Computed tomography-guided reoperation for neurogenic thoracic outlet syndrome

Joshua I. Greenberg, MD, RPVI, Kristen Alix, NP, Mark R. Nehler, MD, Robert J. Johnston, MD, and Charles O. Brantigan, MD

Objective: Persistent or recurrent symptoms after surgical treatment for neurogenic thoracic outlet syndrome (nTOS) is a problem commonly encountered by high-volume referral centers. The mechanical etiology patterns at reoperation include (1) inadequate previous rib resection, (2) rib regrowth, (3) scar tissue formation, or (4) intact scalene muscle. Reoperative TOS surgery has significant potential morbidity, and therefore, careful patient selection and meticulous planning are required. This study evaluated the utility of multidetector computed tomography (CT) in the differential diagnosis of patients with recurrent or persistent nTOS.

Methods: A retrospective record review was performed of a nTOS referral practice of patients treated from 2003 to 2012 to focus on patients reoperated on for recurrent or persistent symptoms. In 2003, a dedicated high-resolution multidetector TOS CT protocol was established to assist in clinical decision making and reoperative planning. A single designated radiologist interpreted all CT images. Imaging, patient clinical characteristics, interventions, and outcomes were reviewed.

Results: The study group included 20 reoperations for recurrent (n = 15) or persistent (n = 5) symptoms. Mean age was 35 years, and 60% of redo cases were in women. Preoperative CT imaging demonstrated the following anatomic patterns: inadequate previous rib resection in 5 (25%), rib regrowth in 5 (25%), scar tissue formation in 10 (50%), and intact scalene muscle in 3 (15%). Operative findings concurred with preoperative imaging in 85% of patients. There were no neurovascular injuries and no major complications. At a mean follow-up of 43 months, improvement or resolution of symptoms was significant in nine patients (45%), moderate in seven (35%), and minimal in four (20%).

Conclusions: Recurrent/persistent nTOS is an often- vexing problem with challenging solutions. These results demonstrate the utility of a TOS protocol CT scan in providing correlative objective findings and in assisting with reoperative planning. Positive radiographic findings that correlate with patient symptoms inform the decision to reoperate. (J Vasc Surg 2015;61:469-74.)

Since its recognition as a distinct medical problem, the treatment of neurogenic thoracic outlet syndrome (nTOS) has relieved the suffering of many patients, allowing them to return to gainful employment. With appropriate patient selection in experienced hands, a sustained improvement can be expected in 80% to 90% of patients.1,2

Reoperative TOS surgery is challenging from a diagnostic and technical standpoint. Thoughtful preoperative planning and meticulous execution of the operative plan are necessary. In 2003, a dedicated high-resolution multidetector computed tomography (CT) TOS protocol was established to assist in clinical decision making and operative planning. Successful application of an imaging protocol to assist in patient selection for redo surgery might improve surgical outcomes.3 The purpose of this study was to evaluate the utility of a TOS-specific CT protocol for patients with recurrent symptoms.

METHODS

Institutional Review Board approval for a consent- exempted study was obtained for patient data entry and analysis.

Study design. A retrospective record review was performed of a TOS referral practice of patients treated from 2003 to 2012. Patient demographics, interventions, and outcomes were identified. All patients seen for recurrent nTOS were initially managed conservatively with physical therapy.

A review of all TOS CT scans was performed, with findings entered into a database. A TOS-specific CT scan was used to assist in patient management. A significant anatomic abnormality near the neurovascular structures was considered a positive CT study. Patients with inadequate previous thoracic outlet decompression were offered completion first rib resection. Patients with a positive CT and symptoms consistent with recurrent nTOS were
treated intensively by a TOS physical therapist unless the anatomic abnormality seen on CT, such as severe compression of neurovascular structures, was thought to contraindicate physical therapy.

Compliant patients with improvement during physical therapy were offered redo surgery after a minimum of 3 months of therapy, but preferably after 6 months. Select patients with negative CT examinations were also offered physical therapy and then surgery if the clinical findings were thought compelling enough to indicate surgery. Neither scalene nor pectoralis minor muscle blocks nor electrodiagnostic studies were routinely obtained unless ordered by referring providers.

Repeat thoracic outlet exploration was accomplished by the safest approach as dictated by symptoms and CT findings using transaxillary or supraclavicular approaches. The supraclavicular approach was typically selected for abnormal muscle bands or reattachments involving the upper or middle trunks of the brachial plexus. Problems involving the rib or the bed of the rib were approached using a transaxillary route. Extensive neurolysis was performed of all nerve trunks involved in the scarred operative field. Pleurectomy was often an adjunctive procedure to approach the proximal neurovascular structures from the thorax for added safety.

Postoperative TOS physical therapy was prescribed. Follow-up after the first postoperative visit occurred at 3-month intervals during the first year and at 6 to 12 months thereafter as dictated by clinical status. Patients without significant residual symptoms, off pain medication, and with full return to work were considered improved or resolved.

CT protocol. All patients with recurrent nTOS underwent a TOS protocol CT scan performed on a 64-slice multidetector Aquilion 64 or Aquilion ONE 320 (Toshiba Medical Systems, Tustin, Calif) in 64-slice mode. Contrast-enhanced scanning was acquired in two postures, first with the arms at the side and then with repeat injection after the arms were repositioned over the head. Each posture was scanned from the mid-C3 vertebra to the madiotic arch. A total of 200 mL iodinated contrast (350 to 370 mg iodine/mL) was used, with 100 mL per position, most commonly with a multiphasic injection: 35 mL at 2.5 mL/s, then 65 mL at 1.6 mL/s, followed by a 20-mL saline chase at 1.6 mL/s, with 65-second delay before the start of scanning. Injection was into the arm opposite the symptomatic side.

Axial and multiplanar reformats were created using 2.5-mm slice reconstruction and a 280-mm field of view. Three-dimensional color volume rendering was also performed. Among the most clinically useful reconstructions were thought to be multiplanar reformats axial oblique parallel to the plane of the first ribs. All scans were centered symmetrically to display left and right.

A single TOS radiologist, who developed the original protocol, interpreted all studies. Findings included bone persistence, bone regrowth, scar tissue formation, and reattachment of thoracic outlet (scalene) musculature. Proximity of these abnormalities to the vasculature and upper and lower brachial plexus was assessed in all cases.

The identification of scar tissue on CT scanning merits description. Scar is usually inferred when excess tissue is seen in a location that cannot be explained by a normal anatomic structure or seen postoperatively. This tissue is typically no more than 0.8 to 1.5 cm in thickness and no more than 2 cm in extent and is very commonly associated with calcified rib regrowth. Scar tissue without rib regrowth is not very common in this experience. It is somewhat subjective and perceptual, but also requires an understanding of normal postoperative anatomy, which our radiologist has experience with. In most cases, after many months of healing, scar tissue is not seen on the postoperative CT scans of TOS patients. This suggests to us that the normal expected scar that likely forms in most postoperative patients is very thin and not visible on CT, even though such a minor scar might be visible to a surgeon on reoperation. In some cases, the presence of abnormal scar can be inferred from distortion of adjacent anatomy that should not occur, such as persistent posterior compression of the subclavian vein from scarring/reattachment of the anterior scalene tendon to Sibson’s fascia after rib resection.

### RESULTS

The 20 patients (60% female) in the study group were an average age of 34.8 years and underwent redo surgery for neurogenic TOS after referral from other institutions (Table 1). Sixteen patients (80%) underwent transaxillary first rib resection with neurolysis. Mean follow-up was 43.3 months from the time of the redo surgery. Time to failure after the initial operation was 26.6 months, and time to operation after consultation for recurrent or persistent nTOS was 21.7 months.

Of the seven patients who initially underwent transaxillary first rib resection, two subsequently underwent supraclavicular reoperation. Two of these patients had abnormal scar tissue on CT, one had regrowth, and the rest had
Although he cautioned that experience was required to make the procedure successful, Roos6 in 1980 reported that brachial plexus compression was visualized and 97% of patients benefited from secondary TOS surgery. Sanders et al8 provided a more sobering review of their 134 operations for recurrent nTOS in 97 patients where long-term failures occurred after the second operation in 50% of patients, unless recurrence was thought to be related to trauma. Finally, more contemporary series from Lindgren et al,9 Ambrad-Chalela,10 Rochlin et al,11 Gelabert et al,12 and Likes et al13 presented limited numbers of patients undergoing reoperation for recurrent nTOS with heterogeneous patient characteristics and presentations, further emphasizing the need for more objective markers of nTOS recurrence for standardization.

Cross-sectional imaging was recognized as a potential useful tool applied to TOS as first described by Collins et al4 in 1995 with the use of magnetic resonance imaging (MRI) to demonstrate neurovascular compression. Smedby et al15 next used an open MRI scanner for positional imaging in an attempt to document nTOS. They reported that brachial plexus compression was visualized and that the distance between the rib and clavicle in patients with TOS symptoms was significantly smaller than in controls. Moreover, there was increasing evidence that neurovascular compression was more likely to be seen on imaging with proactive maneuvers in patients with symptomatic TOS compared with asymptomatic volunteers.16

One difficulty with MRI that persists today is the relative inexperience of many surgeons with its interpretation compared with the more easily understood and “real” appearing CT imaging. In 2002 and 2004, Akal et al17 and Brantigan et al18 published feasibility studies using CT angiography to demonstrate the anatomy of TOS with increasingly striking resolution. MRI provides superior soft tissue contrast resolution imaging but is degraded by motion, is prone to artifacts, and is operator dependent. CT provides better spatial resolution, is more easily understood and interpreted, and is less prone to artifacts and motion. If multidetector CT is demonstrated to be accurate in its prediction of operative findings, it will be a welcome addition to the preoperative algorithm for patients with recurrent or persistent nTOS.

In our series, multidetector CT was able to successfully predict the operative findings in 17 patients (85%). There was no neurovascular injury, and 50% of patients underwent pleural entry, typically as part of a planned pleurectomy to facilitate safe exposure. On average, there were 2.35 operations per patient on the index side for which the patient was originally referred. Eighty percent of patients demonstrated improvement after redo surgery (Fig 1). TOS CT was able to successfully predict the operative findings in 17 patients (85%). There was no neurovascular injury, and 50% of patients underwent pleural entry, typically as part of a planned pleurectomy to facilitate safe exposure.

**DISCUSSION**

Refinements in surgical technique for thoracic outlet decompression are not new. The anatomic problems leading to compression of structures in the thoracic outlet have been documented in detail; however, characterizing the redo thoracic outlet exploration as simply a simple reoperation is minimizing the complex anatomy often found in these patients. There is, however, an unmet need for refined imaging to assist in the diagnosis of nTOS and to resolve the unique anatomy of each patient. High-resolution multidetector CT has evolved significantly, enabling highly detailed multiplanar and 3D reconstructions, and represents a new addition to the thoracic outlet surgeon’s armamentarium. If multidetector CT is demonstrated to be accurate, it would be a welcome addition to the preoperative algorithm for patients with recurrent or persistent TOS given the risks involved with re-exploration.

The first systematic report of patients with thoracic outlet re-exploration was by Roos6 in 1980. He reported 76 patients with recurrent nTOS and described a technically demanding procedure that could be successful, although he cautioned that experience was required to mitigate the significant risks. Urschel et al7 next reported 182 recurrences, although a significant number of these patients would be better characterized with persistent nTOS due to the presence of remnant first ribs; 79% of patients benefited from secondary TOS surgery. Sanders et al8 provided a more sobering review of their 134 operations for recurrent nTOS in 97 patients where long-term failures occurred after the second operation in 50% of patients, unless recurrence was thought to be related to trauma. Finally, more contemporary series from Lindgren et al,9 Ambrad-Chalela,10 Rochlin et al,11 Gelabert et al,12 and Likes et al13 presented limited numbers of patients undergoing reoperation for recurrent nTOS with heterogeneous patient characteristics and presentations, further emphasizing the need for more objective markers of nTOS recurrence for standardization.

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### Table II. Recurrent/persistent thoracic outlet syndrome (TOS) computed tomography (CT) findings

<table>
<thead>
<tr>
<th>Radiographic pattern</th>
<th>Mechanism</th>
<th>Result</th>
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<tbody>
<tr>
<td>Bone persistence</td>
<td>Bucket-handle effect</td>
<td>Distraction of posterior remnant</td>
</tr>
<tr>
<td>Bone regrowth</td>
<td>Sharp edges</td>
<td>Nerve irritation/injury</td>
</tr>
<tr>
<td>Scar tissue</td>
<td>Compression/inflammation</td>
<td>Nerve entrapment/irritation</td>
</tr>
<tr>
<td>Intact scalene muscle(s)</td>
<td>Attachment to rib/pleura</td>
<td>Nerve entrapment</td>
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</tbody>
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Fig 1. Results from redo thoracic outlet surgery for neurogenic thoracic outlet syndrome (nTOS). TAFRR, Transaxillary first rib resection.

### Table I. Pattern of imaging and findings in recurrent/persistent TOS

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Description</th>
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<tbody>
<tr>
<td>N=20 patients</td>
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<tr>
<td>16 TAFRR with Neurolysis (80%)</td>
<td></td>
</tr>
<tr>
<td>5 with residual ribs (25%)</td>
<td></td>
</tr>
<tr>
<td>10 with scar tissue (50%)</td>
<td></td>
</tr>
<tr>
<td>5 rib regrowth (25%)</td>
<td></td>
</tr>
<tr>
<td>3 intact scalene(s) (15%)</td>
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9 improved or resolved (45%)

7 patients moderate improvement (35%)

4 patients minimal improvement (20%)
Four specific radiographic patterns of nTOS recurrent/persistence were identified (Table II). Bone persistence from inadequate resection is the most obvious cause of ongoing symptoms resulting from sharp edges causing nerve irritation with a distraction of the posterior remnant into the neurovascular structures (Fig 2, A and B). Bone regrowth is another finding that may manifest as exuberant callous formation that may cause nerve compression or small islands of ossification that may cause irritation (Fig 2, C and D). This results from an incomplete extraperiosteal bone resection during the first operation that leaves behind growth-promoting periosteum and even bone fragments. We have often found at operation that rib regrowth is a marker of significant scar tissue formation that can cause nerve entrapment and irritation.

Finally, an intact reattached scalene muscle (anterior or middle scalene) can cause nerve or vascular compression. A marker for this on CT may appear as persistent substantial extrinsic compression of the subclavian vein by the anterior scalene tendon, which may become reattached to the anterior rib remnant or pleura. This is best seen with arm elevated posture.

Our algorithm using a TOS CT includes recognizing the pathophysiology and symptomatology of true recurrent nTOS vs persistent nTOS vs a nonspecific diagnosis. The first piece of information sought from a TOS CT is evidence for an incomplete resection. Such evidence in the context of clear TOS symptomatology is an indication for reoperation in our practice. Patients with an adequate previous resection but findings that meet criteria for a positive study are placed on a TOS physical therapy protocol where progress and patient compliance help further refine the decision to reoperate.

Images without concordant symptoms of true brachialplexopathy and the appropriate time course should be scrutinized for other etiologies. For instance, the typical presentation of recurrent nTOS follows the time course of symptomatic relief, followed by recurrent symptoms due to the ingrowth of tissue or irritation by sharp edges. Persistent nTOS can have a very transient period of symptomatic relief, likely from neurolysis performed at initial operation, but usually little to no benefit is realized due to ongoing mechanical compression from residual structures.

Before the TOS protocol CT scan was initiated, the surgeon would try to explore structures that seemed to be involved in the recurrence. The dissection involved the entire thoracic outlet. The surgeon would dissect the structures beginning where the anatomy seemed most normal and dissecting until the problem(s) were found. The CT scan helps define the anatomy and allows the surgeon to plan the operation rather than perform a surgical exploration. Once the anatomy of the problem is defined, the surgeon can choose the approach that is safest in his or her hands. Our recommendation is that the supraclavicular approach is best for abnormal muscle bands or reattachments or problems involving the upper or middle trunks of the brachial plexus. With problems involving the rib or the bed of the rib, we recommend using a transaxillary route.

The most important part of our algorithm is that despite a willingness to undertake challenging thoracic outlet re-explorations, we remain highly selective and
recommend extreme caution when performing these procedures, even in high-volume TOS practices. We continue to recommend an extended trial of physical therapy by an experienced TOS therapist; this is apparent in the relatively long period between the diagnosis of recurrent nTOS and intervention in this series. The goal for physical therapy is to relax muscle spasm and gently mobilize the neck, shoulder, and arm. Physical therapy continues as long as there is progress.

Traditionally, large residual rib remnants that are easily seen on routine X-ray images helped make the diagnosis of persistent nTOS. However, plain X-ray images are inadequate for visualization of more subtle bone regrowth, neurovascular compression, and sharp edges, such as spikes, that might unsuspectingly occur remote from what appeared to be a straightforward remnant rib. We believe that the TOS CT scan is important because it often brings clarity to a difficult diagnostic problem, thereby decreasing anxiety of the patient and surgeon when embarking on a treacherous reoperation. If the clinician believes, based on the clinical presentation, that a patient has a recurrent lower brachial plexus entrapment and a TOS CT angiography shows a mechanical etiology (eg, a bony spike protruding into the lower brachial plexus trunk), then the clinician can proceed with a very informed decision. Similarly, we have found that CT is also useful when it displays scarring or rib regrowth in a key location or when neurovascular structures are trapped in the gap between inadequately resected rib remnants. Thus, the CT facilitates a more directed approach to the resection, allowing the reoperative surgeon to focus on the area of greatest interest.

The known limitations of a nonrandomized, retrospective investigation with a modest patient cohort exist in this study. A randomized study would be almost impossible because each patient with recurrent or persistent TOS is so unique. Patients were selected not just by imaging findings but also by symptoms thought to be consistent with a surgically treatable condition, which can introduce treatment bias.

Many practices lack a radiologist with knowledge and interest in TOS, which could limit the generalizability of these results. Moreover, we do not have imaging data on all patients seen in consultation for TOS to serve as additional control data. In addition, we do not have postoperative cross-sectional imaging on patients who are doing well. Finally, the use of functional survey data and scores was not incorporated into this study because these were not as reliably available as detailed clinic notes documenting patient progress.

A strength of this study is the use of an objective instrument with clearly defined anatomic patterns applied to the thoracic outlet. In patients who have recurrent or persistent TOS, CT often provides objective confirmation that guides treatment. Most of the techniques described in this study are well within the capabilities of most major medical centers. The use of CT imaging must at present be considered no more than a potentially useful adjunct in assessment and decision making regarding treatment of patients with persistent/recurrent nTOS absent more definitive data. Further investigation will be required with more patients from different practitioners and centers to validate these results. Moreover, ongoing studies to identify patients who most benefit from advanced imaging will be important with the changing economic landscape in medicine.

CONCLUSIONS

This study describes the application of a TOS-specific multidetector CT protocol to patients with recurrent or persistent nTOS. The surgical risk is thought to multiply during repeat TOS surgery. For that reason, there is clear value in seeking objective evidence of an anatomic abnormality in patients with recurrent or persistent symptoms at the thoracic outlet. This study demonstrates that when objective CT imaging findings are present with appropriate symptoms, CT predicts with good accuracy the anatomic abnormalities at reoperation that, when treated, are often associated with symptomatic improvement. Thus, CT is potentially useful for preoperative planning in this patient population.

AUTHOR CONTRIBUTIONS

Conception and design: JG, CB
Analysis and interpretation: JG
Data collection: JG
Writing the article: JG, CB
Critical revision of the article: CB, KA, MN, RJ
Final approval of the article: JG, CB, KA, MN, RJ
Statistical analysis: JG
Obtained funding: Not applicable
Overall responsibility: JG

REFERENCES


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