Thoracic Outlet Syndrome Part I: Systematic Review of the Literature and Consensus on Anatomy, Diagnosis, and Classification of Thoracic Outlet Syndrome by the European Association of Neurosurgical Societies' Section of Peripheral Nerve Surgery

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BACKGROUND: Although numerous articles have been published not only on the classification of thoracic outlet syndrome (TOS) but also on diagnostic standards, timing, and type of surgical intervention, there still remains some controversy because of the lack of level 1 evidence. So far, attempts to generate uniform reporting standards have not yielded conclusive results.

OBJECTIVE: To systematically review the body of evidence and reach a consensus among neurosurgeons experienced in TOS regarding anatomy, diagnosis, and classification.

METHODS: A systematic literature search on PubMed/MEDLINE was performed on February 13, 2021, yielding 2853 results. Abstracts were screened and classified. Recommendations were developed in a meeting held online on February 10, 2021, and refined according to the Delphi consensus method.

RESULTS: Six randomized controlled trials (on surgical, conservative, and injection therapies), 4 "guideline" articles (on imaging and reporting standards), 5 observational studies (on diagnostics, hierarchic designs of physiotherapy vs surgery, and quality of life outcomes), and 6 meta-analyses were identified. The European Association of Neurosurgical Societies' section of peripheral nerve surgery established 18 statements regarding anatomy, diagnosis, and classification of TOS with agreement levels of 98.4 % (±3.0).

CONCLUSION: Because of the lack of level 1 evidence, consensus statements on anatomy, diagnosis, and classification of TOS from experts of the section of peripheral nerve surgery of the European Association of Neurosurgical Societies were developed with the Delphi method. Further work on reporting standards, prospective data collections, therapy, and long-term outcome is necessary.

KEY WORDS: Thoracic outlet syndrome, Level of evidence, Consensus statement, Diagnosis, Classification

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ABBREVIATIONS: AA, axillary arch; **AT,** Adson test; **aTOS,** arterial thoracic outlet syndrome; **AWMF,** Arbeitsgemeinschaft der wissenschaftlichen medizinischen Fachgesellschaften; **BBR,** bilateral breast reduction surgery; **BTX,** botulinum toxine; **CCM,** costoclavicular maneuver; **CDC,** clinical diagnostic criteria; **CR,** cervical rib; **CTS,** carpal tunnel syndrome; **DASH,** disabilities of the arm; **EANS,** European Association of Neurosurgical Societies; **EAST,** elevated arm stress test; **FRR,** first rib resection; **FRR plus PLASTY,** first rib resection plus endovenous balloon venoplasty; **KT,** Kinesio taping; **MCS,** mental component scores; **MRA,** magnetic resonance angiography; **NHP,** Nottingham Health Profile; **nTOS,** neurogenic thoracic outlet syndrome; **PCS,** physical component scores; **PT,** physiotherapy; **QD,** quick DASH; **RCT,** randomized controlled trial; **SCP,** supraclavicular pressure; **SF-36,** Short Form Health Survey; **SNBP,** supraclavicular neuroplasty of brachial plexus; **TFRR,** transaxillary first rib resection; **TOS,** thoracic outlet syndrome; **ULTT,** upper limb tension test; **US,** ultrasound; **vTOS,** venous thoracic outlet syndrome.

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The thoracic outlet syndrome (TOS) comprises a group of disorders caused by the compression of the neurovascular bundle at the thoracic outlet by bony, muscular, or fibrous structures. Willshire presented the first description of symptoms related to a supplementary cervical rib in 1860.[1] Thomas and Cushing, Murphy, Peet, and other authors described variations of the condition which is nowadays called "thoracic outlet syndrome."[2-6]

TOS often remains undiagnosed in patients complaining of diffuse numbness, chronic pain of the head and neck, and pain and weakness of the upper extremities. Although TOS is a treatable disorder, patients frequently live with pain, discomfort, uncertainty, and disability. Devastating functional, emotional, and financial impairment resulting in job loss and lifelong disability are potential outcomes of this syndrome if not treated successfully.

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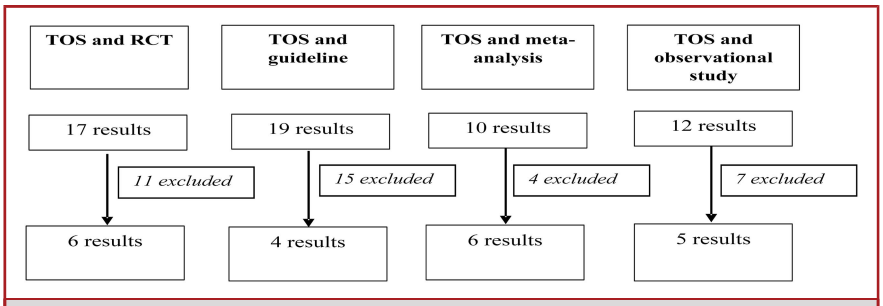

FIGURE 1. *Study flow diagram to summarize the body of intermediate-quality and high-quality evidence in thoracic outlet syndrome. RCT, randomized controlled trial; TOS, thoracic outlet syndrome.*

Compressive structures may include cervical ribs and other bony, muscular, or fibrous anomalies of the thoracic outlet.[7-9] The syndrome's prevalence has been estimated at 10 per 100 000 people and may be dramatically higher in athletes.[10,11]

There are differences in classification and diagnostic approaches because of the heterogeneity of symptoms, anatomy, and treating disciplines. Controversies exist because of the lack of level 1 evidence. So far, attempts to generate uniform reporting standards have not yielded conclusive results. There is extensive literature published on TOS, mainly from single centers and with low-volume data and multicenter high-volume data from surgical quality assurance databases without distinct information on the neurological condition before and after surgery. This article aims to summarize the existing literature focusing on high-quality and medium-quality data such as randomized controlled trials (RCTs), observational studies, meta-analyses, and guidelines. This article also aims to reach a consensus among neurosurgeons regarding diagnosis and classification of TOS. A separate consensus article on the treatment of TOS is currently being prepared and is planned to be published as part II.

METHODS

A literature search on PubMed/MEDLINE was performed on February 13, 2021, yielding 2853 results for "TOS." The individual abstracts were screened and full-text articles were assessed by N.F.D. and A.Z. For our description of "the body of evidence," search results were restricted to intermediate-quality and high-quality studies such as RCTs, observational studies, guidelines, meta-analyses, and Cochrane analyses (Figure 1). Inclusion criterion was English language. Exclusion criteria for this part were review articles, opinions, study protocol suggestions, and retrospective case series. The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) checklist was used for guidance.

An expert was defined as a board-certified neurosurgeon with more than 5 years of specialist practice after board certification as neurosurgeon, who is a member of the European Associations of Neurosurgical Societies' (EANS) section of peripheral nerve surgery and has experience in treatment of more than 30 TOS cases. Fourteen experts with a total of 269 years (mean 19.2 years ± 9.8, range 7-36 years) of postcertification experience in a total of 2800 TOS cases (mean 200 cases ± 148.9, range 30-700 cases per surgeon) participated in the process.

Preparatory work and discussion of the current literature and of the possible structure of consensus recommendations were developed in a meeting held online on February 10, 2021, and refined in the business meeting of the EANS section of peripheral nerve surgery on March 9, 2021. Based on this, a questionnaire was developed and refined in anonymous sessions according to the Delphi method. EANS peripheral nerve surgery section members who fulfilled the inclusion criteria were identified, and the questionnaire was sent to them on May 27, 2021. The response rate was 100%. The final questionnaire is depicted in **Supplementary Material 1**, http://links.lww.com/NEU/C972. The results of the questionnaire were presented in % with mean, standard deviation, and range and analyzed using SPSS Statistics 23.0 (SPSS Inc, IBM).

Data Availability Statement

Data that support the findings of this study are available on reasonable request.

Body of Evidence

Figure 1 depicts the number of articles retrieved by our PubMed search. We identified 6 RCTs (Table 1),[12-17] 4 "guidelines" articles (Table 2),[18-21] 5 observational studies (Table 3),[22-26] and 6 meta-analyses (Table 4).[7,27-31] We also included 2 Cochrane articles from 2010 and 2014.[32,33] They refer to only 1 surgical trial and 1 botulinum toxine (BTX) injection trial that were already included in the 6 RCT articles displayed in Table 1.[12,13] The Cochrane articles were considered of somewhat limited value because of the limited number of high-quality studies included and the authors themselves write in their discussion.

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TABLE 1. TOS and Randomized Controlled Trials

Reference	Inclusion criteria	Exclusion criteria	Treatment	Patient numbers	Trial design	Outcome measure	Main results
Sheth and Campbell[12]	• Symptoms provocation by certain postures (eg, spear-throwing position and downward tugging of the shoulder) • Tenderness in the supraclavicular fossa	• Anomalous cervical rib • Intrinsic weakness • Primarily vascular findings	SNBP (no rib resection) vs TFRR	N = 55, 8 lost to follow-up	Single-center, prospective, no blinding reported, "mean follow-up" of 37 mo, and "randomly assigned" to the 2 procedures	Pain (VAS) and pain relief	• "Less pain (39 vs 61 score range 0-100 on a visual analog scale), higher percentage of pain relief (52% compared with 30%), and less pain (3.7 compared with 5.1) on an affective scale (all *P*, 0.05) in the TFRR vs SNBP group"[12] • TFRR group with 75% of patients with "good or excellent outcomes compared with 48% in the SNBP group (*P*, 0.05)"[12]
Finlayson et al[13]	• Clinical diagnosis of TOS[a] • Symptoms present for ≥6 mo • Age ≥19 y • Medical stability (no acute medical conditions) • Ability to give informed consent • Previous EMG studies and a CT or MRI scan of the cervical spine to rule out alternate diagnoses.	• "Prior treatment with BTX-A • Allergy to BTX-A and history of botulism • Prior scalenectomy • Surgery for TOS planned within 6 mo • Use of blood thinners, ie, warfarin and unfractionated or low-molecular weight heparin • History of myasthenia gravis or Eaton–Lambert syndrome • Inability to complete follow-up assessments at 6 wk, 3, and 6 mo • Pregnancy or planned pregnancy within 6 mo"[13]	"BTX-A reconstituted with 0.75 cc of normal saline injected to the anterior scalene (37.5 units) and middle scalene (37.5 units) muscles using electromyographic guidance"[13] vs placebo injection	N = 38, 1 lost to follow-up	Prospective, single-center, double-blind, randomized, and parallel group trial with follow-up at 6 wk, 3 mo, and 6 mo	• Primary: pain (by VAS) 6-wk postinjection • Secondary: paresthesias (by VAS) and function (DASH) and (SF-36)	• "VAS baseline scores between placebo and BTX-A was 5.03 mm in favor of BTX-A (95% CI 15.7-5.7, *P* = .36) • Changes in secondary outcome measures were not statistically significant"[13]
Ortac et al[14]	• Age >18 y—symptom presence ≥3 mo • 3 of the 4 criteria with yes: (1) pain/paresthesia in the arm/hand (2) symptom aggravation with arm elevation (3) tenderness above the clavicula and over the brachial plexus, and (4) positive elevated arm stress test	• Presence of cervical radiculopathy/myelopathy • History of surgery to the cervical spine • Presence of any inflammatory rheumatic disease • Entrapment neuropathies of the upper extremity • History of major trauma to the head/neck • Any malignity and vii) history of physical therapy/injection during the last 3 mo.	Kinesio taping was applied to the Kinesio taping group 3 times. The control group received placebo taping	N = 60, no reported loss to follow-up	Prospective, single-center, single-blind placebo-controlled, and follow-up 12 mo	Pain and paresthesia (by VAS) pain (10 cm), upper limb function by DASH, and overall health status by NHP, each at baseline (t0), posttreatment (t1), and 8 wk after baseline (t2)	• Comparing "changes in outcome measures between the 2 groups revealed that, except NHP emotional reaction and NHP social isolation, median changes (from t0 to t1) were higher in the KT group than in the control group (*P* < .05 for all variables). Regarding VAS pain, VAS paresthesia, DASH, and 3 NHP • Domains (energy level, pain, and physical abilities), changes from t0 to t2 were also higher in the KT group (*P* < .05 for all variables)."[14]

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TABLE 1. Continued.

Reference	Inclusion criteria	Exclusion criteria	Treatment	Patient numbers	Trial design	Outcome measure	Main results
Kim et al[15]	• "A main complaint of paresthesia in the arm, forearm, and/or hand" • VAS >4 (on a numeric scale of 0-10) for paresthesia in the arm, forearm, and/or hand • Extreme tenderness over the anterior and middle scalene muscles • No weakness in the affected site • Symptoms present ≥3 mo[15]	• "Prior treatment with botulinum toxin, lidocaine, and/or steroid injection of scalene muscles in the affected site • Prior treatment with brachial plexus blockade in the affected site • Prior scalenectomy or surgery for TOS in the affected site • Prior treatment with stretching exercise • Cervical radiculopathy or other peripheral nerve compression syndromes in the electrodiagnostic test • Medial antebrachial cutaneous nerve conduction abnormality • Previous history of adverse effect of lidocaine or steroids • Presence of an unstable medical condition or a known uncontrolled systemic disease • Any conditions or situations that might place the patient at significant risk during the study[15]	• Completion of "1 injection and daily exercise program for 2 wk"[15] in each participant • Comparison of "therapeutic effects between 2-wk after 1 injection and 2-wk exercise"[15]	N = 20, no reported loss to follow-up	Prospective, single-center, single-blind (outcome measurer) crossover design, and follow-up 2 wk	• Primary: "paresthesia in the arm, forearm, and/or hand (by VAS 0-10) • Treatment success was defined as a reduction exceeding 50% in posttreatment VAS compared with pretreatment • Treatment failure defined as <50% VAS reduction"[15]	• Significant decrease of VAS "score of treatment effect compared with baseline in both groups; 6.90 to 2.85 after injection and 5.65 to 4.05 after stretching exercise • *p*50% reduction in posttreatment VAS: 18 of 20 (90.0%) after injection, compared with 5 of 20 (25.0%) after stretching exercise • No cases of unintended brachial plexus block after injection"[15]
Iwuagwu et al[16]	• Patients with macromastia, requesting BBR between August 2002 to April 2003 • None of the women had any known neurological problem of the upper limbs	Not reported	• Neurological assessment and 2 electrodiagnostic neurophysiological tests at different time points • Group 1 (early surgery): 2 tests; 1 before surgery and a second 3 mo postsurgery • Group 2 (delayed surgery): 2 sets of tests; 1 initially and a second test 4 mo later (control)	N = 31, no reported loss to follow-up	Proscpective, single-center, controlled, randomized, consecutive, follow-up 3 (early group) and 4 (delayed group) mo, respectively	SSEP (median and ulnar), F-wave median, and ulnar latencies	• "No statistical difference in conduction times"[16] between both groups • "BBR does not have any effect on the upper limb nerve conduction times"[16]
Plewa and Delinger[17]	Not applicable	Not applicable	• Prospectively evaluated healthy subjects • All subjects underwent provocative testing by a blinded physician: AT, CCM, EAST (Roos), and SCP	N = 53, no reported loss to follow-up	Cross-sectional, observational, prospective, single-center, and randomized order	Provocative testing by a blinded physician, which included AT, CCM, Roos, and SCP	Altered pulse in 11% (AT), 11% (CCM), 62% (EAST), and 21% (SCP), respectively. False-positive outcome in 7% (AT), 7% (CCM), 10% (SCP), or any TOS shoulder maneuver in 10%.

AT, Adson test; BBR, bilateral breast reduction surgery; BTX, botulinum toxine; CCM, costoclavicular maneuver; CT, computed tomography; CTS, carpal tunnel syndrome; DASH, disabilities of the arm; shoulder and hand score; EAST, elevated arm stress test; KT, Kinesio taping; NHP, Nottingham Health Profile; SCP, supraclavicular pressure; SF-36, short form health survey; SNBP, supraclavicular neuroplasty of brachial plexus; SSEP, somatosensory-evoked potential; TFRR, transaxillary first rib resection; VAS, visual analog scale.

[a]To be clinically diagnosed with TOS in that study, "patients had to meet 3 of the following 4 criteria: a history of pain and/or paresthesias in the medial arm, forearm and/or hand; a history of aggravation of symptoms with the arm in the elevated position; tenderness over the brachial plexus above the clavicle; or a positive EAST result, defined as reproduction of pain or paresthesias."[12]

A literature review revealed 17 articles for "thoracic outlet syndrome" and "randomized controlled trial." Six studies had randomized controlled study designs that dealt with diagnostic and therapeutic TOS management that are listed in this Table. Nine other articles were reviews, opinions, and protocol suggestions reported at the respective subitems of this article.

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TABLE 2. TOS and Guidelines

Reference	Methodology	Objectives	Main results
Zurkiya et al[18]	•Literature review"of current indications for diagnostic imaging (focus on potential limitations and benefits of modalities) • Application of well-established methodologies (RAND/UCLA appropriateness method and grading of recommendations assessment, development, and evaluation or GRADE)"[18] • Evidence or equivocal, expert opinion	• To provide "guidelines for use of various imaging modalities for assessment of thoracic outlet syndrome • To localize the site of compression, the compressing structure, and the compressed organ or vessel while excluding common mimics"[18]	Imaging for nTOS: • Chest radiogram • MRI chest Imaging for vTOS: • Chest radiogram • US duplex of subclavian artery and vein • CT chest with iv contrast or catheter venography Imaging for aTOS: • Chest radiogram • Equivalent alternatives are CTA chest with iv contrast, MRA chest without and with iv contrast, US duplex Doppler of subclavian artery and vein, or arteriography of the upper extremity
Illig et al[19]	•Reporting standards for workup, treatment, and assessment of results are presented plus reporting standards for vTOS and aTOS • Methods how these standards were set are not available in the article	• To produce consistency in diagnosis, description of treatment, and assessment of results	• "3 structures are at risk: the brachial plexus, the subclavian vein, and the subclavian artery, producing nTOS, vTOS, and aTOS thoracic outlet syndromes • aTOS, vTOS, and nTOS are separate entities, although they can coexist and possibly overlap • nTOS defined when 3 of the following 4 criteria are present: (1) signs and symptoms of pathology occurring at the thoracic outlet (pain and/or tenderness), (2) signs and symptoms of nerve compression (distal neurological changes, often worse with arms overhead or dangling), (3) absence of other pathology potentially explaining the symptoms, and (4) positive response to a properly performed scalene muscle test injection[19] • Avoidance of the terms mixed TOS, vascular TOS, and disputed TOS
Moriarty et al[20]	• Literature review of current indications for diagnostic imaging, plus discussion of potential limitations and benefits • Consensus methodology (modified Delphi) to rate the appropriateness of imaging and treatment procedures by the panel[20] • Evidence or expert opinion	• To provide guidelines for use of various imaging modalities for assessment of thoracic outlet syndrome • The goal of imaging is to localize the site of compression, the compressing structure, and the compressed organ or vessel while excluding common mimics[20]	• "TOS is characterized by compression of the neurovascular bundle because it passes from the upper thorax to the axilla (arterial, venous, or neurogenic) • nTOS: congenital or acquired • nTOS secondary to bony tissues, such as first rib abnormalities, cervical ribs, and bony tubercles or soft-tissue anomalies, such as fibrous bands or cervical muscle hypertrophy • Goal of further imaging: to confirm the diagnosis of TOS, exclude mimics, such as cervical spondylosis or shoulder joint or lung apex pathology, allow accurate classification into nTOS, vTOS or aTOS, and guide treatment selection • Abduction of the upper limb has been is the postural maneuver of choice for cross-sectional imaging • Digital subtraction angiography, US, CT angiography, and MRA may allow evaluation of vascular structures and the secondary effects of compression • CT and MR allow identification and evaluation of surrounding neurological, soft-tissue, and bony structures."[20]

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TABLE 2. Continued.

Reference	Methodology	Objectives	Main results
Scher et al[21]	• Review of anatomic and pathophysiologic bases with angiographic examples of each stage (series of 12 patients with 15 arterial lesions)	• To classify and guide treatment in subclavian artery compression by a cervical rib because it is an uncommon but potentially disabling condition	• "Stage I lesions: arterial stenosis only and minor poststenotic dilatation >thoracic outlet decompression (usually consisting of cervical rib resection) • Stage II lesions: intrinsic arterial damage usually plus subclavian aneurysm formation >require rib resection, aneurysmectomy, and arterial reconstruction. • Stage III lesions: present with distal thromboembolic complications >thrombectomy or embolectomy in addition to thoracic outlet decompression and arterial reconstruction."[21]

aTOS, arterial TOS; AWMF, Arbeitsgemeinschaft der wissenschaftlichen medizinischen Fachgesellschaften e.V. (working group of medical and scientific societies in Germany); CT, computer tomography; CTA, CT angiography; GRADE, Grading of Recommendations Assessment, Development and Evaluation; MRA, magnetic resonance angiography; nTOS, neurogenic TOS; TOS, thoracic outlet syndrome; UCLA, University of California at Los Angeles; US, ultrasound; vTOS, venous TOS.
A literature review revealed 19 articles for "TOS" and "guideline." A publication that met the standards of a "guideline" of the American National Guideline Clearinghouse or the German AWMF was not found. An excerpt of 4 published "guidances" in the matter of TOS is provided in this Table for methodology and major objectives. The other articles were opinions or case series. For the article of Scher and colleagues, only the abstract was taken into account because full-text access was not available which may result in incomplete data presentation.

This review was complicated by a lack of generally accepted diagnostic criteria for the diagnosis of TOS. There was very low-quality evidence that transaxillary first rib resection decreased pain more than supraclavicular neuroplasty, but no randomized evidence suggets that either is better than no treatment. There is moderate evidence to suggest that treatment with BTX injections yielded no great improvements over placebo injections of saline. There is no evidence from RCTs for the use of other currently used treatments. There is a need for an agreed definition for the diagnosis of TOS, especially the disputed form, agreed outcome measures, and high-quality randomized trials that compare the outcome of interventions with no treatment and with each other.[33]

Anatomy

There are 3 critical structures in the thoracic outlet: the brachial plexus, the subclavian artery, and the subclavian vein. The brachial plexus and subclavian artery pass through the interscalene triangle, which is defined by the triangular space between the anterior and middle scalene muscle and the first rib, whereas the subclavian vein runs anterior to the anterior scalene muscle. The TOS can potentially be caused by the constriction of any of 3 anatomic areas: the interscalene triangle, the costoclavicular space, and the subpectoralis minor space. Individuals with congenital or acquired bony, fibrous, or muscular abnormalities in these areas are at increased risk of developing TOS.

The interscalene triangle is bordered anteriorly by the anterior scalene muscle, posteriorly by the middle scalene muscle, and inferiorly by the first rib. Inside this triangle, the brachial plexus is situated superior, posterior, and lateral to the subclavian artery. The anterior and middle scalene muscles originate from the transverse processes of the C2-C7 vertebrae and attach to the first rib. In cadaver studies, the width of the base of the triangle ranges between 0 and 2.5 cm, with an average of 0.9 cm.[34] In surgical cases, the average distance is 0.67 cm in women and 0.77 cm in men. The interscalene angle was found to be, on average, 11.3°, with a range between 4° and 22°. Although TOS is more prevalent in women than men (4:1), there is little variability in anatomy between male and female cadavers.[35] The scalenus minimus (*also* pleuralis or Sibson muscle: C7 transverse process to the first rib and pleural dome) muscle is present in only 30% to 50% of TOS cases.[36] The insertions of the scalene muscles on the first rib can overlap and cause narrowing of an interscalene space.[37] Moreover, traumatic injury with posttraumatic fibrous tissue scarring or clavicle fractures can cause narrowing of the triangle. Elongated C7 processes may cause a bony compression of the neurovascular thoracic outlet bundle. Elongated C7 processes differ from the term "cervical rib" because cervical ribs are defined as additional bones that articulate with C7.[38] The prevalence of cervical ribs in the general population ranges from 0.5% to 2%, with only 5% to 10% of patients with cervical ribs presenting with TOS. The female to male ratio of cervical rib prevalence is 2:1. Gruber classified cervical ribs in 1869.[39] Roos has described 10 types of abnormal congenital fibrous bands and ligaments.[9] First rib anomalies or large callus formation after rib fracture may also cause TOS.

The costoclavicular space is a triangular area bordered by the first rib inferiorly, the clavicle superiorly, and the anterior scalene muscle at its insertion site posteriorly. The average distance for the costoclavicular space ranges from 6 to 30.9 mm.[35] Poor posture, heavy breasts in women, saggy shoulders, clavicle fracture, acute hematoma, and scar formation can narrow the costoclavicular space that, in turn, may lead to TOS. During shoulder abduction, the scapula and coracoid move downward and the clavicle moves backward and upward. This movement may cause traction on the subclavius muscle and costocoracoid ligament, with subsequent pressure on the neurovascular structures.

The subpectoralis minor (subcoracoid) space is located under the coracoid process and the pectoralis minor muscle insertion to this process. Compression of the neurovascular structures in this region is quite rare and, in most cases, is caused by tension of the pectoralis minor muscle during hyperabduction.[40] People whose professional activity requires keeping arms above the head for long periods are more predisposed to this syndrome. Consensus statements on anatomy are depicted in Figure 2 (statement I and II).

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TABLE 3. TOS and Observational Studies

Reference	Inclusion criteria	Exclusion criteria	Treatment	Patient numbers	Trial design	Outcome measure	Main results
Baldermann et al[22]	• Meeting of CORE-TOS CDC for nTOS criteria • Meeting of the diagnostic criteria for nTOS described in the 2016 reporting standards of the Society for Vascular Surgery	Not reported	6-wk physical therapy and patient without symptom improvement underwent surgery (supraclavicular decompression with or without pectoralis minor tenotomy)	N = 183	Prospective, observational, single-center, hierarchic treatment (all underwent 6 wk of physio and those without improvement underwent decompressive supraclavicular surgery with first rib resection), follow-up: median 21.1 mo for physical therapy and 12.0 mo for surgery	QuickDASH, SF 12, and patient-rated outcomes for physical therapy and surgery	• Satisfactory improvement with physical therapy alone in 27% of patients • Surgery was performed in 60% of patients • The degree of local tenderness to palpation differed slightly between both groups (1.7 vs 2.0, $P = .032$) and so did number of positive clinical diagnostic criteria (9.0 vs 10.1 $P = .001$), Cervical-Brachial Symptom Questionnaire scores (68.0 vs 78.0 ß = .045), and SF-12 QOL scores (35.6 vs 32.0, $P = .019$) • The mean change in QuickDASH scores for physical therapy at follow-up was 15.6 (29.5%) compared with 29.8 (47.9%) for surgery ($P = .001$) • "Patient-rated outcomes for surgery were excellent for 27%, good for 36%, fair for 26%, and poor for 11% • Patients with clinically significant pain catastrophizing exhibited a greater level of functional disability than noncatastrophizing patients ($P < .0001$)."[22]
Duarte et al[23]	Consecutive patients with high-resolution chest CT	Not reported	Costoclavicular distance was measured at the subclavian vein and brachial plexus/subclavian artery sites, with respect to sex, laterality, age group (<50 and ≥50 y), and body mass index group (body mass index <25 and ≥25 kg/m^2)	150 of 156 CT scans from consecutive adult patients (72 female and 78 male).	Observational, single-center, and diagnostic	• Presence of TOS	• "Costoclavicular distances were 1.23 cm (±0.40) and 1.24 cm (±0.47), respectively. • Age (≥50 y) and body mass index (≥25 kg/m^2) increased the costoclavicular distance"[23] • A narrowed costoclavicular distance and a greater chance of developing thoracic outlet syndrome were indicated by measurements of V and NA below the fifth percentile • V and NA measurements increased with age and BMI • No significant differences regarding patient laterality, sex, and height
Chandra et al[24]	• Upper extremity symptoms suggestive of nTOS (including pain, paresthesia, numbness, weakness, and disability)	• Patients with evidence of venous or arterial TOS	2-4 mo of physiotherapy and surgery in case of insufficient improvement, surgery: supraclavicular decompression, rib resection, and middle and anterior scalenotomy	N = 59 (prospective cohort)	Prospective, single-center, hierarchical study design, and follow-up: 6 and 12 mo	QD and QOL scale (0-100, 100 = worse)	• PT was prescribed for all patients and the mean pre-PT QD disability score was 55.1 • "24 patients (41%) were offered surgical decompression based on compliance with PT, interval improvement on QD score, and duplex compression of the thoracic outlet • 21 patients underwent surgery (SURG group) • Significant differences between the SURG and non-SURG cohorts with respect to age, participation in competitive athletics, history of trauma, and symptom improvement with PT • At 1-y follow-up, 90% of patients expressed symptomatic improvement with the mean postoperative QD disability score decreasing to 24.9 ($P = .005$) and 1-y QD scores improving down to 20.5 ($P = .014$)"[24]

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TABLE 3. Continued.

Reference	Inclusion criteria	Exclusion criteria	Treatment	Patient numbers	Trial design	Outcome measure	Main results
Chang et al[25]	• Patients age 18 years and older presenting to an academic medical center TOS clinic • Patients failed physical therapy before their referrals • Informed consent	Not reported	All patients then underwent transaxillary first rib resection	N = 70 (of 105 eligible patients)	Prospective, observational, and single-center. Follow-up: 3, 6, 12, 18, and 24 mo after surgery.	SF-12, DASH, MCS, and return to full-time work	• 66.7% completed the study protocol (44 neurogenic and 26 venous) • "50% of patients with nTOS and 77% of patients with vTOS returned to full-time work or activity within the study follow-up"[25] • nTOS baseline SF-12 scores were significantly worse than patients with vTOS (33.8 vs 43.6, $P < .001$). • No difference in MCS (44.5 vs 43.5, P .78). • "Follow-up SF-12 scores for patients with nTOS improved 0.24 points ($P < .001$) and MCS scores improved 0.15 points per month ($P = .01$) • PCS scores for patients with vTOS improved 0.40 points ($P = .004$) and MCS scores improved 0.55 points per month ($P < .001$). • Patients with nTOS had baseline DASH scores that were significantly worse than patients with vTOS (50.2 vs 25.0, $P < .001$). • DASH scores, also improved with an average of 0.85 points ($P < .001$) for nTOS and 0.81 points for vTOS ($P < .001$)"[25]

aTOS, arterial TOS; BMI, body mass index; CDC, clinical diagnostic criteria; CORE-TOS, Consortium for Outcomes Research and Education on Thoracic Outlet Syndrome; CT, computer tomography; CTA, CT angiography; DASH, Disabilities of the Arm, Shoulder, and Hand score; MCS, Mental Component Scores; MRA, magnetic resonance angiography; SURG, surgery; PCS, Physical Component Scores; TOS, thoracic outlet syndrome; NA, standard costoclavicular distance at the subclavian artery/brachial plexus branches; nTOS, neurogenic TOS; PT, physiotherapy; QD, quick DASH; QOL, quality of life; V, the standard costoclavicular distance at neurovascular bundle crossing points near the subclavian vein; vTOS, venous TOS; US, ultrasound.
A literature review revealed 12 articles for "thoracic outlet syndrome" and "observational studies". Five articles actually were identified as observational study and listed in this Table. Seven other articles were reviews, opinions, retrospective case series of mixed study cohorts, and protocol suggestions reported at the respective subitems of this article.

Classification

The reporting standards of the American Society for Vascular Surgery recommend classifying TOS into 3 categories for the structure at risk: brachial plexus (neurogenic—nTOS), V. subclavia (venous—vTOS), and A. subclavia (arterial—aTOS).[19] They define neurogenic TOS (nTOS) by the presence of 3 of 4 criteria: pain and/or tenderness at the thoracic outlet, "distal neurological changes," absence of other pathology, or positive response to scalene muscle injection (Table 2). Avoiding the terms "mixed TOS," "vascular TOS," and "disputed TOS" is recommended by their standards.[19] Most neurosurgeons use the following categories: vTOS (also referred to as Paget von Schroetter Syndrome), aTOS, and nTOS following the reporting standards mentioned above, but also include the term "nonspecific" or "disputed."[8] Most neurologists distinguish between aTOS, vTOS, traumatic neurovascular TOS, and nTOS. Neurogenic TOS is further subclassified into true neurogenic and disputed by most neurologists.[41-43] Provocative maneuvers, and in particular the Adson test, may help differentiate between aTOS and the other TOS types and are described in more detail below. A more differentiated classification of primarily nonvascular TOS types in an atrophic and/or irritative form depending on the presence of muscle atrophy and/or symptoms of paresthesia, pain, and/or sensory deficit may help guide TOS management decisions. Therefore, in routine clinical practice, the term "disputed TOS" deserves special attention. Some categorize "disputed TOS" as cervicoscapular pain syndrome rather than a type of TOS.[37] Interestingly, the only RCT published on surgical TOS treatment exclusively included "disputed TOS" cases.[13] That study showed that surgical treatment might sufficiently improve the symptoms in some cases with superiority of transaxillary first rib resection over supraclavicular neurolysis. However, nTOS is considered the most frequent form of TOS with rates from 39% to 95 %, and aTOS is regarded as a rare form with rates from 1% to 19% in the literature.[7,27,44-47] Most aTOS cases were shown in association with cervical ribs.[48,49] However, no uniform, interdisciplinary classification standard exists to date.

In our view, the classification of TOS is crucial because timing and type of surgical therapy may depend on the type of TOS. Most TOS cases in the United States are treated by vascular surgeons, although in more than 80 % of cases, neurogenic origin is to be assumed.[50] The predominant surgical therapy is either transaxillary or supraclavicular first rib resection. The incidence of nerve injuries after rib resection is reported to be somewhat low (<1%), but the rate of pneumothoraces ranges up to 26%.[51]

The European community of peripheral nerve surgeons aims for a more precise and differentiated approach to the term "neurogenic TOS" and does not fully agree with the American Society for Vascular Surgery criteria. In our experience, patients with nTOS present with different clinical patterns. The differentiation of nTOS in separate entities may

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TABLE 4. TOS and Meta-analysis

Reference	Methodology	Objectives	Main results
Peek et al[27]	"MEDLINE, EMBASE, and CINAHL database and Cochrane database search for studies published between January 1980 and February 2015, keywords: thoracic outlet syndrome, and treatment and surgical • Inclusion criteria: studies describing outcomes of surgery for TOS, published in English, human studies, and full-text availability. • Exclusion criteria: case series and case reports (n < 5), reviews, abstracts, and studies of endoscopic-assisted or robotic endoscopic–assisted transaxillary first rib resection"[27]	• Summary and comparison of outcomes and major complications of the surgical procedures for the 3 types of TOS: arterial, venous, and neurogenic in retrospective and prospective case series >4 patients	• Improvement of complaints after surgical treatment in all articles included (12 articles met inclusion criteria). • Derkash classification category improvement to excellent/good in 90% of the aTOS and vTOS • Improvement of 28.3 points (DASH) after operative nTOS treatment • Pneumothorax in 2%-23% of patients in individual series
Henry et al[7]	• Major electronic database search • "Data on the prevalence, laterality, and side of CR were extracted from the eligible studies for both healthy individuals and patients with TOS • Data on the type of TOS and surgical approach to excision of CR were extracted"[7]	To provide "a comprehensive evidence-based assessment of CR prevalence and their association with TOS and surgical approach to excision of CR and surgical patients' characteristics"[7]	• CR prevalence higher in patients with TOS than in healthy individuals (pooled prevalence of 29.5% and 1.1%) in 141 studies (n = 77.924 participants) were included in the meta-analysis • Unliateral CR were present in more than 50 % of both healthy and TOS patient groups • "In symptomatic patients, 51.3% had vascular TOS and 48.7% had nTOS"[7] • Surgical excision was performed for most CR using a supraclavicular approach, mainly in female patients
Taterra et al[28]	• Electronic database search for "studies on the AA and its variations • Data regarding the prevalence, morphology, laterality, origin, insertion and innervation of the AA was extracted and included in this meta-analysis. • Usage of the AQUA tool to assess potential risk of bias within the included studies"[28]	• To "investigate the prevalence and anatomic features of the axillary arch (AA—a muscular, tendinous, or musculotendinous slip arising from the latissimus dorsi and that terminates in various structures around the shoulder girdle) because it may complicate axillary lymph node biopsy or breast reconstruction surgery and may cause thoracic outlet syndrome"[28]	• The AA pooled prevalence estimated in this meta-analysis (29 studies, 10.222 axillas) was in 5.3% (unilaterally in 61.6% and bilateral in 38.4%) • In 55.1%, the AA was predominantly muscular • In 87.3%, the AA originated from the latissimus dorsi muscle or tendon • In 35.2%, the AA inserted into the pectoralis major muscle or—in 39.9%, the AA was innervated by the thoracodorsal nerve
Asghar et al[29]	• "Systematic search on major electronic databases (PubMed, EMBASE, Google Scholar, and *Journals of Anatomy, Orthopedics, Plastic Surgery, Sports Medicine*) • Primary outcome: to measure the prevalence of ectopic insertion of pectoralis minor tendons. • Data extraction: conducted for pooled estimation and metanalysis"[29]	• To provide "a comprehensive evidence-based assessment of the anatomic characteristics of ectopic insertion of pectoralis minor."[29]	• "25 studies included for systematic review. • Ectopic insertion of pectoralis minor prevalence was estimated in an overall pooled analysis with 19.27% (95% CI 15%-24%). • Prevalence rate in dissected specimen was 21% (CI 15%-28%) and in arthroscopic evaluation was 22% (95% CI 5%-59%) • Prevalence rate in MRI and USG were 15% and 12%, respectively • Le Double classification distribution of subtypes: 34% for type I, 42 for type II, and 9% for type III. • Incidence of ectopic insertion of pectoralis minor highest in Japanese population • Female and left side have insignificant higher incidences"[29]

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TABLE 4. Continued.

Reference	Methodology	Objectives	Main results
Lugo et al[30]	• MEDLINE search "using the terms 'Paget–Schroetter syndrome,' 'upper extremity DVT,' 'first rib resection,' 'effort thrombosis,' and 'primary upper extremity thrombosis,' with thrombolysis used as an 'AND' term. • Studies with patients >18 y or older with symptoms of 14-d duration or less undergoing thrombolysis for primary axillosubclavian vein thrombosis were included • Exclusion of studies that did not report follow-up, duplicate series from the same institution, and those in which patients were stented were excluded. • Analysis on an intent-to-treat basis, with groups assigned according to each authors' prospectively described algorithm"[30]	• "To perform a meta-analysis of the current literature to compare current treatment regimens"[30] in Paget von Schroetter because no randomized data exists on this issue	• 12 series included; 3 groups according to treatment after thrombolysis: FRR (448 patients), FRR plus endovenous balloon venoplasty (FRR plus PLASTY; 68 patients), and those with no further intervention after thrombolysis (rib not removed; 168 patients) • "Symptom relief at last follow-up was more likely in the FRR (95%) and FRR plus PLASTY (93%) groups than in the rib not removed (54%) group (both <0.0001), same with patency (98%, 86%, and 48%, respectively; both <0.0001 vs rib not removed). • 40% of patients without rib removal eventually required rib resection for recurrent symptoms • No differences in symptom-free rates when comparing FRR with FRR plus PLASTY."[30]
Karaolanis et al[31]	• "Studies reporting on spontaneous thrombosis or thrombosis after strenuous activities of axillary subclavian vein were analyzed according to PRISMA • Pooled proportions with 95% CIs of outcome rates were calculated"[31]	• "Focus on the safety and efficacy of thrombolysis or anticoagulation with decompression therapy. • Detailed description of epidemiological, etiological, and clinical characteristics, along with radiological findings and treatment option details"[31]	• 1.177 (77.9%) had thrombolysis, 658 (43.5%) had anticoagulation, and 1293 (85.6%) patients had decompression therapy of the thoracic outlet in 25 studies with n = 1.511 patients • "78.11% of patients had estimated complete thrombus resolution after thrombolysis; 23.72% were estimated to have partial thrombus resolution • Despite thrombolytic therapy, 212 patients underwent additional balloon angioplasty for residual stenosis while only 36 stents were implanted. • 40.70% of patients had complete thrombus resolution after anticoagulation; partial resolution was present in 29.13% of patients. • During follow-up, a total of 51.75% of the patients with any initial treatment modality had no remaining thrombus, while 84.87% of these patients were free of symptoms. • A subgroup meta-analysis with 20 studies and 1309 patients showed significantly improved vein patency and symptom resolution in patients who had first rib resection with or without venoplasty, comparing with those who had only thrombolysis"[31]

AA, axillary arch; CR, cervical rib; DVT, deep venous thrombosis; FRR, first rib resection; FRR plus PLASTY, first rib resection plus endovenous balloon venoplasty; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses; USG, ultrasonography.
A literature review revealed 10 articles for "thoracic outlet syndrome" and "meta-analysis." Six studies were reviewed in this table because the other 3 were related to aneurysms, whiplash disorders, "shoulder neck-syndrome," or upper extremity thrombosis independent from the thoracic outlet.

have implications on therapy, and we, therefore, propose a subclassification. In general, it should be considered whether pain (local or in the distribution of a nerve/root), motor deficits (weakness, hypotrophy, or atrophy of muscles), and/or sensory symptoms (hypesthesia, dysesthesia) are present and whether there is a dependence on patient/upper extremity positioning which, eg, includes the Adson test and Roos test that are described and discussed in more detail below. Owing to the heterogeneity of symptoms, functional deficits, individual anatomy, and pathophysiology, we believe a new nTOS subclassification may help guide treatment decisions and differentiation of inclusion criteria in future clinical trials.

Hypotrophic nTOS (*nTOS 1*) applies to patients presenting with weakness, hypotrophy or atrophy of upper extremity muscles (usually predominant in more distal muscles). There might be differences ranging

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Consensus Statements:

Anatomy

- *Thoracic outlet syndrome may be caused by compression of the brachial plexus, and/or a., and/or v. subclavia within three possible anatomical spaces, such as the interscalene triangle, costoclavicular space, and pectoralis minor space (I)*
- *The interscalene triangle is considered the most frequent site of entrapment of the above-mentioned neurovascular structures, mainly due to fibrous, muscular, or bony abnormalities (II)*

Classification

- *Classification in arterial or venous and subclassification of neurogenic TOS may be recommended (III)*
- *Neurogenic TOS is considered the most frequent entity, possibly with vascular co-pathology (IV)*
- *Clinical symptoms that lead to classification need to be documented (V)*
- *Subclassification into nTOS 1 to 3 may be helpful to guide the therapeutic management (VI)*

Diagnosis and Diagnostics

- *Diagnostic workup includes medical history, clinical presentation, examination, and machine diagnostics (VII)*
- *Clinical examinations may include provocation tests, such as Roos' test (EAST) and traction (ULTT) test. However, these tests have to be interpreted with caution due to a high rate of false positives (VIII)*
- *Tinel's sign may be considered an important hint for localization of the entrapment site (IX)*
- *Permanent arm swelling and pain demands further diagnostics, including the thrombophilic state, to rule out venous TOS (Paget-von-Schroetter-syndrome) (X)*
- *Special attention to symptoms of arterial TOS (aTOS) may be recommended, such as cold fingers, bluish or pale color of the hand, single fingers or fingertips, weak or no pulse as well as arm fatigue with activity (XI)*
- *Magnetic resonance imaging (MRI) of the brachial plexus may be recommended (XII)*
- *MRI of the cervical spine may be recommended (XIII)*
- *Imaging of the bony conditions of the thoracic outlet may be recommended (X-ray or computed tomography [CT]) (XIV)*
- *When vascular (co-) pathology is assumed based on patient history and clinical examination, vascular imaging may be recommended (ultrasound and/or angiogram) (XV)*
- *Diagnostic workup may include electrophysiological examination at the affected arm to rule out other nerve entrapment syndromes (XVI)*
- *Sensory nerve action potential (SNAP) of the medial antebrachial cutaneous nerve may be useful (XVII)*
- *High-resolution ultrasound of the brachial plexus, especially in provocative positions, may be useful (XVIII)*

FIGURE 2. *Consensus statements of the European Association of Neurosurgical Societies section of peripheral nerve surgery on anatomy, classification, and diagnosis and diagnostics. EAST, elevated arm stress test; nTOS, neurogenic thoracic outlet syndrome; TOS, thoracic outlet syndrome; ULTT, upper limb tension test.*

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TABLE 5. Provocative Maneuvers Used for Clinical Evaluation of Patients With TOS

"SCP" test	Pain on deep supraclavicular palpation of the plexal elements in the triangle between sternocleidomastoid muscle medial and clavicula below compared with the asymptomatic side
"EAST" by Roos	Patients hold both arms in 90° abduction-external rotation with shoulders and elbows in the frontal plane of the chest; hands are opened and closed for 3 min which may provoke symptoms
ULTT	Head rotation away from the side that is being tested, arm elevation in elbow flexion, and wrist extension
CCM	Both shoulders are pulled downward and backward for 30 s
"Adson test"	30° arm abduction and extension and palpation of radial pulse which may weaken or disappear when the neck is extended and turned toward the symptomatic side

CCM, costoclavicular maneuver; EAST, elevated arm stress test; SCP, supraclavicular pressure; ULTT, upper limb tension test.

from selective thenar wasting, as described by Wilson in 1913, to the full picture of a "Gilliat Sumner hand."[52,53]

Irritative nTOS with anatomic abnormality (*nTOS 2*) applies to patients without motor symptoms but with predominant pain and/or sensory symptoms that coincide with anatomic abnormalities (fibrous, muscular, or bony).

Irritative nTOS without anatomic abnormality (*nTOS 3*) applies to patients without motor symptoms but with predominant pain and/or sensory symptoms without classic anatomic abnormalities. Depending on symptom distribution, a further differentiation can be made in *radicular* (*nTOS 3a*), *cervicoscapular* (*nTOS 3b*), or *diffuse* (*nTOS 3c*).

It has to be taken into account that nTOS 2 and nTOS 3 may evolve to nTOS 1 and that the categories nTOS 3b and nTOS 3c may be similar to the old term "disputed TOS." Discovery of anatomic abnormality may depend on the modality of diagnostics and may not be apparent until surgical exposure.

Figure 2 depicts consensus statements on classification (statement III-VI).

Diagnosis and Diagnostics

Diagnostic workup includes the patient's medical history with particular attention to any history of trauma to the thoracic outlet. The intensity and duration of symptoms should be documented together with the impact on daily living and if they are position-dependent or permanent. Arm swelling and pain raise suspicion of vTOS (Paget-von-Schroetter-syndrome). Symptoms of arterial TOS may include cold fingers, bluish or pale color of the hand, single fingers or fingertips, weak or no pulse, arm fatigue with activity, and throbbing forms of pain. A neurological examination with a thorough evaluation of motor, sensory and autonomic functions, identification of signs of atrophy is required together with its proper documentation.[41-43] In this regard, the so-called Gilliat Sumner hand deserves particular attention because its typical presentation is almost pathognomonic.[53] Yet, its existence is not uniformly appreciated in the vascular or neurosurgical communities. The Tinel sign at the interscalene or costoclavicular space may be present. Loss of radial artery pulse may be present; however, its diagnostic value is limited because it is a relatively frequent finding in asymptomatic persons.[17,54] Positional provocative maneuvers are described in Table 5. The diagnostic significance of the supraclavicular pressure test accompanied by a positive Hoffman–Tinel sign radiating along a C8/T1 distribution is rated higher among plexus and nerve surgeons compared with other provocative maneuvers. However, this is not yet evidence-based. Positional provocative maneuvers have a sensitivity and specificity of 72% and 53%, respectively.[55] False-positive results were described as 45% for the "Adson test," 48% for the "costoclavicular maneuver," 77% for the "elevated arm stress test," and 61% for the "supraclavicular pressure test."[17,54]

Specific imaging is recommended when TOS is suspected (see for guidelines Table 2). A radiogram of the thoracic outlet is recommended to diagnose bony anomalies in all suspected TOS forms. An MRI of the brachial plexus is recommended in case nTOS is suspected.[56] For vTOS, an ultrasound duplex of the subclavian artery and vein or a computer tomography of the chest with contrast or catheter venography is advised. In case of suspected aTOS, a thoracic computed tomography angiogram, a thoracic magnetic resonance angiogram without and with intravenous contrast, ultrasound duplex Doppler of subclavian artery and vein, or arteriography of the upper extremity are considered equivalent alternatives.[18,20] Most neurosurgeons additionally perform MRI of the cervical spine to rule out the nerve root or other spinal pathologies.[57,58] This is especially important in TOS without anatomic abnormality (nTOS 3) cases. High-resolution neurosonography of the brachial plexus including examination in provocative postures can be easily combined with duplex of subclavian artery and vein. It also allows for direct visualization of nerves, the compression site ("sickle sign"), a possible compressive pathology, and individual anatomy.[59-62]

Electrophysiological studies need to be interpreted in the context of clinical findings. Still, they may help to diagnose TOS and rule out potential differential diagnoses such as carpal tunnel or cubital tunnel syndromes.[58] For nTOS, the sensory nerve action potential of the medial cutaneous antebrachial nerve was found to be useful.[63]

Symptom improvement after injection of BTX, steroids, or local anesthetics is considered a possible diagnostic criterium by some clinicians and may serve as a positive predictor for symptom relief after surgical therapy in some cases.[13,15]

However, the low sensitivity and specificity of provocative maneuvers and some limitations of imaging in the visualization of fibrous bands or hypertrophic muscles make diagnosis of TOS and classification a tremendous challenge. Further improvement of patient examination strategies and imaging is needed.

Consensus statements on diagnosis and diagnostics are presented in Figure 2 (statement VII-XVIII).

Epilogue and Limitations

The mean agreement rate was 98.4 % (±3.0, range 92.9%-100%), representing an overall high rate of agreement within the EANS section of peripheral nerve surgery regarding anatomy, diagnosis, and classification of TOS (Table 6). The main limitation of this article is that it does not represent a classic guideline as interdisciplinarity, and level 1 evidence is lacking. Furthermore, the number of TOS cases operated by each surgeon

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TABLE 6. Experience of TOS Neurosurgeons and Agreements, Disagreements, and Refinements to the 18 Statements of the Questionnaire

Surgeon	Years	Cases	TOS type	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
#1	7	30	nTOS and vTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#2	9	30	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#3	32	70	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#4	21	250	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#5	33	290	nTOS and vTOS	a	a	a	a	a	**r**	a	**d**	a	a	a	a	a	a	a	a	a	**d**
#6	7	40	nTOS and aTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#7	7	30	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#8	27	300	nTOS	a	a	a	a	a	a	a	**r**	a	a	a	**r**	**r**	a	a	a	**d**	a
#9	27	500	nTOS, vTOS, and aTOS	a	a	a	a	a	**r**	a	a	a	a	a	**r**	**r**	a	a	a	a	a
#10	11	300	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#11	7	30	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#12	25	30	nTOS, vTOS, and aTOS	a	a	a	**d**	a	a	a	a	a	a	a	**r**	**r**	a	a	a	a	a
#13	20	200	nTOS and aTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
#14	36	700	nTOS	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Agreement (in %)				100.0	100.0	100.0	92.9	100.0	100.0	100.0	92.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.9	92.9

aTOS, arterial thoracic outlet syndrome; nTOS, neurogenic thoracic outlet syndrome; vTOS, venous thoracic outlet syndrome; a, aggrement; d, disaggrement; r, refinement

Coloumn 4 refers to the type of TOS treated by the individual surgeon. Refinements: surgeon **#5**, statement VIII: "I do not think there is a high rate of false-positive tests when performed in patients with correct clinical history and symptoms"; VI: "indication may be different for the various TOS types but therapeutic management may be performed the same way with attention to the lower roots and the subclavian artery. Patient enrollment and anticipation of a satisfactory result can differ between the different TOS types"; statement XVIII: "confirmation of compression may help; however, a normal ultrasound at provocative maneuvers would not discourage me from doing surgery if the other factors are convincing"; surgeon **#8**, statement XII and XIII: "imaging MRI of the cervical spine and of the brachial plexus should be mandatory for each case of TOS before indication for surgery is given"; surgeon **#9,** statement VI: "XII and XIII: "for me, both MRI of brachial plexus and cervical spine are recommended, 'may be' should be 'is recommended'" ;surgeon **#12**, statement XII and XIII: "Use 'should' instead of 'may' to emphasize the importance as a diagnostic workhorse in TOS."

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may be imprecise because of underlying long time frames of up to 36 years of practice.

CONCLUSION

We conducted a systematic review of the existing body of intermediate-quality to high-quality evidence regarding the diagnosis, classification, and treatment of TOS. Consensus statements on anatomy, diagnosis, and classification of TOS were reached by experts of the EANS peripheral nerve surgery section. We are planning to publish a separate consensus article on the treatment of TOS. Our work may serve as a basis for future interdisciplinary exchange and guideline development.

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Supplementary Material. Questionnaires that were sent to the EANS peripheral nerve section experts.

COMMENT

The section of peripheral nerve surgery of the European Association of Neurosurgical Societies presented a systematic review and consensus statements on the anatomy, diagnosis, and classification of thoracic outlet syndrome (TOS). Of all the conditions treated by peripheral nerve surgeons, TOS is arguably one of the most controversial and least clearly defined. It does not help that other specialists such as vascular and orthopedic surgeons also manage this condition, lending their perspective to the already confusing pathology. The authors should be congratulated for instituting some order in the hodgepodge of material related to this condition by performing a systematic review of relatively high-quality data and by crafting consensus statements that are informed by evidence and years of clinical and surgical experience. This comprehensive paper can serve as a guide in diagnosing and classifying TOS, and I look forward to the authors' future work on the treatment of TOS.

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