretation of 3D images.	3

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
37. Remy-Jardin M, Remy J, Masson P, et al. Helical CT angiography of thoracic outlet syndrome: functional anatomy. *AJR* 2000; 174(6):1667-1674.	Observational-Dx	79 symptomatic patients	To determine the anatomic characteristics of the thoracic outlet in symptomatic patients before and after postural maneuver.	A statistically significant difference was found between the distribution of the distances (maximum and costosubclavian) measured in the neutral position and after postural maneuver in groups 1 and 2. The median value of these distances was smaller after postural maneuver in groups 1 and 2. A statistically significant difference was found between the distribution of the distances (maximum and costosubclavian) measured in patients of group 1 with arterial stenosis and in patients of group 1 without arterial stenosis. A slight indentation of the anterior wall of the subclavian artery when it arches around the anterior scalene muscle was observed in 39 patients (64%) in group 1 and in 11 patients (61%) in group 2 in the neutral position, in 19 patients (31%) in group 1 and in 6 patients (33%) in group 2 after the postural maneuver. The predominant positional changes of the vascular structures were the posteroanterior displacement of the subclavian vessels observed in groups 1 and 2, the arch made by the subclavian artery above the first rib in 40 patients (66%) in group 1 and 9 patients (50%) in group 2, and the posterior displacement of the axillary artery observed in 36 patients (59%) in group 1 and in 12 patients (67%) in group 2.	3
38. Viertel VG, Intrapiromkul J, Maluf F, et al. Cervical ribs: a common variant overlooked in CT imaging. *AJNR Am J Neuroradiol* 2012; 33(11):2191-2194.	Review/Other-Dx	3,404 consecutive patients	To investigate how often cervical ribs are present on cervical spine CT scans to determine the incidence in humans and the percentage of reported cervical ribs.	Cervical ribs were found in 2.0% (67/3,404) of the population. Of the 67 patients with cervical ribs, 27 (40.3%) had bilateral ribs. The prevalence of cervical ribs in women was twice that in men, 2.8% (39/1,414) vs 1.4% (28/1,990). Although African Americans accounted for 50.1% (1,706/3,404) and whites, 41.2% (1,402/3,404) of the patient population, African Americans were 70.1% (47/67) of patients with cervical ribs, whereas whites were 26.9% (18/67). Radiologists commented on 25.5% (24/94) of the cervical ribs in 25.4% (27/67) of patients.	4

Imaging in the Diagnosis of Thoracic Outlet Syndrome
EVIDENCE TABLE

Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
39. Gu R, Kang MY, Gao ZL, Zhao JW, Wang JC. Differential diagnosis of cervical radiculopathy and superior pulmonary sulcus tumor. *Chin Med J (Engl)* 2012; 125(15):2755-2757.	Review/Other-Dx	10 patients	To investigate the differential diagnosis methods of cervical radiculopathy and superior pulmonary sulcus tumor.	Superior pulmonary sulcus tumor patients have shorter mean history and fewer complaints of neck pain or limitation of neck movement. Physical examination showed almost normal cervical spine range of motion. Spurling's neck compression test was negative in all patients. Anteroposterior cervical radiographs showed the lack of pulmonary air at the top of the affected lung in all cases and first rib encroachment in one case. The diagnosis of superior pulmonary sulcus tumor can be further confirmed by CT and MRI.	4
40. Hasanadka R, Towne JB, Seabrook GR, Brown KR, Lewis BD, Foley WD. Computed tomography angiography to evaluate thoracic outlet neurovascular compression. *Vasc Endovascular Surg* 2007; 41(4):316-321.	Observational-Dx	21 patients	To evaluate the efficacy of CTA with upper extremity hyperabduction to diagnose TOS.	5/6 CTAs were positive. The sixth CT was deemed to be an incomplete study. With mean follow-up of 9.4 months, 95% (n = 19) of patients with a positive hyperabduction test on physical examination were free of symptoms postoperatively. All patients with a positive CTA, with their neurovascular compression localized to the thoracic outlet, had successful operative decompression. CTA with abduction of the arm can be used as an adjunct to confirm the diagnosis of neurovascular compression and then predict successful operative decompression.	4
41. Demondion X, Herbinet P, Van Sint Jan S, Boutry N, Chantelot C, Cotten A. Imaging assessment of thoracic outlet syndrome. *Radiographics* 2006; 26(6):1735-1750.	Review/Other-Dx	N/A	To review the anatomy of the thoracic outlet and discuss and illustrate the functional anatomy, clinical features, causes, imaging features, and treatment of TOS.	Diagnosis of TOS is based on the results of clinical evaluation, particularly if symptoms can be reproduced when various dynamic maneuvers, including elevation of the arm, are undertaken. However, clinical diagnosis is often difficult; thus, the use of imaging is required to demonstrate neurovascular compression and to determine the nature and location of the structure undergoing compression and the structure producing the compression. Cervical plain radiography should be performed first to assess for bone abnormalities and to narrow the differential diagnosis.	4

Imaging in the Diagnosis of Thoracic Outlet Syndrome
EVIDENCE TABLE

Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
42. Matsumura JS, Rilling WS, Pearce WH, Nemcek AA, Jr., Vogelzang RL, Yao JS. Helical computed tomography of the normal thoracic outlet. *J Vasc Surg* 1997; 26(5):776-783.	Observational-Dx	10 volunteers	To determine the detailed anatomy of the thoracic outlet in normal subjects using helical CT, with particular attention to vascular compression with arm movement.	With abduction the scalene-clavicle distance decreased from 18.4 +/- 3.9 mm to 5.2 +/- 2.4 mm (P<0.001), and the costoclavicular distance decreased from 12.6 +/- 2.7 mm to 6.3 +/- 3.3 mm (P=0.005). At these same anatomic planes, the vein diameter decreased from 11.0 +/- 1.6 mm at the neutral position to 5.1 +/- 1.5 mm (P<0.001) and from 16.1 +/- 3.0 mm to 7.4 +/- 2.6 mm with the arm abducted (P<0.001). The artery diameter changed from 6.6 +/- 0.8 mm to 6.2 +/- 0.5 mm (P=0.08) and from 7.2 +/- 0.8 mm to 6.0 +/- 0.5 mm (P=0.001) with arm movement.	3
43. Aralasmak A, Karaali K, Cevikol C, Uysal H, Senol U. MR imaging findings in brachial plexopathy with thoracic outlet syndrome. *AJNR Am J Neuroradiol.* 2010;31(3):410-417.	Review/Other-Dx	60 patients	To review MRI findings of subjects with brachial plexopathy. Different varieties of BPL lesions and imaging techniques are discussed.	MR imaging is valuable in the characterization of BPL lesions. In brachial plexopathy, common lesions can vary according to age groups. For a complete evaluation, visualization of the BPL, including its roots, spinal cord, and neural foramina, is mandatory. In suspicion of TOS, dynamic MRI evaluation of the BPL and subclavian vessels is added to routine protocol.	4

Imaging in the Diagnosis of Thoracic Outlet Syndrome
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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
44. Harigai M, Okada T, Umeoka S, et al. Non-contrast-enhanced MR venography of the upper limb: a comparative study of acquisitions with fresh blood imaging vs. time-of-flight methods. *Clin Imaging* 2012; 36(5):496-501.	Observational-Dx	19 healthy volunteers	To determine whether FBI-MRV is superior to TOF-MRV in the visualization of upper venous structures and compare its visualization capabilities on three major veins — the basilic, brachial, and cephalic veins — and on small venous branches of the upper arm.	The average scores ± standard deviation for visualization by FBI-MRV/TOF-MRV were 2.05±0.62/1.16±0.96, 2.00±0.75/1.47 ±0.51, 1.89±0.88/2.16±0.69, and 2.42±0.61/0.47±0.51, respectively, for the basilic, brachial, cephalic veins, and small venous branches. FBI-MRV had significantly superior visualization of the basilic vein (P=.0026; Fig. 1). Scores for the brachial vein were higher in FBI-MRV than in TOF-MRV without attaining statistical significance (P=.04), after correction for multiple comparisons. Visualization at the axilla was occasionally degraded in both MRV methods, which decreased the average scores of the basilic and brachial veins. TOF-MRV had a higher average score than FBI-MRV for the cephalic vein, but no statistically significant difference was observed (P=.41). Small venous branches were visualized more conspicuously in FBI-MRV (P=.0001). No significant difference was observed (P=.32) in the average scores of incomplete fat suppression that impaired visualization of the venous structures between FBI-MRV (0.53±0.77) and TOF-MRV (0.58±0.69). However, residual fat signal occasionally deteriorated visualization, especially around the shoulder in FBI-MRV.	3
45. Takei N, Miyoshi M, Kabasawa H. Noncontrast MR angiography for supraaortic arteries using inflow enhanced inversion recovery fast spin echo imaging. *J Magn Reson Imaging* 2012; 35(4):957-962.	Review/Other-Dx	10 healthy volunteers	To depict supraaortic arteries using 3D fast spin echo combined with slab selective inversion recovery for noncontrast MRA in healthy volunteers, and to investigate the property of the inflow enhanced inversion recovery-fast spin echo for background suppression and inflow effects.	Inflow enhanced inversion recovery-fast spin echo images showed good visualization of the supraaortic arteries and allowed separation of arteries from veins without image subtraction. The proposed method demonstrated that a high contrast between arteries and background tissues can be acquired with various inversion times, which was in good agreement with the simulation. An inversion time over 1600 msec was favorable in terms of background suppression, arterial signal intensity, and inflow effects.	4

Imaging in the Diagnosis of Thoracic Outlet Syndrome
EVIDENCE TABLE

Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
46. Aralasmak A, Cevikol C, Karaali K, et al. MRI findings in thoracic outlet syndrome. *Skeletal Radiol* 2012; 41(11):1365-1374.	Review/Other-Dx	100 neurovascular bundles	To review MRI findings in patients with TOS.	71 neurovascular bundles were found to be abnormal: 16 arterial-venous-neurogenic, 20 neurogenic, 1 arterial, 15 venous, 8 arterial-venous, 3 arterial-neurogenic, and 8 venous-neurogenic TOS. Overall, neurogenic TOS was noted in 69%, venous TOS in 66%, and arterial TOS in 39%. The neurovascular bundle was most commonly compressed in the costoclavicular, mostly secondary to position, and very rarely compressed in the retropectoralis minor. The cause of TOS was congenital bone variations in 36%, congenital fibromuscular anomalies in 11%, and position 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. For evaluation of patients with TOS, visualization of the brachial plexus and cervical spine and dynamic evaluation of neurovascular bundles in the cervicothoracobrachial region are mandatory.	4
47. Demondion X, Boutry N, Drizenko A, Paul C, Francke JP, Cotten A. Thoracic outlet: anatomic correlation with MR imaging. *AJR* 2000; 175(2):417-422.	Review/Other-Dx	5 cadavers	To describe the normal MR anatomy of the thoracic outlet and its modification after postural maneuvers using an anatomic-MRI correlation.	MRI appears to be a useful technique to study the thoracic outlet and its contents because of its excellent soft-tissue depiction and its multiplanar capabilities. T1-weighted images obtained in the sagittal plane clearly depicted the different compartments of the cervicothoracic-brachial junction. Hyperabduction maneuvers may have potential applications in the assessment of the TOS by showing the location of compression.	4

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Reference	Study Type	Patients/ Events	Study Objective (Purpose of Study)	Study Results	Study Quality
48. Charon JP, Milne W, Sheppard DG, Houston JG. Evaluation of MR angiographic technique in the assessment of thoracic outlet syndrome. *Clin Radiol* 2004; 59(7):588-595.	Observational-Dx	55 consecutive examinations in 51 patients	To evaluate 2D TOF and 3D contrast-enhanced MRA techniques in the assessment of patients with suspected TOS of vascular origin.	Images were sub-optimal in 53% 2D TOF and 10% 3D contrast-enhanced MRA examinations. 3D contrast-enhanced MRA offered vessel coverage from the aortic arch to the distal axilliary arteries, whereas, 2D TOF sequences gave more limited coverage. 8 patients were found to have significant impingement (n = 7) or stenosis (n = 1) of the subclavian artery attributable to TOS. 3D contrast-enhanced MRA also demonstrated other relevant significant stenoses not attributable to TOS (n = 5). All cases of impingement were either seen only, or more prominently, on sequences with the arms abducted. Reformatting the 3D contrast-enhanced MRA studies demonstrated the cause of impingement.	3
49. Demirbag D, Unlu E, Ozdemir F, et al. The relationship between magnetic resonance imaging findings and postural maneuver and physical examination tests in patients with thoracic outlet syndrome: results of a double-blind, controlled study. *Arch Phys Med Rehabil* 2007; 88(7):844-851.	Observational-Dx	29 patients and 12 healthy controls.	To investigate the differences in findings from MRI in the neutral and provocative positions, and to examine the relationship between these differences and the results of physical examination tests in patients with TOS.	There was a significant difference in MRI findings between the neutral and provocative position in the patients (P<.05), but there were no significant differences in the control group. There was a significant difference in the positional change values in MRI between the patients and the control subjects (P<.05). The difference was found in the minimum costoclavicular distance between patients with a positive Halsted maneuver and a negative Halsted maneuver (P<.05).	2

Evidence Table Key

Study Quality Category Definitions

- *Category 1* The study is well-designed and accounts for common biases.
- *Category 2* The study is moderately well-designed and accounts for most common biases.
- *Category 3* There are important study design limitations.
- *Category 4* The study is not useful as primary evidence. The article may not be a clinical study or the study design is invalid, or conclusions are based on expert consensus. For example:
  a) the study does not meet the criteria for or is not a hypothesis-based clinical study (e.g., a book chapter or case report or case series description);
  b) the study may synthesize and draw conclusions about several studies such as a literature review article or book chapter but is not primary evidence;
  c) the study is an expert opinion or consensus document.

Dx = Diagnostic

Tx = Treatment

Abbreviations Key

CI = Confidence interval

CT = Computed tomography

CTA = Computed tomography angiography

FBI-MRV = Fresh blood imaging magnetic resonance venography

MRA = Magnetic resonance angiography

MRI = Magnetic resonance imaging

PE = Pulmonary embolism

PPV = Positive predictive value

TOF-MRV = Time-of-flight magnetic resonance venography

TOS = Thoracic outlet syndrome

UEDVT = Upper extremity deep venous thrombosis

US = Ultrasound