Review Article

Thoracic outlet syndrome: which surgical approach?

Fabio Davoli[1], Guido Staffa[2], Angelo Paolo Ciarrocchi[3], Franco Stella[1]

[1]Department of Thoracic Surgery, AUSL Romagna, S. Maria delle Croci Teaching Hospital of Ravenna, Ravenna, Italy; [2]Peripheral Nervous Surgery Unit, AUSL Romagna, Infermi Hospital of Faenza, Faenza, Italy; [3]Department of Thoracic Surgery, AUSL Romagna, School of Specialization in Thoracic Surgery, University of Bologna, Bologna, Italy

Contributions: (I) Conception and design: F Davoli; (II) Administrative support: F Stella; (III) Provision of study materials or patients: G Staffa; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors. (VII) Final approval of manuscript: All authors.

Correspondence to: Fabio Davoli, MD, PhD. Thoracic Surgeon at S. Maria delle Croci Teaching Hospital of Ravenna - AUSL Romagna, Viale Vincenzo Randi, n.5 48100 – Ravenna, Italy. Email: fabio.davoli78@gmail.com.

Abstract: Thoracic outlet syndrome (TOS) is a collection of different symptoms and disorders that affect the shoulder and upper extremity area, resulting from the compression of the neurovascular structures at the superior aperture of the thorax. The diagnosis of TOS, which includes a physical examination and clinical tests is often difficult. Indications for surgical treatment are debated and often reserved for cases which involve the failure of conservative management. The most common surgical approaches are the supraclavicular and transaxillary while minimally invasive approaches are gaining popularity. This manuscript will discuss the different approaches to the surgical treatment of TOS described over the past 50 years of surgery, focusing on the supraclavicular and the transaxillary approaches. Both techniques offer good results in expert hands; however, the key to success in TOS surgery remains proper patient selection. By a supraclavicular approach it is possible to achieve an accurate diagnosis and an adequate treatment. It is safe and provides an excellent exposure of the neurovascular structures.

Keywords: Neurogenic thoracic outlet syndrome; subclavian vein; subclavian artery; thoracic outlet syndrome (TOS); supraclavicular approach

Received: 10 February 2020; Accepted: 16 March 2020; Published: 25 February 2021.
doi: 10.21037/ccts.2020.03.05
View this article at: http://dx.doi.org/10.21037/ccts.2020.03.05

Introduction

Thoracic outlet syndrome (TOS) includes a wide spectrum of clinical conditions and disorders that result from the compression of the neurovascular structures that serve the upper extremity namely the brachial plexus (neurogenic TOS), the subclavian vein (venous TOS), and the subclavian artery (arterial TOS). In some cases, neurogenic and vascular TOS may occur simultaneously.

The thoracic outlet is an anatomical district in the lower neck found between the clavicle and the first rib through which several important neurovascular structures pass. TOS aetiology is comprised of three areas of potential conflict and compression: the inter-scalene triangle, the costoclavicular space and the subcoracoid space.

Neurogenic TOS (nTOS) is the most common type, consisting of more than 90% of cases in two large studies (1,2) and results from the compression of the C5 through T1 brachial plexus nerve roots. Venous TOS (vTOS), also referred to as Paget–von Schroetter syndrome, comprises 10–15% of cases (3), and is caused by subclavian vein compression within the costoclavicular space. Arterial TOS (aTOS) is by far the rarest form, occurring in 2–5% of TOS cases (3) and is often due to the presence of an anomalous first rib causing compression of the scalene triangle.

Symptoms may range from pain (of the chest wall, axilla, shoulders and neck), numbness, paresthesias, weakness and vasomotor changes of the upper limbs.

Academic classification is based on the pathophysiology of symptoms but any subgroup (nTOS, vTOS and aTOS)

can include either congenital, traumatic or functional acquired causes (4).

Congenital aetiologies are related to anatomical abnormalities, like the presence of a cervical rib (an extra rib which arises from the seventh cervical vertebra) or an anomaly of the first rib such as anomalous first ribs and rudimentary first ribs, and are more often treated surgically. Traumatic causes include post-traumatic fibrosis, joint instability and callus bone or exostosis. Functional acquired causes are due to repetitive activity, work or exercise, which may exacerbate a predisposing anatomical condition.

Diagnosis of TOS is essentially made by a careful physical examination of the shoulder, upper extremity as well as the cervical spine. Electrodiagnostic testing and imaging studies should be performed when further testing is needed in cases where the physical exam and the suspected type of TOS are suggestive. The diagnosis of nTOS is often one of exclusion while that of vTOS is confirmed by demonstrating the stenosis or occlusion of subclavian vessels.

Conservative management is often the initial treatment of choice for nTOS and in the majority of cases it produces satisfactory results. It consists of patient education, TOS-specific rehabilitation, and pharmacologic therapies. Despite this, a general consensus on the best protocols for a focused physical therapy and rehabilitation does not exist. Persistant pain with daily activity refractory to conservative treatment requires surgery for nTOS, while the first-line therapy for aTOS and vTOS is usually surgery. Several techniques have been described for the treatment of TOS, from the posterior to the anterior approaches. Recent developments have allowed video-assisted and robot-assisted surgical approaches to resect the first rib (5-9) with promising results; however, further studies are needed to analyse the long-term outcomes.

Indications for surgery

The diagnosis of TOS is a controversial subject due to the lack of a gold standard diagnostic test. Physical examination and provocative manoeuvres play a central role in the initial diagnosis of TOS, while imaging techniques such as duplex ultrasound and, if needed, angiography or electrodiagnostic testing are commonly used to confirm the initial diagnosis and to prepare a surgical approach. A small percentage of patients with a diagnosis of TOS eventually undergo surgical treatment. About 50% of patients experience relief from physical rehabilitation, while the remaining patients prefer to live with chronic pain.

The indications for the surgical treatment of TOS are multiple but can be summarised as follows: a neurological deficit due to compression of the brachial plexus caused by anatomical abnormalities; refractory and intractable pain to any conservative measures with a good response to muscular block, as well as severe limitation in daily activities and a decrease in quality of life; potential vascular damage in case of aTOS and/or failure of a supervised physical therapy program. Every patient with nTOS should first undergo a supervised rehabilitation program. The duration of physical rehabilitation before considering surgery is a controversial topic, however surgery should be considered after at least 6 months of rehabilitation.

According to Sanders *et al.* and Hempel *et al.* nTOS accounts for approximately 90% of TOS cases which undergo surgery (1,2). In this scenario the most frequent indication is the removal or the correction of an anatomical abnormality. Computed tomography (CT) and/or Angio-CT Scan with 3D reconstruction is mandatory to decide on the surgical strategy and to correctly determine the features of a cervical rib or a dysmorphic first rib. A cervical rib is an extra rib which arises from the seventh cervical vertebra. It is estimated to occur in 1% to 2% of the population (10) (*Figure 1A*,*B*). Costal dysmorphia consists of a wide spectrum of anomalies and a dysmorphic first rib could present with cartilaginous malformations (*Figure 2A*,*B*) and/or asymmetry or bone bridges between the first and the second rib that might be fused in some cases.

The most common anatomical abnormalities in TOS which are potentially suitable for surgical correction are the presence of a cervical rib; a large C7 transverse process; a dysmorphic first rib; the presence of a fibrous band; muscular abnormalities like a double scalene anterior muscle, a "U" shaped anterior scalene muscle and an "ancient" scalene muscle; and finally, vascular abnormalities such as an anomalous course or the presence of angiosomes.

The goal of nTOS surgery is the decompression of the brachial plexus. This can be achieved by the resection of the first rib. However, TOS surgery involves more than just a first rib resection. It is essential to restore the original tenderness and elasticity of the plexus (a "soft brachial plexus") by performing an adequate neurolysis and arteriolysis, to remove fibrous tissue and all anatomical abnormalities and if need be to perform a scalenotomy.

Vascular TOS requires a multidisciplinary team of vascular and thoracic surgeons assisting a neurosurgery team.

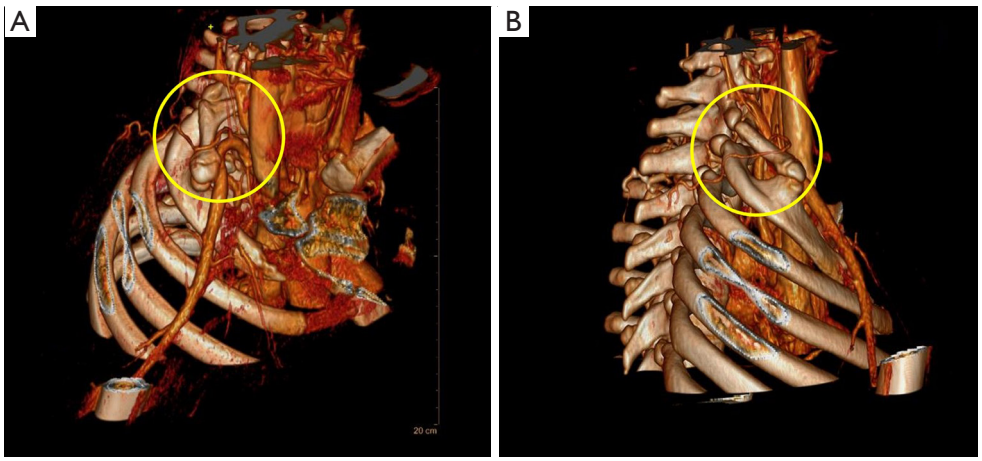

Figure 1 Computed tomography chest scan 3D reconstruction showing the presence of a cervical rib. (A) Sagittal view; (B) lateral view.

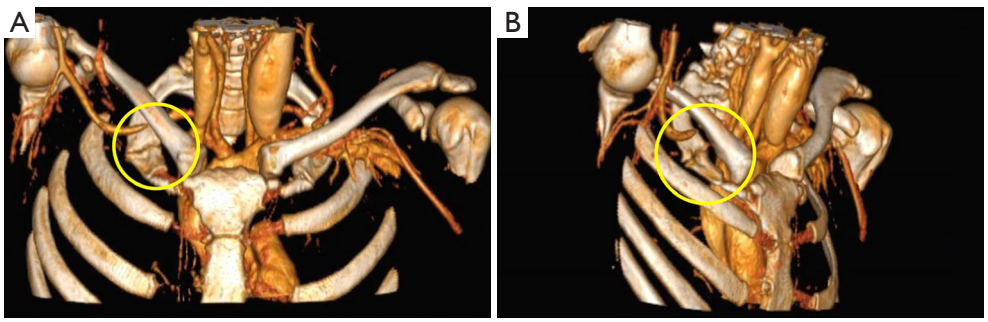

Figure 2 Computed tomography chest scan 3D reconstruction showing the features of a dysmorphic first rib with subclavian vein stenosis. (A) Sagittal view; (B) frontal view.

Surgical techniques and approaches

The aim of the surgical treatment of TOS is the decompression of the neurovascular structures involved. The classic surgical approaches for the treatment of TOS include the supraclavicular and infraclavicular approaches (which can be combined in rare case), the trans-axillary approach and the posterior approach (rarely performed nowadays).

With the development of minimally invasive techniques novel approaches have been described such as the video-assisted-thoracic-surgery (VATS) first rib resection, the robotic/VATS assisted approach (5-9).

No report exists demonstrating the superiority of one approach over another, however the largest series report a 90% success rate with the transaxillary first rib resection which according to them standard surgical procedure (11,12). Similar results have been reported in the literature without first rib resection (13,14). The key to the surgical success of TOS remains the patient selection, the choice of the right indication and a deep knowledge of the anatomy of the thoracic outlet.

Supraclavicular approach

The supraclavicular approach is the most common surgical approach for first rib resection followed by the trans-axillary approach. It enables an accurate evaluation of the thoracic outlet and a safe identification and release of all abnormal anatomical structures that may lead to TOS. According to the basic principles of the surgical treatment of TOS, the supraclavicular approach allows an accurate intra-operative diagnosis with the removal of all the anomalies, including complete first rib resection. The risk of damaging neurovascular structures is minimal and it allows an excellent visualization of the entire plexus.

The patient is placed in a supine position with a big

roll under the cervical and thoracic spine and the head is turned in the opposite direction to the side being treated. There is uncertainty concerning the need for double lumen ventilation, which can be avoided to minimize comorbidities. In case of an accidental opening of the parietal pleura, a chest tube should be inserted.

The entire thoracic outlet structures are well exposed through an s-shaped supraclavicular incision of 5–7 cm; these structures include the subclavian artery, the first rib, the brachial plexus and the scalene muscles. The first step is identification of the supraclavicular nerve, followed by the division of the lateral portion of the sternocleidomastoid muscle. The phrenic nerve and the subclavian artery are noted, and the anterior scalene muscle is divided. The brachial plexus is then mobilized and the middle scalene muscle divided which reveals the lower trunk of the brachial plexus and the congenital bands and thickenings in the suprapleural membrane. The first rib is then divided and removed along with its soft tissue attachments. By this approach one can easily release the brachial plexus, remove fibrotic bands (*Figure 3*), resect the first rib or a cervical rib (*Figure 4A,B*), perform arteriolysis and neurolysis as well as a scalenotomy (*Figure 5A,B*). On the contrary the subclavian vein is poorly exposed, for that reason a combined supraclavicular-infraclavicular approach is advocated in the case of vTOS or accidental damage of the subclavian vein. The complications associated with this procedure are pneumothorax, accidental phrenic nerve lesions and pleural effusion. Results are generally positive with a complete resolution of symptoms in 63.9% to 84% of cases reported in a series by Maxey *et al.* and Terzis *et al.* (3,15).

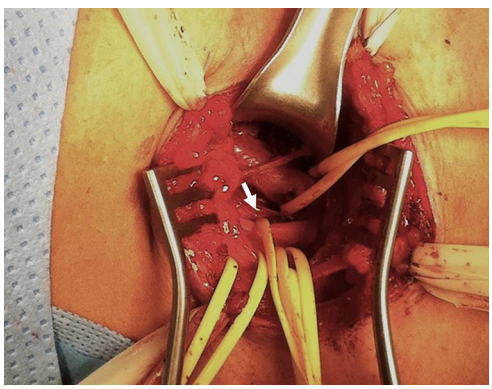

Figure 3 Supraclavicular approach for neurogenic TOS: intra-operative view with a fibrous band (row). TOS, thoracic outlet syndrome.

Despite a worse cosmetic result, we advocate the use of the supraclavicular approach over the trans-axillary one as it is safe and provides the best access to treat the neurovascular structures.

Infraclavicular approach

The infraclavicular approach is rarely the first choice in

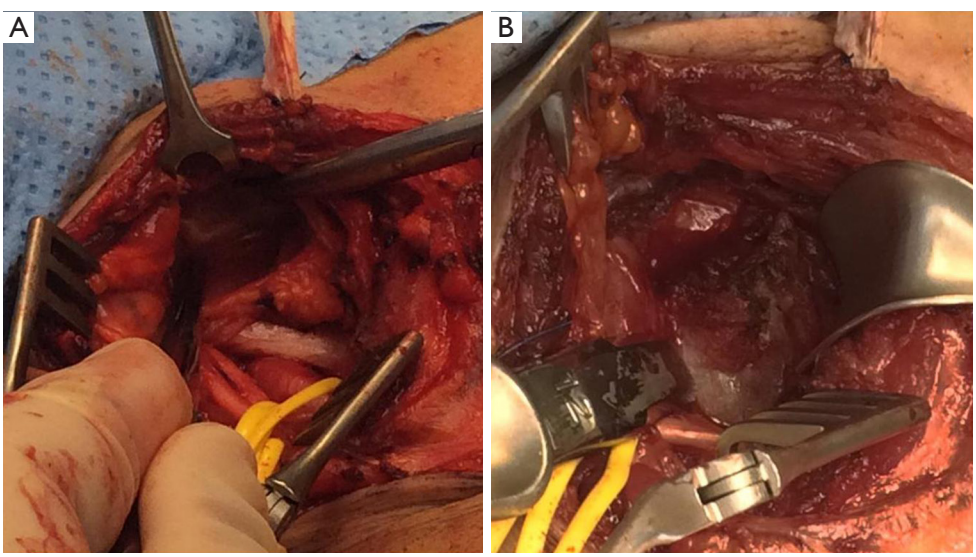

Figure 4 Supraclavicular approach for neurogenic TOS: intra-operative view with a cervical rib before (A) and after (B) its removal. TOS, thoracic outlet syndrome.

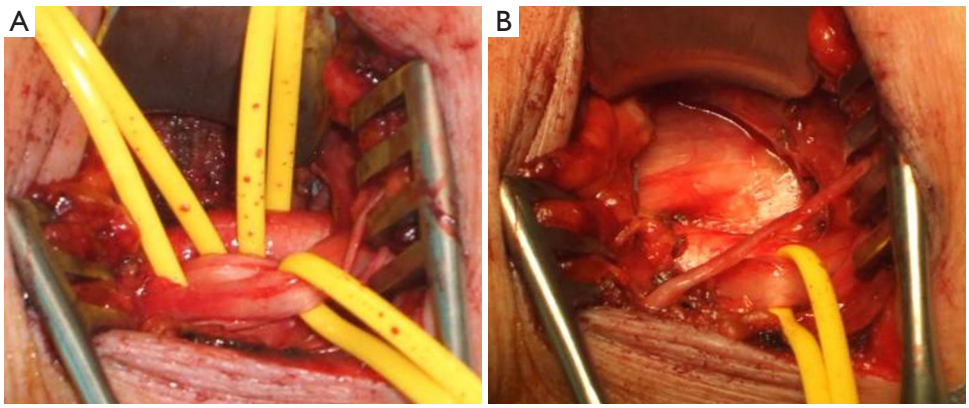

Figure 5 Supraclavicular approach for neurogenic TOS: intra-operative view with an anatomic abnormality of a "U" shaped scalene muscle, before (A) and after (B) the scalenotomy. TOS, thoracic outlet syndrome.

the treatment of TOS. It can be used alone or combined with the supraclavicular approach if access to the distal subclavian vessels is needed.

It is the approach of choice in plexus lesions distal to the clavicle, the treatment of post-traumatic TOS (stretch/contusions, gunshot wounds, lacerations, iatrogenic injuries including puncturing during blocks), in the treatment of tumours of the brachial plexus elements (schwannomas, neurofibromas and malignant nerve sheath tumours) and in the entrapment of brachial plexus elements (16). A transverse incision is made 2 cm the clavicle from the medial part of the clavicle to the manubrium sterni. The pectoral major muscle is divided revealing the subclavius muscle and the subclavian vein. The subclavius muscle is divided, the subclavian vein is mobilised and the first rib edges are mobilised. The phrenic nerve is isolated and retracted medially prior to division of the anterior scalene muscle insertion. The first rib can be resected using an angled rib cutter, allowing excellent exposure of the subclavian vein and the subclavian artery.

Trans-axillary approach

The trans-axillary approach is the second most common approach. It was first described by Roos in 1966 (17) and, since then, has spread rapidly. The original technique requires that the patient is placed in a 45-degree posterolateral position with the arm elevated. In this position, the third rib lies subcutaneously in the axillary fossa, and the first rib is only two intercostal spaces deeper with no intervening muscles or vital structures. An incision is made between the latissimus dorsi and the pectoralis major muscles and the intercostobrachial cutaneous nerve is retracted. The incision is extended to the third rib and dissection is then performed upward toward the first rib. The brachial plexus, subclavian artery, scalenus anterior muscle, and the subclavian vein are visualized. The scalenus anterior and medius muscles are then dissected. The first rib is then divided and removed, and if a cervical rib is present the same is done for that rib. The cosmetic result is excellent, with a 2.5- to 4-inch incision, however complications like superficial and deep infections, pneumothorax, vascular injuries, lymphatic duct injuries and neural injuries may occur.

The recurrence rate is higher than that of the other approaches even when performed by experienced surgeons. The deep exposure makes a comprehensive release of the brachial plexus hazardous or impossible (18). In the series reporting the results of the trans-axillary approach the success rate is given at around 80% (19,20). Considering the prevalence of female patients in TOS, this approach has a significant cosmetic advantage.

Posterior approach

The suprascapular posterior approach to the brachial plexus was first described by Simon and Estander for the surgical treatment of tuberculosis in the early 19th century (21). Claggett was the first to use this approach for the treatment of TOS by resection of the first rib (22). Kline popularised this approach and used it for more than 25 years (23).

However, this approach has gradually been phased out due to its invasiveness and extensive muscle dissection. Today it finds limited use in patients with previous neck

surgery and obesity. Common indications include nTOS associated with a large C7 transverse process or a cervical rib, post-traumatic injuries of the spinal nerves and tumors. It allows excellent exposure of the C7, C8 and T1 spinal nerves, however 5% of surgeries are complicated by scapular winging and require an extensive rehabilitation programme (23).

VATS and robotic assisted first rib resection

With the development of minimally invasive techniques, the opportunity to treat TOS in this way has arisen. Initially a VATS-assisted trans-axillary resection was proposed, then from the late 90s onwards some authors started to report the resection of the first rib by an intrathoracic approach. Ohtsuka and colleagues succeeded in removing the first rib intrathoracically using an endoscopic drill under a video-assisted thoracoscope (6). Loscertales *et al.* reported that VATS first rib resection could be performed safely as a minimally invasive procedure using a bone cutter through extended intercostal incisions (5), while others performed the procedure with an endoscopic rib cutter (8). Patients are placed in the classic lateral decubitus position for a VATS procedure after induction of general anesthesia and are intubated with a double-lumen tube. A total of three thoracic ports are generally used for the operation, one of them may be enlarged for the rib cutting, depending on the technique. Excellent visualization of the thoracic outlet is the main advantage of the thoracoscopic approach. In addition to the obvious advantages of a better cosmetic result, reduced post-operative pain and a shorter hospital stay, the bone and the vascular structures are easily seen, in particular the entire first rib. It is ideal for obese people or muscular patients, however it is absolutely contraindicated in cases of previous subclavian vascular surgery. An interesting series of eight patients reported by Hwang in 2017 demonstrated the safety of the VATS approach in the absence of post-operative mortality and significant blood loss (7). Despite this the VATS approach has several limitations (8). Firstly, a scalenotomy is not possible and secondly an unexpected bleeding during a VATS approach might be catastrophic. A modified technique described by George and Colleagues in 2017 may minimize the intraoperative risks.

Robotic first rib resection was described by Strother in 2015 (9). It is a complex hybrid procedure consisting of a combined RATS/VATS procedure. Similarly to the pure VATS assisted approach, the only therapeutic goal is the removal of the first rib; the authors started with a four-arm robotic dissection, followed by a VATS division of the first rib; at the end the robot is re-introduced to complete the procedure.

Discussion

The surgical treatment of TOS is still a subject of debate. No surgical approach has been demonstrated to be superior over another, however some basic indications are fundamental to achieve success after surgery and to minimize the risk of recurrence.

Patient selection is fundamental as well as the correct indications in case of nTOS and aTOS. TOS due to anatomical anomalies are the simplest cases to evaluate for surgery. These patients can be considered as having a true TOS, while the remainder are a great number of patients without radiological nor electrophysiological signs of nerve irritation (24-26).

The treatment of TOS must include a multidisciplinary team: neurosurgeons, thoracic surgeons, vascular surgeons, physiotherapists, orthopaedic surgeons, neurologists and even psychologists are all potentially involved in the management of a patient affected by TOS.

The choice of the best surgical approach is largely dependent on the experience of the surgical team. On the other hand, the timing of the surgery is dependent on the type of TOS and the level of limitation of daily activities experienced by the patient. TOS patients are seldomly directly referred to the operating room without having first undergone rehabilitation. On the contrary, in our experience 50% of patients ask for surgery after the failure of a supervised rehabilitation program.

A CT—Angio-CT scan is fundamental in planning the surgical strategy: it accurately detects the presence or absence of anatomical anomalies (a dysmorphic first rib, abnormal C7 process and the presence or not of a cervical rib) and their relationship with the subclavian vessels. In more complex cases static and dynamic angiography can be used if needed.

Once the surgical strategy has been determined, it is important to assemble the most suitable multidisciplinary team for the treatment. In general, the neurosurgical team is enough for nTOS, but in the case of aTOS, the presence of a vascular surgeon and/or a thoracic surgeon is mandatory. Liberating the subclavian vessels might be insidious even in the case of a supraclavicular approach.

The trans-axillary approach is the most widely

Table 1 Comparison of supraclavicular and trans-axillary approaches for the treatment of thoracic outlet syndrome

Author	n	Year/ country	Pathology	Mean age	Surgical approach	Scalenectomy	Complications	Persistent symptoms	Recurrence	Mean LOS
Maxey	67	2003/ USA	nTOS: 59; vTOS: 10; aTOS: 3	36.7 years	SC: 64 (95.5%); SC+ IC: 3 (4.5%)	Not performed	Pneumothorax: 2 (2.9%); hematoma: 2 (2.9%); phrenic nerve palsy: 1 (1.5%); brachial plexus injury: 1 (1.5%)	26 (38.8%)	ND	ND
Chang	70	2009/ USA	nTOS: 44; vTOS: 26	ND	TA: All	All	Pneumothorax: 11 (16%); woudn infection: 2 (2.8%); Ematoma: 1 (1.4%)	nTOS: 9; vTOS: 5; total: 14 (20%)	nTOS: 8; vTOS: 1; total: 9 (12,8%)	ND
Tersiz	12	2010/ USA	nTOS	36.9 years	SC: All	All	None	ND	1 (8.3%)	ND
Ciampi	50	2011/ Italy	nTOS	29 years	SC alone: 45 (90%); SC + IC: 5 (10%)	15 (30%)	Pneumothorax: 1 (2%); neuroproaxia: 1 (2%)	ND	1 (2%)	4 days
Caputo	189	2013/ USA	nTOS	35.8 years	SC: 168 (88.9%); SC + IC: 21 (11.1%)	Not performed	Bleeding/hematoma: 1 (0.6%); lymph leak: 5 (3.2%); wound infection: 2 (0.6%)	ND	ND	4.8 days
Hosseinian	102	2017/ Iran	aTOS: 1; vTOS: 3; nTOS: 98	34.5 years	SC: 63 (61.7%); TA: 32 (31.4%); SC+TA: 7 (6.9%)	All	Pneumothorax: 25 (39.7%) SC, 11 (34.4%) TA; Hemo+pneumothorax: 3 (4.7%) SC, 2 (6.2%) TA; Vascular: 2 (3.2%) SC; Neck causalgia: 2 (6.2%) SC, 8 (25%) TA	ND	TA: 7 (6.8%)	ND

TOS, thoracic outlet syndrome; SC, supraclavicular; TA, transaxillary; IC, infraclavicular; LOS, length of stay; ND, not declared.

used method for decompression of the thoracic outlet (17,25,27-33), however different authors suggest that this method alone results in a high recurrence rate (12,18,34). Hosseinian *et al.* (*Table 1*) experienced no recurrence with the supraclavicular approach, yet with the trans-axillary approach they experienced a recurrence rate of 6.8% (35). With this approach complications are frequent even when performed in experienced centers. On the other hand, despite still being advocated, the supraclavicular approach for the thoracic outlet decompression has become more and more popular over the years (2,3,36-38). This is because of the good outcomes reported and the lower rates of relapse and complications (3,15). As reported in *Table 1*, complications associated with TOS surgery in general are fairly uncommon and namely consist of pneumothorax, hemothorax, brachial plexus injury and vascular injury (3,15,35,39-41).

It is important to consider that it is difficult to compare the reported outcomes of the surgical treatment of TOS in the literature especially before the 1990s. Without specific questionnaires to assess the endpoints of treatment, the interpretation of the surgical result was left up to the surgeon or the patients themselves, with outcomes ranging from “good” to “excellent” in most cases (42). This makes a comparison between two approaches, such as the trans-axillary and supraclavicular, very difficult.

In the age of minimally invasive surgery it is natural that a subject of debate such as the surgical treatment of TOS has become a field full of innovation. To resect the first rib by a VATS or a robotic-assisted approach is feasible with acceptable risks, but we have to remember that TOS surgery consists of more than just the resection of the first rib. Moreover, the series reported in literature about VATS first rib resection are too few and the follow-up periods too short to make definitive considerations (5-9).

In conclusion, in our experience, the supraclavicular exploration of the brachial plexus enables a more careful evaluation of the thoracic outlet and a safe identification of all abnormal anatomical structures to be removed. By a supraclavicular approach it is possible to achieve an accurate diagnosis and an adequate treatment at the same time. It is safe and provides an excellent exposure of neurovascular structures. Indications for surgery play a central role in the treatment of TOS and an expert multidisciplinary team can discern between operating and conservative treatment.

Acknowledgments

Funding: None.

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://ccts.amegroups.com/article/view/10.21037/ccts.2020.03.05/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Sanders RJ, Hammond SL, Rao NM. Thoracic outlet syndrome: a review. Neurologist 2008;14:365-73.
2. Hempel GK, Shutze WP, Anderson JF, et al. 770 consecutive supraclavicular first rib resections for thoracic outlet syndrome. Ann Vasc Surg 1996;10:456-63.
3. Maxey TS, Reece TB, Ellman PI, et al. Safety and efficacy of the supraclavicular approach to thoracic outlet decompression. Ann Thorac Surg 2003;76:396-9.
4. Citisli V. Assessment of diagnosis and treatment of thoracic outlet syndrome, an important reason of pain in upper extremity, based on literature. J Pain Relief 2015;04:1-7.
5. Loscertales J, Congregado M, Jiménez Merchán R. First rib resection using videothoracoscopy for the treatment of thoracic outlet syndrome. Arch Bronconeumol 2011;47:204-7.
6. Ohtsuka T, Wolf RK, Dunsker SB. Port-access first-rib resection. Surg Endosc 1999;13:940-2.
7. Hwang J, Min BJ, Jo WM, et al. Video-assisted thoracoscopic surgery for intrathoracic first rib resection in thoracic outlet syndrome. J Thorac Dis 2017;9:2022-8.
8. George RS, Milton R, Chaudhuri N, et al. Totally Endoscopic (VATS) First Rib Resection for Thoracic Outlet Syndrome. Ann Thorac Surg 2017;103:241-5.
9. Strother E, Margolis M. Robotic First Rib Resection. Oper Tech Thorac Cardiovasc Surg 2015;20:176-88.
10. Jones MR, Prabhakar A, Viswanath O, et al. Thoracic Outlet Syndrome: A Comprehensive Review of Pathophysiology, Diagnosis, and Treatment. Pain Ther 2019;8:5-18.
11. Roos DB. The place for scalenectomy and first-rib resection in thoracic outlet syndrome. Surgery 1982;92:1077-85.
12. Urschel HC Jr, Razzuk MA. Neurovascular compression in the thoracic outlet: changing management over 50 years. Ann Surg 1998;228:609-17.
13. McCarthy MJ, Varty K, London NJ, et al. Experience of supraclavicular exploration and decompression for treatment of thoracic outlet syndrome. Ann Vasc Surg 1999;13:268-74.
14. Sanders RJ, Pearce WH. The treatment of thoracic outlet syndrome: a comparison of different operations. J Vasc Surg 1989;10:626-34.
15. Terzis JK, Kokkalis ZT. Supraclavicular Approach for Thoracic Outlet Syndrome. HAND 2010;5:326-37.
16. Tender GC, Kline DG. The infraclavicular approach to the brachial plexus. Neurosurgery 2008;62:180-4; discussion 184-5.
17. Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354-8.
18. Ambrad-Chalela E, Thomas GI, Johansen KH. Recurrent neurogenic thoracic outlet syndrome. Am J Surg 2004;187:505-10.
19. Axelrod DA, Proctor MC, Geisser ME, et al. Outcomes after surgery for thoracic outlet syndrome. J Vasc Surg 2001;33:1220-5.
20. Fulford PE, Baguneid MS, Ibrahim MR, et al. Outcome of transaxillary rib resection for thoracic outlet syndrome-a 10 year experience. Cardiovasc Surg 2001;9:620-4.
21. Hochberg LA. Thoracic Surgery before the 20th Century. New York: Vantage Press, 1960:360-402.
22. Clagett OT. Research and prosearch. J Thorac Cardiovasc Surg 1962;44:153-66.
23. Tender GC, Kline DG. Posterior subscapular approach to the brachial plexus. Neurosurgery 2005;57:377-81.
24. Huang JH, Zager EL. Thoracic outlet syndrome. Neurosurgery 2004;55:897-902.
25. Leffert RD. Thoracic outlet syndrome. J Am Acad Orthop Surg 1994;2:317-25.
26. Wilbourn AJ. Thoracic outlet syndromes. Neurol Clin 1999;17:477-97.
27. Barkhordarian S. First rib resection in thoracic outlet

syndrome. J Hand Surg Am 2007;32:565-70.
28. Degeorges R, Reynaud C, Becquemin JP. Thoracic outlet syndrome surgery: long-term functional results. Ann Vasc Surg 2004;18:558-65.
29. Han S, Yildirim E, Dural K, et al. Transaxillary approach in thoracic outlet syndrome: the importance of resection of the first-rib. Eur J Cardiothorac Surg 2003;24:428-33.
30. Leffert RD. The conundrum of thoracic outlet surgery. Tech Shoulder Elbow Surg 2002;3:262-70.
31. Leffert RD, Perlmutter GS. Thoracic outlet syndrome. Results of 282 transaxillary first rib resections. Clin Orthop Relat Res 1999;368:66-79.
32. Roos DB. Experience with first rib resection for thoracic outlet syndrome. Ann Surg 1971;173:429-42.
33. Samarasam I, Sadhu D, Agarwal S, et al. Surgical management of thoracic outlet syndrome: a 10-year experience. ANZ J Surg 2004;74:450-4.
34. Urschel HC, Kourlis H. Thoracic outlet syndrome: a 50-year experience at Baylor University Medical Center. Proc (Bayl Univ Med Cent) 2007;20:125-35.
35. Hosseinian MA, Loron AG, Soleimanifard Y. Evaluation of complications after surgical treatment of thoracic outlet syndrome. Korean J Thorac Cardiovasc Surg 2017;50:36-40.
36. Altobelli GG, Kudo T, Haas BT, et al. Thoracic outlet syndrome: pattern of clinical success after operative decompression. J Vasc Surg 2005;42:122-8.
37. Dellon AL. The results of supraclavicular brachial plexus neurolysis (without first rib resection) in management of post-traumatic "thoracic outlet syndrome". J Reconstr Microsurg 1993;9:11-7.
38. Sheth RN, Campbell JN. Surgical treatment of thoracic outlet syndrome: a randomized trial comparing two operations. J Neurosurg Spine 2005;3:355-63.
39. Chang DC, Lidor AO, Matsen SL, et al. Reported in-hospital complications following rib for neurogenic thoracic outlet syndrome. Ann Vasc Surg 2007;21:564-70.
40. 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;35:1179-86.
41. Caputo FJ, Wittenberg AM, Vemuri C, et al. Supraclavicular decompression for neurogenic thoracic outlet syndrome in adolescent and adult populations. J Vasc Surg 2013;57:149-57.
42. Burt BM. Thoracic outlet syndrome for thoracic surgeons. J Thorac Cardiovasc Surg 2018;156:1318-23.e1.

doi: 10.21037/ccts.2020.03.05
Cite this article as: Davoli F, Staffa G, Ciarrocchi AP, Stella F. Thoracic outlet syndrome: which surgical approach? Curr Chall Thorac Surg 2021;3:3.

