The thoracic outlet syndrome (TOS), first reported in 1956, is a complex of symptoms and signs caused by compression of neurovascular structures at the thoracic outlet (or inlet). Some authors prefer to use the term “thoracic inlet syndrome” instead, implying the interscalene triangle as the portal of entry and the diaphragm as the exit. Here we use the term “thoracic outlet syndrome” because it has gained wide and well-established usage in the past and present literature.

Three sites in the region spanning from the neck to the axilla may potentially cause TOS: the interscalene triangle, costoclavicular space, and subacoid (or subpectoralis minor) space. However, the vast majority of TOS occurs in the space of the interscalene triangle (Fig. 1), bounded by the scalenus anterior anteriorly, scalenus medius posteriorly, and the first rib inferiorly. Clinical presentation varies depending on the elements that are irritated or compressed, causing neurological and/or vascular symptoms. The overall true incidence of TOS is uncertain, ranging from 3 to 80 cases per 1000.

Background: Thoracic outlet syndrome (TOS) is a highly controversial clinical entity. There is much debate on its terminology, existence, diagnosis, and treatment. The purpose of this study was to describe our opinions about these controversial topics of TOS and the treatment of TOS over the past 30 years.

Methods: From 1985 to 2014, a total of 80 patients underwent decompressive surgery for TOS. Eight patients requested a second surgery on the contralateral limb. They all had at least 1-year follow-up. Preoperative evaluation included provocative tests, plain X-ray, magnetic resonance angiography/computed tomography angiography, and electromyography. Surgical intervention for each patient involved a supraclavicular approach and near-total resection of the anterior scalene muscle and the first rib and of any cervical rib if it was present. Rib resection was performed with the use of Kerrison bone punch forceps. The operative time was typically 2 hours.

Results: Major postoperative complications were rare. Nearly all patients (98%) experienced significant symptom relief, with improvement in soreness and tightness of the shoulder, neck, and arm immediately on the first postoperative day or within a few weeks thereafter. There were no cases with symptoms recurring.

Conclusions: It is evident that decompressive surgery through a supraclavicular approach for TOS not only is an effective and safe procedure but also provides a diagnosis of the cause of TOS. For a patient who meets the criteria for surgical indication, decompressive surgery usually results in resolution of symptoms and no recurrence. (Plast Reconstr Surg Glob Open 2016;4:e728; doi: 10.1097/GOX.0000000000000651; Published online 1 June 2016.)

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The etiology of TOS is multifactorial, including compression from a cervical rib, abnormal first-rib morphology, tight or hypertrophic scalenus anterior muscle, abnormal course of the subclavian vessels, and other abnormal anatomical structures such as fibrotic bands, space-occupying lesions, or posttraumatic sequelae. TOS secondary to a fractured clavicle is not uncommon. Long-term factors, such as bad posture, breast hypertrophy, or prolonged loading of the shoulder (eg, carrying heavy bags), may also play a role in TOS.

Both nonsurgical and surgical treatments have been advocated, and there is no consensus on the indications for surgery. Furthermore, if a decision to operate is made, then the choice of surgical approaches and procedures is myriad; each has its proponents and critics.

The TOS is a highly controversial clinical entity. The purpose of this study was to describe our observations on TOS and the treatment of TOS over the past 30 years.

MATERIALS AND METHODS

From 1985 to 2014 (30 years), a total of 80 patients with TOS underwent 88 surgeries for TOS decompression. Patients with TOS secondary to fractured clavicle and nerve sheath tumor of T1 and T2 located at the lung apex were excluded. The cohort comprised 24 males and 56 females with a mean age of 30 years (range, 11–47). Forty-six cases included right-sided symptoms, and 42 cases included left-sided symptoms. Over half of the patients actually had bilateral involvement, but only the more severely affected side was operated on in most cases. Eight patients with bilateral TOS symptoms also underwent surgery upon their contralateral side, either during the same hospital admission (4 patients) or during the subsequent period of months or years (4 patients). Usually, the side with the subjectively more severe symptoms was decompressed first, regardless of diagnostic test findings.
Preoperative Management

Candidates for surgery were chosen according to strict selection criteria. Patient history consistent with symptom presentations included locations of muscle weakness or spasm; soreness or pain; numbness or tingling over the shoulder, neck, or upper limb; frequent inadvertent dropping of things; and difficulty with overhead arm activities. Physical examination included decreased or abnormal sensation, weak muscle contraction, and provocative tests. Two provocative tests were routinely performed: the limb elevation test (Fig. 2A) and the first-rib compression test (Fig. 2B). For the limb elevation test, the patient was in seated position and the arm was hyperabducted. The first-rib compression test was performed by applying finger pressure to the first rib (the palpable hard body above the middle clavicular area). For both tests, a significantly decreased or absent radial pulsation indicated positive vessel compression. If symptoms and signs were reproducible within 1 minute, positive nerve compression was indicated. In the first-rib compression test, severe tenderness would be induced because of tendinitis of the scalenus anterior attachment on the first rib, which is similar to the lateral epicondylitis of “tennis elbow.”

Plain X-rays of chest and cervical spine were routinely taken (Fig. 3). The width of the vertebral and sternal ends of the first rib was measured. Our previous study suggested that TOS patients have significantly wider first rib dimensions (sternal end width >20 mm or vertebral end width >15 mm). Other studies including electrophysiologic study, magnetic resonance angiography (Fig. 4), and computed tomography angiography were routinely performed to endorse the diagnosis. When necessary, consultation with neurologists and/or neurosurgeons was made to rule out cervical spine problems such as disc problems, osteophyte, or other radiculopathies. During consultation, the use of anatomical drawings to explain the potential causes of TOS and the aim of the surgical decompression process to patients was important. For all TOS patients, postural education regarding avoidance of limb elevation while sleeping and avoidance of sleeping on the affected side was always given, and conservative treatment was followed for weeks or months. If symptoms and signs persisted, surgery was indicated.

Operative Procedures

Surgical intervention in each of the 88 decompressive surgeries for TOS involved a supraclavicular approach and near-total resection of the scalenus anterior muscle and the first rib; the cervical rib was resected too, if present. The supraclavicular approach was performed in 2 ways:

Supraclavicular Fossa Approach Alone

The patient was placed supine, with a shoulder bump to elevate the shoulder girdle and extend the neck. A C-shaped incision was made similar to the supraclavicular brachial plexus exploration, but it was more medial and inferior (Fig. 5). Once the phrenic nerve and the scalenus anterior muscle were identified, the scalenus anterior muscle was dissected free from the overlying phrenic nerve and the underlying subclavian artery. The completely mobilized scalenus anterior muscle was divided at the position above the C5 spinal nerve and detached from its origin on the

Fig. 2. Two reliable provocative tests for TOS: (A) limb elevation test and (B) the first rib compression test.
The transverse processes of C5 and C6 down to its insertion on the sternal end of the first rib (Fig. 6). The vertebral end of the first rib was exposed between the C6 and C7 spinal nerves. Once the sternal and vertebral ends of the first rib were identified, any attachments to the first rib, such as the intercostal and middle scalene muscles, were detached by using periosteal elevators and blunt finger dissection to completely mobilize the rib. The first rib was isolated for its entire length. By using Kerrison bone punch forceps (Fig. 7), both ends of the first rib were cut. The anterior scalene muscle and the first rib were removed en bloc (Fig. 8). The cervical rib, if present, was removed, too (Fig. 9). The average operative time was 2 hours (range, 1.5–3.5 hours).

**Combined Supraclavicular and Subclavicular Fossae Approach**

If the sternal end of the first rib was too deep to be seen, an additional subclavicular fossa approach was performed. Through the same open wound, the inferior skin flap overlying the pectoral muscle was elevated. The pectoralis major muscle was detached from the medial clavicle to the sternoclavicular joint until the subclavius muscle was seen. The supra- and
Fig. 6. The picture shows the right TOS exposure. The proximally detached scalene anterior muscle was elevated from the underlying brachial plexus and subclavian artery. The distal attachment of the muscle to the first rib was visible.

Fig. 7. Various sizes of Kerrison bone punch forceps.

Fig. 8. A harvested specimen of en bloc excision of the scalene anterior muscle and the first rib for the right TOS.
infraclavicular fossae were connected below the subclavius muscle. The subclavian vein, subclavius muscle, and clavicle were elevated together with a flat gauze (Fig. 10). The first rib and the attached scalenus anterior muscle beneath the subclavius muscle were identified. The sternal end of the first rib was cut medially to the scalene anterior attachment. The muscle and the rib were removed en bloc.

After decompression, intraoperative verification of improved radial artery pulsation at the wrist was performed with the arm in full abduction. A suction drain was placed, and the wound was closed in layers. A pressure dressing was applied using an adhesive bandage for several days. No patients in this series needed pectoralis minor tenotomy to decompress the subcoracoid space.

Postoperative Management

On the second day after decompression, erect chest x-ray was routinely obtained. Patients were encouraged to move their neck, shoulder, and arm without any restriction. They were routinely discharged on the fourth or fifth postoperative day. The importance of regular follow-up and of compliance with physiotherapy was emphasized to the patients.

Patient-Reported Outcomes

The most recent 8 years of patients were assessed using a questionnaire addressing 10 of the most common TOS symptoms. This questionnaire was completed preoperatively and at 1 year postoperatively. Patients were asked to rate the severity of the symptoms on a scale 1 to 5 (1 = minimal, 5 = most severe). The results were analyzed using paired t test (SPSS version 23, IBM, New York, N.Y.).

RESULTS

Unusually thick and dense adipofascial tissue surrounding the neurovascular structures was noted in all patients who had undergone operation (Table 1). The first rib was found to be significantly abnormal.
in 70 patients (80%). In these patients, the first rib abnormalities included some or all of the following: wider sternal and/or vertebral end widths, shorter overall length, more vertical posture, lesser curve angle (Fig. 11), and sharper edge on the inner side (Fig. 12). Other abnormal findings involved the scalenus muscle (21 patients, 23%) and nearby blood vessels (6 patients, 7%). Tight or hypertrophic scalenus anterior muscle (either at the proximal origin part or at the distal insertion part), bifid insertion of the scalenus anterior muscle into the first rib with straddling of the subclavian artery, entrapment of the lower trunk of the brachial plexus, and thickened posterior fascia of the middle scalene muscle with palpable intramuscular fibrosis were all observed. Vessel abnormalities including the subclavian artery located anterior to the scalenus anterior muscle or transverse cervical vessels located inferior to the brachial plexus were observed. Eight cases of TOS were attributed to the presence of cervical rib (9%). Only 4 of the 8 patients requested surgery on the contralateral side. However, one third of cases (30 cases, 34%; Table 1) showed no obvious abnormalities, but they still experienced significant symptomatic improvement postoperatively.

Postoperative complications were mostly minor and temporary (Table 2). Temporary weakness or altered sensation in the operated limb was commonly noted (40 patients, 45%) because of traction neurapraxia, which resolved spontaneously within 1–6 months. Four patients (4%) developed pneumothorax because of (parietal) pleura tear, which required pig-tailed chest intubation for 2 to 3 days. Two patients underwent chest tube placement during the surgery, and 2 patients had chest tube placement on the second postoperative day at bedside. There were 4 pleural effusions that resolved with conservative treatment. One chyle leak required re-exploration and suture ligation of the ruptured lymphatic channels with a fascia lata graft owing to tissue fragility.

Thirty-two patients from the most recent 8 years were assessed using a specially designed questionnaire for TOS patients in the outpatient clinic, by telephone, or by post. They all had at least 1 year postoperative follow-up. All patients, except 2, experienced significant symptom relief of shoulder and neck or of arm soreness or tightness (Fig. 13), either on the first postoperative day or within a few weeks thereafter. Those 2 patients who showed no improvement underwent further investigation. Further work-
up by specialized magnetic resonance imaging of the central nervous system revealed abnormal veins on the spinal cord. Neurosurgical intervention in these 2 patients by a neurosurgeon also resulted in symptomatic improvement. No patient reported recurrent symptoms.

**DISCUSSION**

Regarding the choice of nomenclature of thoracic outlet or inlet, we endorse the traditional terminology, that is, the “thoracic outlet.” The diaphragm at the inferior aperture (base) and the interscalene triangle at the superior aperture (roof) of the chest are all thoracic outlets. The diaphragm is the vessel outlet for body and lower limb, and the interscalene triangle is the vessel outlet for body and upper limb (Fig. 14).

On the basis of our clinical observations, we have no doubt that TOS is a valid diagnosis resulting from...
compression of neurovascular structures in the thoracic outlet. Anatomical abnormality causes the thoracic outlet to become narrow. Chronic friction and repetitive intermittent compression of the subclavian vessels and brachial plexus in this region result in true and intractable TOS. The symptoms and signs related to vascular compression often manifest before evidence of nerve compression. Constant thickness of vessel adventitia, brachial plexus epineurium, and the overlying adipofascial tissues along with dramatic symptom relief after decompression are all strong evidences of the causality and the existence of TOS.

TOS rarely presents before the age of 10 years or in those older than 60 years. Children may not have adequate time to develop TOS. In contrast, older patients with TOS might have learned to avoid symptoms by posture adjustment and modification of their working practices and activities of daily living and might have successfully engaged in a rehabilitation program. Surgery in such patients is usually not required.

“Doctor shopping” is frequently observed in TOS patients. Some even undergo surgical intervention for carpal tunnel syndrome (CTS) and cubital tunnel syndrome (CuTS). The coexistence of CTS or CuTS with TOS may or may not be related to the double-crush phenomenon. Persistent symptoms after decompressive surgery for CTS or CuTS, particularly in patients younger than age 50, should trigger consideration of the possibility of an underlying diagnosis of TOS.

One third of TOS cases in our series (34%) had no identifiable etiology. However, surgical decompression almost universally provided resolution of symptoms. The presence of a cervical rib (only 9%) is traditionally regarded as a predisposing factor for the development of TOS, but it does not always cause TOS. Abnormalities of the first rib and scalene muscle are far more frequently associated with TOS.

Normally, the anterior scalene muscle arises from the anterior tubercles of the transverse processes of C3–C6 cervical vertebrae, whereas the middle scalene muscle originates from the posterior tubercles of the transverse processes of C2–C7 cervical vertebrae. Both muscles insert on the first rib to act as accessory muscles to elevate the first rib during inspiration. Fibers of the proximal scalenus muscles interdigitate and completely encircle the C5 and/or C6 spinal nerve. Thus, when tight or hypertrophic, they may dynamically compress the upper plexus and cause “upper plexus compression syndrome” with neurologic symptoms radiating widely to the upper chest, posterior neck, and occiput. Similarly, tight fibers of the distal scalenus anterior muscle may create “lower plexus compression syndrome” with neurologic symptoms radiating along C8/T1 dermatomes, with numbness or tingling, motor weakness, or intrinsic muscle spasm of the hand (Fig. 1).

First-rib abnormalities are considered rare causes of TOS in the literature. However, we often found subtle morphological differences of the first rib in our series of TOS patients. Abnormalities of the first-rib morphology are thought to narrow down the space of the interscalene triangle, thus predisposing to TOS. Based on operative findings and previous investigation regarding the relationship between the 2 dimensions of the first rib and TOS, a more detailed examination of the first rib may be warranted in the diagnostic workup.

The symptoms of TOS vary among patients. TOS should be considered in a young adult patient (especially those referred by a neurologist or a neurosurgeon) who presents with “frequent” pain or soreness in the neck, scapular or suprascapular regions associated with upper limb pain or soreness, paresthesias, and/or motor weakness. Pain and/or soreness often appears after periods of exertion; repeated attacks of drop hand and intermittent spasm of the thumb or finger are all possible evidences of TOS.

The vascular manifestations of TOS may be quite dramatic, with occurrence of sudden pallor, and the neurologic symptoms are usually reproduced momentarily after initiating limb elevation and first-rib compression. All of our patients who had undergone operation were positive for these 2 tests.

Most of the electrophysiology studies showed mild to moderate reduction of amplitude on the median, ulnar, and radial triple nerves, but the reduction was not significant. Computed tomography angiography and magnetic resonance angiography were valuable diagnostic modalities for TOS. Images were acquired with the arms at the side and also with the arm fully abducted, which often demonstrated extrinsic compression of the subclavian artery or vein in the region of the thoracic outlet. We did not routinely use duplex ultrasonography, which is advocated by some groups.

Most TOS patients will tolerate, and even become accustomed to, the TOS. Only a minority of patients are unable to tolerate the chronic discomfort and request surgical treatment. Some authors emphasize the importance of 6–12 months of a nonoperative management period once TOS has been diagnosed. Our experience supports this. Most patients will find improvement with appropriate physical rehabilitation, postural education, shoulder girdle muscle strengthening, and behavioral modification. In our series, surgical de-
compression was indicated for cases that failed conservative treatment.

A number of methods of decompressing the thoracic outlet have been described: scalenotomy, scalenectomy, first-rib resection, claviclectomy, pectoralis minor tenotomy, cervical rib resection, and combinations of these. Various surgical approaches have also been described: transaxillary, supraclavicular, transclavicular, infraclavicular, transthoracic, and posterior. These may also be used in combination. Orlando et al reported a large series of 538 patients of TOS who underwent 594 first-rib resections through a transaxillary approach during a 10-year period that had led to excellent surgical results. However, the rate of implementation of decompressive surgery by their group raises the question of whether conservative treatment measures were adequately explored. Transaxillary approach has more limited access to the usual anatomic structural causes of TOS and also does not provide access to the cervical or other rudimentary ribs. Pneumothorax requiring chest tube placement occurred in 138 patients (23%), which is a substantially higher rate of occurrence than that in our series. Studies have previously demonstrated that first-rib resection combined with scalenectomy is an effective means of decompression for TOS. The procedure employed by the senior author is the culmination of 30 years of evolution and refinement of decompression technique. The scalenus anterior and the first rib can also be removed individually if any difficulty is encountered.

According to literature, complications after TOS surgery are not uncommon and range from trivial to life-threatening. The symptoms of TOS may also recur. However, the low rate of major complications in our series is attributed to the operating surgeon’s familiarity with the anatomy of the region, and the use of Kerrison bone punch forceps. Careful denudation of the first rib to avoid pleural tear and resultant pleural effusion is mandatory. However, if tear of the apical pleura (which is intimately adherent to the periosteum of the first rib) occurs, pig-tailed chest intubation can be used for chest expansion and drainage. Any basal fluid accumulation occurs in the extrapleural space. The accumulated fluid will resolve spontaneously without the need for drainage or chest intubation.

The abundant lymph tissue and lymphatic ducts in the supraclavicular fossa, particularly on the left side, increase the risk of lymphatic injury and chyle leak. Careful ligation or coagulation of the lymphatic tissues helps limit lymph leakage.

CONCLUSIONS

It is evident that decompressive surgery through supraclavicular approach and near-total resection of the first rib and the scalene anterior muscle and of the cervical rib, if present, for TOS not only is an effective and safe procedure but also provides a diagnosis of the cause of TOS. For a patient who meets the criteria for surgical indication, decompressive surgery usually results in resolution of symptoms and no recurrence.

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PATIENT CONSENT

Parents or guardians provided written consent for the use of the patients’ image.

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