Thoracic Outlet Syndrome

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Abstract

The manifestations of thoracic outlet syndrome vary according to which of the neurovascular structures are affected. To provide optimal treatment, the pathogenesis must be understood in terms of both the anatomic variants and the dynamic factors. The diagnosis is primarily clinical, although ancillary diagnostic studies are useful in selected patients. Following a careful examination, the orthopaedic surgeon should be able to initiate a program of appropriate therapy depending on the nature and severity of the clinical manifestations. Initial treatment is oriented toward postural reeducation and periscapular muscle strengthening. Glenohumeral instabilities and painful upper-limb conditions that cause disuse atrophy must be addressed. Operative treatment is reserved for patients in whom a conservative program has failed and for those with significant neural or vascular deficits. The surgeon must be cognizant of the potential complications of the various procedures used to correct thoracic outlet syndrome. Proper selection of surgical candidates should produce significant improvement in most patients.

J Am Acad Orthop Surg 1994;2:317-325

Thoracic outlet syndrome (TOS) may be thought of as a complex of signs and symptoms resulting from compression of the neurovascular supply to the upper limb in the region of the supraclavicular area and shoulder girdle. Although the diagnosis is controversial, patients with symptoms and signs consistent with this diagnosis are seen in orthopaedic practice. The pathogenesis must be understood on both an anatomic and a dynamic basis in order to recognize the condition and to appropriately treat affected patients, many of whom have no obvious underlying structural anomalies, such as a cervical rib. The diagnosis is a clinical one, and although ancillary diagnostic studies may be useful in selected patients, the history and physical examination remain of primary importance.

Anatomy and Pathophysiology

It is important to consider the pathogenesis of TOS from the point of view of the underlying anatomy and its relationship to growth and development as well as the proximity of affected structures to the shoulder joint (Fig. 1). The thoracic outlet extends from the supraclavicular fossa to the axilla and includes the interval between the clavicle and the first rib. The cervical nerve roots exit their foramina to form the trunks of the brachial plexus as they pass through a triangle formed by the anterior scalene muscle medially and the middle scalene muscle laterally with the first rib as the base. The pleural apex is covered by the suprapleural membrane, which separates it from the periosteum of the first rib, which encircles it.

The apex of the axilla is bounded by the clavicle and the subclavius muscle anterolaterally, the upper border of the scapula and the subscapularis muscle dorsally, and the anterolateral border of the first rib medially. The brachial plexus and the subclavian and axillary vessels pass beneath the coracoid process and exit this area with the pectoralis minor muscle anteriorly.

The first rib is usually described as being divided into three parts. The first extends from the head to the neck. The second is oriented almost perpendicular to it and serves as the attachment for the middle scalene muscle, the first digitation of the serratus anterior muscle, and the muscles of the first intercostal space. The third, or vascular, segment contains the scalene tubercle, which is the attachment of the anterior scalene muscle, the costoclavicular ligaments, and the subclavius muscle. The subclavian vein usually is between the subclavius muscle and costoclavicular ligaments and the anterior scalene, which is attached to the tubercle.

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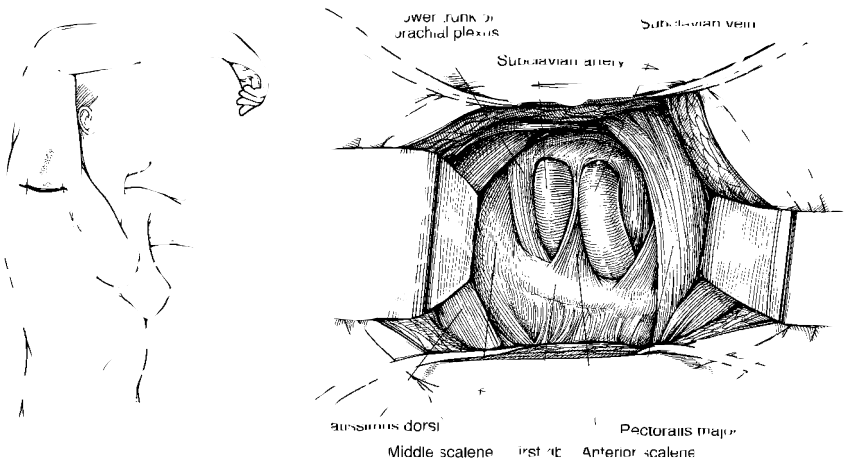

A B

Fig. 1 **A,** Axillary approach for first-rib resection. **B,** The thoracic outlet as seen through the axilla.

The subclavian artery is posterior to the anterior scalene muscle. Immediately adjacent to the subclavian artery, the lower trunk of the brachial plexus crosses the first rib.

In my opinion, the most useful article describing the pathogenesis of TOS is that of Todd,[1] which was published in 1912. With growth and development, since the vertebral column grows faster than the upper limb, the scapula descends, dragging the nerves and vessels with it. Under normal circumstances this does not present a problem. However, if anything should later increase the descent of the scapula, compression could result. This is particularly likely if for any reason the supporting musculature, particularly the trapezius, is weakened due to injury or disuse. Additional aggravating factors are obesity and excessively large breasts in the female.[2]

Todd described the relationship between the angles of the clavicle and the first rib and their differences in the two sexes at different ages, which explains the striking demographic features of TOS. Other authors have commented on the costoclavicular interval, which is narrowed by abducting the arm and bracing the shoulders, as another mechanism for vascular compression.

Although the anterior scalene muscle has been indicted as the primary villain in the pathogenesis of TOS and has been the target of many surgical procedures,[3,4] it alone is rarely the cause.[5] Variations in the manner of insertion of the scalene muscles on the first rib and the occurrence of congenital fibrous bands and adventitious ribs are of importance in some, but not all, patients. Roos[6] has described nine types of congenital bands that can produce compression of the nerves and vessels within the thoracic outlet. The most common of these is one that stretches across the concavity of the first rib from the neck to the scalene tubercle, where it can irritate the lower trunk of the brachial plexus. The anterior scalene muscle, which normally inserts on the scalene tubercle, may extend to cover the surface of the first rib and thereby narrow the interscalene interval and compress the nerves and vessels. The anterior and middle scalene muscles may insert in the form of a conjoined and fibrous edge, which can cause compression if for some reason the scapula descends.

Authors have disagreed about the overall incidence of cervical ribs in the general population. They were originally classified by Gruber in 1869[7] as consisting of four general types, which ranged from very short nubbins with little effect on the neurovascular structures to complete ribs that actually join the manubrium. Incomplete ribs may have a prominent fibrous band extending to the insertion of the anterior scalene, so that they are the functional equivalent of a complete rib in terms of their potential to cause compression. Sometimes the adventitious rib will be joined by bone to the first rib (Fig. 2). The middle scalene can insert on the adventitious rib, which will narrow the space available for the brachial plexus and the subclavian artery. A study of cervical ribs found an overall prevalence of between 0.5% and 1%, with bilaterality in approximately 50% of cases.[8] However, the presence of a rib anomaly does not, in any way, ensure that symptoms in the upper limb can be attributed to that rib.

The conditions that are related to the development of TOS on a secondary basis have as a common denominator their effect on increasing the descent of the scapula. Thus, it would not be difficult to envision how a direct injury to the neck and trapezius muscles in an automobile accident could cause the scapula to droop.[9,10] In addition, injury to any part of the upper extremity that causes pain and disinclination to use the limb can, in susceptible individuals, produce the same result by means of disuse atrophy of the supporting muscles. Patients with glenohumeral instability may experience paresthesias in the upper limb and may have an element of TOS to explain their complaints if

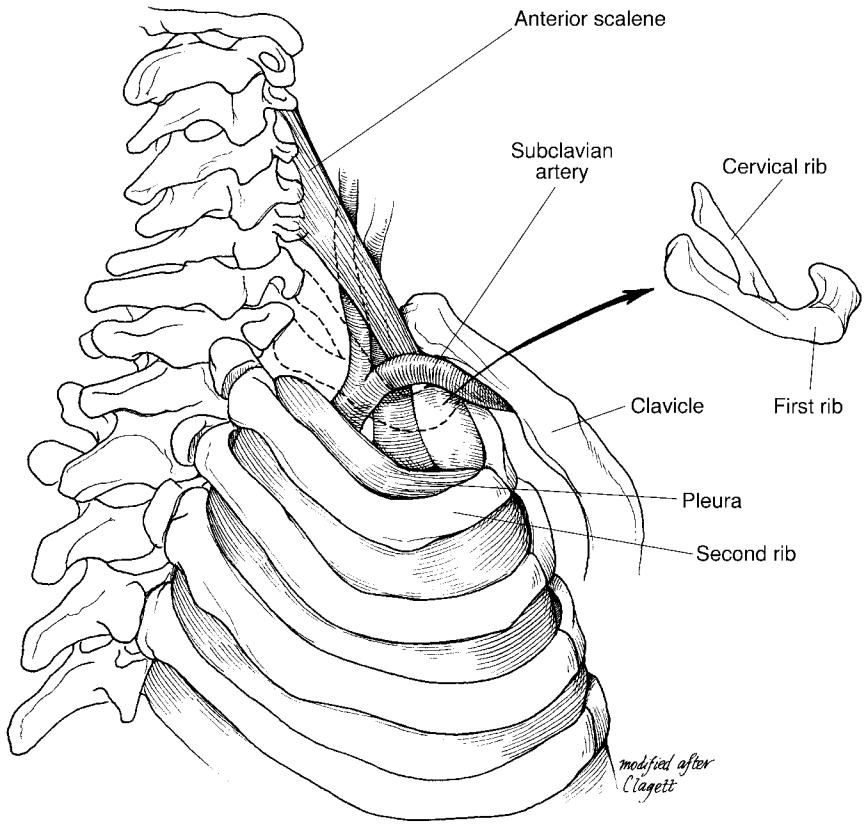

Fig. 2 Posterior-perspective view of a cervical rib and its relationship to the first rib, the pleura, and the subclavian vessels.

the scapular malalignment is not corrected.[11] In many cases, correction of the instability may eliminate the symptoms, but in others, a true TOS may be associated and may ultimately have to be treated surgically if muscle reeducation and postural correction do not succeed.

Obesity cannot cause TOS in and of itself, but it can aggravate it. Emotional depression, which causes patients to adopt a slumping posture, can also make the condition considerably more difficult to treat.

Clinical Presentation

There is a spectrum of possible clinical presentations of TOS, the appearance depending on which of the three structures at risk—the subclavian artery, the subclavian vein, and the brachial plexus—is most affected. Although some classifications present the entity as being either arterial, venous, or neural in origin, these distinctions do not accurately reflect the reality of the intimate proximity of the contents of the thoracic outlet. Although one structure may be compressed more than the other two, especially due to anatomic variations such as congenital bands, it is less likely for any system to completely escape if the underlying cause of compression is a postural abnormality.

In general, the most prominent symptoms stem from neural compression, although historically most of the attention has been focused on the subclavian artery. Consequently, many patients have carried the diagnosis of TOS simply because an examiner was able to demonstrate extinction of the pulses with the arm in various positions. This misconception has sometimes led to overdiagnosis and failure of therapy, to the point where some authors have felt that TOS must be either very rare[12] or nonexistent.

The clinical picture should be examined in terms of the demographic features of the patients as well as the symptoms and signs that are seen in this population. Most authors have agreed that the disorder is most typically found in women, and that they outnumber men with the disorder by a ratio of about 3.5:1. It is very rare to encounter the problem in a prepubertal girl or in a postmenopausal woman unless she has been symptomatic for a long time.

Patients may complain of pain in the neck or shoulder and numbness and tingling involving either the entire upper limb or the forearm and hand. The ulnar side of the limb and the two ulnar digits are predominantly involved, although the middle finger may also be included. Nocturnal pain and paresthesias are common, and they must be differentiated from those due to carpal tunnel syndrome, which commonly affect the radial side of the hand. Roos[13] has described a far less common variety of TOS that affects the upper three nerve roots and is manifested by complaints referred to the neck and upper arm. This variety must be differentiated from cervical disk disease and is usually treated by scalenectomy.

Often the patient will experience difficulty with use of the limb in an elevated, overhead position, such as is required to hold a hair dryer. Some patients will feel numbness when carrying things, typing, or even driving. In some cases there

will be a decline in the strength or dexterity of the hand, even in the absence of obvious atrophy. It will usually involve the ulnar-innervated intrinsic muscles, although some authors have noted that the thenar muscles of opposition are commonly affected.[14] In my experience, weakness of the long flexor muscles of the little and ring fingers is more likely to accompany ulnar-innervated intrinsic muscle weakness, and the median-innervated thenar muscles are more likely to be involved if atrophy of the ulnar muscles is severe.

The sensory findings are very often subtle, are usually on the ulnar aspect of the hand, and may include the medial aspect of the forearm. This sensory pattern can be used to differentiate TOS from ulnar neuropathy. Pain in the arm, shoulder, neck, and chest and headache may accompany any of these other complaints. Chest pain may be particularly frightening if it occurs on the left side, where it may be interpreted as being of coronary origin; such pain has been referred to as "pseudoangina."[15,16]

Venous compression may be intermittent or, less commonly, constant, resulting in swelling of the limb or varying degrees of cyanosis. The most striking result of venous compression is so-called effort thrombosis, which results in acute thrombosis of the subclavian vein.[17,18] This entity should be treated acutely with intravascular thrombolytic agents, followed by anticoagulation to avoid chronic swelling and pain in the arm.[19] Prophylactic first-rib resection is done on an elective basis to prevent rethrombosis after the clot has been lysed or the vein has spontaneously recanalized.[20,21] Fortunately, few patients present with acute arterial insufficiency due to thrombosis of an aneurysm of the subclavian artery. Such cases and others with varying degrees of arterial compromise must be promptly recognized and treated to avoid loss of all or part of the limb.[22-24]

Any of the facets of this disorder may predominate in the presentation to the clinician, who must respond with therapy that is appropriately directed.

Diagnosis

The physical examination should include the neck and supraclavicular fossa on both the affected and the contralateral side. Neck range of motion is usually not restricted, although the trapezius muscle on the affected side may be both tender and atrophic. In many patients, the ipsilateral scapula will be held lower and more anterior, and the clavicle will appear more horizontal than normal. There may be tenderness over the brachial plexus. Tinel's sign may be elicited and referred to the ulnar aspect of the hand, but this is a nonspecific sign. It is important to carefully examine the shoulder girdle, particularly with reference to the stability of the glenohumeral joint, since anterior subluxation may produce the symptoms of "dead arm syndrome," which are similar to and may even overlap those of TOS.[11]

The provocative maneuvers that have been used in the clinical diagnosis of TOS (Fig. 3) must be carefully interpreted to avoid overdiagnosis. It is not significant to be able to merely obliterate the pulse by some position of the arm, since many women who are asymptomatic will exhibit this phenomenon. A test cannot be considered to be positive unless the patient, without prompting, complains of reproduction of the symptoms when the arm is placed in the provocative position. The classic Adson's maneuver (Fig. 3, A)[4] is performed with the arm at the side, the neck hyperextended, and the head turned toward the affected side. The Wright's maneuver (Fig. 3, B), in which the arm is abducted and externally rotated,[25] has a higher rate of sensitivity, which may be increased by having the patient take and hold a deep breath. Even in this test, however, the possibility of ulnar neuropathy at the elbow must be taken into account, and the test should be repeated with the elbow in full extension so that a positive elbow-flexion test will not confuse the issue. Assuming the shoulder-braced position will produce symptoms in patients with narrowing of the costoclavicular interval (Fig. 3, C). Patients with ptosis of the scapula as a cause of the compression will exacerbate their symptoms with downward pressure on the shoulder girdle. The overhead exercise test (Fig. 3, D) requires the patient to flex and extend the fingers with the arms elevated; if there is significant compression, symptoms of fatigue and cramping will occur within 30 seconds. With all of these tests, the examiner should listen over the subclavian artery for the presence of a bruit.

A complete motor and sensory examination should be done for the entire upper extremity. It is particularly important to carefully test the strength of the intrinsic musculature in the hand. The other upper extremity should be subjected to the same examination regardless of whether it is symptomatic or not. The vasomotor status of the limb and the presence or absence of swelling should also be recorded.

Plain radiographs of the cervical spine should be examined for evidence of diskogenic disease, adventitious ribs, or overly long transverse processes. Only if diskogenic disease is strongly suspected is it advisable to perform

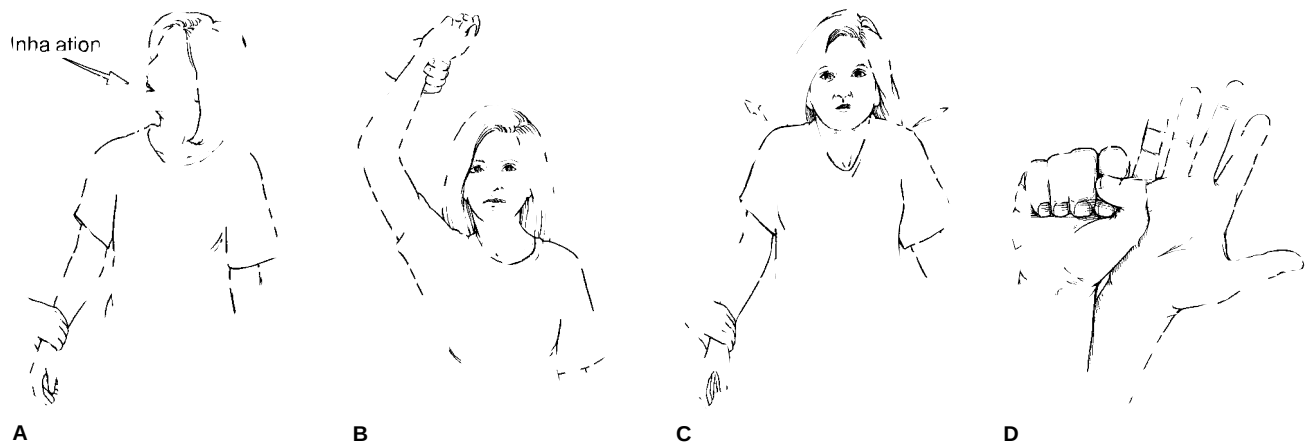

Fig. 3 Provocative maneuvers used in evaluation of patients with suspected TOS. Symptoms must be reproduced for tests to be considered positive. **A,** Adson's maneuver. **B,** Wright's maneuver. **C,** Costoclavicular, or military brace, maneuver. **D,** Overhead exercise test.

magnetic resonance imaging; neither it nor computed tomography has proved helpful in the diagnosis of TOS. A chest film that clearly shows the apices is important because tumors in this region, particularly primary pulmonary tumors, may be responsible for neurovascular compression.

Although it would be very desirable, there is no ancillary diagnostic study on which one may rely for confirmation of the diagnosis of TOS. It has been reported that the measurement of conduction velocity of the ulnar nerve through the thoracic outlet is a reliable indicator of compression, but this work has not been confirmed.[26,27] In my opinion, the test is not useful in TOS unless one is concerned about the possibility of a coexisting lesion of a peripheral nerve, such as a double-crush syndrome.[28] Somatosensory evoked potentials have also not been reliable for diagnostic screening.[29] Digital plethysmography has proved similarly disappointing.[30]

Arteriography and venography should be confined to those cases wherein there is strong evidence of serious vascular pathology. According to some authors, if there is suspicion of a subclavian aneurysm because of the presence of a complete cervical rib in an older patient, it is reasonable to obtain an arteriogram.[23] However, I have not confirmed the presence of an aneurysm in at least a dozen attempts over the past 20 years in such patients. Nevertheless, if an aneurysm is present, it would be best to know that before encountering it through an axillary approach to the first rib. For patients with acute thrombosis of the subclavian vein, venography is indicated as a guide to therapy.

The differential diagnosis of TOS is shown in Table 1. In the final analysis, the diagnosis of TOS remains a clinical one.

Table 1
Differential Diagnosis of Thoracic Outlet Syndrome

Cervical radiculopathy
Supraclavicular fossa pathology
Lung tumors
Brachial neuritis
Carpal tunnel syndrome
Ulnar neuropathy
Reflex sympathetic dystrophy

Conservative Management

The treatment of TOS should be guided by the underlying pathogenesis. In addition, specific contributory factors should be identified whenever possible. If, for example, the condition is aggravated by the patient's having to assume a constant or repetitive elevated position of the arms at work, attempts should be made to alter the ergonomic characteristics of the job. Patients with a poor general state of conditioning should be encouraged to pursue a fitness program in addition to what is done for the shoulder girdles. Obese patients should try to lose weight, and women with overly large breasts may find that better support with long-line bras alleviates their symptoms. In extreme cases of gigantomastia, reduction mammoplasty may be indicated to reduce the drag on the shoulder girdles.

The cornerstone of conservative therapy is a carefully regulated program of muscle strengthening

and postural reeducation exercises taught to the patient by a knowledgeable therapist. Overhead exercises and those that involve shoulder bracing are usually poorly tolerated by patients with TOS. Unfortunately, exercise protocols in the literature include many of these provocative maneuvers.[31] The place of stretching shortened muscles must be carefully evaluated in each patient.[32] In my opinion, deep massage to "mobilize the first rib" is often quite painful and of questionable value. Patients with TOS are also usually intolerant of cervical traction.

The trapezius, rhomboid, and levator scapulae muscles can be strengthened using elastic bands or free weights with the arms elevated less than 90 degrees and with avoidance of bracing of the scapulae. Some patients will have to start their exercise program with simple shoulder shrugs and progress to those with the arms in gradually increasing flexion in diagonal patterns. Patient communication with the therapist and the physician is important to allow modification of the exercise program when necessary. Patients will often not experience symptomatic improvement before 2 months. Nevertheless, they must continue with the exercises until the muscular atrophy and weakness have been reversed and they have developed awareness of correct posture. Swimming has been shown to be of value in patients who can tolerate it, although the backstroke and full breaststroke should be avoided.

Conservative management will not succeed if there is significant outlet compression and more than minimal muscle atrophy in the hand. However, in my practice it has been possible to treat most patients with TOS nonoperatively.

Surgical Treatment

Indications

Indications for surgical treatment are as follows: (1) failure of a carefully supervised exercise and postural program; (2) intractable pain; (3) significant neurologic deficit; (4) impending vascular catastrophe, usually of an arterial origin; and (5) after successful initial treatment of subclavian vein thrombosis.

Many patients seen with TOS will have already undergone unsuccessful treatment with a variety of therapies. It is essential that the surgeon who undertakes treatment leading to surgery be clear as to the nature of that prior treatment. It is most important to understand previous physical therapy, since for many patients treatment has been unsuccessful because it included exercises that were painful or provocative. The best way to assess this possibility is to ask the patient to demonstrate the exercises that were actually done rather than to merely describe them. If it becomes apparent that optimal conservative treatment has failed, it is reasonable to offer surgery. It should be presented as an option only for patients who feel that they simply cannot continue with the condition as it is and who clearly understand the potential risks and benefits of the proposed surgery.

Operative Procedures

At the present time, there is no universal agreement as to the optimal operative approach for decompression of the thoracic outlet.

Procedures that have been used include the following: (1) scalenotomy, (2) scalenectomy, (3) first-rib resection, (4) pectoralis minor tenotomy, (5) claviculectomy, and (6) combinations of these procedures.

The anatomic approaches to these procedures are varied and are often dictated by the specialty training and orientation of the surgeon. Listed not necessarily in order of preference or popularity, they are as follows: (1) supraclavicular, (2) transclavicular, (3) subclavicular, (4) axillary, (5) deltopectoral, (6) posterior, and (7) combined.

The constraints of space do not permit a detailed description of the techniques of each of these operations, which can be found elsewhere.[3,5,13,33-40] What I shall do is offer an overview with pertinent comments regarding the applicability, advantages, and disadvantages of these approaches.

Although scalenotomy was advocated by Adson[3] and was widely practiced from the late 1920s through the early 1960s, it has been largely discarded because of the high rate of recurrence.[5] Clearly, the assumption that the anterior scalene was the single offending anatomic structure is not correct in most cases. The procedure is, therefore, not recommended.

Claviculectomy does decompress the thoracic outlet in patients with costoclavicular compression. It can be disastrous, however, if there is weakness or paralysis of the trapezius because there is then nothing to support the shoulder girdle, which becomes unstable and painful.

Pectoralis minor tenotomy has the appeal of simplicity and safety, but it is difficult to be certain that additional sites of compression do not exist. I therefore cannot recommend it with confidence as the sole surgical treatment for a patient with TOS.

The operative procedures that I believe are most applicable to patients with TOS are scalenectomy and first-rib resection. They can be performed through a variety of operative approaches, which sometimes can be used in combination.

Transaxillary first-rib resection has been popularized by Roos, who first reported it in 1966.[13,33,35] This is

a technically demanding procedure with little or no margin of error, since it involves a deep and truncated operative field that requires precise control. The patient is under general anesthesia in the lateral decubitus position. Complete muscle relaxation is required to allow full access to all structures, and the arm should be supported in abduction by a scrubbed assistant rather than maintained in traction by a mechanical arm-holder, as is used for shoulder arthroscopy. The incision is horizontally oriented over the third interspace (Fig. 1, A) and should, whenever possible, spare the intercostobrachial nerve to avoid numbness over the posterior aspect of the arm. Through this approach, it is possible to resect the first rib as well as most cervical ribs and to evaluate the degree of compression of the lower trunk of the plexus and the subclavian artery and vein. It does not permit visualization of the remainder of the plexus or congenital bands compressing it more cephalad. Also, although the scalene muscles are detached, they cannot be resected in this way.

In the hands of an experienced operator, the procedure has the advantage of being extremely well tolerated and of sparing the anatomic structures surrounding the first rib. However, they must be kept clearly in view at all times, since vascular injury or injury to the lower trunk of the brachial plexus can occur. In addition, one must remember that the long thoracic nerve runs either through or posterior to the middle scalene muscle and must be protected.

Since the dome of the pleura is intimately associated with the suprapleural membrane and the first rib, it may be inadvertently torn as the rib is removed. Pneumothorax can be handled by either aspiration of the pleural cavity with closure or placement of a chest tube. I have found the latter method to be effective.

Transaxillary resection of the first rib is the procedure most commonly performed for the treatment of TOS involving the lower trunk of the brachial plexus, but it requires the most experience on the part of the surgeon. It may be combined with a supraclavicular approach for a more thorough exploration of the area when clinically indicated.

The anterior approach to the thoracic outlet is preferred by some authors because of their belief that it is technically easier, allows greater visualization (particularly of fibrous bands), and has fewer complications.[34,41,42] Anterior scalenectomy without rib resection is advocated by some surgeons, who believe that the latter step is rarely necessary. Whether middle scalenectomy is necessary in a patient who has not undergone previous surgery is not clear, although I have rarely considered it necessary.

Because I believe that much of the compression occurs at the juncture of the lower trunk and the rib, I do practice and advise resection of the first rib. Although one can resect the first and adventitious ribs from above, I find that access to the subclavian vein is less facile than it is through the axilla and that resection of the rib is actually more thorough with the axillary approach. The field is considerably shallower when approached from above, however, which makes vascular control easier. The approach from above may be combined with the axillary approach, or it may be employed for the treatment of recurrences when there is a retained and overly long posterior remnant of the first rib or suspected scarring within the scalene muscles.

The transclavicular approach has few applications except in situations where there is already either a fracture or a nonunion of the clavicle. In my opinion, claviculectomy should not be done for the treatment of an otherwise uncomplicated TOS. However, in cases of postoperative recurrence of thoracic outlet compression with adherence of the subclavian vein to the anterior edge of the resected first rib, this approach may be necessary.

The subclavicular approach is technically difficult and adds increased risk of injury to the subclavian vein, which must be retracted while the rib is removed. I would not recommend it except for access to the anterior portion of the first rib. Even then, its usefulness is limited.

The posterior approach to the thoracic outlet[5] has the advantage of wide exposure of the posterior elements of the first rib and the nerves. It is identical with the approach used for thoracoplasty. The problem is that it requires a large and bloody approach through the all-important trapezius muscle, which supports the scapula. In my opinion, this approach is contraindicated in patients who already have weakness of this muscle and ptotic scapulae and in those who have to do heavy work following their surgery. I rarely use it now, reserving it mainly for patients in whom an axillary approach was unsuccessful and left a retained posterior rib fragment.

With the exception of the posterior approach, which cuts the trapezius, levator scapulae, and rhomboid muscles, there is no need for postoperative immobilization of the upper limb in patients who have had surgery for TOS. It is wise to avoid heavy lifting for about a month postoperatively, but beyond that there are no restrictions. In general, the routine of exercises that was done preoperatively can be resumed 1 month postoperatively.

To avoid recurrences, it is important to ensure that the scapular muscles remain strong and able to support the shoulder girdle.

Recurrences may present in asymptomatic postoperative patients who develop ptosis of the scapula due to neglect of the exercise program. One should try to understand the mechanics of the recurrence. Many times, examination will reveal a droopy shoulder and atrophic musculature. Most patients with recurrences can be rehabilitated with a program of postural reeducation and muscle strengthening. Only after all conservative modes of treatment have been exhausted should one consider the surgical approach, and then it should be tailored to the specific component of the neurovascular supply that is being compressed.[37,43-45]

The results of the surgical treatment of TOS are, like all aspects of this disorder, not simple to quantitate. In some situations, reversal of objective findings may be obvious. In many cases, however, the criteria of success depend largely on the patient's report of relief of symptoms. For some patients with long-standing pain or possible secondary-gain motivation, this may be hard to evaluate. Nevertheless, with proper selection of patients for surgery, the majority should be significantly improved; fewer will be totally cured of their symptoms.[46,47]

Summary

Thoracic outlet syndrome, which causes pain and paresthesias in the upper limb, results from compression of the neurovascular structures supplying it. The diagnosis is a clinical one, although ancillary diagnostic procedures are useful in differential diagnosis. Appropriate conservative management is indicated in most cases and is directed at postural reeducation and shoulder-girdle strengthening exercises. The indications for surgery are defined in terms of significant neurovascular deficits or intractable pain. The surgery is technically demanding.

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