HORACIC outlet syndrome refers to disorders involving the artery, vein, and/or nerves at the thoracic inlet. Vascular obstruction is relatively easily diagnosed based on clinical and radiological studies. Edema, swelling, and cyanosis of the arm may result from compression of the subclavian vein. Arm claudication, and fatigue associated with arm abduction, is a feature of arterial obstruction. Patients may also present with clear neurological deficits secondary to wasting of the muscles innervated by the lower plexus. In such cases, the need for surgical intervention is clear.

There is a fourth group of patients whose presentation is characterized by pain but no clear neurological deficits or clear vascular symptoms. These patients typically complain that their symptoms are aggravated by external rotation/elevation of the shoulder (the so-called spear-throwing position). These symptoms include pain in the shoulder region and numbness/tingling that both extend to the hand. The diagnostic criteria are not well established, and whether patients with these signs and symptoms should undergo surgery is disputed. In addition no clear radiological abnormalities have been validated. The diagnosis is based on history, physical examination, and exclusion of other diagnoses such as cervical spondylosis. Physical examination-detected abnormalities include provocation of symptoms by the spear-throwing position and by downward tugging of the shoulder.

In addition to the question of whether to operate, the choice of surgical approach is disputed as well. Some authors have advocated SNBP, a procedure in which the brachial plexus is dissected free of constricting bands and muscle, whereas others have advocated TFRR. The main goal of the present study was to determine which of these operations is more effective, considering

Surgical treatment of thoracic outlet syndrome: a randomized trial comparing two operations

RISHI N. SHETH, M.D., AND JAMES N. CAMPBELL, M.D.
Department of Neurosurgery, School of Medicine, The Johns Hopkins University, Baltimore, Maryland

Object. Various surgical approaches have been proposed for the treatment of thoracic outlet syndrome (TOS). The authors of this study focused on the differences in outcome after supraclavicular neuroplasty of brachial plexus (SNBP [no rib resection]) and transaxillary first rib resection (TFRR) in patients in whom the dominant clinical problem was pain.

Methods. Fifty-five patients were randomized to undergo TFRR or SNBP. Patients with an anomalous cervical rib, intrinsic weakness, and primarily vascular findings were excluded from the study. Preoperatively, the following findings were typically observed: provocation of symptoms by certain postures (the so-called spear-throwing position as well as downward tugging of the shoulder) and marked tenderness in the supraclavicular fossa.

The intergroup severity of the symptoms was comparable. Eight patients were lost to follow up. There were 24 TFRRs (in two cases the procedure was bilateral) and 25 SNBPs. The mean follow-up interval was 37 months. In both groups pain decreased significantly after surgery. By all measures the TFRR operation conferred superior results. Patients reported significantly less pain (39 ± 7 compared with 61 ± 7; score range 0–100 on a visual analog scale), greater percentage of pain relief (52 ± 8% compared with 30 ± 7%), and less pain (3.7 ± 0.4 compared with 5.1 ± 0.5) on an affective scale (all p < 0.05) in the TFRR and SNBP groups, respectively. In the TFRR group, 75% of patients reported good or excellent outcomes compared with 48% in the SNBP group (p < 0.05).

Conclusions. Transaxillary first rib resection provided better relief of symptoms than SNBP. The major compressive element in patients with TOS-associated pain appeared to be the first rib.

Key Words • thoracic outlet syndrome • brachial plexus • peripheral nerve • pain • nerve entrapment

Thoracic outlet syndrome refers to disorders involving the artery, vein, and/or nerves at the thoracic inlet. Vascular obstruction is relatively easily diagnosed based on clinical and radiological studies. Edema, swelling, and cyanosis of the arm may result from compression of the subclavian vein. Arm claudication, and fatigue associated with arm abduction, is a feature of arterial obstruction. Patients may also present with clear neurological deficits secondary to wasting of the muscles innervated by the lower plexus. In such cases, the need for surgical intervention is clear.

There is a fourth group of patients whose presentation is characterized by pain but no clear neurological deficits or clear vascular symptoms. These patients typically complain that their symptoms are aggravated by external rotation/elevation of the shoulder (the so-called spear-throwing position). These symptoms include pain in the shoulder region and numbness/tingling that both extend to the hand. The diagnostic criteria are not well established, and whether patients with these signs and symptoms should undergo surgery is disputed. In addition no clear radiological abnormalities have been validated. The diagnosis is based on history, physical examination, and exclusion of other diagnoses such as cervical spondylosis. Physical examination-detected abnormalities include provocation of symptoms by the spear-throwing position and by downward tugging of the arm. Patients typically feel marked tenderness in the supraclavicular region and a Tinel sign (paresthesias in the hand and fingers with digital percussion in the supraclavicular fossa) may be present. Spondylotic disease has been deemed unlikely to be the cause of such symptoms, particularly when neck range of motion is normal.

In addition to the question of whether to operate, the choice of surgical approach is disputed as well. Some authors have advocated SNBP, a procedure in which the brachial plexus is dissected free of constricting bands and muscle, whereas others have advocated TFRR. The main goal of the present study was to determine which of these operations is more effective, considering

Abbreviations used in this paper: SNBP = supraclavicular neuroplasty of the brachial plexus; TFRR = transaxillary first rib resection; TOS = thoracic outlet syndrome; VAS = visual analog scale.
both risk and symptomatic relief. Comparison of the outcomes will provide an opportunity to determine whether surgery has any role in the treatment of this condition. If surgery has no role and if prior reports of improvements are attributable to the disease’s natural history, then the outcomes of the two operations should be similar.

Clinical Material and Methods

General Procedures

Approval for the study was obtained through the institutional review board. Patients were entered into the study based on inclusion/exclusion criteria described in Patient Selection. Patients were randomly assigned to undergo SNBP or TFRR. Outcomes were derived from an evaluation of questionnaire and interview results.

Patient Selection

Patients selected in our study were adults with pain as the predominant presenting symptom and in whom TOS had been diagnosed by the senior author (J.N.C.). Patients with neurological deficits, as evidenced by muscle atrophy or sensory loss (at rest), and those who presented with symptoms of vascular occlusion were excluded from the study. Other exclusion criteria included prior TOS surgery, findings of cervical spondylosis, and cervical rib-induced plexus compression. Typically, there was a triad of findings: symptoms (increased shoulder pain and tingling/numbness extending into the hand) provoked by the throwing position and downward tugging of the shoulder, as well as tenderness in the supraclavicular fossa. In all cases, neurological examination ruled out the possibility of a neurological deficit. Because prior experience indicated that electromyography and nerve conduction studies typically revealed no abnormal findings in this group of patients, these studies were not typically performed. Likewise imaging studies, when conducted, of the brachial plexus did not reveal any abnormalities. All patients had previously been referred for physical therapy that involved stretching and shoulder girdle strengthening, but no improvement had been shown.2,18,26

Patient Randomization

Once patients were selected as surgical candidates, the operative choices were explained to them. They were told that they could select one or the other procedure or that the operation would be randomly selected for them; if patients selected one procedure, they were excluded from the study. Patients were told that the comparative risks and benefits of the two operations were unknown. All patients in this study agreed to the randomization procedure and none was excluded. Once randomized, no patient dropped out of the study to undergo the alternative operation.

Collection of Outcome Data

A standard questionnaire was mailed to the patients. All patients were then interviewed over the telephone or in person by an individual (R.N.S.) not involved in patient care.

The outcome measures for pain were percentages of pain relief, pain level status represented by a score on a VAS (100-mm line), and categorical assessment of pain relief (excellent, good, fair, or poor). Patients were asked to indicate their average pain level as well as the pain level at its worst and best. Patients also identified where they felt pain, numbness, and tingling. Patients were also asked if their symptoms were better or same during the arm raise maneuver after surgery.

Surgical Approach

Supraclavicular Neuroplasty of the Brachial Plexus. Surgery is performed after induction of general endotracheal anesthesia with the patient in the supine position. A small bump (2-cm-thick sheet) is placed under the shoulder, and the head is turned in the opposite direction. A 7-cm transverse incision is made one finger’s breadth above the clavicle, starting medially at about the middle of the belly of the sternocleidomastoid muscle. Care is taken to preserve the supraclavicular cutaneous nerves in the lateral part of the incision. After mobilization of the scalene fat pad and omohyoid muscle, the phrenic nerve is isolated along the anterior scalene muscle. The anterior scalene muscle is then divided completely and the upper, middle, and lower trunks of the plexus are freed circumferentially (complete neuroplasty). The neuroplasty is then advanced to the level of the C-8 and T-1 nerve roots (Fig. 1).

Vessel loops are placed around the nerve roots, and special care is taken to remove any bands or other soft tissue that might be compressing the roots or lower trunk. The first rib is left intact. The middle scalene muscle is taken down to make more room for the lower trunk. Connective tissue arising from the apex of the pleura is removed from the area around the lower plexus, and on occasion the pleura is opened. No attempt is made to close the pleura if this happens, and no patient in this series received a chest tube. A small drain is placed in the wound prior to closure.

Transaxillary First Rib Resection. Surgery is performed after induction of general endotracheal anesthesia with the patient in the supine position. A bump is placed under the shoulder, tilting the plane of the patient upward by approximately 20 to 30°. The table is elevated sufficiently to bring the operative field to a point just below the shoulder level of the surgeon. The arm is elevated and secured to an anesthesia screen (Fig. 2 left). The surgeon is positioned to allow complete access to the axilla. The scrub nurse is positioned on the opposite side and is in a position to hold a retractor when necessary. A 6- to 7-cm curvilinear incision is made at the base of the anterior part of the axilla, at a point just inferior to where the skin breaks away from the chest wall. This anterior incision is designed to avoid injury to the long thoracic nerve. Dissection proceeds directly to the chest wall and then up to the area of the first rib. The intercostobrachial nerve can be visualized or at least palpated as it exits the second intercostal space and is carefully preserved. If it interferes with the operation, the nerve is mobilized until it can be retracted safely. Sometimes it is easier to retract the intercostobrachial nerve upward, whereas at other times it is better to allow the nerve to fall away below the retractor. The lower edge of the first rib is cleared of muscle, and the pleura is mobilized away from the rib. A tear in the pleura is of no consequence as long as a drain is used postoperatively to prevent a hemotorax. The anterior scalene muscle is severed at its inser-
Two surgical approaches in treating TOS

Fig. 1. Operative approach used in the SNBP procedure. The inset shows the location of the skin incision, and the main figure shows the anatomy of the important structures. Dissection proceeds to the C-8 and T-1 nerve roots and the lower trunk. A = artery; m = muscle; n = nerve; v = vein.

Statistical Analysis

Except where indicated, intergroup differences and pre- and postoperative differences were analyzed using t-tests. Confidence limits are presented as the mean ± standard error of the mean unless otherwise indicated.

Results

A total of 117 patients with TOS were evaluated and were considered potential candidates for the study. Of these, 62 patients were excluded according to our selection criteria. After the initial screening, 55 patients were randomized to undergo one of the two surgeries. Eight patients were lost to follow up (four in each group). Forty-seven completed a follow-up questionnaire and responded to questions in a follow-up interview.

Of the 47 patients, 40 (85%) were women. The mean age of the population at the time of surgery was 37 ± 7 years (± standard deviation; range 18–58 years). Excluding patients lost to follow up, there were 24 TFRR and 25 SNBP procedures. Two patients underwent TFRR involving both limbs. Twenty-six procedures were left sided.

The mean duration of preoperative symptoms was 47 ± 5 months (range 3–150 months). The mean follow-up duration was 37 ± 5 months (± standard error of the mean; range 3–138 months). The preoperative pain severity was rated high in most patients. More than 65% of patients described their pain as distressing or intolerable (VAS score > 75).

Symptoms developed in 38 patients (81%) after a traumatic event (16 were involved in a motor vehicle accident; 19 in a work-related incident; three in a nonwork-related event); in the other 19% the origin of symptoms was spontaneous. The mean duration between the onset of symptoms and surgery was greater in the nine patients with
FIG. 2. Left: The operative setup used in the TFRR procedure. The incision is made just at the anterior lower margin of the axillary hairline. The arm is suspended on an L-shaped apparatus. A roll is placed under the scapula, and the table is positioned so that the operative site is just below the surgeon's shoulder level. The scrub nurse is positioned on the opposite side to help with retraction. Right: The diagram shows the surgeon's view for the transaxillary approach. The subclavian vein, anterior scalene muscle, subclavian artery, and brachial plexus all appear draped over the rib in an anteroposterior position. The rib is resected in a piecemeal fashion by using a bone rongeur, after the muscle and pleura have been dissected away (see inset). The intercostobrachial nerve is noted and preserved. The posterior extent of the rib resection is within 1.5 cm of the transverse process so that the plexus can be fully decompressed. The posterior resection of the rib helps minimize the need for retraction and allows the operation to be conducted safely via a small incision.
Two surgical approaches in treating TOS

TABLE 1
Summary of demographic data obtained in patients undergoing different surgeries for TOS-related symptoms

<table>
<thead>
<tr>
<th></th>
<th>TFRR</th>
<th>SNBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>male/female ratio</td>
<td>4:20</td>
<td>4:21</td>
</tr>
<tr>
<td>postop period (mos)</td>
<td>42 ± 7</td>
<td>31 ± 7</td>
</tr>
<tr>
<td>age (yrs) at op</td>
<td>35 ± 2</td>
<td>38 ± 2</td>
</tr>
<tr>
<td>VAS pain severity</td>
<td>77 ± 3</td>
<td>82 ± 3</td>
</tr>
<tr>
<td>increased symptoms w/ arm abducted (%)</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>onset attributable to trauma (%)</td>
<td>71</td>
<td>71</td>
</tr>
</tbody>
</table>

spontaneous-onset symptoms (60 ± 18 months) compared with the 16 patients involved in a motor vehicle accident (33 ± 4.7 months; p = 0.03) but not in the 19 patients sustaining a work-related injury (47.7 ± 8.8 months; p = 0.25).

Comparison of Preoperative Data

Characteristics in patients who underwent TFRR were similar to those who underwent SNBP with regard to male/female ratio, age at onset, follow-up duration, pain severity, and incidence of inciting trauma (Table 1). The way in which pain was distributed among different areas was also similar between the groups, and the majority of patients reported neck, shoulder, arm, forearm, and hand/finger pain (Fig. 3A). Complaints of numbness and tingling were also common and these symptoms were felt in the hand and fingers in more than 80% of the patients (Fig. 3B).

Outcome After Surgery

Pain. Four measurements were assessed to determine the change in pain after the two operations: change in VAS score, percentage of pain relief, change in the affective ratings of pain, and categorical assessment of pain relief. Analysis of these findings demonstrated that TFRR was associated with greater benefits than SNBP. As a measure of internal validity of test questions, we compared postoperative VASs and affective scale scores (Fig. 4). These results were highly correlated (R² = 0.83).

Patients used the VAS to rate their average pain, least amount of pain, and greatest amount of pain. The mean intergroup preoperative VAS score (mean pain level) was similar (TFRR 77 ± 3 and SNBP 82 ± 3; p = 0.28). The mean rating of average pain after surgery was lower for the TFRR-treated patients (39 ± 7) compared with the SNBP-treated patients (61 ± 7; p = 0.03) (Fig. 5). Similarly, the mean VAS score for the “least pain experienced” postoperatively was significantly lower in patients who underwent TFRR (30 ± 6) than in those treated with SNBP (49 ± 7; p = 0.04). Even though the “greatest amount of pain” felt during the day in the postoperative period was lower in the TFRR-treated group (47 ± 8), this difference was not significantly different compared with the SNBP-treated group (67 ± 8; p = 0.09).

Patients were asked to indicate the percentage of pain relief, and this value was significantly higher in patients treated with TFRR (52 ± 8%) than in those who underwent SNBP (30 ± 8%; p = 0.005).

Patients were asked to rate their pre- and postoperative pain by using a nine-point affective scale. The pain-related labels on this scale were as follows: none, not bothersome, slightly annoying, annoying, very annoying, very distressing, intolerable, and very intolerable. For purposes of statistical analysis numbers were assigned to each category from 0 (indicating no pain) to 8 (representing very intolerable pain). Changes in these affective ratings of pain paralleled changes in VAS scores. Before the surgery patients rated their pain as very distressing to intolerable (6.5 ± 0.2). After SNBP there was a significant improvement from the baseline level (distressing, 5.1 ± 0.5; p = 0.005 [Fig. 6A]). The TFRR-treated patients also improved (very annoying, 3.7 ± 0.4; p < 0.0001 [Fig. 6B]), and this improvement was significantly better than that following SNBP (p = 0.03). The patients who underwent TFRR were significantly more likely to report good or excellent pain relief (75% compared with 48%, respectively; p = 0.02).

Numbness. Preoperatively the overall number of areas in which numbness was felt were comparable between groups (TFRR, 5.2 ± 0.61 and SNBP, 5.5 ± 0.5; p = 0.77 [Fig. 3B]). The number of numb areas was significantly reduced after both surgeries (TFRR, 2.8 ± 0.6; p < 0.001 and SNBP, 4.6 ± 0.6; p < 0.05) but the difference between the two operations was significant (p = 0.03).

Seventy-two percent of the patients whose preoperative symptoms were aggravated by arm raising felt improve-
ment after TFRR, whereas only 48% of the patients with this symptomatic trigger felt an improvement after SNBP. When asked if they would undergo this surgery again for the same result, 19 (79%) of the 24 TFRR-treated patients reported that they would, whereas 14 (56%) of the 25 SNBP-treated patients said they would.

Patients who fared well after TFRR in general were working preoperatively. Patients who did not work before surgery were unlikely to return to work. Patients not working because of pain symptoms preoperatively, therefore, are at significant risk for not faring well after surgery.

No patients in this series suffered from a brachial plexus injury, pneumothorax, infection, hematoma, or other serious complications as a result of surgery.

**Discussion**

Thoracic outlet syndrome represents a group of impingement disorders, involving the subclavian vein, the subclavian artery, and/or the brachial plexus. Different surgical approaches have been advocated for its treatment, including posterior thoracotomy for removal of the first rib, TFRR, and SNBP both with and without first rib resection.6,10,15,17,21,22,24,25,26,31,35,44 We report here the first randomized study to compare two surgical approaches, TFRR and SNBP without rib resection.

**Patient Selection**

Our patients presented with pain and neurological symptoms, but without bona fide neurological deficits (clear weakness, muscle atrophy, or ongoing sensory deficit). We chose these patients because they represented the most common group with TOS that presented to the senior author (J.N.C.). We excluded other patients to ensure a population of those included in the series. These patients clearly had a neurological disorder as nearly all complained of prominent sensory symptoms (described as pins and needles), and numbness, as well as pain that extended from the shoulder to the hand. The sensory distribution varied but tended to be more prominent on the ulnar aspect of the hand. No patient had symptoms restricted to the thumb and index finger.

Most patients had distinctive tenderness in the supraclavicular fossa, increased pain/hand numbness with arm abduction and external rotation of the shoulder (spear-throwing position), and increased pain/hand numbness with downward movement of the shoulder.

**Transaxillary Resection, the Optimal Operation**

By all measures the TFRR operation proved the better procedure for relief of symptoms. The outcomes were measured after a substantial postoperative duration (mean 36 months). Thus, these results represent long-term outcomes.

Although the literature is replete with series involving the surgical treatment of TOS, one may argue that improvements seen reflect biased reporting, placebo effects, and/or those derived due to passage of time independent of surgical effects. That one operation in this study yielded decidedly better outcomes than the other provides evidence that surgery may confer benefits over natural history.

Our patients reported severe symptoms that had been present typically for many years. Nearly all patients had undergone extended trials of physical therapy that did not prove successful.29 Arguments that these symptoms should be treated conservatively must be considered in terms of the substantial disability that these patients have sustained. Clearly the decision to recommend surgery should be influenced by a risk–benefit analysis. Substantial complication rates have been reported for TOS.7,8,10,37 In this series no patient suffered any morbidity, but the senior author (J.N.C.) has observed transient brachial plexus deficits in other surgically treated patients. Thus, patients who undergo surgery must be mindful that even in experienced hands risks are not insubstantial.

Some authors have advocated that none of these patients should be treated surgically.9,45,46 Because the surgery-associated morbidity rate is low and because approxi-
Two surgical approaches in treating TOS

![Bar graphs depicting pre- and postoperative pain determined using a category scale (SNBP, p = 0.005; TFRR, p = 0.0001). Upper: Preoperatively, almost all patients complained of their pain as distressing to intolerable. Lower: Postoperatively, however, the number of cases in which patients complained of distressing and intolerable symptoms was 33% in the TFRR group and 68% in the SNBP group. Patients fared better after the TFRR in their perception of pain (p = 0.03). For presentation purposes the original scale is reduced from nine to four categories by grouping the descriptors in groups of two (See Fig. 4; the “no pain” designation actually included three categories: no pain, not bothersome, and slightly annoying).](image)

imately 75% of the TFRR-treated patients reported good or excellent results, surgery appears a justifiable option. This analysis is predicated on the estimation of the morbidity rate being low. The TFRR procedure entails risks likely related to one’s surgical experience. Reports of substantial morbidity have been advanced as reasons to be cautious when advocating TOS surgery.\(^7,8,10,37\)

The results of this study implicate the first rib as the major factor in causing TOS. The implication is that the rib occupies a high position such that it pushes up on the lower aspect of the plexus. At the time of surgery one observes the lower trunk draped over the rib. Whether that constitutes an impingement, however, is a subjective judgment. High-resolution peripheral nerve magnetic resonance imaging has been indicated as a means of identifying compression. Continued experience with magnetic resonance imaging will have to be obtained to determine how sensitive it is. We have seen several cases in which the lower trunk appears to be deviated superiorly in the region of the first rib. A caveat is that many patients only experience neurological symptoms when their arm is in certain positions (for example, the spear-throwing position). Ideally neuroimaging should be performed with the patient’s arm in the symptom-provoking position, but physical constraints may make this impractical.

Of course in conducting a first rib resection other structures are involved. These include the anterior and middle scalene muscle and other fibrous bands that may attach to the first rib. Because the supraclavicular approach involved manipulation of these structures, these putative compression points likely do not account for the major compression in most patients. It has yet to be determined in a control trial whether the addition of neuroplasty would augment the improvements derived from TRFF. Indeed, many patients in this series did appear to benefit from the supraclavicular approach (48% of patients reported a good or excellent outcome). There may well be a subclass of patients in which the supraclavicular approach yields an improved outcome. Indeed it has been policy since this study was completed to offer a supraclavicular approach to patients in whom TFRR produced an unsatisfactory outcome. Our impression anecdotally is that offering this surgical option is helpful, at least in some cases.

Another type of surgery that has been advocated is the first rib resection via the supraclavicular approach.\(^7,24,37\)

This surgery offers the advantages of the transaxillary approach (that is, rib resection) with the additional possibility of retracting soft-tissue structures compressing the plexus. The reason for not undertaking this approach is based on the senior author’s impression that it puts the plexus at risk of injury due to retraction. This issue is deserving of further consideration, however.

McCarthy, et al.,\(^7\) found that supraclavicular decompression for TOS led to benefit in 76% of their patients. In their study, however, approximately one third of the patients harbored a cervical rib (compared with none in the present series). The median follow-up duration was 12 months (whereas it was > 3 years in the present study), and outcome was determined by the surgeon’s review of patient charts (compared with independent systematic review in the present study). Cheng and associates\(^7\) compared supraclavicular rib resection and supraclavicular neurolysis and found similar short- and long-term results. They advocated rib-sparing surgery based on its associated lower morbidity rate.

Wenz and Husfeldt\(^44\) reported on 80 patients who underwent TFRR and were followed for 6.6 years. They observed complete resolution or improvement of symptoms in 85% of their cases. Pain relief was achieved in 75% of our TFRR-treated patients. Wenz and Husfeldt\(^44\) had treated all the forms of TOS, and in some of their patients cervical ribs were present. In a retrospective study Cuypers and coworkers\(^9\) evaluated the findings in 92 patients who underwent TFRR and found that the surgery was successful in only 52%; 37% of the patients had arterial and venous compression. Lacking a randomized series, the relevance of these data is unclear, in particular because of the more heterogeneous patient population.
Analysis of Treatment Failures

In many patients surgery failed to yield a benefit and in the majority only partial symptomatic relief was achieved. Several possibilities could account for this. Some patients in this study likely had some other occult cause of their symptoms not addressed by surgery. A second possibility is that the surgery was inadequate. In the SNBP operation, however, we undertook a thorough circumferential neuroplasty of each brachial plexus element and retraction of the anterior and middle scalene muscles, as well as other bands, including the fibrous tissue arising from the apical pleura and, in some cases, arteries and veins that might conceivably obstruct the plexus. The failure to resolve all pain symptoms in the TFRR-treated patients could relate to an inadequate rib resection. Our goal was to resect the rib to within 1.5 cm of the transverse process, and this was uniformly achieved in all cases. We favor the notion that relief of symptoms is incomplete because compression alone is not necessarily the sole problem in TOS. The structures removed during TOS surgery have a suspension-related function. The brachial plexus may be tethered by the weight of the arm tugging downward on the plexus. Indeed in some cases symptoms were palliated when the patients wore a sling that helped to hold up the arm, preventing the weight of the arm from pulling down on the plexus. This tethering effect on the plexus will not be helped by further efforts at decompression. Indeed further removal of supporting structures could, in fact, make the tethering worse.

Conclusions

This is the first randomized trial of two different operations in the treatment of TOS. The TFRR provided better relief of symptoms, in particular pain, than the SNBP without rib resection. It is likely that the first rib is the major cause of compression in the majority of patients.

Acknowledgments

Drs. Lee Dellon, Lawrence Empting, and Neal Naff all played important roles in helping with this study at various stages.

References

Two surgical approaches in treating TOS

**Diagnosis and Treatment.** New York: Futura, 1986, pp 3–36
44. Wenz W, Hasfeldt KJ: Thoracic outlet syndrome—an interdisciplinary topic. Experience with diagnosis and therapy in a 15-year patient cohort (80 trans-axillary resections of the 1st rib in 67 patients) and a literature review. [*Z Orthop Ihre Grenzgeb* 135:84–90, 1997 (Ger)]

Manuscript received January 3, 2005. Accepted in final form August 26, 2005.

Current address for Dr. Sheth: Department of Neurological Surgery, University of Miami, Lois Pope Life Center, 1095 Northwest 14th Terrace (D4-6), Miami, FL 33136.

Address reprint requests to: James N. Campbell, M.D., Department of Neurosurgery, School of Medicine, The Johns Hopkins University, 600 North Wolfe Street, Meyer 5-109, Baltimore, Maryland 21287. email: jcampbel@jhmi.edu.