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Diagnosis and Treatment of Thoracic Outlet Syndrome: A Systematic Review of Imaging Modalities, Conservative Interventions, and Surgical Approaches

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Abstract

Introduction

Thoracic outlet syndrome (TOS) is a rare condition that primarily affects people in the first half of their lives. TOS is divided into three types depending on the affected structures: neurogenic, arterial, and venous. The spectrum of symptoms is broad, ranging from their complete absence to life-threatening thromboembolic events. Due to the lack of clear guidelines, diagnosis is difficult and prolonged.

Materials and methods

This review includes an analysis of recent clinical trials and studies. It was prepared
by analyzing data from PubMed, covering the period from 2008 to 2025. The studies were selected using the keywords: „thoracic outlet syndrome", „brachial plexus compression", „neurovascular compression", „Paget-Schroetter syndrome", „rib resection" and „diagnostic imaging", along with time filters.

Aim of the study

This study aims to review the methods of diagnosis and treatment of thoracic outlet syndrome, focusing on imaging techniques and conservative management.

Summary

The study shows that difficulties in accurately diagnosing and classifying thoracic outlet syndrome (TOS) still persist. A correlation between clinical symptoms and imaging results is necessary. Both conservative and surgical treatment methods are highly effective in reducing the symptoms of the condition. The approach to diagnosis and treatment should be tailored individually by a highly qualified specialist with experience in this field.

Keywords

TOS, thoracic outlet syndrome, brachial plexus compression, first rib resection, botulinum toxin

Introduction

Thoracic outlet syndrome is a group of diverse clinical symptoms. It most commonly affects young individuals between the ages of 20 and 50, and is more frequent in women. The term „thoracic outlet syndrome" was first described in 1956 by Peet et al. (1,3,4). The disease is caused by compression of the neurovascular bundle by structures of the thoracic cavity. This leads to pain, numbness, and tingling in the affected upper limb(11). Due to its nonspecific symptoms, it is a really diagnostic challenge. There are three clinical types of TOS depending on the structures being compressed: venous (vTOS), arterial (aTOS), and neurogenic (nTOS). Neurovascular compression can potentially occur in three areas: the interscalene triangle,

the costoclavicular space, or the space beneath the pectoralis minor muscle. The interscalene triangle is bordered anteriorly by the anterior scalene muscle, posteriorly by the middle scalene muscle, and inferiorly by the medial surface of the first rib(3,4,14).

The most common subtype of TOS is neurogenic TOS (nTOS), accounting for approximately 90% of cases. The symptoms of nTOS are caused by compression and irritation of the brachial plexus and include numbness, pain, paresthesias, vasomotor changes, and muscle atrophy in the upper limb. These symptoms often worsen when the arms are raised overhead. At the same time, patients do not have other conditions that could cause similar complaints, such as cervical spine degeneration(2,3,4,8,24). In the differential diagnosis, all disorders affecting motor or sensory fibers originating from the C8 or T1 spinal cord segments should be considered, including the commonly occurring mononeuropathies of the median or ulnar nerve(20,21).

In patients with venous TOS (vTOS), symptoms result from compression or thrombosis of the subclavian vein. vTOS includes Paget-Schroetter syndrome (thrombosis occurring after physical exertion)(14). Venous TOS (vTOS) often occurs as an isolated condition, but the combined presence of vTOS and neurogenic TOS (nTOS) is relatively common(13). Furthermore, vTOS should be suspected in any young person presenting with sudden upper limb swelling who has no predisposing factors such as a central venous catheter, active malignancy, or a history of thromboembolic disease(29). The most common cause of arterial thoracic outlet syndrome (aTOS) is a fully developed cervical rib. Compression of the subclavian artery can cause damage to the intimal layer, turbulent blood flow, or the formation of an aneurysm. This leads to chronic ischemia of the upper limb, its cooling, pain that worsens with physical exertion, limb pallor, claudication, and coldness and even disappearance of the pulse in the limb. Arterial TOS is the rarest subtype(2,3,4,21). Symptoms characteristic of each TOS subtype are presented in Table 1.

Table 1. Symptoms characteristic of TOS

TOS subtype	Symptoms
nTOS	• Heaviness of the limb, • Paresthesias, • Neck pain, • Trapezius muscle pain, • Shoulder and/or arm pain, • Supraclavicular pain, • Chest pain, • Occipital headache, • Paresthesias in all five fingers or only in the fourth and fifth fingers.
vTOS	• Swelling of the limb, • Dull pain, • Feeling of heaviness, • Dilation of superficial veins, • Subclavian vein thrombosis
aTOS	• Ischaemia • Pallor • Claudication • Coldness

Thoracic outlet syndrome (TOS) occurs more frequently in manual workers and athletes who perform activities involving raising their arms overhead. It is believed that increased muscle mass caused by chronic occupational or sports activity reduces the space in the thoracic outlet and increases the likelihood of compression of the neurovascular bundle. TOS can develop when the duration or intensity of the compression exceeds the body's capacity for recovery after exertion(25).

There are several types of anatomical abnormalities that cause TOS. These include bony abnormalities such as a cervical rib, bone spurs, or an elongated transverse process of C7. Soft tissue abnormalities include hypertrophy of the scalene muscles or an excessively broad attachment of the middle scalene muscle to the first rib(3,4,9).

Due to diagnostic difficulties, the lack of standardized tests, and the complexity of the problem, there are no clear guidelines regarding the diagnosis and treatment of TOS(3). This article is based on an analysis of articles from the PubMed database published between 2008 and 2024. The article addresses the questions: what are the most common imaging studies used for diagnosing TOS, and what treatment methods are currently available.

2. Imaging Methods

As mentioned above, each subtype of TOS has its characteristic clinical presentation,

and therefore each requires somewhat different imaging studies. Moreover, a negative imaging result does not

exclude the diagnosis of TOS. For all patients suspected of TOS,

a chest and cervical spine X-ray is recommended. X-rays are easily accessible, relatively inexpensive, and expose the patient to a low dose of radiation. They allow identification of anatomical anomalies and exclusion of bone and joint diseases. However, X-rays do not allow assessment of nerve or vessel compression. In many patients, the X-ray image is normal because the problem is located in the soft tissues. Therefore, additional imaging studies are needed to confirm the diagnosis(5,10,14).

Ultrasound with Doppler function enables evaluation of soft tissues. It is inexpensive, does not involve radiation exposure, and allows real-time assessment, for example during provocative tests. Provocative tests used in the diagnosis of TOS are presented in Table 2. (2,4,5).

Table 2. Provocative tests in TOS diagnosis

Name of the test	How to perform
Adson Test	1. Sitting or standing with the arm abducted to about 30 degrees at the shoulder and fully extended backward. 2. Extending the neck and rotating the head toward the tested side. 3. Taking a deep breath and hold it.
Elevated Arm Stress Test (EAST)	1. Sitting or standing with both arms abducted to 90 degrees and externally rotated at the shoulders. 2. The elbows should be flexed to 90 degrees, with shoulders and elbows aligned in the frontal plane. 3. Opening and closing hands slowly and repeatedly (approximately twice per second) for 3 minutes.
Upper Limb Tension Test	1. Arms abducted to 90° with elbows flexed 2. Active dorsiflexion of both wrists 3. Head is tilted ear to shoulder, in both direction

Furthermore, Doppler ultrasound allows differentiation between the vascular and neurogenic forms of TOS. It assesses blood flow in the vessels and detects stenosis or thrombosis.

It enables identification of the degree of vascular compression caused by surrounding soft tissues. Ultrasound is also useful in evaluating the brachial plexus and possible compression by scalene muscles or fibrous bands, which helps diagnose neurogenic TOS. The main limitation of the examination is the experience of the performing physician(24,26,32). However, nerve or vascular changes may be subtle enough to go undetected by ultrasound. Confirmation of the diagnosis often requires computed tomography (CT) with contrast

or magnetic resonance imaging (MRI).

CT plays a particularly important role in assessing vascular compression and is performed with angiographic options (CT angiography). CT angiography can precisely visualize the location and size of stenosis in the subclavian vein or artery, which aids in planning further management. The examination is fast and accurate but requires patient preparation for contrast administration(5,10). The examination should be performed in a neutral

position (arms relaxed alongside the torso) as well as in a dynamic position (limbs in hyperabduction and external rotation). Next, the diameter of the artery or vein is compared in the neutral position and in hyperabduction. The degree of compression is determined based on the extent of vessel narrowing. Stenosis of the subclavian vein by at least 50% of its diameter or the subclavian artery by at least 30% of its diameter indicates TOS(4,28).

To confirm neurogenic TOS, MRI of the neck and chest should be performed, supplemented by electromyography (EMG) and electroneurography (ENG). EMG evaluates motor function of muscles innervated by specific nerves, while ENG assesses the ability of these nerves to conduct impulses. In neurogenic TOS, ENG shows slowed conduction in the C5–C8 roots of the brachial plexus or in the radial, median, or ulnar nerves. EMG reveals signs of muscle denervation. MRI sensitivity is too low to consider it a screening test; however, its specificity is sufficiently high, making it a key examination in decision-making regarding further treatment(22). MRI is the most precise method for depicting relationships between structures in the thoracic outlet(3,4,5,6).

In summary, establishing a diagnosis of TOS requires multiple examinations and is not always straightforward. Imaging results should always be interpreted in the context of the patient's medical history and physical examination(6,10).

3. Conservative Treatment Methods

Conservative treatment of thoracic outlet syndrome largely relies on physiotherapeutic methods aimed at reducing the pressure on nerves and blood vessels, improving posture, and strengthening the muscles that stabilize the shoulder girdle. The most commonly used techniques include manual therapy, corrective exercises, and neuromobilization.

Manual therapy involves mobilization and relaxation of soft tissues (such as the scalene muscles, pectoralis minor muscle, and fascia). These procedures help the tissues return to their original position. Regular manual therapy significantly reduces pain symptoms in patients with neurogenic TOS. Physiotherapy, in addition to muscle strengthening, also includes work on lost hand functions if they have been impaired. (17,31)

Corrective exercises focus on improving posture, especially in patients with shoulder protraction and thoracic hyperkyphosis. The rehabilitation program includes strengthening the trapezius, serratus anterior, and scapular stabilizing muscles, as well as stretching the shortened pectoral muscles. Patient education on ergonomics, particularly regarding prolonged computer use, is also an important component(5,7).

The type of physiotherapy should be carefully selected individually by a qualified specialist, based on the patient's medical history, physical examination, and imaging results. Consistency is also important, as well as performing exercises at home or individually at the gym. To increase the effectiveness of treatment, it is beneficial to combine different physiotherapy methods. Certainly, an attempt at conservative treatment should precede qualification for surgical intervention(4).

In addition, to relieve pain and reduce skeletal muscle tension, muscle relaxants such as baclofen or tolperisone are used. If neurogenic symptoms such as numbness or burning predominate, gabapentin or pregabalin may be added to the therapy. In cases of chronic neuropathic pain, tricyclic antidepressants (e.g. amitriptyline) can be used. However, pharmacotherapy does not eliminate the cause of TOS; it only alleviates symptoms while the medications are being taken(2).

As supportive treatment for TOS, injection of the scalene muscles or pectoralis minor muscle with botulinum toxin can be used. The effectiveness of botulinum toxin appears to be controversial and remains a subject of further

research. Nevertheless, some studies report that in approximately 70% of patients for whom conservative treatment was ineffective, it alleviates pain and symptoms of scalene muscle contracture The procedure lasts about 15–30 minutes, is performed under ultrasound guidance, and reduces compression symptoms for about 3–6 months. It is essential that injections are not the only treatment method, but rather supplement physiotherapy[2,4,7]. A multidisciplinary approach-regular physiotherapy, patient education, and pharmacotherapy-yields positive results in up to 70% of patients(5).

In summary, there are several effective ways to alleviate the symptoms of TOS. However, treatment is long-term and requires a great deal of discipline from the patient.

4. Surgical Treatment Methods

If there is no improvement after six months of properly conducted conservative treatment, or if life-threatening symptoms occur, surgical treatment should be considered(3,16,27). More than half of patients with neurogenic (nTOS) and arterial (aTOS) thoracic outlet syndrome can be effectively treated by first rib resection(18). The operation is typically performed using a transaxillary, supraclavicular, or paraclavicular approach The surgical approach should be determined by a surgeon experienced in this type of procedure based on their preference(23,27). The transaxillary approach is preferred for nTOS due to easier exposure of compressed structures and reduced risk of injury, while the supraclavicular approach is more advantageous in aTOS, as it allows safe visualization of the subclavian artery and facilitates dissection of compressive structures(16). In patients undergoing surgery, the success rate exceeds 90%(3,5,31).

Surgical treatment for aTOS consists of three stages: first, resection of the cervical and/or first rib; second, assessment of the subclavian artery for patency, stenosis, or aneurysm; and third, restoration of blood flow if there is occlusion, which may require embolectomy. First-line treatment for venous TOS (vTOS) includes thrombolysis and early decompression by first rib removal (12,15). Long-term treatment of upper limb deep vein thrombosis with anticoagulant drugs alone is ineffective because it does not address the pathophysiology of venous thoracic outlet syndrome (vTOS), which can be corrected surgically(19). Patients require anticoagulation both before and for several months after surgery. The most common postoperative complications include pneumothorax, injury to the neurovascular bundle, limb numbness, ischemia, thrombosis, and chronic pain. Some complications resolve over time, but others may lead to rehospitalization and reoperation, especially if the rib was not completely resected.(2,10,11,30) An alternative method is scalenectomy, which involves cutting or removing one or more scalene muscles, but first rib resection provides better long-term results than scalenectomy. In most patients, long-term outcomes and benefits of surgery are at least satisfactory(9,12,14,18). The main goal of surgical treatment is to relieve compression of the neurovascular structures in the thoracic outlet(17).

5. Conclusions

As outlined above, the entire diagnostic and therapeutic process for TOS is complex and requires knowledge and commitment from medical personnel. A multidisciplinary team should consist at minimum of a neurologist, a vascular surgeon or thoracic surgeon, a physiotherapist, and a psychologist. TOS symptoms significantly impact patients' daily lives. Sometimes symptoms appear in specific positions adopted by the patient, such as hyperabduction of the upper limb, or after intense physical exertion. Patient-reported symptoms should never

be underestimated. Before deciding on treatment, laboratory and imaging results must be analyzed and correlated with physical examination findings. It is essential to ensure that the cause of TOS is accurately identified and that other causes of the patient's symptoms are excluded. Thanks to advances in technology and medicine, diagnosing patients has become accessible even to centers with lower levels of referral. Nevertheless, there remains a need for further research on this condition.

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Authors' contributions

Conceptualisation: JW
Methodology: PK
Software: MS
Check: PB, KD
Formal analysis: WF
Investigation: DK
Resources: PF
Data curation: IK
Writing-rough preparation: DK
Writing-review and editing: WF
Visualization: KD
Project administration: PF, IK
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