# Redo surgery for neurogenic thoracic outlet syndrome is useful

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## ABSTRACT

**Objectives:** Surgery for neurogenic thoracic outlet syndrome (NTOS) has shown good outcome in numerous case series. However, 5% to 30% of patients will have persistent or recurrent symptoms, caused by incomplete first rib resection, reattachment of residual scalene muscle, fibrous scarring around the brachial plexus, or a wrong NTOS diagnosis. In patients with a sound diagnosis of recurrent or persisting NTOS, not responding to conservative measures, a secondary procedure can be considered. We report the results of redo thoracic outlet decompression surgery through the supraclavicular approach (SC-REDO-TOD) for persistent or recurrent NTOS.

**Methods:** A retrospective review of a prospective database was performed. Every patient referred from September 2016 until January 2020 was eligible for inclusion. In an SC-REDO-TOD, we perform complete (cartilage-cartilage) resection of the first rib, any bony and fibrous anomalies, complete anterior and middle scalenectomy, and complete neurolysis of the brachial plexus (complete anatomical decompression of the brachial plexus). Clinical outcomes were assessed by questionnaires including the Disability of Arm, Shoulder and Hand (DASH), Cervico-Brachial Symptoms Questionnaire (CBSQ), and TOS (thoracic outlet syndrome) Disability scale.

**Results:** In total, 45 patients had a SC-REDO-TOD. The median duration of hospital admission after SC-REDO-TOD was 1.41 days (interquartile range, 1.00 day). In total, 30 (66.66%) of 45 patients had recurrent NTOS, and 15 (33.33%) of 45 patients had persisting NTOS. Postoperative complications were seen in eight patients (18.18%). One patient had postoperative complications with permanent impairment (Horner syndrome). Seven patients had postoperative complications with full recovery (three patients had a chylous leakage that was treated with a median-chain triglycerides diet for 6 weeks, three patients had transient phrenic nerve palsy with full recovery <6 weeks, and one patient had a discrete Horner syndrome that resolved in 6 weeks). The median time of follow-up was 19.50 months (interquartile range, 14.00 months) and the response rate to the questionnaires was 91.11% at 6 months and 64.44% at 12 months. We found a positive and statistically significant difference for DASH score, CBSQ score, and TOS Disability Scale score comparing scores for all patients. (DASH score: $P < .001$; CBSQ score: $P < .001$; TOS Disability Scale: $P < .001$). Patients with first rib remnants showed a significant better response (lower DASH, CBSQ and TOS Disability Scale scores) compared with patients without first rib remnants (DASH score: $P = .004$; CBSQ score: $P \leq .014$; TOS Disability Scale: $P = .009$).

**Conclusions:** SC-REDO-TOD after a previous NTOS surgery shows good results with a low risk of permanent impairment. Patients with NTOS with first rib remnants after primary surgery seem to benefit the most from SC-REDO-TOD surgery. (J Vasc Surg 2022;76:531-7.)

**Keywords:** Neurogenic thoracic outlet syndrome; Redo surgery; Supraclavicular approach

Neurogenic thoracic outlet syndrome (NTOS) is caused by compression of the brachial plexus at the thoracic outlet.[1,2] Compression of the brachial plexus can lead to a wide variety of symptoms, including pain, numbness, paresthesia, and muscle weakness in the head, neck, shoulder, upper and lower arm, and the hand and fingers. Conservative treatment consisting of targeted physiotherapy and pain relief is the mainstay in the treatment of NTOS.[1,3-7] Patients with a diagnosis of NTOS, based on the Society for Vascular Surgery (SVS) reporting standards, who do not benefit from conservative treatment, can be selected for thoracic outlet decompression (TOD).[1,7-12] However, according to the literature, 5% to 30% of patients will have persistent or recurrent symptoms, caused by incomplete first rib resection, reattachment of residual scalene muscle, fibrous scarring around the brachial plexus, or a wrong NTOS diagnosis.[11-16]

The reporting standards from the North American SVS, published in 2016, report two categories of symptoms after surgery for NTOS. Persistent (sometimes called

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residual) NTOS is diagnosed when symptoms never improve (and suspicion remains high that NTOS was, indeed, the correct diagnosis), whereas recurrent NTOS is diagnosed when symptoms recur after an initially successful period following the initial TOD.[1] The optimal approach for reintervention remains unclear, and there is little information available regarding overall outcomes. In this paper, we report clinical characteristics and operative findings, and compare baseline and operative outcomes of SC-REDO-TOD in patients with persistent or recurrent signs and symptoms of NTOS after previous TOD.

## ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center, retrospective cohort study
- **Key Findings:** Redo surgery for neurogenic thoracic outlet syndrome (NTOS) was performed in 45 patients. There was a statistically significant decrease in Disability of Arm, Shoulder and Hand, Cervico-Brachial Symptoms Questionnaire, and Thoracic Outlet Syndrome Disability scale scores before and after surgery. Complications were seen in eight patients (18.18%). One patient had permanent Horner syndrome, whereas all other complications resolved during follow-up. Patients with a first rib remnant had significantly better outcomes after surgery compared with patients without first rib remnants.
- **Take Home Message:** Redo surgery for recurrent or persisting NTOS should be considered when the diagnosis of NTOS is clear.

## METHODS

### Patient and data selection

A retrospective review of a prospective database was performed. Ethical committee approval was acquired to start and use this database. Every patient referred to our outpatient clinic from September 2016 (start of using the SVS reporting standards) until January 2020, was eligible for inclusion. Patients with arterial or venous TOS were excluded from this analysis. Patients with previous supraclavicular surgery at the symptomatic side were excluded from analyses.

### Data selection

We compiled data on clinical presentation, diagnostic work-up, treatment, type of surgical procedures performed, postoperative care, outcomes, and complications. Clinical outcomes were assessed by questionnaires including the DASH (Disability of Arm, Shoulder and Hand), CBSQ (Cervico-Brachial Symptoms Questionnaire), and TOS Disability scale. The patients routinely fill in these outcome questionnaires at a 3-, 6-, 12-, and 24-month postoperative intervals. If there was missing data on the outcome of the supraclavicular redo surgery, a reminder questionnaire was sent.

### Diagnostic and treatment algorithm

An overview of our TOS care pathway for initial NTOS diagnosis can be seen in the Supplementary Fig (online only). The TOS care team consists of two nurse specialists (NST) in TOS, two TOS surgeons, two neurologists with a special interest in TOS, three physiotherapists dedicated to shoulder problems and with an extensive experience in treating patients with TOS, three interventional-radiologists, three pain-anesthetists, and one orthopedic surgeon with special interest in shoulder pathology. Every patient is seen by a NST, a TOS surgeon, a neurologist, and a physiotherapist. For primary diagnoses of NTOS, the NST, neurologist, and surgeon independently take a thorough history and perform clinical examination based on their specific expertise. If one of the team members suspects an orthopedic problem, consultation with the orthopedic surgeon is initiated. All patients are sent for an x-ray of the thorax and of the thoracic aperture to look for bony anomalies. A recent analysis of our data showed that duplex ultrasound is not useful in the diagnosis for NTOS, so we abandoned this investigation.[17] A scalene muscle block is performed on all patients with a clinical suspicion for NTOS. Further details of primary work-up for NTOS can be seen in previous publications.[18]

Patients with NTOS with recurrent or persisting complaints after previous TOD surgery are evaluated by the TOS surgeon, neurologist, and physiotherapist. Every patient is assessed with an x-ray of the thoracic outlet (to look for any bony anomalies or remaining first/cervical ribs). In case of doubt of the initial NTOS diagnosis, additional testing was performed on indication (scalene muscle block, electromyography, computed tomography scan, magnetic resonance imaging). In patients with recurrent NTOS, SC-REDO-TOD is offered only if NTOS-specific physiotherapy (minimally 3 months) does not lead to satisfactory improvement.

**Surgical treatment.** In a SC-REDO-TOD, we position the patient in a semi-Fowler position (20°/25°) and tilt the head 45° away from the affected side. A transverse incision of 5 to 7 cm is made approximately 2 cm above the clavicle from the lateral border of the sternocleidomastoid muscle to the border of the trapezius muscle. During dissection, attention is paid to the supraclavicular nerves running from cranio-caudally in the incision, the phrenic nerve(s), and long thoracic nerve. The scalene fat pad is mobilized and pushed lateral.

We perform a complete resection of the remaining anterior and middle scalene muscle combined with a complete neurolysis of the brachial plexus (all five nerve roots/three trunks) resecting all overlying and surrounding tissue on the brachial plexus. If patients have a first rib or cervical rib remnant, this is removed up to the level

**Table I.** Overview of demographic data, symptoms, and clinical examination, based on the North American Society for Vascular Surgery (*SVS*) reporting standards for thoracic outlet syndrome

| Characteristics | N = 45 | |
|---|---|---|
| Demographic data | | |
| Age, years | 42.0 | 13.0 |
| Female sex | 35 | 77.78 |
| BMI, km/m$^2$ | 22.98 | 5.98 |
| General symptoms | | |
| Pain | 39 | 86.67 |
| Numbness | 17 | 37.78 |
| Paresthesia | 25 | 55.56 |
| Muscle weakness | 24 | 53.33 |
| Increases complaints | | |
| Raising of arm | 22 | 48.89 |
| Driving car | 6 | 13.33 |
| Repetitive exercises/sport | 5 | 11.11 |
| Daily use of arm | 30 | 66.67 |
| Symptom duration, years | 0.77 | 3.61 |
| Sleep deprivation | 12 | 26.67 |
| Unfit for work | 23 | 51.11 |
| Medication | | |
| None | 9 | 20.00 |
| Paracetamol | 5 | 11.11 |
| Non-steriodal anti-inflammatory drugs | 6 | 13.33 |
| Morphine derivates | 9 | 20.00 |
| Combination of above | 8 | 17.78 |
| Medication for neuropathic pain | 7 | 15.56 |
| Clinical findings | | |
| Gilliat Sumner Hand | 1 | 2.22 |
| Tinel positive | 22 | 48.89 |
| MSA/MSM pressure positive | 36 | 80.00 |
| MPM pressure positive | 18 | 40.00 |
| EAST positive | 22 | 48.89 |
| If positive: how many seconds | 74 | 120 |
| ULTT positive | 28 | 62.22 |
| Scalene block | | |
| Positive | 19 | 42.22 |
| Negative | 6 | 13.33 |
| Not performed | 20 | 44.44 |
| Presence of cervical rib | 4 | 8.89 |
| Recurrence triggered by | | |
| Spontaneous | 32 | 71.11 |
| Trauma | 6 | 13.33 |
| Intensive training/physiotherapy | 7 | 15.56 |

*BMI,* Body mass index; *EAST,* elevated arm stress test; *IQR,* interquartile range; *MPM,* pectoral minor muscle; *MSA,* scalenus anterior muscle; *MSM,* scalenus medius muscle; *ULTT,* upper limb tension test.
Data are presented as number (%), mean and standard deviation, or median and interquartile range.

of the cartilage of the costo-vertebral joint. At the end of the procedure, the fat pad is split at the level of the omohyoid muscle into two parts. The deep part is draped underneath the brachial plexus and on the pleura and secured both medial and lateral below the T1 root as well as medially underneath the phrenic nerve. The superficial part is closed over the brachial plexus as usual. A closed-suction drain was placed in the wound at the end of each procedure. If necessary, a pleuracath is inserted in the pleura intentionally for drainage or in case of an iatrogenic pleura defect.

### Statistical analyses

To assess differences in proportions, the $\chi^2$ test or the Fisher exact test (in case of small numbers) was performed. To assess differences between DASH, CBSQ, and TOS Disability scores between groups at a certain time point, we performed the Student *t* test for normally distributed variables and the Mann-Whitney test for skewed variables. To assess differences in DASH, CBSQ, and TOS Disability scores over the whole period of follow-up, we used the Wilcoxon signed ranks test. A *P*-value $\leq$ .05 was considered as statistically significant. Statistical analyses were performed using SPSS (SPSS Inc, Chicago, IL).

## RESULTS

In total, 856 patients were referred to our center from September 1, 2016 until January 1, 2020. A TOS diagnosis was made in 612 patients (72.8%); 545 (89.1%) had NTOS, 64 (10.5%) had vascular TOS, and three (0.5%) had arterial TOS. The diagnosis of TOS was excluded in 228 patients (27.1%). We found alternative diagnoses in 131 patients (15.6%). In 97 patients (11.5%), a clear diagnosis could not be assessed. Of all the patients with NTOS, 210 (38.5%) were treated conservatively, and 335 (61.5%) were treated with trans-axillary thoracic outlet decompression (TA-TOD). SC-REDO-TOD was performed in 45 consecutive patients. Five patients had previous supraclavicular surgery for TOS at the symptomatic side during this same time period and were excluded from these analyses. In total, 30 (66.66%) of 45 patients had recurrent NTOS, and 15 (33.33%) of 45 patients had persisting NTOS. Of the patients with recurrent NTOS, 25 (83.33%) of 30 were from our center, and five (16.66%) of 30 were referred from other centers. Of the patients with persistent NTOS, four (26.66%) of 15 patients were from our center, and 11 (73.33%) of 15 patients were referred from other centers. In total, six (13.33%) of 45 patients did not fill in postoperative questionnaires and were excluded from this analysis.

An overview of demographic data, symptoms, and clinical examination can be seen in Table I. The median interva lfor SC-TOD after TA-TOD was 1.5 years (interquartile range [IQR], 0.67 years). Recurrence was triggered by

**Table II.** Functional outcome scores during follow-up

| | Before SC-REDO-TOD | | 6 months after SC-REDO-TOD | | *P*-value | 12 MONTHS AFTER SC-REDO-TOD | | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Functional outcome | Median 25th – 75th percentile | | Median 25th-75th percentile | | | Median 25th-75th percentile | | |
| CBSQ score | 75.63 | 67.69-83.57 | 44.66 | 34.87-54.45 | **<.001** | 55.63 | 37.69-93.57 | **0.66** |
| DASH score | 59.26 | 53.44-65.08 | 40.16 | 31.98-48.33 | **<.001** | 43.26 | 29.44-49.08 | **0.014** |
| TOS disability scale | 6.82 | 6.19-7.45 | 4.13 | 3.30-4.95 | **<.001** | 4.02 | 3.19-4.65 | **<.001** |

*CBSQ,* Cervical Brachial Score Questionnaire; *DASH,* Disability of the Arm, Shoulder, and Hand; *SC-REDO-TOD,* redo thoracic outlet decompression surgery through the supraclavicular approach; *TOS,* Thoracic Outlet Syndrome.
Median and 25th-75th quartiles are mentioned.
*P* values comparing results before and after are mentioned at each time interval (Wilcoxon signed ranks test).

trauma in six patients (13.33%), strenuous activity or physiotherapy in seven patients (15.56%), and without any identifying provocation in 32 patients (71.11%). Scalene muscle blocks were positive in 19 (42.22%), negative in six (13.33%), and not performed in 20 patients (44.44%).

**Results of SC-REDO-TOD.** Postoperative complications were seen in eight patients (18.18%): with permanent impairment in one patient. Three patients had a chylous leakage that was treated with a medium-chain triglycerides diet for 6 weeks, three patients had transient phrenic nerve palsy with full recovery <6 weeks (documented with serial chest x-ray), and two patients had a discrete Horner syndrome; one permanent and one resolved in 6 weeks. There were no patients with postoperative pneumothorax.

**Clinical outcome.** An overview of clinical outcome can be seen in Table II and the Fig. Median time of follow-up was 19.50 months (IQR, 14.00 months). Response rate to the postoperative questionnaires after SC-REDO-TOD was 91.11% at 6 months and 64.44% at 12 months. In total, 12 patients (26.66%) using pain medication on a daily basis were able to stop their medication at 6 months after surgery. We found a positive and statistically significant difference for DASH score, CBSQ score, and TOS Disability Scale score at 6-month follow-up, compared with baseline. (DASH score: $P < .001$; CBSQ score: $P < .001$; TOS Disability Scale: $P < .001$). At 12-month follow-up, we found a statistically significant difference for DASH score and TOS Disability Scale score, but not for CBSQ score, compared with baseline (DASH score: $P = .014$; CBSQ score: $P = .66$; TOS Disability Scale score: $P < .001$). Comparing persisting and recurrent NTOS, we found no differences in CBSQ score ($P = .54$), DASH scores ($P = .59$), or TOS Disability Scale score ($P = .83$) before and after SC-REDO-TOD.

Comparing the DASH, CBSQ, and TOS Disability Scale scores of patients with and without residual first or cervical rib remnants at 6 months of follow-up, there was a statistically significant difference in patients with first rib remnants compared with patients without (Fig; Table III).

## DISCUSSION

TOD surgery for NTOS is not always successful, and results greatly vary between case series.[1,7,9,11,13,19-30] Some patients experience no improvement or recurrence of complaints after initially successful surgery. In this paper, we clearly see success of reoperation for recurrent or residual NTOS. In this section, we discuss the differential diagnosis and the possible mechanisms of recurrent of persistent NTOS, the 'scalene fat pad wrap,' the preferred surgical approach, and the role of first or cervical rib remnants in patients with NTOS. There are multiple causes of pain complaints after TA-TOD. A frequent complication after TA-TOD is neuropathic pain of the intercostobrachial nerve 2. To be able to access the axilla, this nerve is identified and retracted behind a speculum. This traction can lead to damage of the nerve and consequent neuropathic pain. This in exceptional cases incapacitating pain can be treated with medication or a local anesthetic block. Another cause of recurrent pain can be found in inflammation of the costosternal joint of the second rib. These patients have elicitable pain next to the sternum and can be treated with local corticosteroid injection with good results. We have not found a clear etiological mechanism for this complaint at this moment. A double crush syndrome (focal nerve compression at more than one level) can also be a cause of persisting complaints after TOD. Therefore, neurologic evaluation with electromyography can be useful.[31-33]

The etiology of recurrent or persisting NTOS is multifactorial. Previous studies have shown that incomplete first rib resection (dorsal segment left in situ), reattachment of residual scalene muscle(s) to the brachial plexus or Sibson's fascia, and fibrous scarring around the brachial plexus are major contributors to recurrent or persisting complaints after TA-TOD.[11-16,26,34] That is why we use a supraclavicular approach to remove all possible anatomical factors that could compress the brachial plexus (anatomically complete decompression).[14] Usually, we are able to identify the cause of brachial plexus compression during redo surgery: scar tissue originating from a residual part of the first/cervical rib, fibrosis of the scalene muscle remnants, intertwining fibers of the scalene

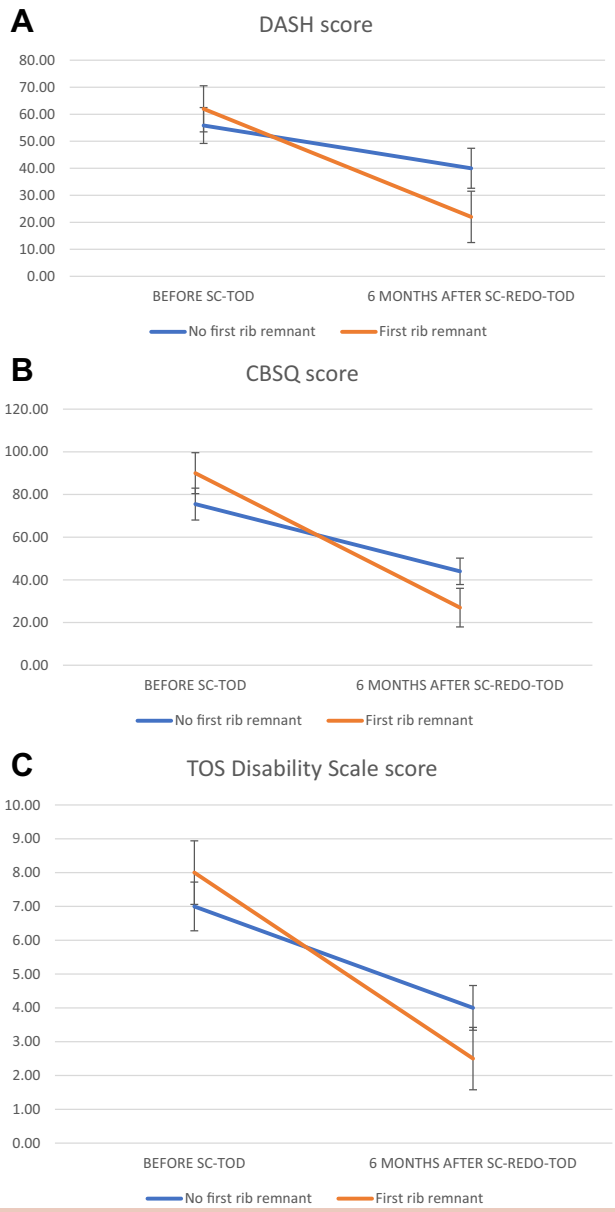


**Fig. A**, Disability of the Arm, Shoulder and Hand (*DASH*) scores; **B**, Cervical Brachial Score Questionnaire (*CBSQ*) scores; **C**, Thoracic Outlet Syndrome (*TOS*) Disability Scale; at 6-month follow-up. Median and 25th and 75th percentile are presented. The Wilcoxon signed rank test was used to calculate differences between the two time intervals. CBSQ score without first rib remnant: before redo thoracic outlet decompression surgery through the supraclavicular approach (*SC-REDO-TOD*): median, 75.00 (interquartile range [IQR], 24) and after SC-REDO-TOD 44.00 (IQR, 50) $P = .042$. CBSQ score with presence of first rib remnant: before SC-REDO-TOD 95.50 (IQR, 43) and after SC-REDO-TOD 21.50 (IQR, 36) $P = .014$; DASH score without first rib remnant: before SC-REDO-TOD 55.83 (IQR, 33.34) and after SC-REDO-TOD 40.00 (IQR, 22.92) $P = .014$. DASH score with presence of first rib remnant: before SC-REDO-TOD 62.08 (IQR, 34.83) and after SC-REDO-TOD 22.08 (IQR, 25.5) $P = .004$. TOS Disability Scale score without first rib remnant: before SC-REDO-TOD 7.00 (IQR, 3.00) and after SC-REDO-TOD 4.00 (IQR, 4.00) $P = .042$. TOS Disability Scale score with presence of first rib remnant: before SC-REDO-TOD 8.00 (IQR, 3.00) and after SC-REDO-TOD 2.50 (IQR, 4.00) $P = .009$.

muscles, or scar tissue from Sibson's fascia compressing and retracting the brachial plexus. In many cases, an impression can be seen on the nerve where it was most profoundly compressed by scarring tissue.

To reduce scar formation around the brachial plexus after SC-REDO-TOD, we make use of the 'fat pad wrap.' This way, the brachial plexus is completely embraced by fatty tissue. Other surgeons have proposed to use the Surgiwrap bioresorbable sheet for the same purpose; to protect the brachial plexus from new scar tissue.[35]

There are no comparative studies that compare supraclavicular or trans-axillary approach of the thoracic outlet for primary NTOS. Only one retrospective single-center cohort trial was able to show similar outcome between the supraclavicular and the trans-axillary approach.[28] Therefore, the surgical approach for both primary and redo TOD surgery is generally based on the surgeon's preference. In our center, we choose to perform a TA-TOD as a first approach to treat patients with NTOS. First, through the axilla, the exposure and removal of the whole first rib is more easily performed compared to SC-TOD. Second, the pectoral minor muscle has been identified as a cause of recurrence or residual NTOS.[15,36] The same incision used for thoracic outlet decompression though the axilla can be used to perform a tenectomy of the pectoral minor muscle. Up to 4 to 5 cm of muscle can be removed. Third, a trans-axillary approach leaves the supraclavicular region without any scar tissue, likely making redo surgery through a supraclavicular approach easier. Total removal of the scalene muscles with complete neurolysis of the brachial plexus, together with resection of any (leftover) bony anomalies or first rib is possible that way. Fourth, the trans-axillary approach offers the best cosmetic result.

The role of remnant ribs in recurrence and residual NTOS has been studied in other case series (Table III).[11,34] Removal of these first/cervical rib remnants have resulted in excellent results.[11,14,34,37,38] Recurrence is mostly caused by scar tissue entrapping the brachial plexus. The remaining first or cervical ribs might be part of this scar tissue, creating fibrous attachments between nerves, scalene muscle, or Sibson's fascia. These attachments restrict normal nerve gliding.[39] In these patients, the etiological pattern is clearer, and therefore more easily treated. In patients with persistent complaints after TOD, compression of the brachial plexus might not have been fully achieved in patients that have part of the first/cervical rib still in place. Comparison of the patients with and without rib remnants showed statistically significant differences. This observation can be useful for patient selection for REDO surgery after previous surgery for NTOS.

**Table III.** Overview of bony anomalies and remnants of the first rib after trans-axillary thoracic outlet decompression (*TA-TOD*)

| | TA-TOD in our center, No. | n = 29, % | TA-TOD in other hospitals, No. | n = 14, % |
|---|---|---|---|---|
| First rib remnant | | | | |
| Posterior less than 2 cm | 0 | 0.00 | 1 | 7.14 |
| Posterior more than 2 cm | 0 | 0.00 | 8 | 57.14 |
| Anterior less than 2 cm | 0 | 0.00 | 1 | 7.14 |
| Anterior more than 2 cm | 0 | 0.00 | 3 | 21.43 |

The results are separated between our hospital and referrals from other hospitals.

This study has some limitations. This is a retrospective, single-center study. Although this data is prospectively assessed, certain types of bias cannot be eliminated. We only had complete follow-up data of the patients that were treated in our center. We do not have complete information on the signs and symptoms, nor the DASH, CBSQ, or TOS Disability Scale scores of referred patients before and after trans-axillary first rib resection. Another limitation is that we could not identify the causal mechanism for residual or recurrent NTOS. Residual ribs are one thing, but why patients have stronger scarring formation after TA-TOD causing recurrence is not clear.

## CONCLUSIONS

SC-REDO-TOD after a previous NTOS surgery shows good results with a low risk of permanent impairment. Patients with NTOS with residual first rib remnant after primary surgery seem to benefit most from redo surgery.

## AUTHOR CONTRIBUTIONS

Conception and design: JG, SH, MS, BN, JT
Analysis and interpretation: JG, SH, MS, BN, JT
Data collection: JG, LS, NP, MS, BN, JT
Writing the article: JG, LS, NP, SH, MS, BN, JT
Critical revision of the article: JG, LS, NP, SH, MS, BN, JT
Final approval of the article: JG, LS, NP, SH, MS, BN, JT
Statistical analysis: JG, LS, SH
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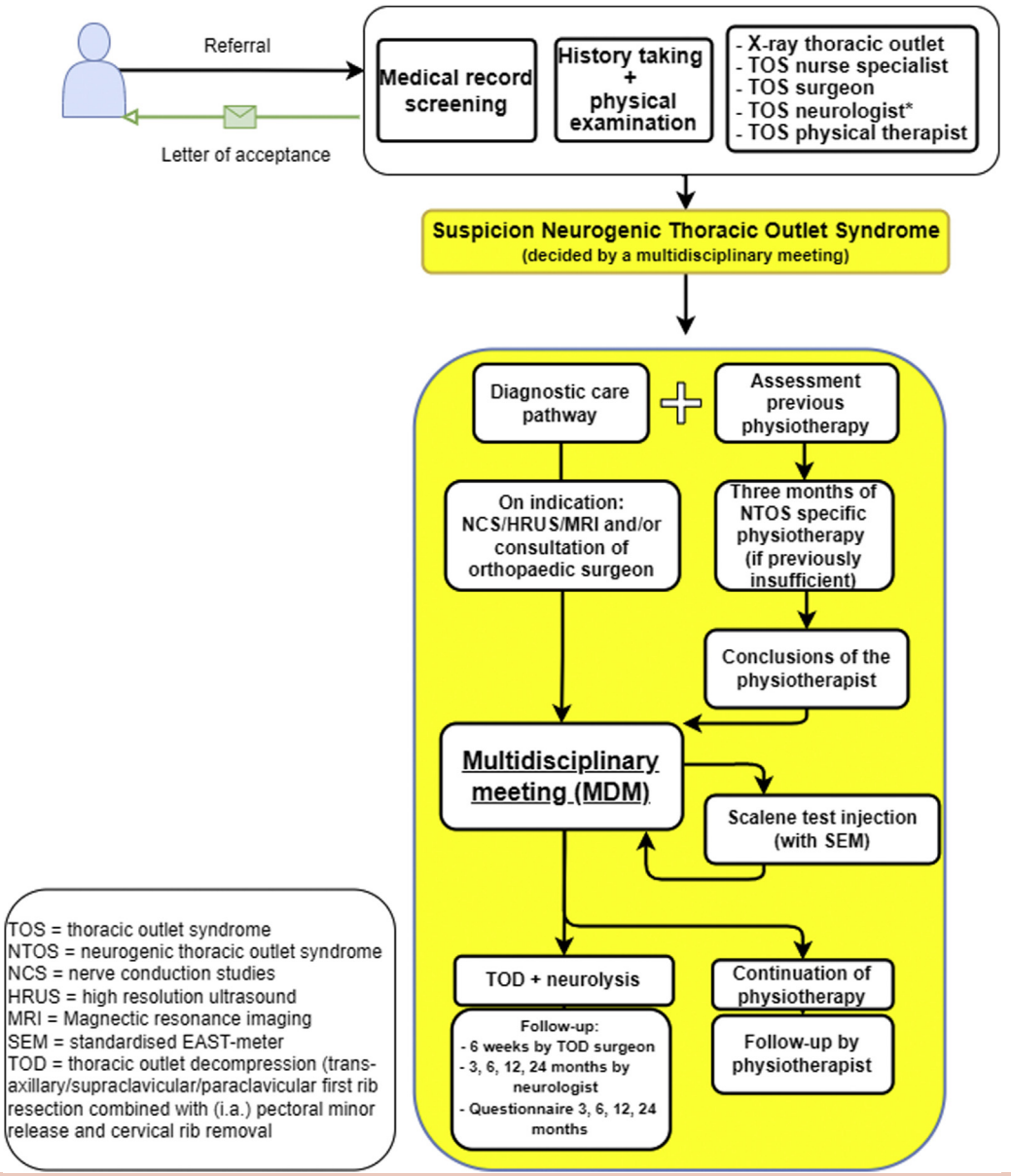


**Supplementary Fig (online only).** An overview of our thoracic outlet syndrome (*TOS*) care pathway for initial neurogenic thoracic outlet syndrome (*NTOS*) diagnosis.