Experience with First Rib Resection for Thoracic Outlet Syndrome

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SURGICAL treatment of thoracic outlet syndrome began over 100 years ago with the first reported excision of a cervical rib performed by Coote at St. Bartholomew's Hospital, London in 1861.[4] Appreciation of this syndrome was so slow to develop it was not until 29 years later that the second case of cervical rib removal was reported by Planet in 1890 (performed by Perier).[8] Bramwell in 1903 was the first to suggest the relation of a normal first thoracic rib to brachial plexus compression.[2] In 1908, Roberts presented a detailed description of the various anatomic forms cervical rib could assume, and described the variety of clinical symptoms with remarkable clarity and perception.[10] Thomas Murphy was the first to remove a normal first thoracic rib for this syndrome in 1910 using the supraclavicular approach, with complete relief.[5]

Despite numerous papers on this topic during the subsequent 60 years, only recently has the medical profession begun to appreciate the relative frequency of the outlet syndrome. This may reflect the protean forms the syndrome may assume due to the mixed neurologic, arterial and venous symptoms that vary in different patients, the difficulty of diagnosis in some cases, and the disappointing long-term results of scalenotomy which became the preferred operative procedure following Adson and Coffey's paper in 1927.[1] Ochsner, Gage and DeBakey felt the benefit of scalenotomy resulted from lowering of the first rib from pulling of the intercostal muscles unopposed by the scalenus anterior.[7]

Later the syndrome fell into relative obscurity until 1962 when Clagett rekindled enthusiasm for removal of the first thoracic rib for relief of all forms of the outlet syndrome, favoring the posterior thoracoplasty approach for excision of the rib.[3] Operative relief thus became more predictable, and clinical appreciation more precise. With the description of a simpler technic of first rib resection in 1966 using an axillary approach,[11] surgical relief of this common syndrome became technically easier and more acceptable to both patient and physician. Recent reports by Sanders *et al.*,[14] Urschel *et al.*[16] and Rainer *et al.*[9] attest to the ease and effectiveness of this technic. Nelson and Davis recently reviewed the entire outlet syndrome.[6]

Five years' experience with the axillary technic of rib resection has led to the development and appreciation of important operative details that contribute greatly to the safety, ease and benefit of this procedure. The purpose of this paper is to describe these technical details, report the extension of the basic procedure to four related conditions, review the complications and overall results in a series of 276 cases with a follow-up of nine months to five years.

Principles

Physical therapy should be routinely used as initial treatment for thoracic outlet syndrome.[13] Its effectiveness, however,

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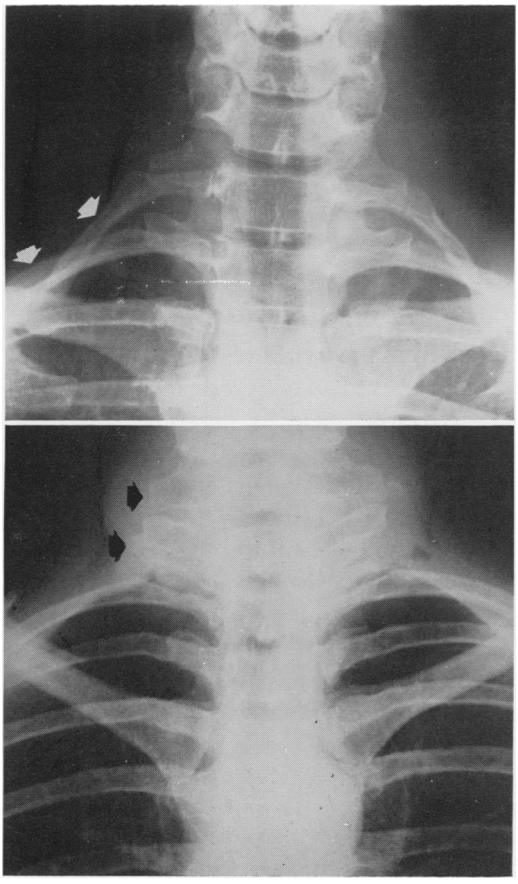

FIG. 1a. (top) Large bilateral cervical ribs in a 39-year-old woman with severe thoracic outlet syndrome. Arrows pointing to right cervical and first thoracic ribs.

FIG. 1b. (bottom) Same patient after resection of cervical and first thoracic ribs showing short stumps (1 cm. or less from transverse process) of ribs resected bilaterally at separate operations with complete relief of symptoms.

seems limited to the patients with mild or moderate outlet syndrome as patients with severe symptoms often cannot tolerate or will not benefit from physical therapy. As long as therapy offers relief, it should be continued. When it fails or makes the patient worse, it should not be unduly pursued.

In the present series to be reported, those who could tolerate therapy were treated for weeks, months or years before operation. Only those with severe symptoms who failed to obtain relief were considered surgical candidates. The only patients who were operated upon without undergoing physical therapy were those who could not tolerate it because of marked increase of pain when therapy was attempted. If conservative management fails and the patient has severe distress or significant incapacitation, first rib resection currently seems to offer the quickest and most sustained relief.

The first thoracic rib forms the floor of the compression compartment, trapping or scissoring the brachial plexus and subclavian vessels between the rib and other structures which may contribute to the neurovascular compression. These structures may be the clavicle (most common), a cervical rib, an anomalous cervical band from an elongated C7 transverse process (abortive cervical rib), the subclavius muscle, a bony callous or exostosis. By resecting the first thoracic rib, the floor of the compression compartment, or lower blade of the scissor, is removed, thereby releasing the entrapment of the brachial plexus and subclavian vessels allowing them to drop away from the clavicle. The details of various entrapment mechanisms have been described by Roberts,[10] Adson [1] and Clagett.[3]

To decompress the brachial plexus and subclavian vessels completely and permanently, almost the entire first rib must be resected leaving only the head and neck. Partial removal of the rib, as is usually performed from the supraclavicular approach, is often inadequate as a long rib stump may entrap the plexus or vessels by periosteal scar tissue leading to severe brachial neuritis, ischemia or venous congestion. Three of these cases were encountered in the series reviewed, and all were relieved by completing the rib resection using the axillary approach.

The posterior stump of the first rib should be left so short it lies posterior to the T_1 cervical root clearly seen at operation, and should not extend more than 1 cm. anterolaterally from the transverse process of the first thoracic vertebra when

seen by chest roentgenogram (Fig. 1b). Anteriorly, the rib should be resected into the costal cartilage attaching to the sternum so the stump will be completely clear of the subclavian vein.

An occasional patient will have an unusually high second rib with the smaller first rib lying medially like a ring-within-a-ring. This makes first rib removal more difficult, but using the axillary approach no case required resection of the second rib to expose the first rib, as sometimes is necessary with the posterior approach. After removal of the first rib and before closure, the patient's arm should always be placed in the 90° abduction-external-rotation (AER) position with the surgeon's fingers lying on the second rib and the patient's shoulder depressed caudad to test for a possible compression between clavicle and *second* rib. If the clavicle almost touches the second rib (less than one finger's width separation), the junction of the middle and posterior third of the second rib at the level of the scalenus posterior muscle insertion should be resected immediately to avoid compression between clavicle and second rib at a later time if there is settling of the shoulder girdle. Five patients in this series who initially were completely relieved by first rib resection later developed recurrence of original symptoms. Because they were found to have typical physical signs of neurovascular compression again at the level of the clavicle, three had partial resections of the second rib at the level of the posterior scalene muscle insertion with complete relief again. Two have not yet come to reoperation but may ultimately require it. It is thought that settling of the shoulder girdle after first rib resection, usually imperceptible and insignificant, allowed the clavicle to compress the neurovascular bundle against an unusually high second rib, as shown by later subclavian artery bruit and occlusion in the AER position not present at earlier postoperative examination. The anterior and posterior thirds of the second rib were left for muscle, lung and breast support as they are well away from the neurovascular bundle, unlike the first rib. Posterior scalenotomy alone might be adequate for this type recurrence, allowing the second rib to descend unopposed by the scalene tether.

Four other patients were found at operation to have clavicles practically touch the second rib when the arm was in the AER position after resection of the first rib. Because of the experience noted above, an 8 cm. section of the second rib at the level of posterior scalene muscle insertion was resected immediately with complete relief and no complications.

Operative Technic

The patient is placed with hips in the straight lateral position and the thorax tilted posteriorly 60° with sandbag support at the back for the best exposure of both the anterior and posterior extremes of the rib to be resected. The forearm, arm, axilla and chest are prepared and draped into the surgical field with two layers of stockinette covering the entire extremity so it may be freely manipulated during operation. The transverse incision is made low in the axilla at the point where the skin first breaks from the rib cage up to the axilla when the arm and shoulder are forcefully elevated toward the ceiling (Fig. 2). At this location, usually over the third rib, the incision lies just below the axillary hair line in women for shaving comfort, and just above the brassiere strap to avoid clothing irritation. The slightly curved transverse "smile" incision is made so it lies precisely in the axillary skin lines (axillary breast fold in women), thus becoming almost imperceptible after 6 months. A higher transverse incision enters the axillary fat nodes and vessels causing more troublesome dissection and bleeding without increasing exposure.

The first structures encountered are the small lateral thoracic artery and the tho-

FIG. 2. Photograph which demonstrates location of left axillary incision at level where skin breaks up from rib cage to axilla when arm and shoulder are forcefully elevated. Note assistant elevating extremity with forearm "wrist lock" technic.

racoepigastric vein lying vertically in the subcutaneous tissue in the mid-axillary line. They are divided and the incision is further deepened to the serratus anterior muscle on the rib cage before angling upward to develop the axillary tunnel. An areolar tissue plane will be encountered on the serratus anterior muscle which can easily be developed by finger dissection to the first rib passing deep to the fat, nodes and vessels of the axilla.

The second structure encountered is the taut intercostobrachial nerve in mid-field coming from the second intercostal space. It should be widely dissected from surrounding areolar tissue leaving a pedicle of fat and accompanying veins. Trauma or ischemia of this nerve will cause numbness of the axilla and medial and posterior aspects of the arm (triceps area) which is common postoperatively, but gradually clears in a few weeks or months, if the nerve is preserved.

The third structures often encountered as dissection progresses deeper toward the first rib are the small superior thoracic artery and vein. The are located vertically in mid-field coming off the axillary vessels just lateral to the edge of the first rib and pass into the first intercostal space. They should be anticipated, clamped, divided and tied to avoid troublesome bleeding before proceeding further. A light membrane of fascia forming a cul-de-sac at the lateral edge of the first rib is broken through by finger-tip dissection along the rib. This simple maneuver fully exposes the contents of the thoracic outlet: the large fluttering blue subclavian vein anteriorly, the small ribbon of scalenus anterior muscle inserting on the medial edge of the first rib at the palpable scalene tubercle; the pencil-sized pink pulsatile subclavian artery immediately posterior to the scalenus anterior; the large yellowish T_1 root of the brachial plexus immediately posterior to the artery; and the large scalenus medius muscle posterior to the plexus (Fig. 3).

To afford maximal exposure of the contents of the thoracic outlet, it is imperative for the assistant to elevate the extremity by a wrist-lock around the patient's forearm and antecubital fossa (Fig. 2). He should be standing on a stool so he has low purchase, holding the arm at the level of his waist to get maximal mechanical advantage. He must strictly avoid a circumferential squeezing hand-hold around the patient's arm, as this compresses nerves, vessels and muscles against the humerus resulting in unnecessary postoperative pain. With the low wrist-lock position, he can comfortably hold the arm from the chest wall, and at appropriate times forcefully elevate the whole extremity and *shoulder* toward the ceiling. This maneuver is absolutely essential to the operation as it affords safe clear exposure of the deep structures. With elevation of the shoulder, the thoracic outlet opens, almost like a huge clam shell, to expose with remarkable clarity the structures mentioned above.

Before proceeding, the surgeon should check the costoclavicular "scissor" by placing a finger on each side of the scalenus

anterior muscle on top of the first rib. The patient's shoulder is then depressed caudad, as in the lateral supine position the shoulder falls cephalad toward the ear which opens the costoclavicular space. With the fingers in place and the shoulder depressed, the patient's arm is put in the 90° abduction-external-rotation (AER) position. Usually a remarkably hard pinch is felt by the surgeon's fingers in patients with thoracic outlet syndrome as the clavicle often rests directly on the bone of the first rib at the level of the scalene tubercle. This maneuver confirms the usual preoperative impression of severe costoclavicular compression of the neurovascular structures, and explains why patients with the outlet syndrome have great difficulty using the arms and hands for any elevated activity.

The subclavius tendon is felt anteriorly on the first rib as a taut band under the head of the clavicle. It is dissected free at its origin at the costochondral junction by spreading with long scissors parallel to the oblique yellow tendon, and divided under direct vision with great care to avoid injury to the subclavian vein immediately posterior and medial to it. It is divided to allow more room for use of the rib shears or rongeur as far medially as possible on the costal cartilage and to avoid postoperative compression of the vein.

The scalenus anterior muscle is dissected free by finger dissection and divided at its insertion directly on the rib to avoid injury to the phrenic nerve which is not visualized but curves around the scalenus anterior 2–3 cm. above the rib. The medial fibers of the scalenus anterior must be divided with special care to avoid opening the cupola of the pleura which rises above the first rib in contact with the medial surface of the scalenus anterior. A right angled hemostat is helpful for this maneuver by insinuating the hemostat carefully behind and around the muscle and pulling it outward laterally as the insertion of the muscle is divided on the rib by long scissors. A scalpel should not be used in this region for if it were to slip, it would drop into the mediastinum and spear vital and poorly accessible structures.

Every fiber of the scalenus anterior need not be divided initially as the medial fibers may be finished later with the periosteal elevator after the pleura has dropped inferiorly to the second rib level. The scalenus medius is pushed off the rib with periosteal elevators as it inserts on top of the posterior third of the rib and has no distinct tendon.

The first rib is cleaned of all muscle attachments from the sternum to the transverse process of the vertebra, using periosteal elevators. When turning the lateral edge of the rib and freeing its undersurface from intercostal muscle, the surgeon must be careful to avoid puncturing the pleura. The Matson, Coryllos and Overholt No. 1 periosteal elevators or raspatories seem best suited for stripping the rib. The right angle hook of the latter two elevators are useful in cleaning off the "inside" (medial) edge of the first rib, using the left index finger as a guide to protect important structures from damage by the tip of the elevator. The periosteum should be *left on* the rib to minimize postoperative scar tissue entrapment of the plexus.

The patient's arm and shoulder should be relaxed intermittently to prevent stretch-emptying of the small vessels supplying the brachial plexus, thus preventing ischemic neuritis from prolonged forced elevation. This and the occasional need to maneuver the arm in different attitudes are the reasons a brace or rack to hold the arm and shoulder in forceful elevation has not been used. An assistant holding the arm permits safer, quicker and more flexible control.

The rib is resected posteriorly as close to the transverse process of the vertebra as possible, preferably using a right angled rib shear. If the shear is placed with great care deeply behind the T_1 root, which is clearly visible, a single cut divides the rib

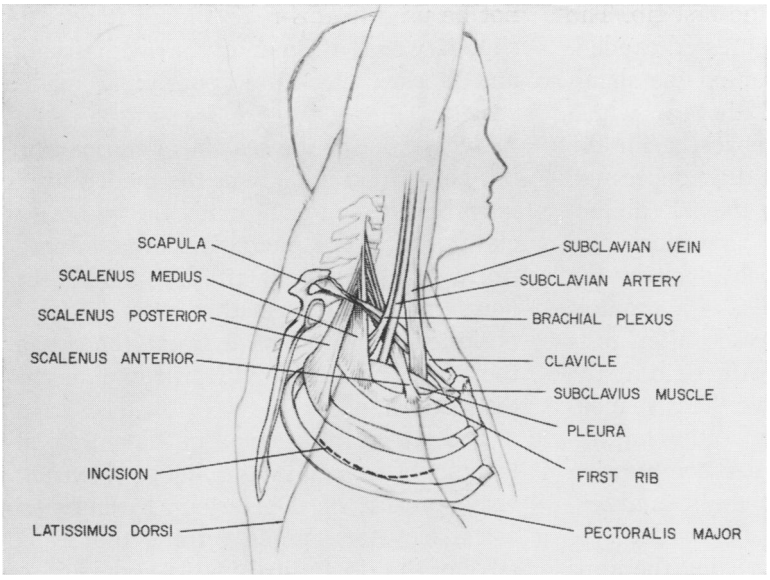

FIG. 3. Schematic drawing illustrating anatomy of the right thoracic outlet from the axillary view with the upper extremity and shoulder elevated.

obliquely 1 cm. from the transverse process with a smooth edge and no corners or spicules that would require rongeur revision (Fig. 6). This is the most demanding and potentially dangerous part of the procedure, and must be performed with meticulous technic. A special right angled rib shear designed specifically for this maneuver adds to the safety, ease and speed of dividing the rib. If used properly, it leaves a short stump that will not later entrap the plexus in periosteal scar tissue. A small curved spatula root retractor designed to lay on the T_1 root immediately behind (deep to) the tips of the rib shear prevents the root being nipped or damaged by the shear. The special shear and root retractor * shown in Fig. 4a, and 4b are in position of use.

The remaining stump must be carefully felt to detect any anterior "corner" or spicules. If present, they must be rongeured with great care because of the proximity of the T_1 root which must be clearly visualized at all times. Generally, this is best performed with a medium sized Sauerbruch or Stille-Luer rib rongeur, using the paddle-shaped root retractor to protect the T_1 root. A "duck-bill" rongeur may be used, but often the handles are too short and the "bite" taken is so narrow new spicules result.

After the posterior aspect of the rib is divided, the loosened rib, still attached anteriorly at the costal cartilage, may be grasped with a bone holder and forceably pulled laterally in a flat trajectory and avulsed from the costal cartilage. The intercostobrachial nerve must be gently retracted aside to avoid damage at this time as it lies vertically across the middle of the operative field. This simple quick maneuver often completes the rib resection and leaves the anterior stump short and smooth at the level of the costal cartilage. It can usually be performed only in women, however, as the costocartilaginous junction in men is often too strong to permit avulsion. In men the rib is divided with a rib shear as close to the sternum as possible, and the remaining stump rongeured smoothly into the costal cartilage with a Sauerbruch rongeur.

Related Procedures

Ensuring short smooth stumps usually completes the procedure. In some in-

* Manufactured by Pilling Company, Delaware Drive, Fort Washington, Pennsylvania 19034.

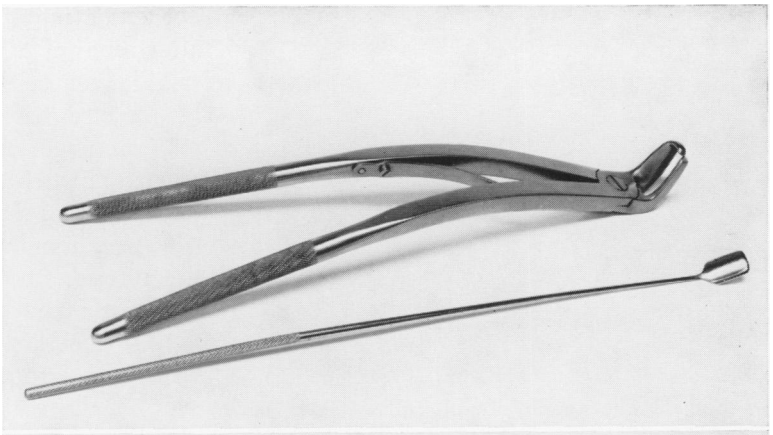

FIG. 4a. (top) Photograph of right angled rib shears specifically designed to fit axillary approach to the posterior aspect of the first rib, and the long handled cervical root retractor.

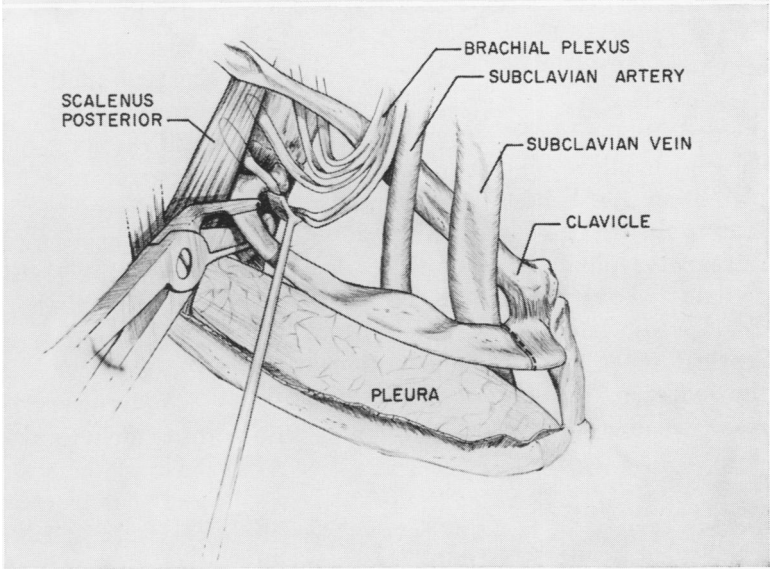

FIG. 4b. (bottom) Drawing of right angled rib shears and root retractor in place for resecting posterior aspect of first rib. Shears should be placed 1–2 cm. more posterior than depicted to divide rib flush with the neck of the rib as shown in Figure 6. Dotted line shows level of anterior division through costal cartilage.

stances, however, additional operative maneuvers may be indicated, such as removal of a cervical rib or congenital band; upper extremity sympathectomy for sympathetic dystrophy, severe vasospastic phenomenon or true causalgia *associated with* thoracic outlet syndrome; 3–4 rib therapeutic or tailoring thoracoplasty; or subclavian-axillary vein thrombectomy in a fresh effort-vein thrombosis. As each of these additional procedures has been performed in the present series (removal of cervical ribs or bands, 49 cases; sympathectomy, 8 cases; thoracoplasty, 1 case; venous thrombectomy, 2 cases) and their technic using the axillary approach has not previously been published, brief descriptions of each follows.

Cervical Rib

A cervical rib may be resected through the axillary approach, usually after the first thoracic rib is removed. Cervical ribs less than 2 cm. in length as measured on oblique cervical spine films, do not require resection as they are too short and lie too far posteriorly to be involved in neurovascular compression. A congenital fibrous band usually coming off the tip of such a rib or a long C7 transverse process (abortive cervical rib) and inserting at the scalene tubercle must be removed, not merely

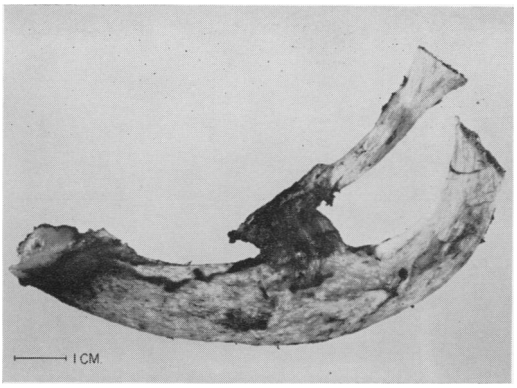

FIG. 5. Photograph of surgical specimen of combined cervical and first thoracic rib resected from woman whose roentgenograms are shown in Figure 1. There is a true joint where the ribs join at the scalene tubercle.

divided. Preferably the *tip* of a short cervical rib should be rongeured to resect completely such a band so it cannot reattach later to the rib bed by scar tissue and cause recurrent symptoms. A short cervical rib actually should not be resected as it is so closely associated with the C7 and C8 cervical roots that instrument damage to the roots may result from over-enthusiastic resection of a *short* cervical rib that does

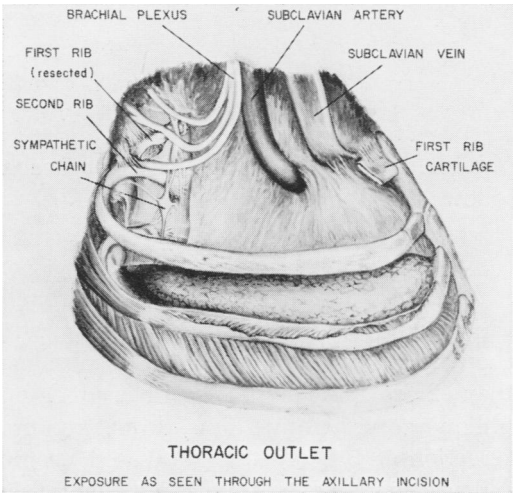

FIG. 6. Composite drawing showing the axillary view of the short anterior and posterior stumps of the resected first rib; the exposed sympathetic chain with the stellate ganglion on the neck of the first rib; and the second rib cleared off for complete resection for a thoracoplasty with the pleura dropped intact to the third rib.

not enter into neurovascular compression after removal of its congenital band.

A longer cervical rib, however, should be resected back to the 1 cm. level, as it may impinge on or entrap the brachial plexus (Fig. 1). Fortunately, it is easier to expose and resect than the short cervical rib. After removal of the first thoracic rib, the anterior tip of the cervical rib is easily felt 1 cm. above the remaining stump of the previous first thoracic rib. It cannot be visualized without careful dissection, however, as the scalenus medius muscle completely envelopes it. Blunt-tipped periosteal elevators with protection of the tip by the surgeon's left index finger are used to push away the muscle covering the cervical rib. With a long elevator or the special root retractor mentioned earlier, the separated muscle "curtain" can be held aside to give visual exposure of the cervical rib. Only under direct vision and with ample exposure should the rib then be resected with an appropriate rongeur or right angled rib shear.

A large cervical rib will usually be found to attach to the first thoracic rib at the level of the scalene tubercle. After careful and complete dissection, the combined cervical-first rib specimen may be resected intact (Fig. 5) and then avulsed from the costal cartilage anteriorly. This technic is usually easier and quicker, but if exposure is not perfect, separate rib resection is safer, removing the first thoracic rib first to aid in exposure for the more demanding cervical rib.

Resection of a cervical rib over 2 cm. in length adds a few minutes to the operating time but should add nothing to the blood loss or complications. It carries a higher risk of plexus injury, and therefore should be performed with great care and only by surgeons completely familiar with the anatomy and axillary technic of first rib resection. The first thoracic rib is *always* resected in cases requiring operation for cervical rib.

Sympathectomy

Using the axillary approach, the *extrapleural* technic of sympathectomy is not difficult after removal of the first rib. The medial aspect of the pleura is carefully stripped from the vertebral bodies and mediastinum by finger dissection down to the third or fourth thoracic vertebra and the lung allowed to collapse to this level. The stellate ganglion is located on the remaining neck of the resected first rib by palpation anterior to the visible T_1 cervical root. The stellate, T_2, T_3, and T_4 ganglia and the sympathetic chain are isolated by instrument dissection under direct vision inferiorly along the lateral aspect of the vertebral bodies (Fig. 6). The sympathetic chain is resected to the desired level, using long thoracic instruments and steel clips. Bleeding is negligible, and lung and pleura readily expand to normal postoperatively without using drains. A small extrapleural fluid shadow medial to the cupola of the lung is noted on postoperative chest roentgenogram, but is quickly absorbed.

Venous Thrombectomy

The conserative treatment of subclavian-axillary vein thrombo-phlebitis (effort vein thrombosis) is often unsatisfactory, leaving the patient with a chronically edematous, uncomfortable, discolored, congested post-phlebitic upper extremity predisposed to recurrent thrombophlebitis.[15] Removing the underlying cause of venous irritation and thrombosis, namely the costoclavicular or costo-subclavius-muscle compression of the subclavian vein, along with early removal of the obstructing thrombus, should afford the best chance of restoring the circulation of the upper extremity to normal and avoiding recurrence. Previous attempts at thrombectomy in this area have often failed, probably because the underlying cause of the thrombosis, the venous compression between first rib and clavicle, was not relieved concomitantly. Both thrombectomy and relief of the underlying venous compression can readily be accomplished together using the axillary approach.

After completion of first rib resection, the proximal extent of the thrombus can easily be determined visually and by gentle palpation. The normal flat fluttering quality of the large subclavian vein is absent and the vein appears distended and rigid. The vein is carefully dissected from surrounding areolar tissue and a small vascular clamp is applied medially just proximal to the end of the thrombus. The vein is encircled with a tape distally toward the axilla for control, and a 1 cm. venotomy is made on the inferior surface of the subclavian vein at the level where it formerly crossed the first rib (Fig. 7a). Fresh thrombus will suddenly extrude from the vein under pressure and may be emptied by suction or appropriate common duct stone forceps. A large catheter with an end hole or a malleable Abraham laryngeal cannula attached to suction, is passed proximally and distally (Fig. 7b) to remove as much clot as possible with the aid of saline irrigation.

Balloon catheters seem too stiff to accommodate the back-angle of the axillary vein from this approach. More effective emptying of the thrombus in the venous system peripheral to venotomy is obtained by a circular rubber bandage (Esmark) compression of the extremity beginning at the hand and wrapping tightly to the axilla. This technic also avoids the "snow-plow" effect of the balloon catheters of displacing thrombus from the major vessel into the lumen of branch veins, thus plugging them and preventing the smaller branch veins from emptying into the large collecting vein. The compression bandage may actually help squeeze out thrombus from collateral veins into the major vein where the clots may be retrieved. Its use should be repeated until no new thrombus is recovered and peripheral venous flow is brisk. The distal control tape is then tightened for hemostasis while the

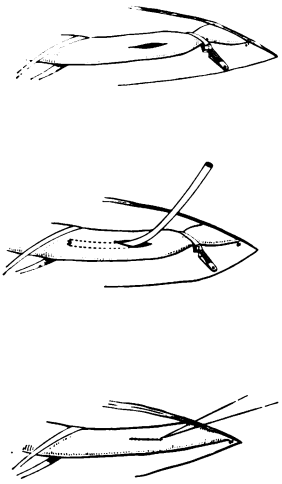

FIG. 7a. (top) Drawing showing the axillary view of the technic of subclavian-axillary vein thrombectomy. Note vascular clamp proximally and tape distally to control bleeding.

FIG. 7b. (center) Rubber catheter in vein to aspirate thrombus.

FIG. 7c. (bottom) Closure of venotomy with 6-0 vascular suture.

short proximal vein stump from the venotomy to the vascular clamp is emptied of accumulated thrombus by irrigation, suction and forceps. Saline filling of the vein lumen is performed to displace air to avoid air embolus after restoration of flow while the venotomy is meticulously closed with 6-0 vascular suture (Fig. 7c). Heavier suture is unnecessary and should be avoided to minimize thrombus formation at the venotomy site. The distal tape is released to test hemostasis, and finally the proximal vascular clamp is removed to restore normal flow. The axilla is closed in the routine fashion described below, preferably with no drains. Postoperatively the extremity must be *constantly* elevated for several days to promote rapid venous flow across the diseased vein and venotomy site until it is covered with new endothelium. Light intravenous heparinization (0.5–1.0 mg./Kg. body weight is continued several days followed by oral antiprothrombin therapy for several months.

Hemostasis obviously must be meticulous after vein closure but has proved to be no problem, even with continuous light heparinization and the increased venous collaterals around the obstructed subclavian-axillary vein. Postoperative relief is usually noted immediately by the patient. Removal of the thrombus and the rib to decompress the costoclavicular space allows the natural thrombolytic enzymes in the blood to bathe the diseased vein lumen. This permits comfortable constant elevation of the upper extremity without causing painful brachial plexus and subclavian artery and vein compression seen with the "conservative" management of this problem.

Thoracoplasty

A fourth application of the axillary approach for first rib resection has been its use in therapeutic or tailoring thoracoplasty. The first rib is removed as described. The serratus anterior, intercostal and scalenus posterior muscles and the pleura are stripped off the second rib circumferentially with periosteal elevators, exposing the rib from sternum anteriorly to the neck of the rib posteriorly.

The pleura safely drops intact to the third rib and the bare second rib lies suspended and is easily resected with angled rib shears as far anteriorly and posteriorly as desired (Fig. 6). The same procedure is then used for the third, and if necessary, the fourth rib. Operative exposure significantly increases with each rib resected from above downwards, and the pleura is readily preserved as it drops out of harms way below the rib being resected. Four complete ribs may be easily resected through the original 7–11 cm. transverse incision in the lower aspect of the axilla. Extending the incision is unnecessary. Removal of the ribs in a 1-2-3-progression is far easier and safer due to increasing exposure and dropping the pleura out of the field below the rib being resected than the the old technic of 3-2-1 removal where the surgeon constantly faces the pleura to the end of the procedure. Bleeding and postoperative dis-

comfort are minimal compared to the "classic" posterior or parascapular thoracoplasty.

These newly reported technics illustrate other operative procedures that may be performed through a small inconspicuous incision in the axilla which offers excellent exposure and minimal postoperative discomfort and complications.

Closure

With the completion of any of the procedures described above, the same simple quick closure is used. The pleural integrity is first tested with saline irrigation during forced lung inflation.

If no pneumothorax is demonstrated, the cavity is flooded with saline to displace the air in the operative area during closure. If this is not done, air trapped in the deep operative field by closing the skin will migrate into the tissues causing subcutaneous emphysema which dissects up the neck and down the chest. Saline left in the operative area has never caused infection in over 200 cases, and is absorbed in a few days with no morbidity. It is safer and more comfortable than subcutaneous emphysema.

If pneumothorax is demonstrated by signs of streaming air bubbles and disappearing fluid level, a catheter is placed in the pleural opening and attached to suction during closure of the wound. No attempt is made to suture the pleura, as the cupola is too thin to hold sutures and merely tears further. The entire operative cavity is again flooded with saline during forced expansion of the lungs and the shoulder brought down to seal the apical area from the ambient air. The saline displaces air that would otherwise be trapped in the large operative cavity when the skin is closed. Trapped air could then be aspirated into the pleura thus increasing pneumothorax. With the air previously in the pleura emptied by forced lung expansion by the anesthesiologist while a suction catheter lies in the cupola, and trapped air in the operative cavity displaced by saline, the suction catheter may be removed during skin closure with no fear of later collapse of the lung.

The shoulder and arm are brought down and allowed to relax while the subcutaneous fascia of the axilla is closed. There are no muscles to repair. The skin is approximated, preferably with continuous 4-0 chromic *subcuticular* catgut. This type of buried closure seals the wound edges and avoids contamination by external sutures that may act as wicks to inoculate the wound with organisms from skin, sweat and clothes. It permits use of a simple spray plastic dressing which forms a sterile seal of the wound in the operating room, and avoids gauze and tape dressings which are unpleasant in the axilla. After the plastic dressing has dried, applying powder to the axilla keeps the arm from pulling the plastic off the incision.

No postoperative wound care of any kind is required. There are no drains or sutures to remove, and no dressing to change. This is particularly convenient for the patients themselves as they may bathe or shower 1–2 days postoperatively, and are usually discharged in 3–4 days with no concern about wound care or dressings at home or later suture removal.

Complications

Using the axillary approach as described in 276 operations in 232 patients (44 bilateral), complications have been few and none serious (Table 1). No patient has been made worse by these procedures. The most common complication has been operative pneumothorax, which has occurred in about 10% of cases. Each was recognized prior to wound closure, treated as described above with no postoperative infection or prolongation of hospitalization. Three developed hemothorax postoperatively which was tapped once with no sequelae.

Patients who do have operative pneumothorax often have chest pain postopera-

TABLE 1. *Complications of First Rib Resection in 276 Cases*

Pneumothorax	28	(10.1%)
Recurrence	10	(3.6%)
Rib regeneration	1	(0.3%)
Wound infection	7	(2.5%)
Causalgia	5	(1.8%)
Wound separation	5	(1.8%)
Hemothorax	3	(1.1%)
Plexus injury (temporary)	1	(0.3%)
Major vessel injury	0	

tively felt in the *lower* thorax anteriorly and laterally, and may run a febrile course. They feel otherwise well, however, and usually have no demonstrable infection or atelectasis. This clinical picture was considered to be due to a sterile pleuritis, and treated with phenylbutazone (Butazolidin, 100 mg. t.i.d.) with relief of chest pain and resolution of the fever in 12–24 hours. A 1–2 day course of treatment has been adequate with no recurrence of those symptoms, fever or complications. It permits early discharge of the patient from the hospital which might otherwise be delayed by a low-grade febrile course. It does not, of course, replace usual measures of postoperative pulmonary care.

Recurrence of symptoms after initial operative relief, seen in about 4% of cases, seems to have two causes: scar tissue entrapment of the brachial plexus and subclavian artery by the bed of the first rib; and neurovascular compression between clavicle and second rib. Five patients had scar tissue entrapment, four of whom underwent neurolysis, again through the axillary approach, with complete relief thus far. To help avoid re-attachment of the neurovascular bundle by the active fibro- and osteoblastic cells of the periosteum, two later patients had inert tissue-pads placed between the neurovascular structures and the rib bed. An upside-down axillary fat pedicle was swung up to the thoracic outlet and lightly sutured in place in one. The other had a redundant *posterior* scalenus muscle, disconnected when an 8 cm. segment of second rib was removed, sutured to the deep pectoral fascia, passing between the neurovascular bundle and periosteal bed as a loose sling. Both patients were relieved of incapacitating symptoms. A free fat or muscle pad would probably work satisfactorily, also.

In each instance of recurrent symptoms with good physical findings for neurovascular compression, a distinct mechanical cause for recurrence was found at operation and responded to appropriate correction. From this experience, it is felt that with typical recurrent outlet syndrome, conservative management has little to offer (it failed in each case mentioned), and early reoperation is indicated if symptoms are severe. On reoperation, using the same approach and incision, the axillary tunnel has been found to be free of scar tissue, probably because it is developed in a natural areolar tissue plane between the anatomically distinct thorax and shoulder (with accompanying axilla). The only impressive scar tissue was found at the first rib bed where the artery and T_1 root were tightly bound.

With recurrence, costoclavicular compression of the neurovascular bundle against the *second* rib must be carefully considered and tested also. If there is any question of this, an 8 cm. segment of second rib should be freed and resected at reoperation.

One patient has proved regeneration of the first rib resected with recurrence of symptoms, but she has not returned for further evaluation. This complication is rare (0.36%), and should be prevented by leaving all the periosteum on the rib during resection.

Wound infection occurred in five of the first 30 patients (16.7%) when Penrose drains were used postoperatively for 24 hours. Because of this unacceptably high infection rate and cultures showing *Staph aureus* organisms, it was felt the drains were inoculating subcutaneous tissue in a retrograde fashion from the skin surface of

the axilla. Postoperative drainage was discontinued, and only two minor wound infections have occurred in the succeeding 246 patients. One of these again had Penrose drains used for potential bleeding as she was heparinized during and after subclavian vein thrombectomy. The fear of bleeding was unfounded, the drains were unnecessary, but again resulted in a *Staphylococcus aureus* wound infection. Avoiding drains, using a subcuticular skin closure and a plastic spray dressing has eliminated wound infections in the axilla, an area usually considered predisposed to this complication.

Causalgia in the distribution of the intercostobrachial nerve no doubt resulted from excessive trauma, partial division or ischemia of the nerve involved. Although the burning hypersensitivity of the upper inner and posterior arm area was distressing and proved refractory to treatment, each cleared spontaneously in 3 months. No causalgia has been seen in the past 100 patients when greater care has been taken to avoid stripping the blood supply and damage to the intercostobrachial nerve by leaving a protective pedicle of fat and veins around the nerve. Temporary numbness in the distribution of this nerve is common, but is of little consequence to the patient and gradually disappears if the nerve is preserved.

Wound separation occurred in five patients with leakage of saline and serum from the operative area. In each, the patient was home and suddenly reached upward, thus tending to pull the incision open. Each was treated at home with daily showers and gauze dressing and healed in a few days without infection. This complication can be eliminated by having the patient avoid high reaching for 2 weeks postoperatively. With the arm down, the transverse incision edges fall together and heal rapidly.

One patient had a radial nerve palsy postoperatively for 3 months. This resulted from trauma to the brachial plexus during operation, probably from the curved Deaver retractor used to help expose a short cervical rib. She was the second patient operated upon by the axillary approach. Deaver retractors have since been avoided because of their deep curve in favor of the right angled Heany vaginal retractors, and all instruments except the small root retractor have been kept off the brachial plexus at all times. No further incidence of plexus injury has been seen in the succeeding 274 patients. No damage to the subclavian or axillary vessels has been encountered, and blood transfusion has never been required. Blood loss is uniformly less than 100 ml.

TABLE 2.

Number of operations		276
Number of patients operated on		232
Patients with bilateral procedures		44
Women	176	(75.9%)
Men	56	(24.1%)
Total patients	232	
Cervical ribs	27	(9.7%)
Cervical bands	22	(8.0%)
Hypoplastic first rib	3	(1.1%)
Total anomalies	52	(18.8%)

Results

Five hundred sixty-six patients were evaluated for possible thoracic outlet syndrome. Of these, 232 or 41% ultimately required operation after failure of conservative management. The number of patients, operations, sex of patients operated upon and congenital anomalies encountered are shown in Table 2. The overall results in the

TABLE 3. *Results of First Rib Resection*

Good–Excellent	245	(88.8%)
Fair–Poor	31	(11.2%)
Worse	0	
Total operations	276	

276 operations are shown in Table 3. Relief of all symptoms was considered an excellent result and mild residual was called a good result. Thus, 88.8% of all patients had significant benefit from the first rib resection after conservative treatment had failed. Fair to poor results reflected little or no definite or sustained benefit.

Although the details of the technic for subclavian vein thrombectomy with first rib resection have been thoroughly developed, results of venous thrombectomy await a larger series and longer follow-up. They appear encouraging in two cases thus far.

First rib resection offers such specific relief for true thoracic outlet syndrome that failure to benefit from the procedure probably results from error in diagnosis, and misapplication of the procedure, or inadequate operation.

The 11.2% failure rate compared with the 60% failure rate of scalenotomy reflects the difficulty of diagnosis of the outlet syndrome in some patients. Thorough history, detailed physical examination, and ancillary tests [12, 16] must be employed for accurate diagnosis, especially in difficult and atypical instances to avoid mistaking an "incidental" subclavian artery compression with pulse changes for a "causative" outlet compression. Every effort must be made to reduce the diagnostic error to spare patients unnecessary or inappropriate operations.

Summary

The major developments in the surgical management of thoracic outlet syndrome are reviewed. Complete details of first rib resection using the axillary approach for operative relief of the outlet syndrome are presented, and extension of the axillary technic to (1) cervical rib resection, (2) thoracic sympathectomy, (3) axillary-subclavian vein thrombectomy, and (4) thoracoplasty is described. Complications encountered, means of avoiding them and general results in a series of 276 cases are discussed.

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