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A Comprehensive Review on Thoracic Outlet Syndrome for the Surgeons

Abbas Jaafar Khaleel Al-Anbari
Consultant cardiovascular and thoracic surgery, Department of Surgery, College of Medicine, Al-Nahrain University, Iraq

Noor Abbas Hummadi Fayadh
College of Medicine at Al-Nahrain University, Baghdad, Iraq

Hayder Abdul-Amir Makki Al-Hindy
Department of Pharmacology and Toxicology, College of Pharmacy, University of Babylon, Iraq, Babylon, Iraq

Ass. Prof., Pediatrician
Cardiac Physiology, Department of Pharmacology and Toxicology, University of Pharmacy, Babylon, Iraq

Corresponding author:

Ass. Prof., Pediatrician, Cardiac Physiology, Department of Pharmacology and Toxicology, University of Pharmacy, Babylon, Iraq

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Abstract: Thoracic outlet syndrome is brought on by a compression of the neurovascular bundle at the thoracic outlet. Although detection and treatment have improved, difficulties with diagnosis still exist and have an impact on patient management. This study sought to emphasize the importance of TOS in medical education by conducting a thorough analysis of its anatomical characteristics. The complicated condition of TOS is brought on by compression at the thoracic outlet. The neurogenic (n TOS), venous (vTOS), and arterial (a TOS) subtypes of TOS differ in terms of anatomical features, etiology, categorization, and pathogenesis. We looked at clinical assessment, diagnostic techniques, and conservative therapies such as physical therapy and injectable therapy. For refractory instances, surgical procedures such as initial rib resection and scalenectomy were investigated. For a precise diagnosis and successful treatment, it's essential to understand the complexities of its anatomy and etiology. Although conservative therapies frequently work well, resistant instances could necessitate surgical intervention. Positive results are influenced by improvements in surgical methods and minimally invasive procedures. While continuing research aims to overcome diagnostic issues and customize treatment plans for specific individuals, improved imaging techniques assist in diagnosis. A thorough understanding of TOS is necessary for medical education to promote precise diagnosis and top-notch patient care.

Keywords: Arterial, venous, subclavian vein, neurogenic thoracic outlet syndrome, brachial plexus.

Introduction: Since the 19th century, a variety of illnesses known as thoracic outlet syndrome (TOS) have been identified. These conditions cause compression of the neurovascular bundle that leaves the thoracic outlet. The thoracic outlet is three entries that are formed by the clavicle meeting the first rib and includes the lower neck of the body as well as the location to which some important neurovascular systems pass [1].

The subclavian artery, subclavian vein, the brachial plexus, are some of these structures. Compression of this region results in various symptoms, including discomfort, weakness, paresthesia, weakness in the upper extremities, and muscle atrophy [2].

Twenty years ago, it was debatable whether such a sickness even existed, making it difficult to accept it as a medical diagnostic. However, the illness is now more widely known, and its symptoms and mechanism are better understood. As more patients receive successful therapy, TOS is rising in popularity as a diagnosis in vascular surgery clinics all around the world. The medical team is now having trouble diagnosing it because it is being underreported or possibly going unnoticed.

Objectives: The main aim of this research study is to do a systematic review of the data concerning the topographical and anatomical aspects of TOS and stress the scarcity of this topic in contemporary medical education.

Anatomy and embryology

The thoracic outlet is anatomically defined as the region between the manubrium of the sternum, first thoracic vertebra, and first rib. The subclavian vein and subclavius tendon are situated anteriorly. The scalene then divides the subclavian vein and artery. To reach the artery, the middle scalene muscle travels laterally and posteriorly over the brachial plexus (Figure 1). This minuscule space is already occupied by the subclavius, anterior scalene, and prevertebral muscles. With each breath and every neck, thorax, and arm movement, the thoracic outlet's volume changes. Cervical ribs or aberrant first ribs, which have the propensity to be more cephalad or united with the second rib, may also affect the size of the thoracic outlet [3]. As the region continuously contracts and expands, the osseous structures may press upon the brachial plexus or subclavian arteries. The simultaneous development of fibrosis and scarring could result in invasion or inflammation [4].

Etiology, classification, and pathophysiology

The pathophysiology of the symptoms is classically used to classify TOS, into subgroups based on venous (vTOS), neurogenic (n TOS), and arterial (a TOS) pathologies. These categories can also be attributed to traumatic, congenital, or functionally acquired factors individually [5-7]. nTOS accounts for around 4/5th of instances, making it by far the most prevalent [8]. An anomalous first rib or the existence of a cervical rib are two examples of congenital causes. The hallmark pathology of TOS is brought on by a variety of reasons, such as trauma, repetitive motions, and anatomical differences. The most frequent traumatic causes are falls and whiplash injuries. Functional acquired or traumatic events frequently occur at high speeds, most frequently in the context of a car accident. Direct compression of the nerves or vasculature might result from hemorrhage, hematoma, or displaced fracture. A recognized cause is a midshaft clavicular fracture in particular [9]. Fibrosis can manifest symptoms even after the first insult. Subjects with a cervical rib are allegedly more possibly to experience such an outcome after suffering a whiplash injury, which is known to be associated with TOS, most often of the neurogenic type [10].

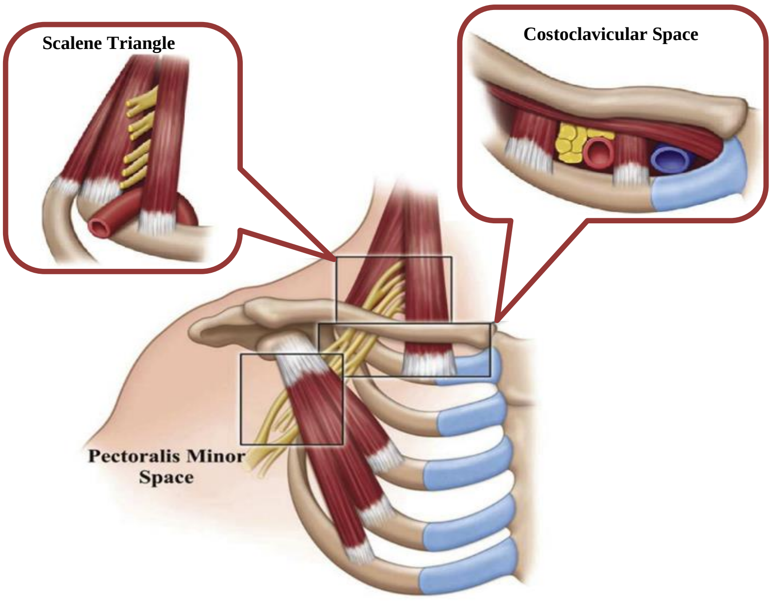


Figure 1: The three thoracic outlet anatomical spaces

Epidemiology of thoracic outlet syndrome

The exact frequency of TOS is challenging to determine due to the wide array of causes and lack of professional agreement for diagnostic techniques. A frequency of 3-80/1000 is reported in several papers [11]. Over 80% of instances of TOS are neurogenic, with venous and artery etiologies coming in second and third [8]. Historically, TOS has more of a female predominance and symptoms typically appear between the ages of 20 and 50 [6].

The trunks and cords of the brachial plexus, initiating from cervical roots C5 to T1, play a role in nTOS. nTOS might be categorized as true or uncertain. True nTOS is usually unilateral and primarily affects females between their teenage years and 60s. On the other hand, uncertain nTOS often presents as bilateral and lacks certain objective findings. There are different types of nTOS based on the involvement of blood vessels. vTOS, which forms 3-5% of patients, affects the subclavian and axillary veins. aTOS, seen in 1-2% of patients, involves the subclavian and axillary arteries. In contrast, aTOS is typically unilateral and affects both genders, often appearing in young adults. It is more common in men and is associated with repetitive upper limb activity. aTOS is prevalent in younger people and often affects the dominant arm [6, 8, 12].

Clinical evaluation

True nTOS results from the irritation or compression of brachial plexus nerves. Manifestations include paresthesia, pain, and weakness following nerve root distribution [10]. Pain in the medial side of the arm, forearm, and hand besides hand weakness and numbness in the fourth and fifth fingers are symptoms of lower plexus (C7-T1) compression. Upper plexus (C5-C7) compression causes cervical, shoulder, chest, and supraclavicular aching, as well as arm weakness and paresthesia of digits one to three [13]. Chronic nTOS can cause muscle weakness and atrophy. Reproducing symptoms aids diagnosis, often achieved through specific maneuvers [14]. Disputed nTOS may exhibit similar symptoms and associated issues such as headaches. vTOS presented with upper extremity swelling, pain, and heaviness owing to subclavian vein compression. Arterial TOS [15] is the rarest but most serious subtype, associated with pulse weakening, ischemia, and potential embolization [2]. It's typically linked to cervical rib presence. Prompt recognition and treatment are crucial for preventing complications [16].

Diagnostic Evaluation:

By their various compressed architectures, aTOS, vTOS, and nTOS each have distinctive clinical features [16]. However, it is significant to recognize that when numerous structures are compressed, there are frequently overlaps in symptomatology. Furthermore, even while exploratory tests are often helpful in validating the assumed diagnosis, negative outcomes do not exclude TOS [17]. To effectively diagnose TOS and create a successful treatment strategy, a thorough history and clinical examination plus a focus on identifying neurovascular impairment, together with additional diagnostic testing and imaging, are required. The history includes details about the start, progression, location, intensity, nature, and timing of the presentations, as well as the causes of each symptom's exacerbation and relief [18]. The “Northwick Park Neck Pain Questionnaire” and the “McGill Pain Questionnaire” are two precise questionnaires used in the evaluation of pain and debility, which may also offer significant insight into the symptoms also be useful in gathering patient medical history [19].

The clinical examination covers a wide range of topics, including the cervical alignment, posture, and stability of the shoulder blades [20]. It is typically necessary to perform additional testing on the muscular, bony, and neurological structures of the thoracic outlet. Cautious observation, together with palpation and several provocative techniques make up the examination clinically. The neck and thoracic spines, the first rib, in addition to numerous shoulder girdle joints are all examined in the thoracic outlet's bony examination. The scalene muscles, the trapezius, minor and major pectorals, and accessory musculatures of the shoulder joints are all evaluated for strength and coordination as part of the muscular exam. Reflexes and feelings are tested during neurological tests of patients [21]. In particular, since vibration sense is soon affected after compression of the outlet, loss of vibration is strongly predictive of thoracic outlet syndrome [19].

Provocative tests

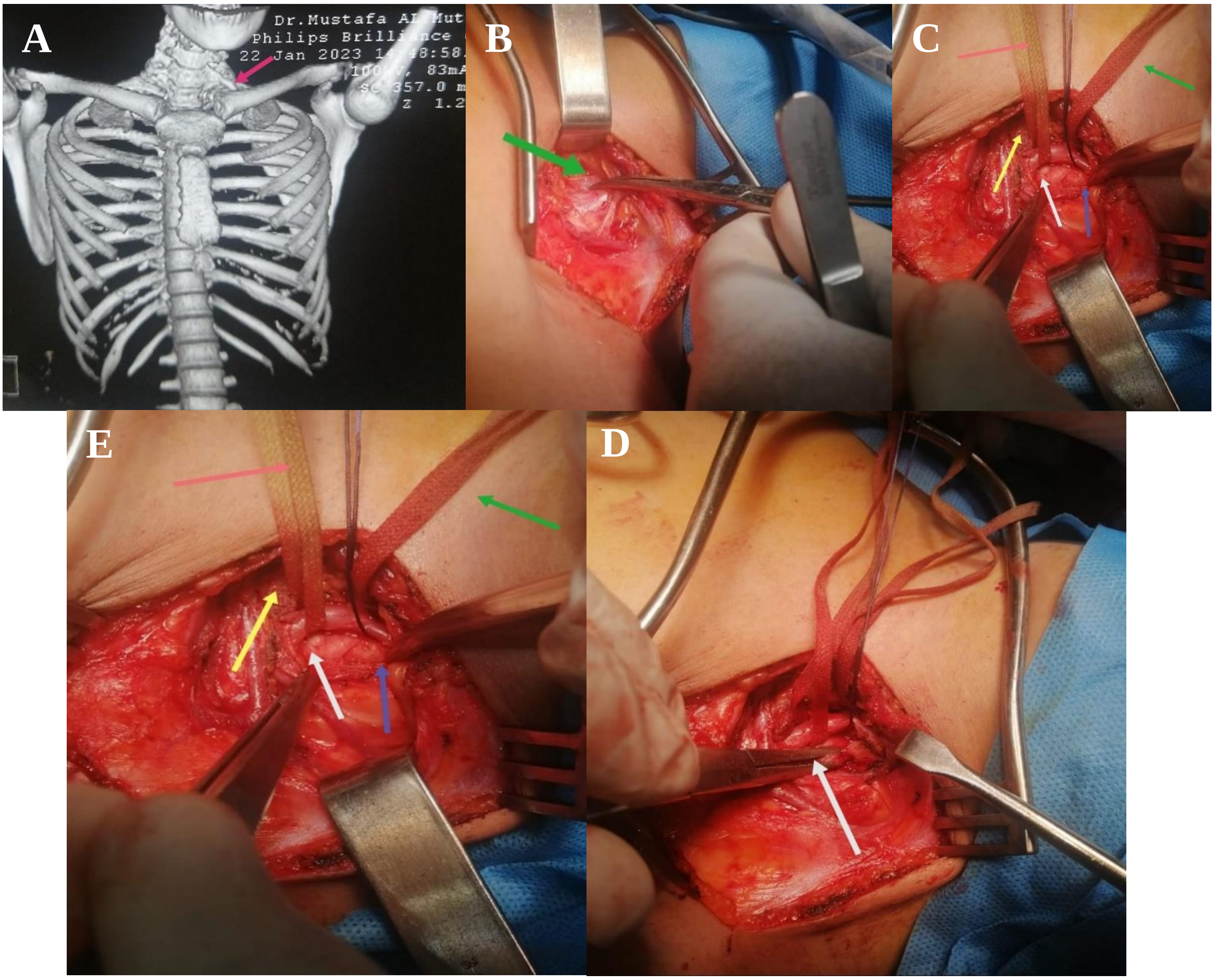
One characteristic of TOS is the ability to reproduce manifestations via certain arm and shoulder movements. Three standard physical exam techniques can be used to detect TOS The “upper limb tension test (ULTT)”, the Adson test, and the “elevated arm stress test (Roo’s test)”. These movements are intended to replicate sensations of pain, paresthesia, or pulselessness by targeting particular anatomical regions that are frequently implicated with TOS. The costoclavicular gap is made smaller by the EAST, and subsequent hand grasping may cause paresthesia or discomfort in cases of neuronal TOS or diminished radial pulsation in cases of arterial TOS. In the context of TOS, discomfort or paresthesia can be caused by the

ULTT stressing on the brachial plexus [22]. Adson's test is applied to determine any compression of the structural parts of the scalene triangle using a weakened radial pulse [14]. Provocative tests can significantly support a TOS diagnosis, even if they have only a sensitivity of 72% and a specificity of 53% [21]. This is especially true when performed in conjunction with imaging techniques.

Imaging modalities and Supplementary Diagnostic Tests

Although a thorough physical examination and patient history frequently raise a robust diagnosis of TOS, scanning is frequently required to approve the TOS subtype and functional site of anatomical compression precisely. Plain thoracic radiograms are useful as the first test in the diagnosis of all three kinds of TOS, particularly if the clinical presentation is ambiguous [22]. Bony abnormalities linked to TOS, such as first rib anomalies, localized bone lesions, cervical ribs, and congenital deformities, can also be found on chest X-rays [10, 22]. By offering a more in-depth analysis of the anatomy, CT scans, and MRI also play crucial contributions in the diagnosis of TOS subgroups [22].

Imaging modalities are crucial in the context of TOS for excluding alternative diagnoses like brachial neuritis, cervical disc disease, and carpal tunnel syndrome.



28 years old female presented with pain and paresthesia of the left little and ring fingers of 6 months duration. Figure A: CT scan shows left sided cervical rib. Figure B: Supra clavicular incision, identified phrenic nerve at anterior border of scalenus anterior. Figure C: Yellow arrow = scalenus anterior was cut, pink arrow = tape around subclavian artery, green arrow = tape around phrenic nerve, white arrow = brachial plexus, blue arrow = cervical rib. Figure D: Cervical rib had been cut then resected. Figure E: Pink arrow = tape around phrenic nerve, blue arrow = tape around subclavian artery, white arrow = brachial plexus, and cervical rib totally

resection had been done

Electromyography, nerve conduction investigations, and test injections can all be used to diagnose TOS [23]. However, due to the often negative, nonspecific, and intermittent results, electromyography and nerve conduction investigations are rarely employed alone and are frequently used along with other investigative procedures to exclude various causes of neuropathic pain [10].

Due to its accessibility, noninvasive nature, and ability to be employed during dynamic maneuvers, duplex ultrasonography (DUS) is used to diagnose subclavian artery aneurysms in patients with vTOS and aTOS [24, 25]. Ultrasonography may be done six months in symptomless aTOS patients if surgery is not required for ongoing surveillance. To assess exterior vascular compression in vTOS cases with negative DUSs, venography, which is regarded as a cornerstone of the diagnosis of the condition, may be paired with intravascular ultrasonography [24]. The American College of Radiology has determined that MR angiography, CT scan, and venography are valid analytical techniques that are appropriate for the analysis of TOS on a vascular basis [25]. These techniques can also detect dynamic changes in posture.

Numerous researchers examined and used nerve conduction studies (NCS) and upper extremity needle electromyography (EMG) for the diagnostic evaluation of cases with TOS. In opposition to the traditional view, nTOS subjects frequently present with abnormal sensory symptoms showing a weakness of muscle and decreased amplitude in NCS [26].

Thoracic Outlet Syndrome Management

Conservative Management

The conservative management protocol is often used as the first line of treatment in a patient who shows no other signs of vascular compromise, muscle atrophy, or overall dysfunction and the management entails a combination of these interventions: rest, education, activity modification, physical therapy, and NSAIDs [27]. As a result of the fact that TOS has multiple factors, specific treatments are selected depending on the etiology of the patient is. Surgical interventions are often considered if a patient's case does not improve with conservative measures for approximately 4-6 months [28].

The ultimate objective of conservative therapy is to reduce neurovascular strain to lessen the severity and frequency of symptoms using noninvasive techniques [28]. An organized rehabilitation program that includes physical therapy, Finkelstein's test, application of heat, massage, and manipulation, acupuncture, NSAIDs, and muscle relaxants is effective in 59-88% of TOS patients in conservative management which is effective for more than one year. However, the ideal conservative therapy regimen is still unknown [29]. Several researches have been conducted to evaluate general prognostic factors for TOS patients under conservative management because, as traditions have shown, conservative treatment is effective in the vast majority of patients. In addition to disputes on local physical treatment adhesion, postural and lifestyle modifications for long periods, and sedentary work involving minimal exertion are other facilitative prognosis factors [16]. The extent and severity of TOS symptoms, past trauma, and patient weight are typical poor prognostic indications of conservative therapy [30]. Interestingly, there has been a correlation between psychological problems like depression and subpar individual outcomes of conservative and/or surgical therapies [30, 31].

It can be concluded that physiotherapy could be helpful in soothing the pain endured by symptomatic nTOS patients as long as the individual patients follow all the recommended treatments to the letter. Special exercises, which have a direct focus on the improvement of the facilitative back and shoulder postural muscle's strength as well as flexibility are recommended and the utility of these routines has proved to be effective in alleviating pain [31].

The advantages of thoracic outlet manipulation therapy in the context of TOS are still unknown. While some research has indicated therapeutic gains from manipulating the thoracic outlet's expansion, other investigations report symptoms getting worse as a result of activation of the neurovascular bundle [5, 32]. Alternatively, methods that passively retract and uplift the shoulder blade, like the use of braces or bandages that adhere to the body, have shown hopeful improvements in upper limb function, paresthesia, pain, and overall quality of life in cases with moderate to severe manifestations [33]. For patient support, avoiding painful movements, and maximizing the physical therapy advantages, ergonomics, and posture control education is also vital [28, 31, 32].

Besides standard conservative therapy, anterior and ventral medial spinal cord strokes of mild severity are treated with intravenous heparin to eliminate thrombus enlargement and restore the blood flow to the ischemic areas [2, 34-36]. Unfortunately, such subtypes entail conservatism and thrombolytic treatment mostly they do not respond and require surgical intervention. Moreover, recent surgeons have also proved that trans-axillary thoracic outlet decompression is better than simply assigning a patient to continued conservative management and can be done to patients who are unresponsive to such measures [37].

Injection Therapy

Scalene muscles and the scalenus minimums muscle can compress structures within the scalene triangle. Botulinum toxin (BTX-A) can decompress muscle by trigger point injections, anesthetics or steroids can be helpful for patients who are not receptive to conservative therapy [38]. BTX-A, which has historically been employed to treat pain from excessive muscular contraction, prevents the production of acetylcholine, which may lessen pain by influencing neuropeptides such as the substance P and CGRP [39]. Studies with varying outcomes cast doubt on BTX-A's effectiveness in the treatment of TOS [39, 40]. However, no discernible pain relief was found in a randomized trial [41]. The likelihood of central sensitization increases with longer TOS duration [16].

Numerous clinical reports cite prolonged symptom relief in TOS patients through BTX-A intramuscular injection [38, 40]. Nevertheless, a controlled trial [41] found no significant improvement in pain or symptoms. This study's subjects had longer symptom duration than controls (6 vs. 3 years), heightening the risk of central sensitization [42]. Unlike other studies [43], a trial used EMG, not fluoroscopy/ultrasound/CT, for BTX-A injection guidance. No baseline pain requirement was set. 90% of successful BTX-A subjects experienced post-decompression relief [44, 45]. Steroid/local anesthetic injections like bupivacaine, lidocaine, and triamcinolone, combined with exercises, also show TOS treatment efficacy [16, 46]. Relief shoots from muscular, not brachial plexus, blockage.

Surgical Interventions of TOS

Conservative treatment is effective in about 60–70% of nTOS cases, but surgery is occasionally required [22, 47]. If symptoms increase following 4-6 weeks of conservative therapy, surgery may be considered [24]. Due to structural difficulties producing subclavian artery problems, refractory vTOS, and aTOS cases always require surgery [24, 48, 49].

First rib resection and anterior scalenectomy (FRRS) provide alleviation in more than 50% of cases with refractory aTOS and nTOS [16, 48]. For TOS, the transaxillary method is favored since it lowers the risk of damage and ensures rapid exposure [47, 48, 50]. The supraclavicular approach is beneficial for aTOS because it makes it easier to remove ribs and other structures that affect the subclavian artery.

When treating subclavian artery problems with aTOS, the supraclavicular approach is beneficial. Resections performed surgically result in 90% patient improvement [50]. Subclavian artery compression, thrombosis, and embolism are brought on by aTOS, which is frequently brought on by bone deformities like fused cervical ribs [51]. The surgical therapy aims to eliminate the source of compression; initial rib resection and scalenectomy are controversial [52]. Scalenectomy is less intrusive and provides faster healing [53]. Damage to the subclavian artery necessitates graft or bypass surgery for treatment [48, 54]. Embolectomy and blood flow restoration may be necessary [48].

Antithrombotic therapy and early FRRS with subclavius tendon dissection are the main therapies for acute vTOS. Venography determines whether venoplasty is necessary after treatment [48, 55]. Recent research raises doubts about thrombolytic therapy's ability to reduce the requirement for venoplasty [48]. Surgical decompression, pre-op thrombolysis, and post-op anticoagulation are required for chronic vTOS. Surgical surgery may be necessary in cases of intermittent blockage [56].

Due to inadequate sight, rib resections might cause neurovascular injury. Robotic endoscopic cameras improve the visibility of the first rib's neurovascular bundle, though their impact on outcomes is unclear [57]. Robot-assisted transthoracic cervical rib resections provide better wound healing, fewer neurological problems, and promising scarring [58], demonstrating the advantages of minimally invasive techniques.

Prognosis and Follow-Up

As robotic and thoracoscopic-assisted procedures lessen brachial plexus manipulation, minimally invasive techniques have more recently produced superior results in the removal of the first rib [59]. Although more education, tools, and experience are needed, they could reduce the global surgical risk.

Invasive decompression has produced actual excellent results overall. 95% of individuals with nTOS who underwent surgery reported "excellent" outcomes. Patency rates for patients with vTOS were higher than 95% in a 5-year follow up research. Major depression or concomitant diseases that distort the initial diagnosis are obstacles to successful outcomes [60].

Surgical advancement and future directions

Resection of the first rib by scalenectomy is still the optimum procedure of decompression, but as minimally invasive techniques become more popular, some institutions are now using Video-assisted thoracoscopic surgery to improve visual clarity during surgery and potentially reduce damage to the neurovascular bundle [61]. The endoscopic-assisted axillary and robotic-assisted procedures are two additional strategies that have the potential to be beneficial. The latter aims to lower the risk of pneumothorax [62].

In terms of our knowledge and approach to TOS, there has been significant advancement over the last decade but there are still certain information gaps that need to be filled. For instance, diagnosis still poses a significant barrier. For patients with TOS, the advent of a trustworthy and impartial diagnostic technique like imaging would mark a new era. One interesting research direction has been the comparison of TOS patients with controls using preoperative MRI or CTA. Post-operative imaging scheduling is also up for discussion, with different schedules being used across institutions. For instance, residual post-surgical inflammation may be present during venograms performed two weeks after the first rib resection and scalenectomy; this deserves more research [8].

Complications of TOS

When conservative treatments fail, surgical therapy for TOS is required. Long-term post-surgical pain to permanent incapacity are only a few of the complications associated with surgical operations. The type of TOS and the operating room visibility both have an impact on the procedure's outcome [63]. Possible complications comprise, but are not limited to, the subsequent issues:

• **Pulmonary embolism**: A pulmonary embolism is a different consequence that can result from a blood clot. This happens when a blood clot forms in a blood vessel and proceeds to obstruct the blood flow in a pulmonary artery. It might be a potentially fatal problem [64].

• **Nerve damage**: The discomfort brought on by neurogenic TOS might cause permanent nerve damage if left untreated.

• **Blood clots**: Compression of a subclavian vein leads to vTOS. Blood clots frequently form as a result of this in the affected veins.

• **Gangrene**: When the blood supply to a section of tissue is cut off, gangrene develops and the tissue dies. Infection of the dead tissue has the potential to be exceedingly damaging and even lethal.

• **Chronic pain**: Usually, this manifests in the arm, chronic discomfort and persistent swelling, particularly with venous TOS, may develop.

• **Ischemic ulcers**: Ischemic ulcers could develop when blood flow is decreased because of aTOS. With aTOS, these lesions frequently develop on the fingertips [8, 63, 65, 66].

The scar tissue in the operative region, which was directly related to the surgical approach, was most likely the origin of the spontaneous recurrence [67]. Technical concerns relating to the primary surgery, which could have arisen due to a lack of adequate operation exposure in failed procedures, could have been real but pseudorecurrences. The differential is between a resection of a cervical rib with an aberrant first rib or a resection of the first rib whilst leaving a cervical rib intact. For example, among the technical errors mentioned above these errors may lead to compression of the nerve at the horizontal fibers of the second scalene muscle, an incomplete first-rib resection, an ectopic rib, a pectoralis minor tendon [68], and an adhesive residual scalene muscle [69]. The position of the patient as well as the surgeon being comfortable did not require both of them to sit in a strained position during the supraclavicular approach therefore decreasing intraoperative iatrogenic injury [70]. However, compared to the transaxillary technique the supraclavicular has the benefits that according to Sanders and Hammond [3] and Hempel et al. [70] other operations can be performed including neurolysis, neck exploration, sympathectomy, and anterior and middle scalenectomy. Additionally, individuals with traumatic TOS or other non-work-related aetiologies of TOS react better to TOS surgeries [63].

Better cosmetic outcomes are obtained with the transaxillary technique [71], but transaxillary surgeries have a greater rate of postoperative surgical failures due to an inadequate vision of the surgical region and compression of the brachial plexus. The proximal plexus can be reached more easily using the supraclavicular route, which appears to be the preferable surgical method [63]. Additionally, it enables access to the cervical rib's proximal area and the proximal nerve, which could be squeezed by an abnormal rib head. Moreover, with the help of this method, one can identify another remaining aberrant anatomy, for example, the presence of a fibrous band arising from the vertebral transverse process. This procedure creates a window for the supraclavicular fat that should be used to envelop the plexus after neurolysis to reduce the chances of the re-emergence of the syndrome. However, it can be stated that the supraclavicular approach seems to be the most commonly used method in most of the TOS surgeries; hence, further studies are recommended to accumulate clinical evidence [63]

CONCLUSION

Neurovascular compression at the thoracic outlet is one aspect of the still-complex and complicated syndrome known as TOS. Despite previous difficulties in diagnosis and recognition, improvements in diagnostic procedures and therapeutic approaches have been performed as a result of our increasing understanding of the pathophysiology, etiology, and anatomical bases of the condition. For a significant number of cases, conservative approaches—including physical therapy, injectable treatments, and lifestyle changes—offer effective relief. Because of the development of minimally invasive procedures, surgical therapies such as scalenectomy and first rib resection become worthwhile possibilities for cases that are resistant.

This review emphasizes the value of precise diagnosis and personalized treatment approaches. The thorough investigation of TOS anatomy, subtypes, clinical assessment, and diagnostic techniques benefits clinical practice and medical education. Even while difficulties still exist, particularly in diagnosing this complex disease, ongoing research and improvements in imaging methods show promise for improving diagnostic precision. This information is essential for both identifying the various TOS symptoms and creating potent therapy strategies.

A deeper grasp of TOS's complexities emerges as medical knowledge increases, setting the foundation for better patient outcomes. Medical professionals, researchers, and educators must keep working together to better understand the complexity of TOS, improve diagnosis procedures, and improve treatment regimens. In the end, this will make it possible for medical personnel to offer people with TOS improved care, enhancing their quality of life and lessening the burden of this condition.

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