Thoracic Outlet Compression Syndrome and Its Surgical Treatment Modalities

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Abstract

The term "thoracic outlet compression syndrome" (TOCS) means compression of the very important neurovascular structures in the thoracic outlet area causing complex symptoms and signs in the upper extremity, shoulder girdle region, upper chest, neck, and head. These complex symptoms and signs include upper extremity pain, numbness, tingling, weakness, and some vasomotor changes. The most commonly compressed structures with descending frequency are the brachial plexus and subclavian vein and artery. More than 70 % of patients have a history of trauma to the neck, shoulder girdle, or upper extremity, which are the main etiological factors in the development of TOCS. Several sportive activities such as American football, baseball, swimming, and wrestling may cause this problem.

Anatomy

Anatomically three places at the thoracic outlet region are usually responsible for the development of compression on the neurovascular structures (Fig. 1). These are (1) interscalene triangular space, (2) costoclavicular space, and (3) less commonly subpectoralis minor space.

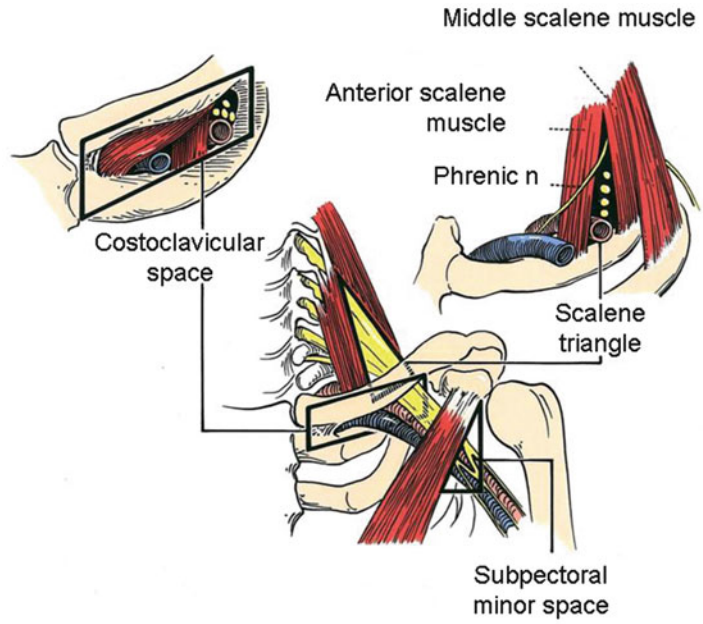

Fig. 1 Three anatomical areas of the thoracic outlet region are usually responsible for TOCS symptoms (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

History

Historically, in 1921 Astley Cooper first described the symptoms of TOCS. The term TOCS was first introduced by Peet and Rob in 1957 and 1958 (Atasoy 1996). The existence of cervical ribs was known at the time of Galen in 150 AD (Brantigan and Roos 2004; Atasoy 2004a). X-rays taken on a more than 3,000-year-old Egyptian mummy showed the presence of a cervical rib (Atasoy 1996). Murphy performed the first resection of a first rib in 1908 (Adson and Coffey 1927; Atasoy 2004a). Adson and Coffey introduced the scalenotomy in 1927 (Adson and Coffey 1927). Unrefined scalenectomy was performed in 1938 (Atasoy 1996). Roos and Owens described transaxillary first rib resection in 1966 which has since gained popularity (Roos 1966). In the late 1970s and early 1980s, refined scalenectomy was described by Sanders and Roos (Sanders et al. 1979; Roos 1982; Atasoy 1996). Since late 1989 the author has combined transaxillary first rib resection with immediate transcervical scalenectomy as a total decompression of the thoracic outlet region with gratifying results (Atasoy 1996, 2004b) (Table 1).

After gaining more knowledge and experience in this field, the author now mainly performs transcervical scalenectomy because soft tissue changes, either congenital or acquired, are the main etiological factors in the development of TOCS in at least 70 % of cases (Fig. 2a). This approach is also being used particularly for

Table 1 Evolution of thoracic outlet syndrome surgery

Name of operation	Year first performed	Surgeon who introduced it
Cervical rib resection	1861	Coote
First rib resection	1908	Murphy
Scalenotomy	1927	Adson/Coffey
First rib resection – posterior approach	1961	Clagett
First rib resection – supra- and infraclavicular approach	1960s	Various surgeons
First rib resection – transaxillary approach	1966	Roos
Scalenectomy	1938	Adson
Refined scalenectomy	1979	Sanders
Combined approach (transaxillary first rib resection followed immediately by transcervical anterior and middle scalenectomy)	1989	Atasoy

(Adson and Coffey 1927; Atasoy 1996, 2004b)

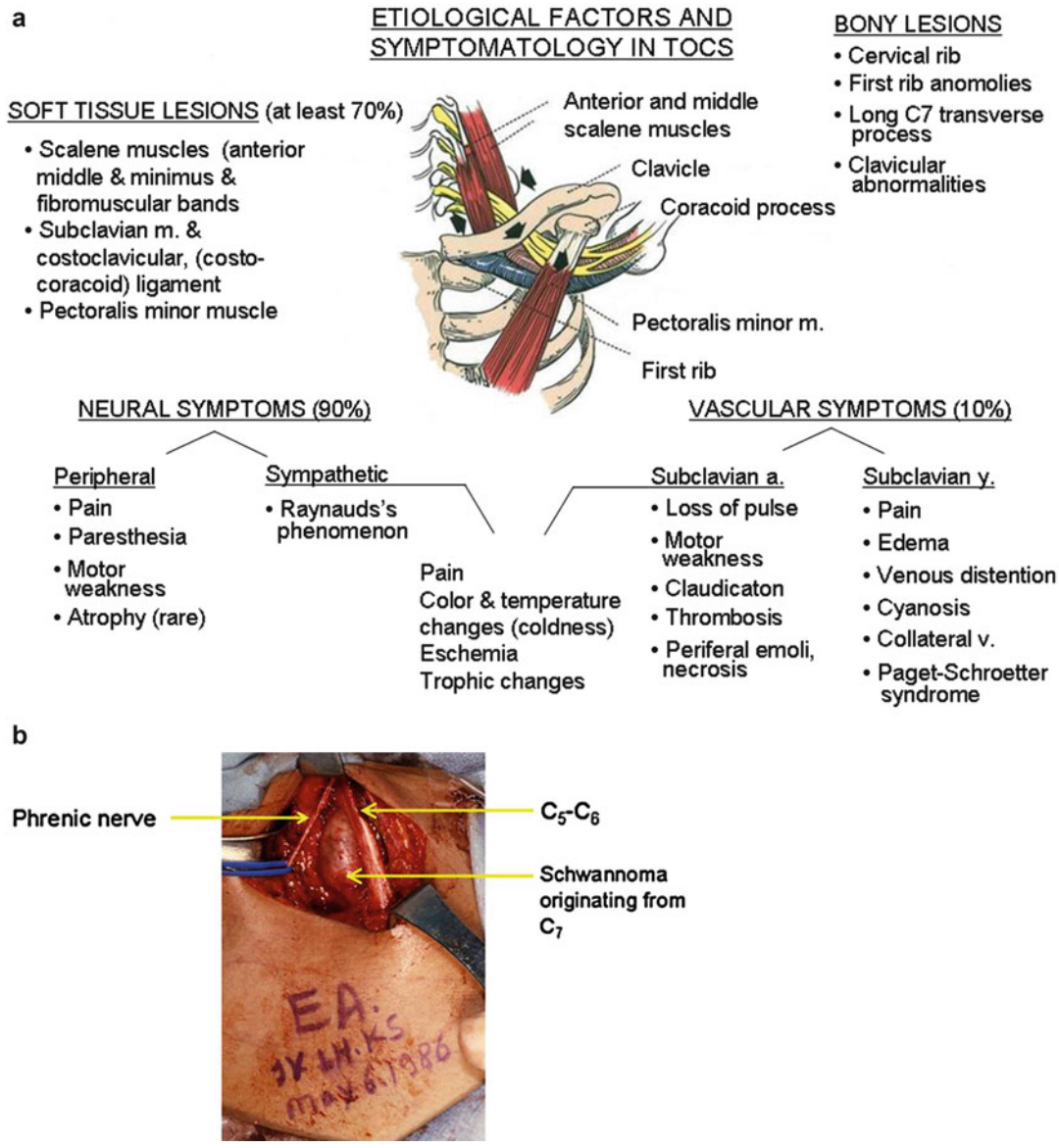

Fig. 2 (**a**) Summarized etiological factors and symptoms of TOCS (with permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) Schwannoma originating in the left C7 root causing a space-occupying lesion in the interscalene space for the development of TOCS (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

overweight patients because transaxillary first rib resection is more difficult and is a high risk in these patients. Older patients in poor health are also candidates for this approach. However, when the combined procedure is indicated and performed, it will totally decompress the neurovascular structures and create a wider space for these structures to pass through and a lesser chance of recurrence.

Etiology and Incidence

There is a low incidence of TOCS reported in literature (0.5–0.7 %) (Atasoy 1996). But the author believes it is much more, at least 1–2 % of all population. Many people have the milder symptoms of TOCS and do not seek medical help.

Many of them think it is part of aging, although many patients with TOCS are of younger age (20–40) category. In the author's hand surgery practice, nearly 50 % of newly referred patients have complaints of upper extremity pain, numbness, tingling, and weakness.

After getting a detailed history and examinations, the author got the impression that almost 50 % of these patients' complaints are suggestive of TOCS. The oldest patient he had was 70 years old, and the youngest was 10 years old. Female to male ratio was about 4:1.

Two tissue groups are usually known as a factor in the development of TOCS – these are soft tissue and osseous structures (Fig. 2a). The soft tissue group is the main etiological factor, and it comprises 70–80 % of all cases of TOCS (Fig. 2b). This group includes congenital or acquired scalene muscle changes and abnormal bands and ligaments. The osseous group comprises of only 30 % or less of all etiological factors in the development of all TOCS. It includes all bony structures in the thoracic outlet region such as the cervical rib, first rib, second rib, and clavicular abnormalities, either congenital changes or acquired changes such as excessive callus formation after a fracture of the first rib or clavicle (Fig. 3a–d).

A trauma to the neck, shoulder girdle, and upper extremity is the main cause for the development of symptoms of TOCS. There is at least 70–80 % history of trauma in all TOCS cases. The trauma can be a repetitive or a single blow type. The trauma can cause inflammation, swelling, thickening, spasm, and even contracture in the scalene muscles and their sheath. Also some muscle fiber changes have been reported (Sanders and Hammond 2004a). These changes will cause narrowing especially at the interscalene triangle and initiation of the symptoms.

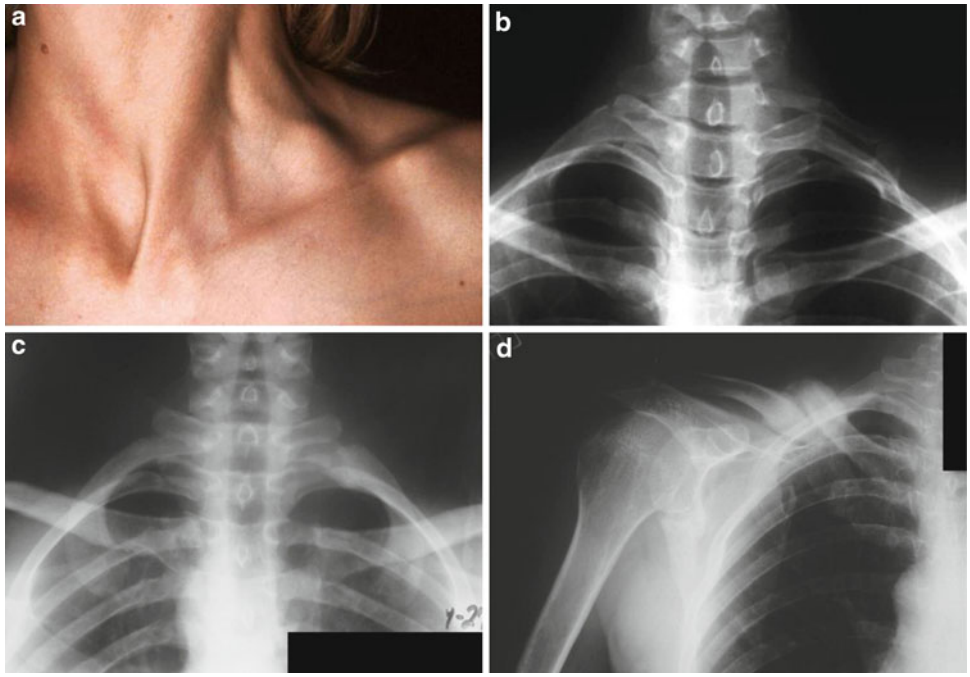

Fig. 3 (**a**) Very prominent tip of the left cervical rib causing TOCS symptoms (with permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) An x-ray of the same patient which shows fused cervical rib with the first rib (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**c**) Fracture of very posterior part of the first rib while playing American football (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**d**) Fracture of right clavicle with excessive callus formation following a wrestling match (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

Symptomatology

In the symptomatology of TOCS, usually there are three parts of brachial plexus involvement: (1) upper plexus (C5, C6, C7 root involvement), (2) lower plexus (C8–T1 root involvement), and (3) combination (entire plexus involvement).

The lower and combined types comprise nearly 90 % of all TOCS cases. Depending on the level of involvement, patients will have either outer or medial side of the upper extremity symptoms, headaches, fascial and jaw pain, earache, stuffiness, and neck, shoulder, upper back, and pectoral myofascial pain (Fig. 4a, b). The symptoms are worse during daily activities and involve upper extremity weakness, tiredness, heaviness, and pain, and some numbness and tingling are quite common complaints with above shoulder activities. Sleeping on the symptomatic extremity very often can cause arm pain, numbness and tingling, and coldness in the arm and hand.

Classification

Thoracic outlet compression syndrome is classified in two groups: (1) neurogenic TOCS which comprises at least 90 % of all TOCS cases and (2) true vascular group which includes about 10 % or less of all cases of TOCS, including venous and arterial type. Venous compression is much more commonly seen than the arterial compression. The venous type comprises nearly 80 % of all vascular TOCS.

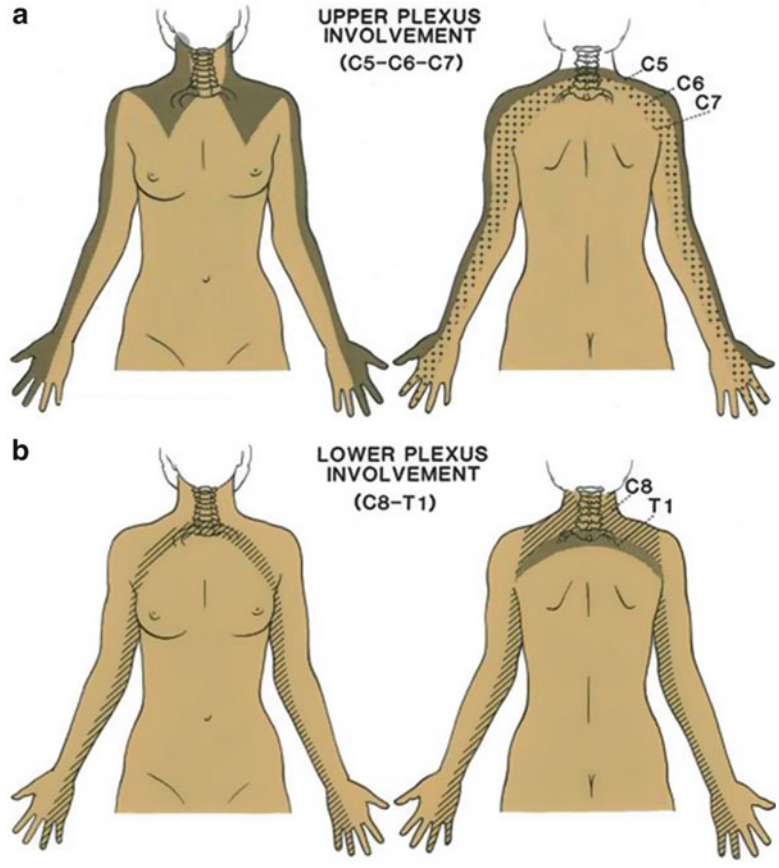

Fig. 4 (**a**, **b**) Pain distributions with the upper (C5, C6, C7) and lower (C8, T1) plexus involvement to the upper extremity, upper chest, and neck areas (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

Neurogenic Classification

Neurologists have classified the neurogenic TOCS in two groups: (1) true neurogenic with some positive laboratory findings and (2) disputed neurogenic TOCS which is the most commonly seen and has no positive findings with EMG/NCS. The routine cervical spine x-ray, MRI of the cervical spine, computed tomography scan, and vascular studies do not reveal any positive findings. In 2008 Machanic and Saunders reported medial antebrachial cutaneous nerve measurement as a fairly reliable finding in the diagnosis of neurogenic TOCS (Machanic and Sanders 2008).

The physician must rely on the patient's history, subjective complaints, and positive findings on physical examination. A negative EMG/NCS cannot rule out the presence of TOCS, if the patient has a strong history of complaints and important findings with physical examination. For this reason, the author strongly believes that a strong history of complaints and very sufficient positive findings with physical examination are the "gold standard" in making a diagnosis (Atasoy 2010).

Vascular Classification

The compression on the subclavian vein usually occurs at the area between the anterior scalene muscle insertion to the first rib and subclavius tendon, costoclavicular ligament insertion in the very medial part of the first rib. The subclavian vein thrombosis may occur in this area, and it is called "effort thrombosis" or Paget-Schroetter syndrome. The subclavian artery compression is rarely seen, and it may occur with abnormal insertion of the middle scalene muscle to the first rib, abnormal bands located under the subclavian artery, and excessive callus formation after clavicular and first rib fracture. In most cases the patient has both neurogenic and arterial TOCS syndrome.

All sportive activities require some degree of aggressiveness. Probably the most aggressive sport is American football. In spite of wearing protective gear, braces, pads, and helmets, the American football is the most traumatic sport, causing more injuries to the head, neck, both upper and lower extremities, and spine, which can cause lifelong problems to the player.

The best thing is to avoid more aggressiveness and traumatic incidence, but it is practically impossible because of the nature of this sportive activity.

The author has seen several cases of subclavian vein compression in sports injuries: a college swimmer, high school baseball player, college basketball payer, and college tennis player. Most of them had a combination of venous compression symptoms as well as neurogenic TOCS symptoms. The symptoms can occur with too much pressure from the coaches, family, and spectators to the players for more hustling and aggressive playing activity. If there is some congenital narrowing of the space where the subclavian vein passes through between the anterior scalene muscle and subclavius tendon, costocoracoid ligament insertions to the first rib at the very medial part of the first rib then the compression on the subclavian vein may occur.

The compression and even thrombosis of the subclavian vein may occur in weight lifters and wrestlers and in difficult competitive sports. The author has seen a few young female swimmers who had compression of the vein and later developed thrombosis of the subclavian vein.

If the patient has pure subclavian vein compression, only a transaxillary first rib resection would be indicated. If there is some evidence of neurogenic TOCS symptoms, the patient will require a combined surgical procedure involving transaxillary first rib resection and transcervical anterior and medial scalenectomy at the same setting.

Fractured first rib and clavicle has been seen after a falling accident during an American football game. The fracture involved the very posterior part of the first rib causing only neurogenic TOCS involving the lower brachial plexus (C8–T1) (Fig. 3c). The patient was successfully treated with transaxillary first rib resection in the early 1980s before the combined approach was utilized. The other case with a fracture clavicle with excessive callus formation had the symptoms

of neurogenic TOCS and was treated with a combined transaxillary first rib resection and transcervical anterior and middle scalenectomy, which was performed after the combined approach began to be used in late 1989 (Fig. 3d). Improvement in advanced protective garments and bracing has been quite helpful in preventing these kinds of injuries in young football players.

Examination and Diagnosis

The patient's involved extremity should be carefully examined for any temperature or color change, venous distention, and any evidence of atrophy. Evidence of any associated peripheral nerve compression such as carpal tunnel, cubital tunnel, pronator teres, and even radial tunnel compression should be investigated.

Both supra- and infraclavicular areas should be examined for any evidence of tenderness and the presence of radiating Tinel's sign to the extremity, including the individual digits by compression and percussion. The grip strength should be measured in both hands. The presence of bilateral upper back and pectoral myofascitis should also be checked. The scapular region should be examined for any evidence of winging of the scapula.

Nearly 50 % of patients will have complaints of coldness in the involved extremity. This is usually secondary to the compression of the brachial plexus that creates sympathetic overactivity resulting in vasomotor changes with coldness and color changes in the involved extremity. In many cases the diagnosis is overlooked, and the patient is treated for the diagnosis of reflex dystrophy (regional pain syndrome).

Some specific tests for TOCS, such as neck tilt (reverse Adson), hyperabduction (Wright's), costoclavicular compression, and Roos' test, which is also called elevated arm stress test (EAST), should be performed. Roos' test is considered one of the most reliable tests and is generally considered normal if the patient has no symptoms at the end of 3 min (Fig. 5a–e).

Sometimes distal nerve compression in the involved extremity, such as carpal tunnel, cubital tunnel, pronator teres, and even radial tunnel compression, can be an early sign of TOCS, especially in young working adults. This is called a double crush, triple crush, or even quadruple crush syndrome, and they are not uncommon with TOCS (Mackinnon 1992). Nearly 40–50 % of TOCS cases have these associated distal nerve compressions with EMG/NCS and physical examination. This can be explained on the basis that the compression of the proximal part of the nerve interferes with antegrade axonal transport, which may lead to a disturbance of the distal part of the axon's membrane composition making the axon less resistant to the external compression (Upton and McComas 1973; Pang and Wessel 1988; Wood et al. 1988; Szabo 1989). Also the reverse crush syndrome has been proposed. The patients should be informed of these possibilities and additional nerve decompression surgeries in these areas either before or after TOCS surgery.

The surgeons who are treating patients with TOCS should have a good knowledge of peripheral nerve compression in the upper extremity and should be able to perform distal nerve decompression either before or after the TOCS surgery, rather than referring these patients to other surgeons. Generally not much emphasis is given to the weakness of the extremity and associated myofascial trigger points in the upper back and the pectoral area. The chance of helping arm symptoms with surgery is about 80 % or better after all necessary surgery, but helping the quite symptomatic myofascial trigger points is about 50-50 with all existing treatment modalities.

Another matter is markedly decreased grip power and upper back myofascial pain. The prognosis is guarded if the patient has markedly decreased grip strength (50 % or more) and profoundly symptomatic myofascial trigger points. These myofascial trigger points remain symptomatic and sometimes are intractable for months and even years. Patients should be informed about these matters before surgery. They will require muscle relaxants, soothing cream or liniments and pain patches (Lidoderm 5 %), physical therapy modalities, and intermittent injections with long-lasting anesthetic medication and small amount of steroids.

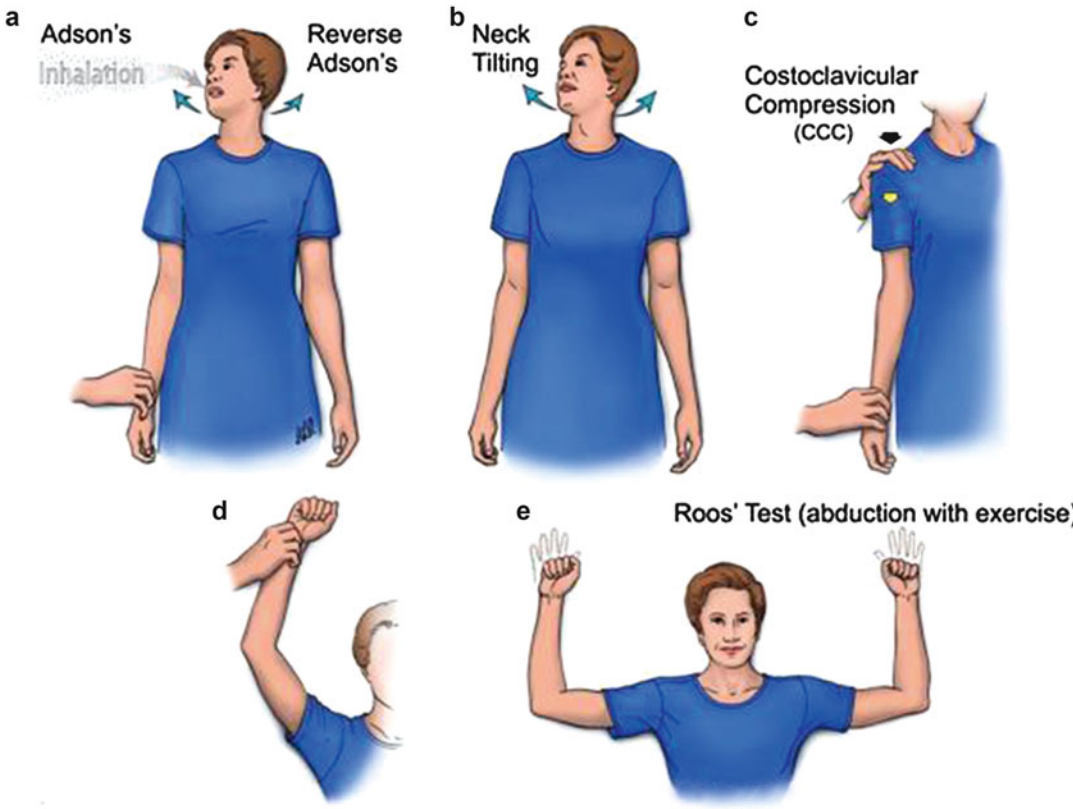

Fig. 5 Very beneficial tests used in the diagnosis of TOCS: (**a**) Adson's, reverse Adson's. (**b**) Neck tilting (tilting the neck to the other side of the symptomatic extremity). (**c**) Costoclavicular compression test (*CCC*). (**d**) Wright's test (hyperabduction). (**e**) Roos' test, elevated arm stress test (*EAST*) up to 3 min (probably one of the most important tests) (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

Conservative Treatment

Although surgery for TOCS and other required surgeries for carpal tunnel, pronator teres, cubital tunnel, and radial tunnel can help very much by reducing arm and hand symptoms substantially, the chronic upper back myofascial pain and upper extremity weakness are two of the most important factors in preventing them from returning to their original work or activities. In many cases myofascial pain and weakness have been present for a long time prior to their first physician consultation. Job modifications and restrictions such as avoiding repetitious, strenuous activities and limited weight lifting should be strongly recommended. Also slower-pace activities and setting their own pace are very important for these patients.

Because guarding the weak, symptomatic upper extremity and overuse of the other extremity, there is a 50 % chance of developing similar problems in the normal extremity.

Before planning any surgical intervention, the patient should be treated with conservative measures, such as job modification, physical therapy for TOCS, and medications. If the patient has a long, strong history of complaints, physical findings compatible with TOCS, and the symptoms have been present for several months or even years with very limited help or no help from physical therapy, surgical intervention is strongly recommended, especially if the patient has evidence of muscle atrophy and swelling in the extremity.

Conservative treatment includes an exercise program for TOCS including first rib relaxation,

scalene muscle stretching, and nerve gliding exercises. Unfortunately, patients with well-established TOCS symptoms which have been present for a good 6 months to even years can expect to have practically no substantial help from physical therapy. Most of the physicians who treat patients with TOCS believe that physical therapy cannot cure especially with well-established TOCS.

Two types of muscle relaxants are used: (1) centrally affecting groups that relax the tight muscles and also help the patient sleep better. This group includes Soma (carisoprodol) 350 mg, Flexeril (cyclobenzaprine) 10–20 mg, and Zanaflex (tizanidine) 4–6–8 mg. One of these can be taken before 9:00 pm. (2) Spinal cord affecting group that usually does not make the patient sleepy but relaxes tight muscles. They are taken during the daytime. This group includes baclofen (Lioresal) 10–20 mg bid, Skelaxin (metaxalone) 800 mg ½–1 tab bid or tid (depending on the size of the patient), and Robaxin (methocarbamol) 500–700 mg bid and tid (again depending on the size). Also a lower dose of Zanaflex (tizanidine) 2–4 mg (depending on the patient's weight) bid or tid can be taken.

Soothing liniments, creams, pain patches (Lidoderm 5 %), and analgesics are used for painful myofascial trigger points. A Theracane or similar handheld massager could be helpful to massage painful myofascial trigger points. Some type of soft ball should be used on the cover of the hard knob of the massager for comfort.

Markedly painful myofascitis trigger points can be treated with injections of long-lasting local anesthetics and low-dose steroids (i.e., 20–30 cm^3 of 0.5 Marcaine and 2–3 cm^3 10 % Kenalog). The amount would depend on the size of the patient. Some patients may require repeat injections several weeks or a few months apart if steroids are used with the injection.

Other physical treatment modalities, proper postural training exercises to correct faulty posture and poor body mechanics, should be taught to the patient. In addition to the muscle relaxants, nonsteroidal anti-inflammatory drugs, moist heat (in chronic cases), moist cold packs and cold spray (with acute cases), ultrasonography with phonophoresis and iontophoresis, and transcutaneous electrical nerve stimulator (TENS) can be used for very symptomatic myofascial trigger points.

Injection into the anterior scalene muscle, about 1.5 in. above the clavicle, can be done by using a 1-in 25-gauge needle with 5–7 cm^3 of 0.5 % Marcaine and 1 cm^3 Celestone or low-dose 10 % 1 cm^3 Kenalog (Atasoy 1996). If the injection is effective, which is generally temporary, it can be repeated within a few weeks. If no substantial help is achieved, no more injections should be given (Atasoy 1996).

Surgical Procedures

Anterior scalenotomy is not used any longer because of the high rate of recurrence (60 %).

Transcervical full first rib resection is more difficult, and if it is not fully resected, the chance of recurrent symptoms is a high possibility. The risk of subclavian vein injury can be higher. In a true vascular TOCS with subclavian vein compression, full division of the costocoracoid ligament and subclavius tendon is difficult and can be a problem. Injury to the T1 root is another high possibility. For this reason some surgeons intentionally open the pleura and compress the lung for easier removal of the first rib. This will cause more morbidity and longer recovery time.

With true venous vascular TOCS, some surgeons sporadically perform thoracoscopic first rib resection. Thoracoscopic removal of scalene muscles carries a very high risk because of the high possibility of injury to the brachial plexus and other important nerves, and therefore, thoracoscopic scalenectomy has not been tried. Robotic removal of the first rib may be available in the future.

Transaxillary removal of the first rib used to be the procedure recommended for lower TOCS cases; however, it is very rare to see pure TOCS only with lower plexus (C8–T1) involvement. Usually 90 % or even higher rate of TOCS cases has combined upper and lower plexus involvement. The main indications for transaxillary first rib resection are changes in the bony structures in the thoracic outlet area such as fracture first rib or clavicle with excessive callous formation, symptomatic longer cervical rib of more than 2.5 cm, bifid first rib, fused first and

second ribs, pure subclavian vein compression, and recurrent subclavian vein thrombosis without any symptoms of concomitant nerve compression. If these patients have any neurological symptoms, they will also require transcervical scalenectomy at the same setting.

General current knowledge and experience leads to the transcervical anterior and middle scalenectomy because of soft tissue changes in the thoracic outlet area, which comprise at least 70 % or higher etiological factors in the development of neurogenic TOCS. Very muscular and excessively overweight patients are candidates for this kind of intervention because complete transaxillary first rib resection carries higher risks and also can be quite difficult on these kinds of patients.

Patients who develop recurrent symptoms after transaxillary first rib resection are candidates for scalenectomy.

After injuries in the neck, shoulder girdle area, and upper extremity, changes may occur in the scalene muscles such as swelling, inflammation, scarring, spasm, and thickening in the sheath tissue covering scalene muscles. Even fiber changes and increased connective tissue in the muscle have been reported (Sanders 1991). Many of these cases have involvement of the plexus (C5–T1) in different degrees.

Even though injuries in the neck, shoulder girdle, and upper extremity are quite common, the development of TOCS symptoms is relatively rare.

The beginning of TOCS symptoms following these kinds of injuries can be explained on the basis of an already existing "congenital" narrowing in the thoracic outlet area, especially at the interscalene space with the presence of congenital bands, muscles, cervical ribs, thick scalene muscles, and their sheaths. Following any kind of trauma, either a huge trauma such as whiplash injury or repetitious strenuous type of injury, some changes will take place in the thoracic outlet area. These changes are swelling, inflammatory reaction, spasm and scarring in the scalene muscles, and thickening of the sheath covering the scalene muscles. These changes most likely become a triggering factor for the development of TOCS by causing more narrowing of the space leading to pressure on the brachial plexus and subclavian vessels. Some swelling in the nerves has been reported (Brantigan and Roos 2004).

Similarly, the same changes may occur in a patient who had surgery for TOCS with good results. Several weeks, months, and years following injury to the neck, shoulder girdle area, and even to the upper extremity, the changes in scar mechanics in the surgical area can cause inflammation, swelling, or more fibrous tissue development leading to pressure on the brachial plexus and the subclavian vessels, and hence, recurrent symptoms will follow.

Combined Transaxillary First Rib Resection

After performing more than 700 first rib resections before 1989, nearly 200 transcervical scalenectomies between 1985 and 1989, and more than 850 transaxillary first rib resections and immediate transcervical anterior and middle scalenectomies during the last 22 years, the author is very convinced that if the patient's physical condition is suitable (i.e., not very muscular or excessively obese), these two interventions can be combined at the same setting for total decompression of the thoracic outlet region creating larger space for the neurovascular structures to pass through easily and with less chance of recurrence.

In the combined operation, after removal of the first rib, the scalenectomy can be accomplished with much more ease since both scalene muscle insertions to the first rib have already been divided during the first rib resection.

Technique of Transaxillary First Rib Resection

Under general anesthesia with a Foley catheter in the bladder, the patient is placed in lateral position on the operating table with a 4–6-in.-thick towel covered rolled foam under the opposite axilla and stabilized with chest brace, straps, and tape. Two transversally positioned pillows are placed on the

table under the opposite leg, and two are placed between the legs. After routine prepping and draping, the patient's arm is held in a wrist lock position by the assistant. This position is very important for performing an easier surgery with adequate removal of the first rib (Fig. 6).

A smile type curved skin marking is done on the axilla where the chest and axilla meet each other when the arm is elevated. The marking is about 5–6 in. long at about the level of the third rib. The incision is made along the marking, and then the dissection is carried out upward on the chest wall below the axillary fat pad, which contains all the lymphatics. At the top of the operative field, the first rib and subclavian vein can be seen. By gently pushing the fatty tissue upward with a sponge stick, more exposure of the first rib, subclavian vein, anterior scalene muscle, subclavian artery, lower plexus, and posteriorly the middle scalene insertion to the first rib can be seen more clearly (Fig. 7). Attention is given to the anterior portion of the first rib which is removed first. Partial and sometimes nearly full division of the pectoralis minor muscle will facilitate the exposure in this area. Then the anterior scalene muscle is divided just above the first rib by careful insertion of a right angle clamp around the muscle and cutting it with scissors. Next the subclavian vein is gently pushed upward, and then the subclavius tendon and costocoracoid ligament are divided just over the first rib by using an Overholt rib stripper until passing a little beyond the costochondral junction (Fig. 8). This is important for the patient who has subclavian vein compression or who has subclavian vein thrombosis. Then the lower border of the anterior part of the first rib is cleared until passing beyond the costochondral junction. After clearing and dissection of the

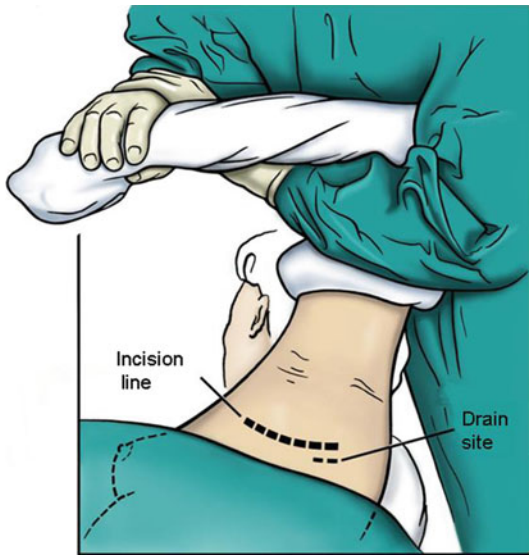

Fig. 6 Left transaxillary first rib resection: holding the left arm in wrist lock position and marking incision just below the hairline (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

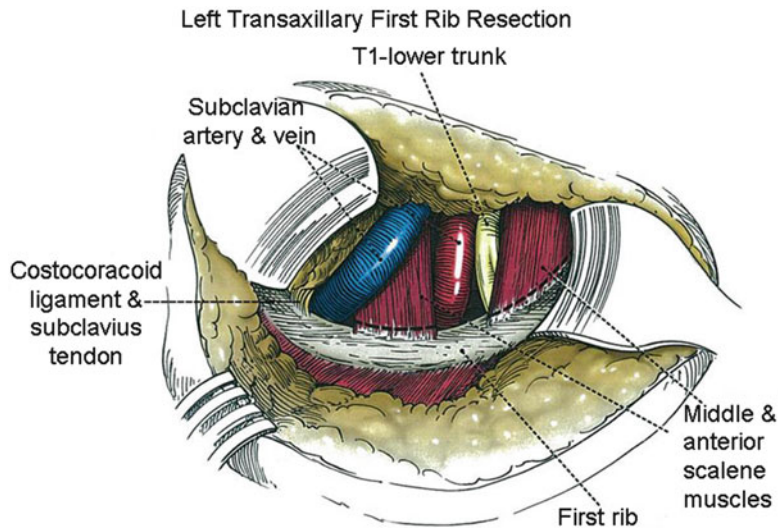

Fig. 7 Exposure of left first rib, anterior and middle scalene muscles, subclavian artery and vein, and lower trunk (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

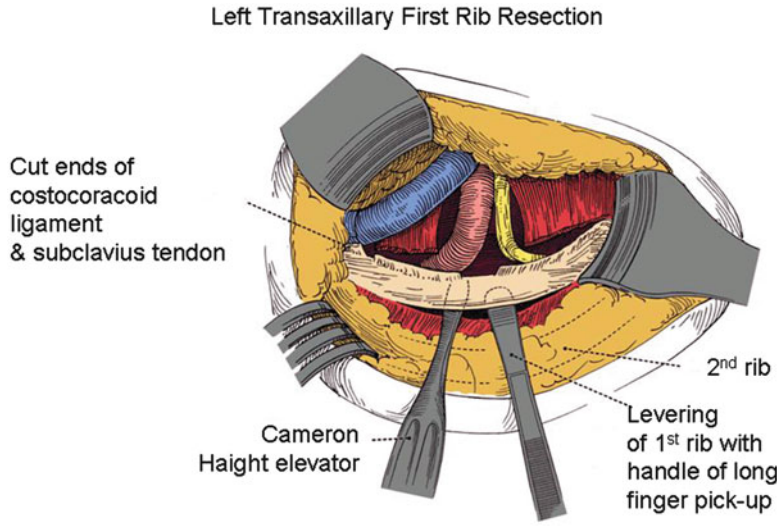

Fig. 8 Incising anterior and middle scalene muscles, costoclavicular ligament, subclavius tendon, and freeing of the first rib (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

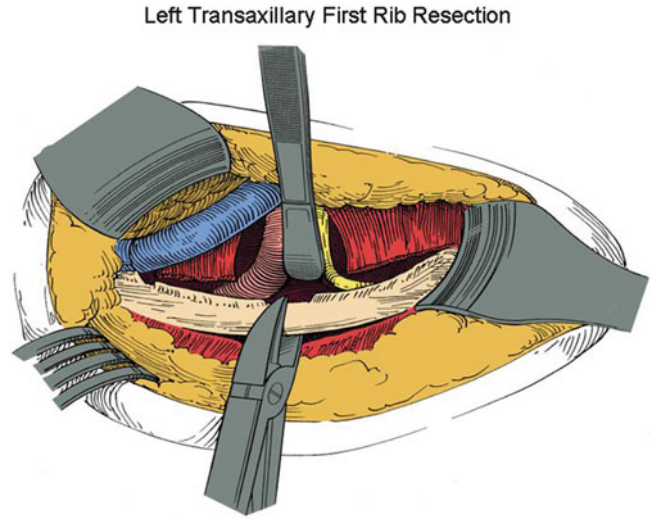

Fig. 9 Cutting the first rib near its middle area (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

posterior periosteum, the first rib is cut with a rib cutter (Fig. 9). The anterior portion of the first rib is held lifted with a Kocher clamp, and further dissection is carried out along both the upper and lower borders of the first rib and posteriorly off the periosteum. The dissection is carried out a good centimeter beyond the costochondral junction, and avulsion of the portion of the first rib is attempted at the costochondral junction following scoring this area with the curved end of the Overholt strippers. If the avulsion is not possible (it is usually possible in most cases) then the first rib is cut at or very close to the costochondral junction (Fig. 10). The sharp tips are rongeured with a Weck first rib rongeur.

Then attention is given to the posterior portion of the first rib which is picked up and lifted with a long finger pickup or Kocher clamp, and the middle scalene insertion along the upper border of the posterior rib is divided by staying very close to the rib. Next the intercostal muscles are divided and stripped along the inferior border of the rib. Sometimes division and stripping the insertions of the first and even second digitations of the serratus anterior muscle are needed, especially in patients who have prominent thick digitations.

This posterior part of the first rib is lifted up with a Kocher clamp and further dissections carried out posteriorly off the periosteum close to the junction of the first rib and the transverse process of T1. Then the rib is cut as far as possible with the rib cutter, and the remaining and very posterior part is removed either by Sauerbruch or Weck first rib rongeur close to the transverse process of T1. No more than 1 cm of the posterior part of the first rib should be left (Figs. 11, 12, 13, and 14a, b). Nearly 90 % of the first rib is removed.

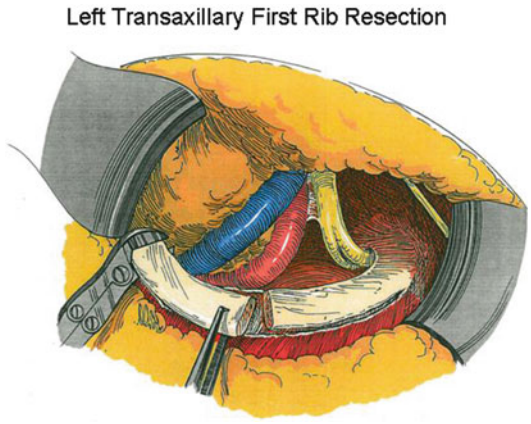

Fig. 10 Removal of the anterior part of the first rib (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

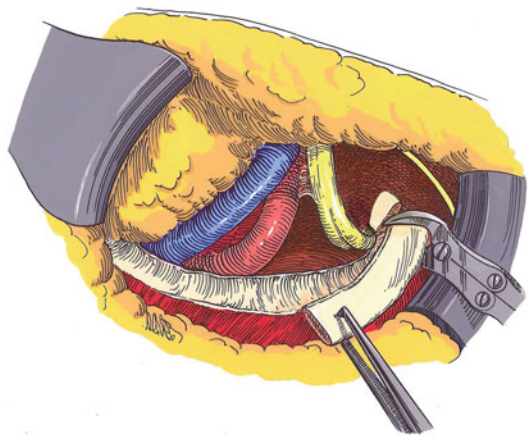

Fig. 11 Removal of the posterior part of the first rib. The remaining posterior portion of the first rib is removed by Sauerbruch rongeur (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

Technique of Transcervical Scalenectomy

Transcervical scalenectomy is usually performed in two stages. In the first stage the anterior scalenectomy is performed. In the second stage middle scalenectomy is carried out. The patient in supine position, the back and head are elevated nearly 40°, and a long piece 8 in. wide and 4 in. (approx. 20cm and 10cm) of thick foam is placed under and across the shoulders to keep the neck moderately hyperextended and turned toward the other direction. Both arms are kept crossed taped on the lower anterior chest wall. After routine prepping and draping, superficial structures and planned skin incision along the skin crease and about 1.5–2 cm above the clavicle nearly 3 ½–4 in. long (7 ½–10 cm) are marked (Fig. 15a, b). Following marking of the skin incision, first proximal then distal flaps are elevated including full-thickness skin and platysma. The external jugular vein and the branches of the cervical plexus are protected. Approximately two-thirds of the clavicular insertion of the sternocleidomastoid muscle are divided just a little above the clavicle, and the prescalene fatty tissue is exposed. The omohyoid muscle, which obliquely crosses the field, is located and divided by electrocautery (Fig. 15c). Also the transverse cervical artery and accompanying vein are dissected, ligated, and divided. Next the prescalene fatty tissue is divided longitudinally near its middle by staying a good 2 cm from the internal jugular vein. The divided fatty tissue is elevated and dissected toward both sides. Then the anterior scalene muscle, the upper trunk of the brachial plexus (C5–C6), and a portion of the middle scalene muscle will be visible. Next the phrenic nerve is exposed, and usually it crosses the anterior scalene muscle from lateral to medial directions starting at the C5 and extending to the lower medial side of the muscle. It is fairly common to see some variations in the origin and the course of the phrenic nerve, even the presence of an accessory phrenic nerve. Careful dissection of the phrenic nerve, even leaving some adipose tissue around the nerve, is quite important to keep vascularity intact as much as possible (Fig. 16a, b). Then a Silastic vascular

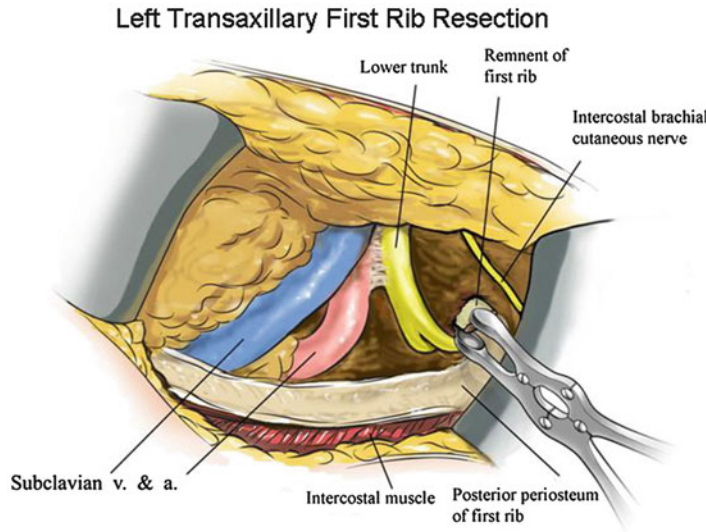

Fig. 12 Rongeuring of the very posterior portion of the first rib with a smaller Weck rongeur, up to the transverse process of the T1 vertebra (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

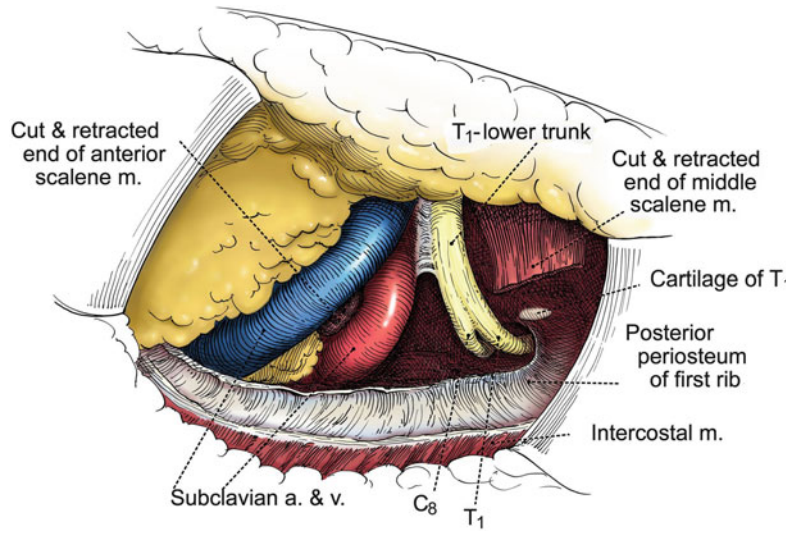

Fig. 13 View following about 90 % removal of the left first rib. Exposure of important structures: subclavian vein and artery and lower trunk (C8–T1) of the brachial plexus (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

loop is passed around the nerve for gentle intermittent traction, and more dissection of the nerve is carried out during the anterior scalenectomy.

If the patient just had a prior transaxillary first rib resection, it is easier to do the scalenectomy. When the lower end of the anterior scalene muscle is exposed, bloody fluid is usually under the intact anterior scalene muscle sheath. The sheath is opened, the bloody fluid drained, and then the freshly cut end of the anterior scalene muscle will be visible. The cut end of the muscle is gently pulled upward, and the subclavian artery is exposed. Following further lifting and pulling up of the muscle, more dissection is carried out along the brachial plexus on the lateral side and ascending cervical artery on the medial side and the anterior scalene muscle sheath on the back. When the junction of the phrenic nerve with the C5 is reached, some dissection is made under the junction, then the muscle is pulled down away from the junction of the phrenic nerve with C5, and the muscle is cut with scissors while going under the junction (Fig. 16a).

Next the exposed fibrofatty posterior sheath is dissected, several small blood vessels are cauterized, and some of the posterior sheath is removed

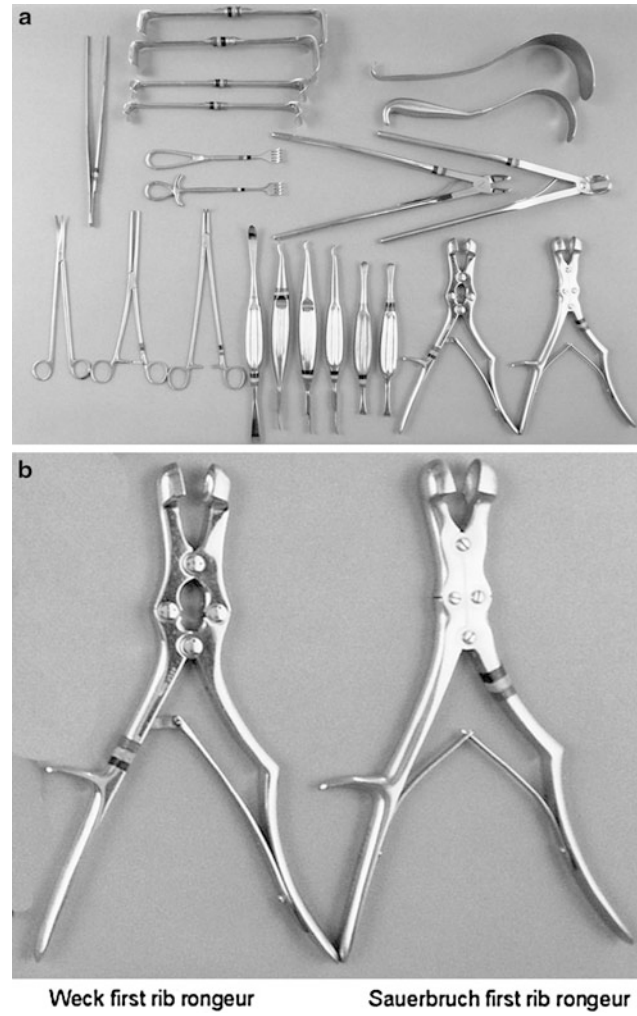

Fig. 14 (**a**) Major instruments used during a first rib resection (with permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) Weck and Sauerbruch rongeurs (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

as safety permits. Then full exposure of C5–C6 and C7 is achieved. At the lower end of the operative field, the dorsal scapular artery (also called deep transverse cervical artery), which is present in most cases, can be seen. It usually passes between C7 and C8 roots and sometimes between C6 and C7 and goes through the middle scalene muscle (Fig. 16b). In order to better visualize the lower part of the plexus (C8 and T1), the artery should be ligated and divided. This also helps for easier and much less bloody operative field while doing the middle scalenectomy.

If the scalenectomy is to be done as a primary operation, the anterior scalene muscle is divided about its middle portion, and while lifting the muscle with a pickup forceps, carefully repeated small cuttings are done on the muscle until the subclavian artery becomes visible. It is rare but sometimes the subclavian artery may pass through the muscle. After full visibility of the artery is achieved, and while staying very close to the distal part of the anterior scalene muscle, further dissection is carried out and this portion is removed. In the case of any lymphatic vessel injury with leakage of chylous fluid, clamping the area and applying a suture ligature with a 5-0 Vicryl on non-cutting needle or vascular clip can obtain control.

The next step is middle scalenectomy. The lateral part of the prescalene fat is exposed, and more lateral dissection will be needed to see the middle scalene muscle clearly. First, the long

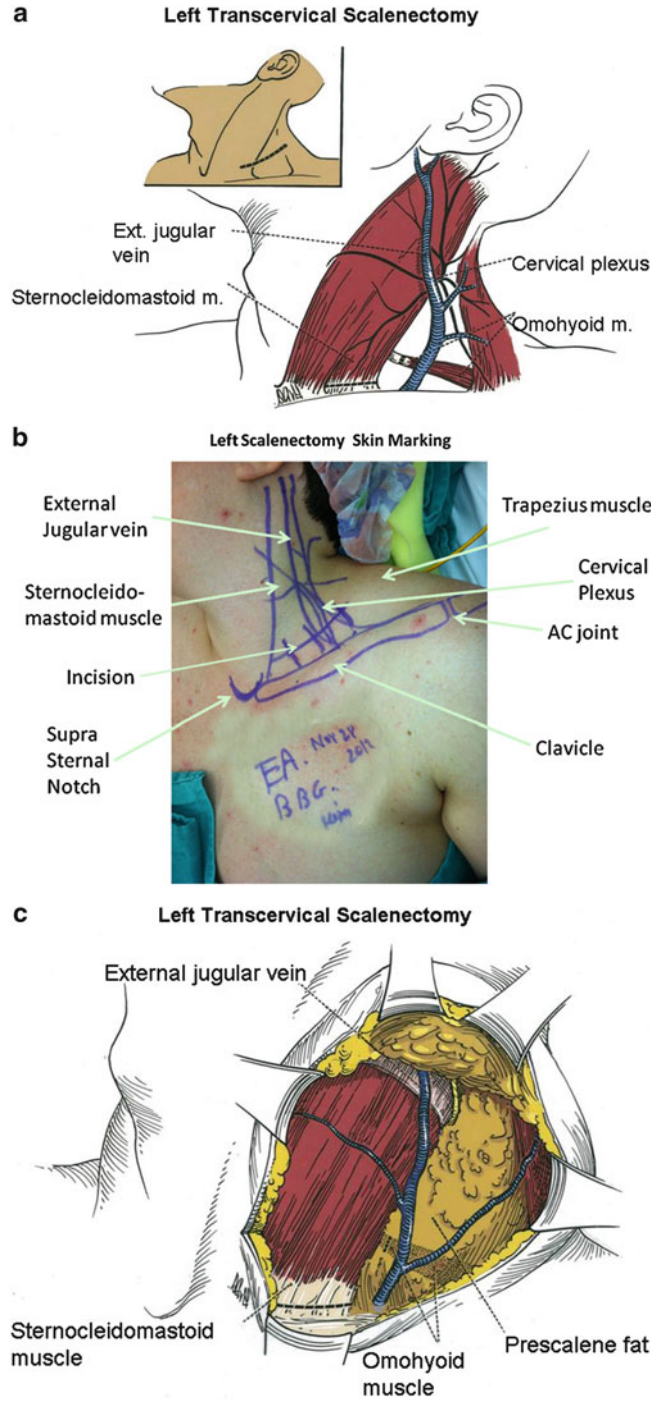

Fig. 15 (**a**) Left transcervical anterior and middle scalenectomy: marking of incision and superficial anatomy (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) Left scalenectomy: skin markings and detailed structures (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**c**) Superficial anatomy: after raising upper and lower flaps including skin and platysma muscle (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

thoracic nerve should be exposed. It is usually located at the lateral border of the muscle and leaves the muscle at the junction of the middle and lower third. It is not uncommon to observe the nerve at different locations, and sometimes two or three branches can be seen on or in the muscle exiting through the lower anterior portion. In some cases, it is even found located on the medial

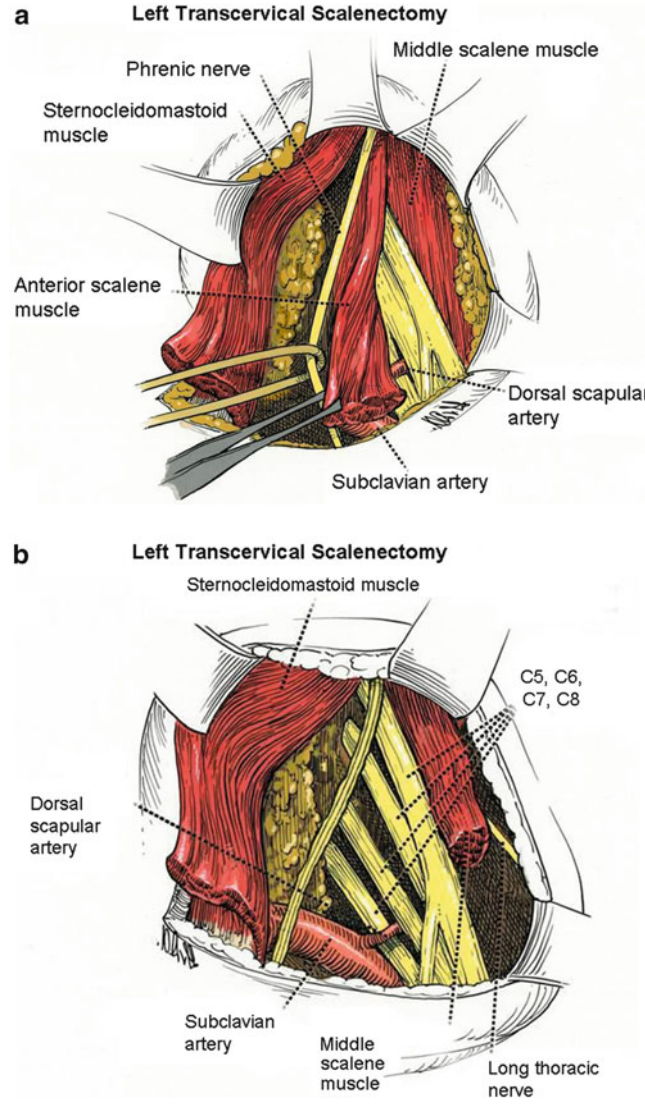

Fig. 16 (**a**) Division of almost all the clavicular head of the left sternocleidomastoid muscle, mobilizing of the phrenic nerve, and removal of the anterior scalene muscle (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) Completion of left scalenectomy: 80–90 % of the anterior scalene and about 50 % of the distal part of the middle scalene muscle have been removed. C5–C8 branches of the brachial plexus, subclavian and dorsal scapular arteries are exposed (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

side of the muscle. When only one is observed, the surgeon should look for the possibility of the presence of other branches.

If the first rib resection was performed just prior to the scalenectomy, the sheath of the middle scalene muscle is exposed, opened, and freshly divided, and the lower end of the muscle is clearly seen. The long thoracic nerve is visualized and preserved. If the dorsal scapular artery is present, it should be religated and divided. This will make dissection and removal of at least 50 % of the muscle easier.

If the scalenectomy is the only procedure to be performed, the lower part of the middle muscle should be exposed, and the long thoracic nerve should be located, and if any extra branches are found, they all should be preserved. Next, the very lower part of the middle scalene muscle is picked up and pulled proximally, and then it is partially divided as low as possible near to its insertion to the first rib. Next, while tapping the partially divided area with the back of the long finger forceps, one can hear the hitting of the bony area. This area is carefully scraped with a smaller bone scraper, and the first rib is well exposed (Fig. 17a, b). After careful trimming the lower free end of the middle scalene muscle, more

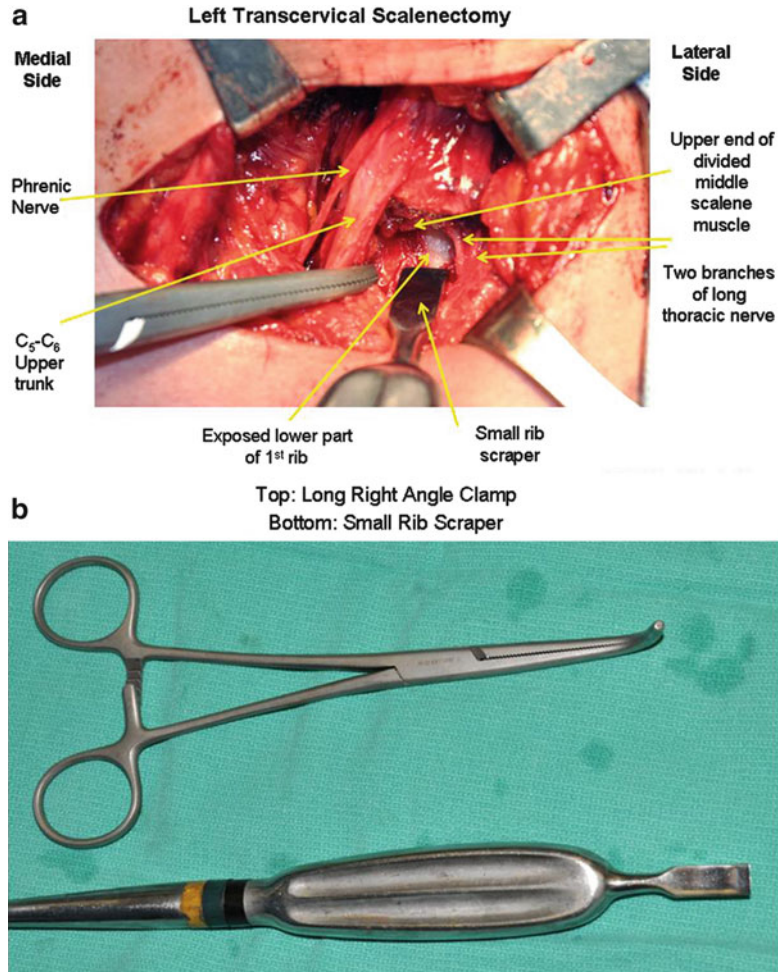

Fig. 17 (**a**) View after division of middle scalene muscle, as low as possible. Very lower part of first rib is located and scraped with a smaller rib scraper (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc). (**b**) Large right angle clamp and small rib scraper (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

proximal scraping is carried out by staying on the first rib up to its neck (Fig. 18).

During scraping, the branches of the long thoracic nerve are out of danger because the branches are more anteriorly located and away from the first rib and close to the anterior surface of the middle scalene muscle (Fig. 18). During this part of the surgery, some intermittent traction on the brachial plexus is done with a large right angle clamp (Fig. 19). A few remaining tendinous insertions of the middle scalene muscle along the concave medial edge of the first rib are divided with scissors.

Next, attention is directed to the lower part of the anterior scalenectomy site. The C8–T1 are exposed and the presence of some soft perineural tissue at the lower medial side of the C8 is picked up with a long finger forceps (Figs. 19 and 20). Next the closed jaw of a large right angle clamp is passed under the C8–T1 across and moved a few times up and down while staying on the top of the first rib to ensure full freedom of the lower plexus from the first rib (Figs. 21a, b, 22a, b, and 23). Following good hemostasis, routine wound irrigation is carried out as previously described; two 1/4-in. (0.6 cm) Penrose drains are inserted at the lateral corner of the incision and through the prescalene fat. One drain is placed to the middle scalene space and the other to the anterior scalene space. Then the wound is closed in layers. Prescalene layer is closed with 5-0 Vicryl, then the platysma and deep dermis with 5-0 Vicryl, and superficial dermal closure is carried out with 5-0 Monocryl and then Steri-Strips to the skin. A compression dressing is applied. Usually the drains are removed in 1 or 2 days

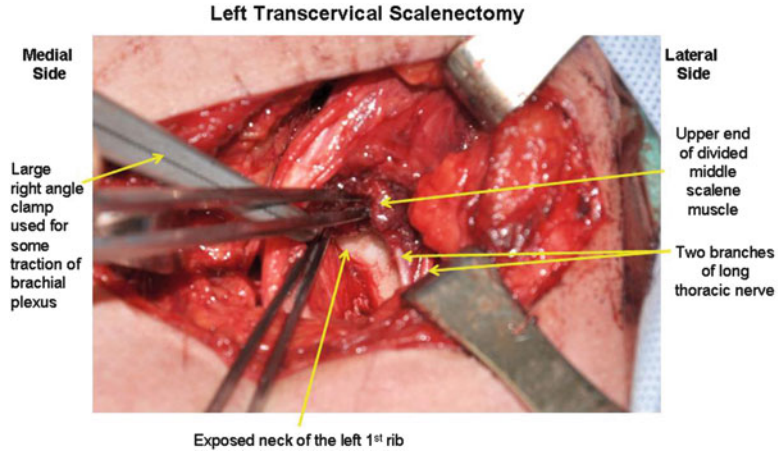

Fig. 18 More scraping of the proximal part of the left first rib, exposing the neck of the first rib, and removal of the more deep and upper part of the middle scalene muscle (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

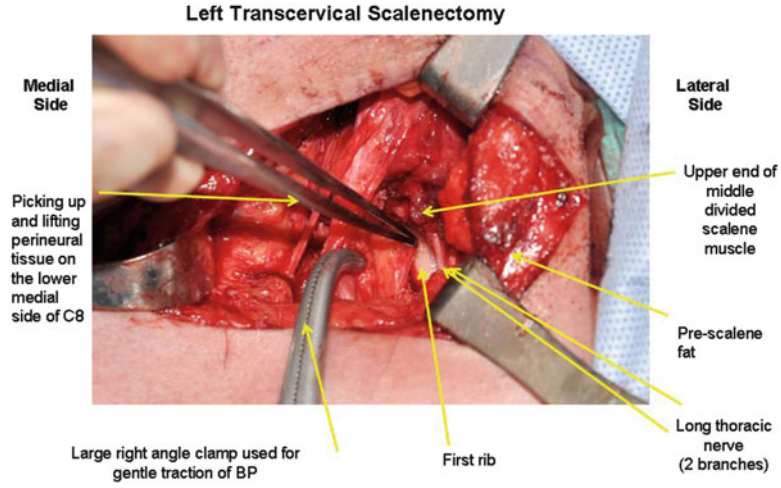

Fig. 19 Picking up and gently lifting of the perineural tissue on the lower lateral side of C8 (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

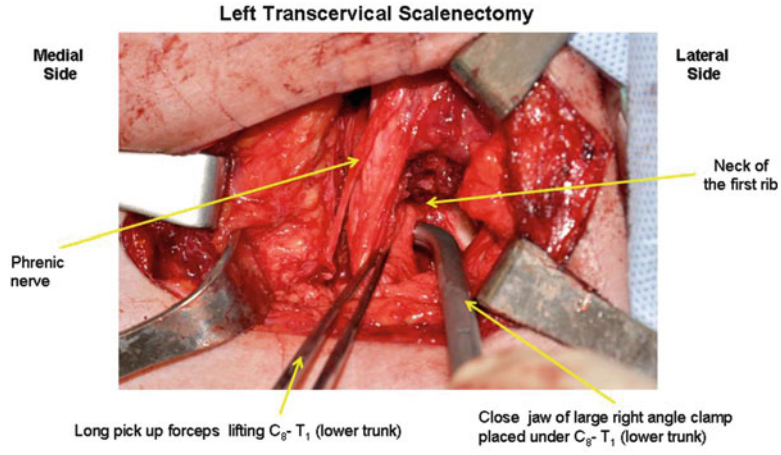

Fig. 20 Passing the closed jaw of the large right angle clamp under C8–T1 (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

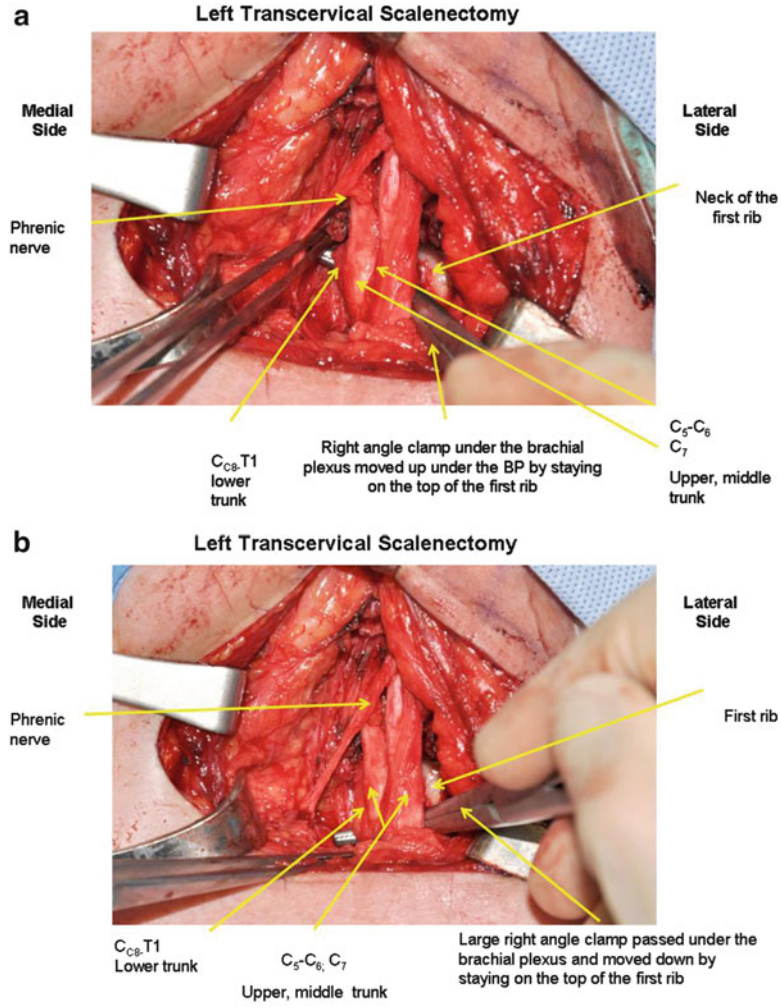

Fig. 21 (**a**, **b**) Closed end of the right angle clamp moved up and down under the brachial plexus by staying at the top of the first rib to ensure full freedom of C8 and T1 from the first rib (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

postoperatively. The patient is given instructions on daily dressing changes with some compression to the operative site for the next 5–6 days and postoperative exercises for several months (Fig. 24) and return to the office in 1 or 2 weeks. During the scalenectomy nearly 80–90 % of the anterior scalene muscle and 50–60 % of the middle scalene muscle are removed.

Summary

There are a few surgical procedures available for TOCS. The choice of the procedure for any particular patient depends on the patient's history, symptomatology, physical findings, as well as laboratory studies and general condition.

For neurogenic TOCS, which is the most common type, if there is no change in the bony structures such as the first rib, clavicle, or the presence of any cervical rib of no more than 1 in (2.5 cm), the transcervical scalenectomy is the first choice, especially for large, overweight patients.

For full decompression of the thoracic outlet region, the combined approach is generally considered for the smaller patients with or without bony changes (larger cervical rib, old fractured first rib, or clavicle with callus formation).

If the patient is having pure subclavian vein compression without any neurological symptoms

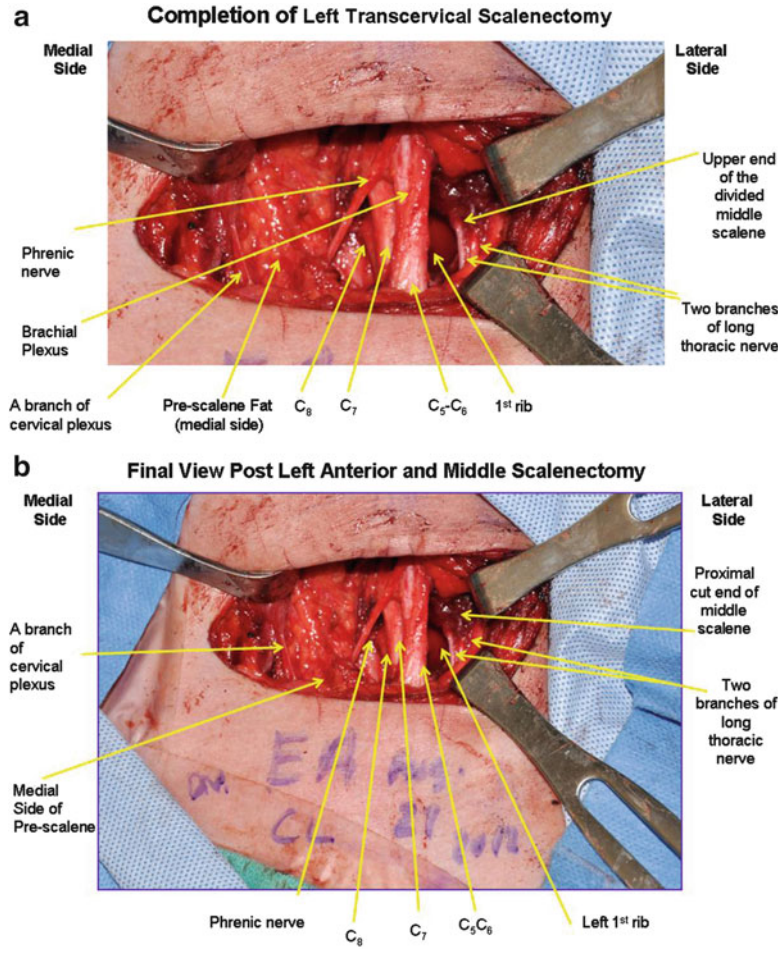

Fig. 22 (**a**, **b**) View following removal of 80–90 % of the anterior scalene muscle and removal of 50 % of the middle scalene muscle (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

and if the patient's general condition is suitable, the best procedure would be complete transaxillary first rib resection. If the patient's physical and general condition is not satisfactory, a thoracoscopic first rib resection would be the best procedure.

If the thoracoscopic surgery is not available, transcervical scalenectomy can be considered. In the future robotic removal of the first rib may be available.

If there are venous compression symptoms and neurogenic TOCS is present, a combined procedure can be considered depending on the patient's size and condition.

In a case of arterial TOCS (which is quite rare), the transaxillary approach is the first choice, but it can be combined with the transcervical procedure.

Treatment of Vascular TOCS

If subclavian vein thrombosis is present and if the patient is in early stages (within 2–3 days), thrombolytic agents can be tried through the axillary subclavian vein to lyse the clot, and the patient should be heparinized. If the clot has been dissolved, then whenever the patient's condition is suitable for surgery, the transaxillary first rib resection should be performed to prevent the reoccurrence of compression and clotting. However, the patient's size is a very important factor in the choice of surgery. If the patient is very big and muscular or markedly obese, the transcervical scalenectomy would be the best choice.

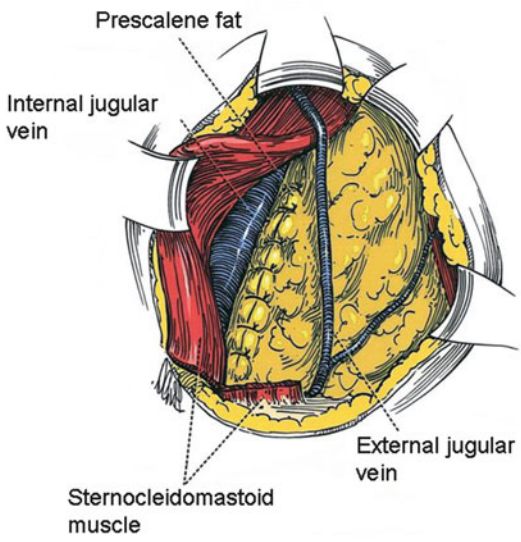

Fig. 23 Suturing prescalene fat and covering the brachial plexus (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

If the patient is seen several days after the occurrence of the thrombosis, the subclavian vein may be partially opened by the thrombolytic agents, the patient should continue to have heparin a few more days, and then Coumadin treatment should be started and continued for 3–4 months. Depending on the patient's size, either a transaxillary first rib resection or transcervical scalenectomy should be considered.

If a patient who was seen several months to a few years after the subclavian vein obstruction and thrombosis, and was treated with anticoagulant therapy (Coumadin), gradually developed collateral venous circulation bypassing the thrombosed area, they usually develop improvement of their symptoms and continue to have minimal symptoms. Most of these patients will not require any surgery. But, if they continue to be symptomatic with chronic arm swelling, cyanosis, pain, and discomfort, they are treated with Jobst compression garment and eventually may require vascular surgical procedures such as endovenectomy combined with venous patch graft, stent insertion, and even internal jugular axillary vein bypass procedure to bypass the chronically obstructed area. Unfortunately, the success rate in these procedures is not high.

Arterial TOCS is very rare. It may require transaxillary approach for removal of the offending structures such as the cervical rib, first rib, and associated bands and muscles. If the patient has symptoms of neurogenic TOCS, transcervical scalenectomy should be performed at the same time.

Complications

The thoracic outlet region has been classified as "tiger country" because of anatomical potential for disaster due to the presence of several important structures such as major blood vessels (subclavian artery and vein), thoracic duct, and several major nerves (brachial plexus, phrenic nerve, long thoracic nerve, and intercostal brachial cutaneous nerves) (Leffert 2004).

Within the last 23 years, the author has performed over 850 combined procedures and has never had any wound infections that required surgical drainage, but he did have several minor skin suture infections that required local treatment and antibiotic for about 1 week. There were several prescalene seroma formations that require one to three needle aspirations.

The author has never had any major artery, vein, or nerve injuries. In literature the incidence of reported pneumothorax was as high as 33 % (Atasoy 2004c); however, the author had about 10 % of pneumothorax, and about half of them require chest tube insertion. Literature also reported the rate of subclavian artery injury as 1 %, subclavian vein 1–2 %, major nerve injuries involving brachial plexus 0.5–1 %, and long thoracic nerve 1–2 % (Sanders 1991; Wehbe and Whitaker 2004). The phrenic nerve injury, which causes mainly exertional shortness of breath, more commonly occurs with a reported rate of 6–12 % (Sanders and Hammond 2004b). It is more likely higher than that, but most have never been reported and usually are temporary, lasting a few weeks, months, and rarely over a year. Because of anatomical variations in the course of the nerve, the presence of scar tissue especially in redo cases of TOCS requires more dissection and more gentle traction on the nerve.

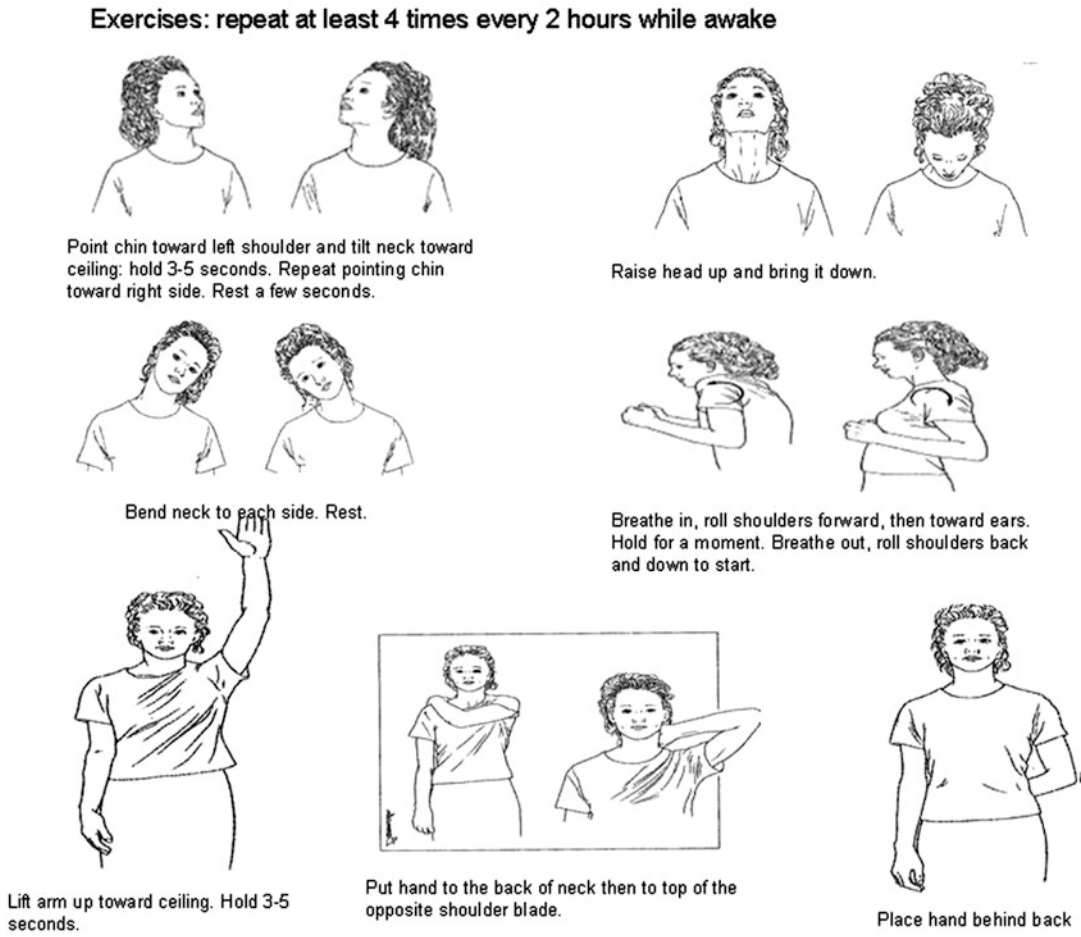

Fig. 24 Postoperative exercises. The most important thing to preventing the harmful effect of developing scar tissue is starting very early active and some passive exercises (day after surgery) with shoulder and neck. This is very important to prevent recurrence as much as possible. The patient should perform vigorous active and some passive range of motion exercises with the neck, together with shoulder shrugging, including full shoulder elevation and abduction every 2–3 h at least 3–4 times in each direction for at least the next 6 months (With permission from the Christine M. Kleinert Institute for Hand and Microsurgery Inc)

In these conditions, patients are more vulnerable to phrenic nerve irritation or injury.

After transaxillary first rib resection, patients have relatively minor but common complications of some hypesthesia and paresthesia in the axilla and along the medial and posterior lateral aspect of the upper arm. It usually happens due to the required retraction at the posterior part of the operative field on the second and third intercostal brachial cutaneous nerves. Anatomically, if these nerves are located more anteriorly, they are subject to more intermittent retraction. Generally, the discomfort improves within 3–4 months. If the paresthesia is disturbing and long lasting and bothers the patient, nerve blocks in the axilla can be tried. If blocking of the nerves (second, third intercostal brachial cutaneous nerves) gives good temporary relief, a transaxillary approach with division and removal of these nerves is considered. The long thoracic nerve injury is relatively uncommon. It may occur during the first rib resection and scalenectomy, especially in redo surgery for recurrent TOCS in the continuously symptomatic patients who have had a prior inadequate intervention for TOCS.

As previously stated, the long thoracic nerve is usually formed by three branches from C5, C6, and C7 inside the middle scalene muscle and exits the muscle at the junction of its middle and lower portions. It is fairly common to see some variation in its formation and course. The surgeon should keep this in mind during the surgery. In the transaxillary approach the surgeon should stay very close to the posterior part of the first rib while stripping and cutting the first rib. Some patients may have mild symptoms of scapular winging because of manipulation of the long thoracic nerve. It usually disappears within 3–4 months.

Cervical plexus injuries are relatively rare and may occur on the medial infraclavicular branches if they are anatomically located more anterior than usual. This injury may occur during the transcervical first rib resection and scalenectomy.

Very rarely some degree of Horner syndrome may occur because of a variation of anatomical location of the stellate ganglion on the transverse process of the T1 vertebra. It is practically impossible to see the stellate ganglion during transaxillary first rib resection. If it is located more laterally in the transverse process of T1, it may be vulnerable to some kind of injury. The author has seen only one case of Horner syndrome on a patient after transaxillary first rib resection. The patient had gradual improvement.

The author has never had any thoracic duct injury, except some injury to the smaller branches leading to the thoracic duct in three cases on the left lower neck. Two of them were easily controlled with suture ligation; the other was treated at the office and was placed on a low-fat diet for 3–4 months and compression garment to the operative site. This patient had full recovery. In literature, about 5 % of symptomatic drainage has been reported on the left side of the neck (Wehbe and Leinberry 2004).

Following transaxillary first rib resection, female patients may rarely develop mild swelling and discomfort in the ipsilateral breast (about 1 % or less). A support bra can be helpful. It usually resolves within a few weeks without any residual problem.

Results

The causes of recurrence are scar tissue formation, previous insufficient surgery for TOCS, and trauma to the neck, shoulder girdle area, and upper extremity. With the author's personal observation, patients can be categorized in two groups for recurrence. The first group includes recurrence after a single surgical intervention whether it was a transaxillary first rib resection or transcervical scalenectomy between the mid-1970s to late 1989. In the second group the recurrent symptoms occurred after a combined procedure.

In the author's practice the long-term results of separately performed first rib resection and scalenectomy as a one-stage operation (surgery prior to late 1989) revealed an improvement rate of about 70 % with a 30–35 % recurrence rate (Atasoy 2004b).

Since 1989, more than 850 patients were operated on with a combined transaxillary first rib resection and transcervical scalenectomy as a one-stage procedure. Between late 1989 and the end of 2002, 532 patients from a wide geographic range had the combined intervention. Only 358 of these patients were located, and only 102 (nearly 30 %) responded to a questionnaire. There is no uniform grading for most surgical results, and the results are subjective according to the patients' statement. Based on the patients' response to the questionnaire, 90–95 % reported improvement of their symptoms, and recurrence rate was nearly 5–10 % (Table 2). In most there was 50 % improvement of grip strength.

Beginning in 2003 to the end of 2012, 350 patients from a wide geographic area had the combined procedure. Questionnaires were sent to these and only 57 responded. Nineteen of these patients had bilateral combined surgeries performed several months apart for a total of 76 surgeries.

A simple and easier grading system was used according to the patients' opinion about their percentage of improvement after this combined procedure. Results were based on these 76 procedures and revealed 95 % improvement of symptoms (Table 3).

Table 2 Results of combined first rib resection and scalenectomy

Percent improvement	Description	Number of patients
70–100 %	Excellent (almost complete relief of symptoms)	36
50–70 %	Good (disappearance of all major symptoms)	24
30–50 %	Better (almost 50 % improvement of all symptoms)	26
10–30 %	Fair (partial relief of symptoms)	9
Less than 10 %	Poor (no improvement)	5

Results based on 102 respondents to a questionnaire, out of 532 surgeries (Atasoy 2004b)

Table 3 Results of combined first rib resection and scalenectomy

Percent improvement	Description	Number of patients
70–100 %	Excellent (almost complete relief of symptoms)	50
50–70 %	Good (disappearance of all major symptoms)	9
30–50 %	Better (almost 50 % improvement of all symptoms)	6
10–30 %	Fair (partial relief of symptoms)	7
Less than 10 %	Poor (no improvement)	4

Results based on 57 respondents to a questionnaire; 76 operations, 19 of which were bilateral, out of 350 patients

Prior to late 1989, in the first group there were 938 patients with a recurrence rate of 39–35 %. In the second group (from late 1989 to 2002) there were 538 patients who had this combined procedure with active and some passive range of motion exercises starting the next day after surgery with a recurrence rate of 5–10 % (Atasoy 2004c) (Table 2). With an improved technique and early postoperative exercises (similar to flexor tendon repair in no man's land), the recurrence rate dropped remarkably from 30–35 % to 5–10 %. Since 2003, more than 350 patients who have had this combined procedure have better results (Table 3).

It should be noted that physicians should start patients on immediate neck and shoulder girdle active and some passive range of motion exercises on the first postoperative day to decrease the harmful affect of developing scar tissue formation around the brachial plexus and vessels and possibly prevent recurrence. The author strongly believes it is important to start postoperative exercises. Patients should be informed about the need for this well before the surgery and postoperatively.

Recurrent symptoms usually occur when excessive scar tissue forms after surgery in the operative field causing adhesion between the nerves and surrounding structures such as the remaining portion of the scalene muscles, first rib, cervical rib, and chest cage, and sometimes the recurrence can develop after an insufficient procedure performed for TOCS. Reattachment of the scalene muscles to the remaining portion of the first rib or bed of the first rib can cause recurrent symptoms. The author believes that the incidence of recurrence is higher in thin patients who do not have adequate amount of adipose tissue near and around the brachial plexus in comparison with normal or somewhat overweight patients.

The recurrent symptoms many times can occur after trauma to the neck, shoulder girdle, and even to the upper extremity. In these situations, a change in the scar tissue mechanics such as stretching and traction causing inflammation, swelling, thickening, or shortening may occur and apply pressure on the neurovascular structures.

Repetitive, strenuous activities in the upper extremity after previous TOCS surgery can bring about recurrent symptoms. Again, the key for preventing the harmful effect of developing scar tissue as much as possible is to start active and passive range of motion exercises with the neck and shoulder girdle the day after surgery.

If the recurrent symptoms are severe enough after job modification and a trial of physical therapy and medication, a surgical procedure would be the last resort. The surgery depends on what was performed before, and the findings are on the cervical spine x-ray. If there is no evidence of more than a one centimeter remnant of the posterior part of the first rib or regrown first rib after the initial surgery, generally a transcervical scalenectomy is

the choice for external neurolysis of the brachial plexus and removal of the muscle or remnants of these muscles.

The initial surgeries for decompression of the brachial plexus such as first rib resection, scalenectomy, or combined procedure are generally considered demanding, difficult, and risky operations. The surgical procedures available for recurrent TOCS are even more difficult, more demanding, and riskier than the primary surgeries (Atasoy 2004b, c).

Cross-References

- Different Treatment Modalities in the Nerve Entrapments of Upper Extremity
- Fractures of the Clavicle
- Nerve Entrapment Syndromes in the Shoulder: Diagnosis, Principles, and Different Techniques for Nerve Decompression
- On-the-Field Management of American Football Injuries
- Spine Injuries on the Field
- Traumatic Athletic Injuries of the Hand

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