9-1-2019

Physical therapy management, surgical treatment, and patient-reported outcomes measures in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome

Joshua Balderman

Ahmmad A Abuirqeba

Lindsay Eichaker

Cassandra Pate

Jeanne A Earley

See next page for additional authors

Authors

Joshua Balderman, Ahmmad A Abuirqeba, Lindsay Eichaker, Cassandra Pate, Jeanne A Earley, Michael M Bottros, Senthil N Jayarajan, and Robert W Thompson

Physical therapy management, surgical treatment, and patient-reported outcomes measures in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome

Joshua Balderman, MD,[a,b] Ahmmad A. Abuirqeba, BA,[a,b] Lindsay Eichaker, DPT,[c] Cassandra Pate, MSPT, LMT,[c] Jeanne A. Earley, MHS, PT,[c] Michael M. Bottros, MD,[a,d] Senthil N. Jayarajan, MD, MS,[a,b] and Robert W. Thompson, MD,[a,b] St. Louis, Mo

ABSTRACT

Objective: To assess the results of physical therapy management and surgical treatment in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome (NTOS) using patient-reported outcomes measures.

Methods: Of 183 new patient referrals from July 1 to December 31, 2015, 150 (82%) met the established clinical diagnostic criteria for NTOS. All patients underwent an initial 6-week physical therapy trial. Those with symptom improvement continued physical therapy, and the remainder underwent surgery (supraclavicular decompression with or without pectoralis minor tenotomy). Pretreatment factors and 7 patient-reported outcomes measures were compared between the physical therapy and surgery groups using t-tests and χ^2 analyses. Follow-up results were assessed by changes in 11-item version of Disability of the Arm, Shoulder, and Hand (QuickDASH) scores and patient-rated outcomes.

Results: Of the 150 patients, 20 (13%) declined further treatment or follow-up, 40 (27%) obtained satisfactory improvement with physical therapy alone, and 90 (60%) underwent surgery. Slight differences were found between the physical therapy and surgery groups in the mean ± standard error degree of local tenderness to palpation (1.7 ± 0.1 vs 2.0 ± 0.1; $P = .032$), the number of positive clinical diagnostic criteria (9.0 ± 0.3 vs 10.1 ± 0.1; $P = .001$), Cervical-Brachial Symptom Questionnaire scores (68.0 ± 4.1 vs 78.0 ± 2.7; $P = .045$), and Short-Form 12-item physical quality-of-life scores (35.6 ± 1.5 vs 32.0 ± 0.8; $P = .019$) but not other pretreatment factors. During follow-up (median, 21.1 months for physical therapy and 12.0 months for surgery), the mean change in QuickDASH scores for physical therapy was −15.6 ± 3.0 (−29.5% ± 5.7%) compared with −29.8 ± 2.4 (−47.9% ± 3.6%) for surgery ($P = .001$). The patient-rated outcomes for surgery were excellent for 27%, good for 36%, fair for 26%, and poor for 11%, with a strong correlation between the percentage of decline in the QuickDASH score and patient-rated outcomes ($P < .0001$).

Conclusions: The present study has demonstrated contemporary outcomes for physical therapy and surgery in a well-studied cohort of patients with NTOS, reinforcing that surgery can be effective when physical therapy is insufficient, even with substantial pretreatment disability. Substantial symptom improvement can be expected for ∼90% of patients after surgery for NTOS, with treatment outcomes accurately reflected by changes in QuickDASH scores. Within this cohort, it was difficult to identify specific predictive factors for individuals most likely to benefit from physical therapy alone vs surgery. (J Vasc Surg 2019;70:832-41.)

Keywords: Brachial plexus; Chronic pain; Compression neuropathy; Depression; Disability; Patient-reported outcomes measures; Pain catastrophizing; Physical therapy; Quality of life; Surgical treatment; Thoracic outlet syndrome

Neurogenic thoracic outlet syndrome (NTOS) is a relatively rare, complicated, and, at times, controversial condition characterized by dynamic positional compression of the brachial plexus at the level of the supraclavicular scalene triangle or the subcoracoid (pectoralis minor) space.[1-3] Some of the longstanding, but unresolved, questions about NTOS have involved the most appropriate criteria for the diagnosis, accurate
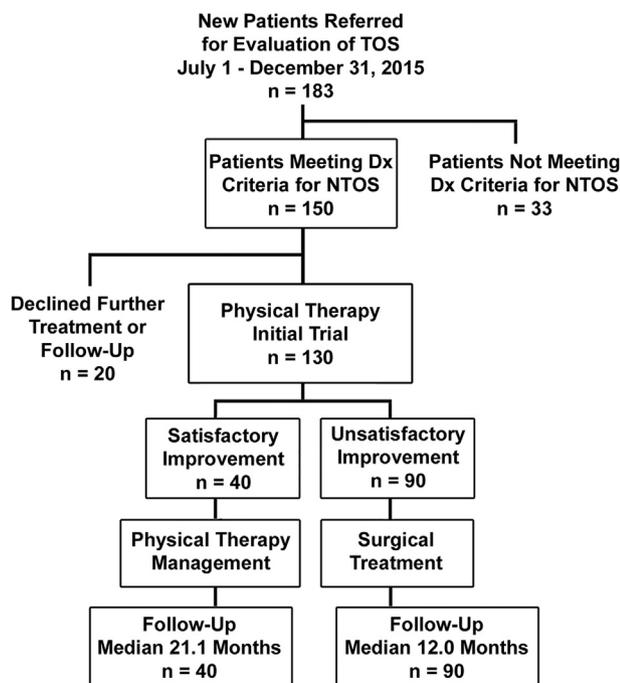
Fig 1. Schematic flow diagram for a prospective observational cohort of patients with neurogenic thoracic outlet syndrome (*NTOS*). *Dx,* Diagnostic.

assessment and reporting of treatment results, and approaches to better predict individual patient outcomes for various treatment options.[1-5] During the past decade, the Consortium for Research and Education on Thoracic Outlet Syndrome (CORE-TOS) sought to address the question of diagnostic standards, using a Delphi approach to develop a set of consensus-based clinical diagnostic criteria (CDC) for NTOS.[6,7] Our group, and others, has also attempted to establish more accurate methods to quantify the disability and assess the treatment results in patients with NTOS using patient-reported outcomes measures (PROMs) for different, but related, domains, such as pain, functional disability, depression, physical and mental quality of life (QOL), and pain catastrophizing.[7-19]

In a recent report, we described a prospective observational cohort study in which the relative strengths of the 14 CORE-TOS CDC and 7 PROMs were examined in patients with suspected NTOS.[7] The results helped validate the utility of the CDC used for evaluation of NTOS and demonstrated strong correlations between PROMs covering different domains of symptomatic disability. The purpose of the present study was to extend our analysis of this prospective cohort to compare the results of physical therapy management and surgical treatment during follow-up using both PROMs and patient-rated outcomes and to evaluate the potential associations between the clinical features at initial presentation and treatment outcomes.

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective cohort study of prospectively collected data
- **Key Findings:** During a median follow-up >12 months of 130 patients with neurogenic thoracic outlet syndrome, 40 (31%) obtained symptom improvement with physical therapy alone and 90 (69%) underwent surgery, with a percentage of decline in Disability of the Arm, Shoulder, and Hand scores of 29.5% ± 5.7% and 47.9% ± 3.6%, respectively.
- **Take Home Message:** Despite substantial pretreatment disability, surgery for neurogenic thoracic outlet syndrome can be effective when physical therapy is insufficient, with substantial symptom improvement in ∼90% of patients. These outcomes were reflected by changes in Disability of the Arm, Shoulder, and Hand scores, but no specific factors predicted which patients will benefit from physical therapy alone or will require surgery.

METHODS

Study population and clinical diagnosis. All the subjects in the present study gave written informed consent for the report of their medical data through a protocol approved by the human research protection office at Washington University (St. Louis, Mo). The initial study population consisted of all new patients referred to the Washington University Center for Thoracic Outlet Syndrome at Barnes Jewish Hospital from July 1 to December 31, 2015. Data collected from office notes, hospital records, imaging studies, and records from the treating physicians and therapists were entered into a prospectively maintained database. Of the 183 newly referred patients, 150 (82%) had met the predefined CORE-TOS CDC for NTOS, as reported previously.[7] Each patient had also met the diagnostic criteria for NTOS described in the 2016 reporting standards of the Society for Vascular Surgery.[2] The results from the imaging studies and electrophysiological tests were not considered necessary to establish a clinical diagnosis of NTOS but were used for selected patients to help assess or exclude other conditions. Ultrasound-guided local anesthetic anterior scalene and pectoralis minor muscle blocks were also used selectively to identify variations in anatomy and, potentially, provide prognostic information.[20-22] The 150 patients with a verified diagnosis of NTOS represented the starting patient population for the present study (Fig 1).

Treatment algorithm. All patients with NTOS underwent a physical therapy evaluation and treatment guided by 1 of 3 physical therapists aligned with our TOS Center at The Rehabilitation Institute of St. Louis. The physical

Table I. Patient characteristics at presentation

Characteristic	Physical therapy alone (n = 40)	Surgical treatment (n = 90)	*P* value
Age, years	37.7 ± 2.3	36.9 ± 1.4	.759[a]
Female gender	29 (72)	66 (73)	1.000[b]
NTOS			
Bilateral	11 (27)	21 (23)	.661[b]
Recurrent	1 (2)	9 (9)	.174[b]
Symptom duration			
3-6 months	6 (15)	11 (12)	.779[b]
6-12 months	8 (20)	14 (16)	.614[b]
1-2 years	5 (12)	12 (13)	1.00[b]
2-5 years	13 (32)	21 (24)	.287[b]
>5 years	8 (20)	32 (35)	1.00[b]
>2 years	21 (52)	53 (59)	.566[b]
Previous injury			
None	11 (27)	16 (18)	.244[b]
Accidental	7 (17)	18 (20)	.814[b]
Recreational	13 (32)	24 (27)	.531[b]
Occupational	9 (22)	32 (35)	.157[b]
All types	29 (72)	74 (82)	.244[b]
Degree of tenderness[c]	1.7 ± 0.1	2.0 ± 0.1	.032[a]
Subcoracoid findings only	2 (5)	4 (4)	1.00[b]
3-Minute EAST, seconds	103.0 ± 10.2	97.0 ± 6.3	.610[a]
Positive CDC,[c] n	9.0 ± 0.3	10.1 ± 0.1	.001[a]
QuickDASH score	52.9 ± 3.4	60.3 ± 2.1	.058[a]
CBSQ[c]	68.0 ± 4.1	78.0 ± 2.7	.045[a]
McGill pain score	29.4 ± 2.1	29.6 ± 1.1	.928[a]
BPI			
Severity	4.9 ± 0.3	5.0 ± 0.2	.785[a]
Interference	5.2 ± 0.4	5.4 ± 0.2	.616[a]
Zung SDS score	42.5 ± 1.6	43.0 ± 1.0	.774[a]
SF-12 physical QOL[c]	35.6 ± 1.5	32.0 ± 0.8	.019[a]
SF-12 mental QOL	46.1 ± 1.8	47.8 ± 1.1	.423[a]
PCS score			
Overall	24.9 ± 2.3	24.5 ± 1.5	.864[a]
Rumination	9.1 ± 0.8	8.7 ± 0.5	.679[a]
Magnification	3.9 ± 0.6	4.4 ± 0.3	.459[a]
Helplessness	12.0 ± 1.2	11.4 ± 0.7	.651[a]

BPI, Brief Pain Inventory; *CBSQ*, Cervical-Brachial Symptom Questionnaire; *CDC*, clinical diagnostic criteria; *EAST*, elevated arm stress test; *NTOS*, neurogenic thoracic outlet syndrome; *PCS*, Pain Catastrophizing Scale; *QOL*, quality of life; *QuickDASH*, 11-item version of the Disabilities of the Arm, Shoulder, and Hand; *SDS*, Self-rating Depression Scale; *SF-12*, Short-Form, 12-item questionnaire.
Data are presented as mean ± standard error for continuous measures and number of patients (%) for categorical variables. Of the 150 patients, 20 (13%) declined further treatment or follow-up, leaving 130 for assessment of physical therapy management alone (n = 40) or surgical treatment (n = 90).
[a]Unpaired *t*-test.
[b]Fisher's exact test.
[c]*P* < .05.

therapy program consisted of scalene and pectoralis muscle stretching and relaxing exercises, with a focus on shoulder girdle and scapular mobility, mechanics, postural improvement, and diaphragmatic breathing, using caution with strengthening, weight training, and the use of resistance bands.[23-27] For patients residing at a distance from St. Louis, the physical therapy trial was implemented by a therapist located closer to the patient, with guidance, oversight, and follow-up assessment provided by the TOS Center therapist. Physical therapy was conducted for 4 to 6 weeks, unless the patient had previously undergone physical therapy considered appropriate
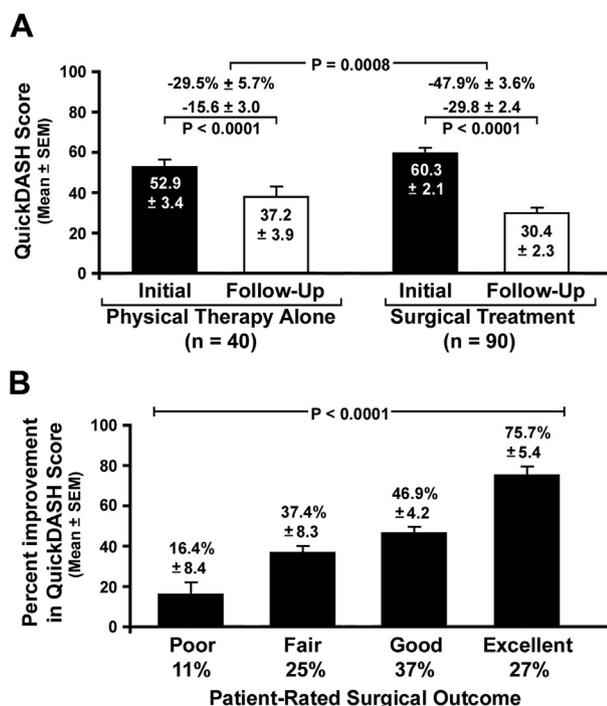
A

B

Fig 2. Treatment outcomes after physical therapy or surgery for neurogenic thoracic outlet syndrome (NTOS). **A,** Bar graphs depicting Disability of the Arm, Shoulder, and Hand (*QuickDASH*) scores before and during follow-up after physical therapy and surgical treatment. Two-group comparisons were performed using the unpaired *t*-test. **B,** Bar graph depicting the response to treatment measured by the percentage of improvement in Quick-DASH scores and patient-rated outcomes for surgical treatment. Multiple-group comparison was performed using the Kruskal-Wallis analysis of variance. *SEM,* Standard error of the mean.

by the TOS Center therapist or if their symptoms had worsened during the initial therapy visits, in which case, earlier consideration was given for surgical treatment.

During the office follow-up visit and reassessment, patients who experienced an improvement in symptoms during the initial course of physical therapy were encouraged to continue with physical therapy. Surgery was offered to patients who had a sound clinical diagnosis of NTOS, a significant level of disability, and insufficient improvement in symptoms with physical therapy, as determined by the assessment of the physician, therapist, and patient.

Surgical treatment. Throughout the study period, surgery for NTOS consisted of supraclavicular decompression (with complete anterior and middle scalenectomy, first rib resection, and brachial plexus neurolysis) or subcoracoid decompression (pectoralis minor tenotomy), or both, as previously described in detail.[28-30] The site of operative decompression was determined for each patient from the clinical examination findings at the level of the scalene triangle or subcoracoid space, as

previously described.[13] Postoperative complications, hospital stay, and readmissions were all recorded in the prospective database. The surgery patients resumed physical therapy 3 to 4 weeks postoperatively, preferably with the same TOS Center therapist with whom they had worked during the initial physical therapy trial.

Follow-up and patient-reported outcomes measures. The patients were seen for office visits every 3 to 4 months after the start of treatment, and more frequently when necessary. At each visit, the patients were asked to complete the Disabilities of the Arm, Shoulder and Hand (QuickDASH) survey instrument, Cervical-Brachial Symptom Questionnaire (CBSQ), McGill pain questionnaire (McGill), Brief Pain Inventory, Zung self-rating depression scale, Short-Form, 12-item physical and mental summary scales (SF-12), and pain catastrophizing scale (PCS), as previously described.[7] The patients who had undergone surgery were also asked to rate their treatment outcome using a simple scale with the descriptors "excellent" (relief of almost all major symptoms with only some mild residual symptoms that do not significantly limit enjoyment of life), "good" (relief of most major symptoms with some mild residual symptoms that significantly limit enjoyment of life), "fair" (partial relief of some symptoms while other major symptoms persist), or "poor" (not enough relief in symptoms to have made the operation worthwhile).

Statistical analysis. The principal outcomes measure was the percentage of improvement in the QuickDASH score between the initial evaluation and the longest follow-up interval. Descriptive data are presented as the mean $\pm$ standard error or the median and range. For the 2-group comparisons, a χ^2 analysis or the unpaired Student *t*-test with a 2-tailed distribution were used to determine statistical significance. For multiple-group comparisons, the Kruskal-Wallis nonparametric analysis of variance (ANOVA) test was used with the Dunn multiple comparisons test. In selected instances, Spearman correlation tests were performed with calculation of the *r* and R^2 values. Receiver operating characteristic curves were constructed to assess a cutoff point for change in QuickDASH scores that corresponded to positive patient-rated outcomes. The cutoff point was calculated on the basis of the best trade-off value between sensitivity and specificity. Multivariate logistic regression analysis was performed with calculation of the odds ratios to predict the optimal change in the QuickDASH scores. All statistical tests were performed using Prism, version 6.0h (GraphPad Software Inc, San Diego, Calif), with $P < .05$ considered statistically significant.

RESULTS

Outcomes of initial physical therapy trial. Of the initial cohort of 150 patients meeting the CDC for NTOS, 20 (13%) declined further treatment or follow-up (Fig 1). Of

Table II. Response to treatment stratified by surgical procedure

Variable	Patients, No.	Initial assessment (QuickDASH)	Follow-up assessments		
			QuickDASH	Delta DASH	Change, %
SCD, ipsilateral PMT	70	62.6 ± 2.2	27.7 ± 2.5	−34.5 ± 2.8	−55.2 ± 3.6[a]
SCD, bilateral PMT	12	61.7 ± 4.3	42.5 ± 6.4	−20.7 ± 4.6	−34.2 ± 7.5
SCD alone	4	39.5 ± 16.0	11.3 ± 7.3	−17.8 ± 10.1	−41.8 ± 21.0
PMT alone	4	36.9 ± 12.2	30.5 ± 12.3	−6.4 ± 6.5	+4.6 ± 35.2[a]

PMT, Pectoralis minor tenotomy; *QuickDASH*, 11-item version of the Disabilities of the Arm, Shoulder, and Hand; *SCD*, supraclavicular decompression.
Data are presented as mean ± standard error.
[a]$P = .002$, 1-way analysis of variance with Tukey's multiple comparisons test.
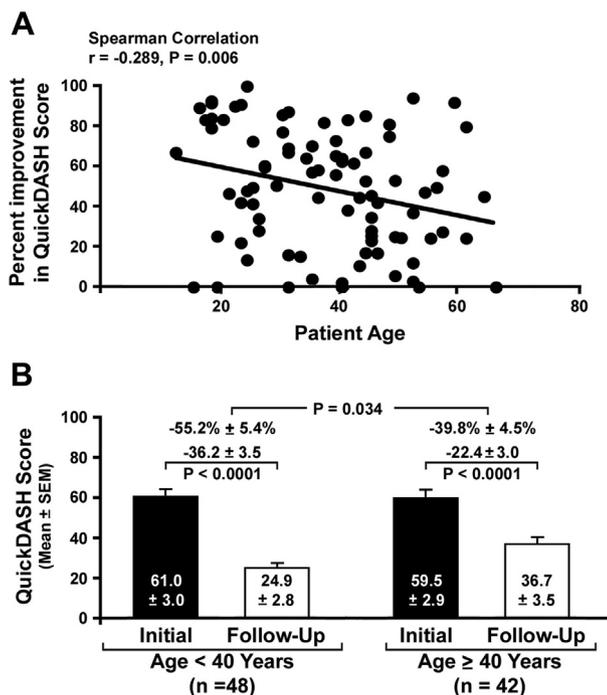

Fig 3. Influence of patient age on outcomes of surgical treatment for neurogenic thoracic outlet syndrome (NTOS). **A,** Scatter plot illustrating the relationship between patient age and response to surgical treatment, measured by the percentage of improvement in Disability of the Arm, Shoulder, and Hand (*QuickDASH*) scores. **B,** Bar graph depicting QuickDASH scores before and during follow-up after surgical treatment for patients aged <40 years and ≥40 years. Two-group comparisons were performed using the unpaired *t*-test.

frequency of positive scalene muscle blocks (Table I). The mean degree of local tenderness to palpation, total number of positive CDC, and CBSQ scores were lower for the physical therapy group than for the surgery group, and the SF-12 physical QOL scores were lower in the surgery group. The pretreatment QuickDASH scores were not significantly different between the 2 groups.

Surgical treatment. In the surgical treatment group, 20 patients (22.2%) had presented with bilateral NTOS, 4 (4.4%) with a cervical rib, and 7 (7.8%) with recurrent NTOS after having undergone a previous procedure at another institution. The mean interval between the initial office visit and surgery was 115 ± 11 days. The operations performed included supraclavicular decompression and ipsilateral pectoralis minor tenotomy in 70 patients (77.8%), supraclavicular decompression and bilateral pectoralis minor tenotomy in 12 (13.3%), supraclavicular decompression alone in 4 (4.4%), and isolated pectoralis minor tenotomy in 4 patients (4.4%). No intraoperative complications developed; however, five patients (5.5%) experienced prolonged lymph drainage that required medical management (low-fat diet and octreotide). The mean hospital stay was 4.3 ± 0.2 days and four patients (4.4%) required readmission within 30 days (1 each for subclavian vein thrombosis, thoracic duct embolization, drainage of a superficial wound infection, and excision of a stitch granuloma).

Follow-up and treatment outcomes. The mean follow-up interval was 20.4 ± 0.8 months for the physical therapy group and 12.3 ± 0.7 months postoperatively for the surgery group. The mean follow-up QuickDASH score for the physical therapy group was 37.2 ± 3.9 compared with 52.9 ± 3.4 at the initial presentation, with a mean decline in the QuickDASH score of 15.6 ± 3.0 (29.5% ± 5.7%; $P < .0001$; Fig 2, *A*). For the surgical treatment group, the mean follow-up QuickDASH score was 30.4 ± 2.3 compared with 60.3 ± 2.1 at the initial presentation, with a mean decline in the QuickDASH score of 29.8 ± 2.4 (47.9% ± 3.6%; $P < .0001$). Although significant improvement was seen in both groups, the percentage of improvement in the QuickDASH scores was greater for the surgery group than for the physical therapy group

the remaining 130 patients, 40 (27%) obtained satisfactory symptom improvement with the initial physical therapy trial and chose to continue conservative management. Finally, 90 patients (60%) experienced insufficient improvement with physical therapy and subsequently elected to undergo surgery.

No differences were found in the presenting characteristics between the physical therapy and surgery groups in age, gender, symptom duration, previous injury, pain-related PROM scores, pain catastrophizing scores, or

Table III. Influence of muscle block findings on response to treatment stratified by treatment received

Variable	Patients, No.	Initial assessment (QuickDASH)	Follow-up assessment		
			QuickDASH	Delta DASH	Change, %
Physical therapy alone					
All patients	40	52.9 ± 3.4	37.2 ± 3.9	−15.6 ± 3.0	−29.5 ± 5.7
No block performed	8	59.5 ± 8.4	43.3 ± 9.7	−16.2 ± 6.7	−27.1 ± 11.3
Block performed	32	51.2 ± 3.7	35.7 ± 4.3	−15.5 ± 3.4	−30.1 ± 6.6
Positive finding	26	53.6 ± 4.1	37.4 ± 4.9	−16.2 ± 3.9	−30.6 ± 7.1[a]
Negative finding	6	40.7 ± 8.3	28.5 ± 8.7	−12.2 ± 7.2	−27.9 ± 18.3[a]
Surgical treatment					
All patients	90	60.3 ± 2.1	30.4 ± 2.3	−29.8 ± 2.4	−47.9 ± 3.6
No block performed	28	55.8 ± 4.2	25.8 ± 2.9	−30.0 ± 4.2	−46.2 ± 7.1
Block performed	62	62.3 ± 2.4	32.4 ± 3.0	−29.7 ± 3.0	−48.7 ± 4.2
Positive finding	50	62.3 ± 2.8	30.3 ± 3.3	−31.8 ± 3.2	−52.2 ± 4.5[b]
Negative finding	12	62.3 ± 4.1	41.1 ± 7.5	−21.2 ± 7.6	−34.3 ± 10.7[b]

QuickDASH, 11-Item version of the Disabilities of the Arm, Shoulder, and Hand questionnaire.
Data are presented as mean ± standard error.
[a]$P = .875$, unpaired *t*-test.
[b]$P = .092$, unpaired *t*-test.

($P = .001$). The results of the outcomes measures were somewhat different among the patients undergoing different surgical procedures ($P = .002$, ANOVA). However, the number of patients in the isolated pectoralis minor tenotomy and the supraclavicular decompression alone groups was too low (n = 4 each), and the range of outcomes too broad, to permit reliable between-group comparisons (Table II). The overall patient-rated outcomes for surgical treatment were excellent for 27%, good for 36%, fair for 26%, and poor for 11% of the surgery group, with a strong relationship between the percentage of decline in the QuickDASH score and the patient-rated outcomes category ($P < .0001$, ANOVA; Fig 2, *B*).

Determinants of outcomes after surgical treatment. Based on the results from previous studies, patient age at the initial presentation was examined as a potential factor in determining the outcomes of surgery.[12,31-33] A significant association was found between patient age and the percentage of improvement in the QuickDASH score during follow-up ($P = .006$, Spearman correlation), with younger patients having better outcomes (Fig 3, *A*). The mean follow-up QuickDASH score for patients aged <40 years (n = 48) was 24.9 ± 2.8 compared with 61.0 ± 3.0 at the initial presentation, with a mean decline in the QuickDASH score of 36.2 ± 3.5 (55.2% ± 5.4%; $P < .0001$; Fig 3, *B*). The mean follow-up QuickDASH score for patients age ≥40 years (n = 42) was 36.7 ± 3.5 compared with 59.5 ± 2.9 at the initial presentation, with a mean decline in the QuickDASH score of 22.4 ± 3.0 (39.8% ± 4.5%; $P < .0001$). Although significant improvement was found in both groups, the percentage of improvement in the QuickDASH scores for patients

aged <40 years was greater than that for patients aged ≥40 years ($P = .034$).

Previous studies have indicated that positive anterior scalene and pectoralis minor muscle blocks might predict better outcomes from surgical treatment for NTOS.[33-35] In the present cohort, muscle blocks were performed as part of the initial pretreatment evaluation for 32 patients (80%) in the physical therapy group and 62 patients (69%) in the surgical treatment group. For the patients in the physical therapy group with negative muscle block findings, the mean decline in the QuickDASH score was 27.9% ± 18.3% compared with 30.6% ± 7.1% for patients with positive block findings ($P > .05$; Table III). These results demonstrate that positive muscle block findings did not effectively predict the treatment outcomes for the patients undergoing physical therapy management alone. For the patients in the surgical treatment group with negative muscle block findings, the mean decline in the QuickDASH score was 34.3% ± 10.7% compared with 52.2% ± 4.5% for patients with positive block findings ($P = .092$). This finding indicates significant improvement in the surgical group, regardless of the outcome of the pretreatment muscle block, with a trend toward a greater percentage of improvement in the QuickDASH scores for patients with positive muscle block findings that did not reach statistical significance.

One of the goals of the present study was to examine the use of various PROMs measured at the initial patient presentation to serve as predictors of treatment outcome, with a particular interest in pain catastrophizing.[7] The mean decline in the QuickDASH score was 28.8 ± 2.9 (48.2% ± 4.7%) for patients with low pain catastrophizing at the initial presentation (PCS score <30;

65% of patients; Fig 4, A). The mean decline in Quick-DASH score was 31.2 ± 4.2 (47.5 ± 5.8 percent) for patients with high pain catastrophizing at initial presentation (PCS score ≥30; 35% of patients). Thus, the pretreatment levels of pain catastrophizing did not have a significant influence on the surgical treatment outcomes ($P > .05$). However, in assessing the potential changes in pain catastrophizing during follow-up, those with favorable patient-rated outcomes had significant decreases in the mean PCS scores. In contrast, those with poor patient-rated outcomes exhibited no change (Fig 4, B).

Multivariate analysis. In attempting to better identify the predictors of clinical outcomes, the patients who had undergone surgery were divided into "responders" (patient-rated outcomes of fair, good, or excellent) and "nonresponders" (patient-rated outcomes of poor). A threshold cutoff distinguishing the 2 groups was found at a percentage of improvement in the QuickDASH score of 27.4%. Multivariate logistic regression analysis was performed with a spectrum of pretreatment variables, controlling for patient age, gender, and symptom duration >2 years. The pretreatment SF-12 physical QOL score was the only variable with predictive value in distinguishing positive from negative responses to surgery (odds ratio, 1.12; $P = .031$; Fig 5).

DISCUSSION

In the present study, we assessed the results of physical therapy management and surgical treatment for patients with NTOS using well-defined CDC for NTOS and a series of PROMs in a prospective, observational patient cohort. Our results have demonstrated that even with substantial levels of pretreatment disability, physical therapy alone was effective in 31% of the patient cohort that had continued treatment and follow-up. Surgical treatment was effective when physical therapy alone was insufficient, with substantial symptom improvement in ~90% of patients. We observed that surgical treatment outcomes were accurately reflected by changes in the QuickDASH scores measured during follow-up, reinforcing the validity of this instrument to quantify the treatment results of patients with NTOS. We also found no pretreatment factors that allowed for a sound prediction regarding the individual patients who might respond sufficiently to physical therapy alone but that an empirical treatment trial was necessary. For patients undergoing surgery, other than age at presentation, CBSQ score, and SF-12 physical QOL score, we could not identify any specific pretreatment factors or patient profiles that reliably predicted the outcomes.

The treatment algorithm followed in the present study is based on long-established clinical practice and experience in the management of NTOS but differs from the process described by some investigators. For example, Chandra et al[36] described a "highly selective" algorithm
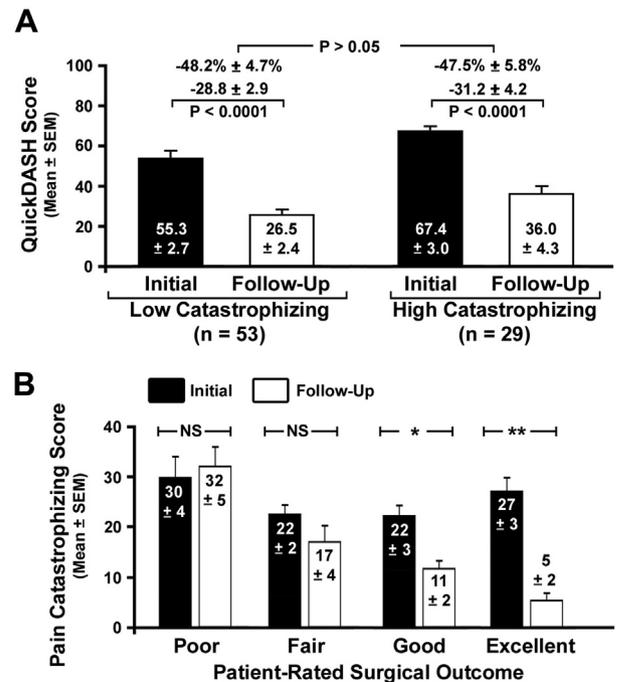
Fig 4. Association between pretreatment pain catastrophizing and outcomes of surgical treatment for neurogenic thoracic outlet syndrome (NTOS). **A,** Bar graph depicting Disability of the Arm, Shoulder, and Hand (*QuickDASH*) scores before and during follow-up after surgical treatment for patients with low (Pain Catastrophizing Scale [PCS] score <30) and high (PCS score ≥30) pain catastrophizing. **B,** Bar graph depicting changes in pain catastrophizing after surgical treatment for NTOS stratified by patient-rated outcomes for surgical treatment. Two-group comparisons were performed using the unpaired *t*-test. *$P < .01$; **$P < .0001$. *NS,* Not significant ($P > .05$); *SEM,* standard error of the mean.

with all patients undergoing an initial trial of physical therapy and surgical treatment reserved for those exhibiting improvement. This approach appears counterintuitive, because some patients with the most disabling symptoms and the greatest potential for improvement might not be offered surgical treatment, and at least some of those with improvement after the initial physical therapy trial might undergo surgical treatment unnecessarily. Thus, we believe the algorithm followed in the present study is more aligned with the typical clinical practice approaches used by most physicians who treat patients with NTOS.

The physical therapy regimen used throughout the present study was specific to NTOS, differing from the physical therapy approaches typical for other neck and upper extremity conditions.[23-27] This is important to ensure an adequate trial of conservative management before considering surgery. We also found that the initial physical therapy trial was valuable even for patients considered likely to require surgical treatment, because the physical therapy trial allowed the therapist to establish
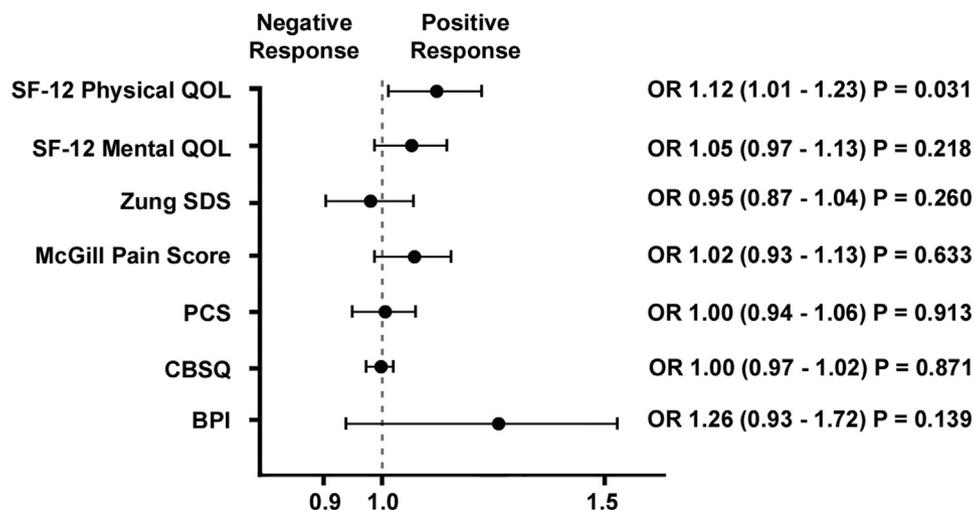
Fig 5. Forest plot for multivariate logistic regression of pretreatment patient-reported outcomes measures (PROMs) to predict response to surgical treatment for neurogenic thoracic outlet syndrome (NTOS). Data shown indicate odds ratios (*ORs*) and 95% confidence intervals (CIs; in parentheses) for each PROM and corrected for age, gender, and symptom duration >2 years. *BPI*, Brief Pain Inventory; *CBSQ*, Cervical-Brachial Symptom Questionnaire; *PCS*, Pain Catastrophizing Scale; *SDS*, Self-rating Depression Scale; *SF-12*, Short Form, 12-item quality of life questionnaire.

a baseline status for the individual patient, teach NTOS-specific protocols, help manage expectations for treatment, and better anticipate specific needs that might arise during postoperative rehabilitation. An integrated multidisciplinary center has an advantage compared with practice settings in which NTOS is treated only on an occasional basis without established protocols.

It is notable that our initial assessment approach did not include the routine use of anterior scalene and pectoralis minor muscle blocks nor were positive findings from muscle blocks considered necessary before patients could be considered for surgery. Although Lum et al,[33] Jordan and Machleder,[34] and Jordan[35] described better outcomes from surgical treatment for patients with positive findings from pretreatment muscle blocks, we found in our cohort that muscle blocks did not serve as a statistically significant predictor of the surgical treatment outcome. The present cohort was relatively small for rigorous analysis of this question and we found found a strong trend toward improved outcomes in patients with positive findings from a muscle block. Thus, we cannot conclude that the findings from muscle blocks have no predictive value and believe this question warrants ongoing study.

The assessment of patient disability using well-defined PROMs represents a quantifiable approach to evaluate the effectiveness of a treatment. In the present study, the most useful PROMs for the evaluation of patients with NTOS appeared to be the QuickDASH, CBSQ, and SF-12 physical QOL. The use of changes in the QuickDASH score to assess treatment outcomes has a distinct advantage, providing an objective measure of

the disability with an instrument widely used for patients with NTOS and other upper extremity conditions.[7,10-13,15,16,19,36,37] In contrast, PROMs related to the domain of pain appeared redundant and not as useful in assessing disability, overall functional limitations, and QOL. Although in our previous study, high pain catastrophizing was evident in 38% of patients with NTOS, the pretreatment PCS scores did not predict the outcomes after surgical treatment. This suggests that pain catastrophizing is more variable than previously considered and might respond favorably to improvements in physical symptoms. Our data showed that follow-up PCS scores decreased significantly in those with favorable patient-rated outcomes.[38,39] It remains unclear whether this was simply a consequence of symptom improvement; however, persistently high pain catastrophizing might help identify patients at risk of poor outcomes. On multivariate analysis of other predictors of outcome, we found that only the SF-12 physical QOL score was significantly associated with the response to surgical treatment. The odds ratio for this association was nonetheless relatively small, indicating that the results predicted from this single instrument should not be considered strong enough to guide treatment decisions.

The present study had several limitations. First, as noted in our initial study, the patients in our cohort likely exhibited a greater degree of disability at initial presentation than might be seen in other practice settings, and patients with milder degrees of NTOS might have a greater likelihood of satisfactory improvement with physical therapy alone.[7] Our outcomes thereby reflect a dedicated

multidisciplinary referral program for the management of NTOS and might not translate to practices with less experience with physical therapy or surgical treatment.

One difficulty with the QuickDASH instrument has been that for patients with bilateral symptoms, the functional improvement after treatment for 1 limb might be overshadowed by persistent limitations in the contralateral (untreated) limb. The QuickDASH scores can also vary inconsistently at different follow-up intervals after treatment. In the present study, we chose to use the QuickDASH score measured at the longest follow-up interval rather than at a single fixed follow-up interval; however, neither approach can capture any fluctuations in disability over time or with different patient trajectories. We also did not investigate late secondary injury or long-term recurrence of NTOS, but these will be the subject of future investigation. Because of the recognized potential for late recurrence after surgical treatment for NTOS, follow-up examinations for ≥2 years postoperatively have been suggested for analysis of late outcomes.[2,40]

Finally, the present study represents just 1 cohort of patients accrued during a 6-month period. The results might, therefore, differ somewhat with a larger cohort. It would be valuable to have a larger database of patients with NTOS available, such as a national registry, for larger scale studies in the future.[2,41,42]

CONCLUSIONS

The results of the present study have demonstrated contemporary outcomes for physical therapy and surgical treatment in a well-studied cohort of patients with NTOS, reinforcing that surgery can be effective when physical therapy is insufficient, even with substantial pretreatment disability. Substantial improvement in symptoms can be expected for ~90% of patients after surgical treatment for NTOS and is reflected by changes in the QuickDASH scores. Patients undergoing surgical treatment experienced a greater extent of improvement compared with those undergoing physical therapy alone. However, in our cohort, it was difficult to identify specific predictive factors for individuals most likely to benefit from physical therapy or from surgical treatment.

AUTHOR CONTRIBUTIONS

Conception and design: JB, AA, JE, MB, RT
Analysis and interpretation: JB, AA, SJ, RT
Data collection: JB, AA, LE, CP, JE, MB, RT
Writing the article: JB, SJ, RT, SJ, RT
Critical revision of the article: JB, AA, LE, CP, JE, MB, SJ, RT
Final approval of the article: JB, AA, LE, CP, JE, MB, SJ, RT
Statistical analysis: JB, SJ, RT
Obtained funding: RT
Overall responsibility: RT

REFERENCES

1. Povlsen B, Hansson T, Povlsen SD. Treatment for thoracic outlet syndrome. Cochrane Database Syst Rev 2014;26: CD007218.
2. Illig KA, Donahue DM, Duncan A, Freischlag JA, Gelabert H, Johansen K, et al. Reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome. J Vasc Surg 2016;64:e23-35.
3. Thompson RW. Thoracic outlet syndrome: neurogenic. In: Sidawy AN, Perler BA, editors. Rutherford's Vascular Surgery and Endovascular Therapy. 9th ed. Philadelphia: Elsevier; 2018. p. 1619-38.
4. Mackinnon SE, Novak CB. Thoracic outlet syndrome. Curr Probl Surg 2002;39:1070-145.
5. Sanders RJ, Hammond SL, Rao NM. Diagnosis of thoracic outlet syndrome. J Vasc Surg 2007;46:601-4.
6. Thompson RW. Development of consensus-based diagnostic criteria for NTOS. In: Illig KA, Thompson RW, Freischlag JA, Donahue DM, Jordan SE, Edgelow PI, editors. Thoracic Outlet Syndrome. London: Springer; 2013. p. 143-55.
7. Balderman J, Holzem K, Field BJ, Bottros MM, Abuirqeba AA, Vemuri C, et al. Associations between clinical diagnostic criteria and pretreatment patient-reported outcomes measures in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome. J Vasc Surg 2017;66:533-44.
8. Axelrod DA, Proctor MC, Geisser ME, Roth RS, Greenfield LJ. Outcomes after surgery for thoracic outlet syndrome. J Vasc Surg 2001;33:1220-5.
9. Jordan SE, Ahn SS, Gelabert HA. Differentiation of thoracic outlet syndrome from treatment-resistant cervical brachial pain syndromes: development and utilization of a questionnaire, clinical examination and ultrasound evaluation. Pain Physician 2007;10:441-52.
10. Cordobes-Gual J, Lozano-Vilardell P, Torreguitart-Mirada N, Lara-Hernandez R, Riera-Vazquez R, Julia-Montoya J. Prospective study of the functional recovery after surgery for thoracic outlet syndrome. Eur J Vasc Endovasc Surg 2008;35: 79-83.
11. Rochlin DH, Gilson MM, Likes KC, Graf E, Ford N, Christo PJ, et al. Quality-of-life scores in neurogenic thoracic outlet syndrome patients undergoing first rib resection and scalenectomy. J Vasc Surg 2013;57:436-43.
12. Caputo FJ, Wittenberg AM, Vemuri C, Driskill MR, Earley JA, Rastogi R, et al. Supraclavicular decompression for neurogenic thoracic outlet syndrome in adolescent and adult populations. J Vasc Surg 2013;57:149-57.
13. Vemuri C, Wittenberg AM, Caputo FJ, Earley JA, Driskill MR, Rastogi R, et al. Early effectiveness of isolated pectoralis minor tenotomy in selected patients with neurogenic thoracic outlet syndrome. J Vasc Surg 2013;57:1345-52.
14. Jayaraj A, Duncan AA, Kalra M, Bower TC, Gloviczki P. Outcomes of transaxillary approach to cervical and first-rib resection for neurogenic thoracic outlet syndrome. Ann Vasc Surg 2018;51:147-9.
15. Chang DC, Rotellini-Coltvet LA, Mukherjee D, De Leon R, Freischlag JA. Surgical intervention for thoracic outlet syndrome improves patient's quality of life. J Vasc Surg 2009;49: 630-7.
16. Glynn RW, Tawfick W, Elsafty Z, Hynes N, Sultan S. Supraclavicular scalenectomy for thoracic outlet syndrome: functional outcomes assessed using the DASH scoring system. Vasc Endovasc Surg 2012;46:157-62.
17. Orlando MS, Likes KC, Mizra S, Cao Y, Cohen A, Lum YW, et al. A decade of excellent outcomes after surgical intervention in 538 patients with thoracic outlet syndrome. J Am Coll Surg 2015;220:934-9.

18. Peek J, Vos CG, Unlu C, van de Pavoordt HDWM, van den Akker PJ, de Vries JPM. Outcome of surgical treatment for thoracic outlet syndrome: systematic review and meta-analysis. Ann Vasc Surg 2017;40:303-26.

19. Gelabert HA, Rigberg DA, O'Connell JB, Jabori S, Jimenez JC, Farley S. Transaxillary decompression of thoracic outlet syndrome patients presenting with cervical ribs. J Vasc Surg 2018;68:143-9.

20. Torriani M, Gupta R, Donahue DM. Sonographically guided anesthetic injection of anterior scalene muscle for investigation of neurogenic thoracic outlet syndrome. Skeletal Radiol 2009;38:1083-7.

21. Benzon HT, Rodes ME, Chekka K, Malik K, Pearce WH. Scalene muscle injections for neurogenic thoracic outlet syndrome: case series. Pain Pract 2012;12:66-70.

22. Bottros MM, AuBuchon JD, McLaughlin LN, Altchek DW, Illig KA, Thompson RW. Exercise-enhanced, ultrasound-guided anterior scalene muscle/pectoralis minor muscle blocks can facilitate the diagnosis of neurogenic thoracic outlet syndrome in the high-performance overhead athlete. Am J Sports Med 2017;45:189-94.

23. Novak CB. Conservative management of thoracic outlet syndrome. Semin Thorac Cardiovasc Surg 1996;8:201-7.

24. Walsh MT. Therapist management of thoracic outlet syndrome. J Hand Ther 1994;7:131-44.

25. Lindgren KA. Conservative treatment of thoracic outlet syndrome: a 2-year follow-up. Arch Phys Med Rehabil 1997;78:373-8.

26. Aligne C, Barral X. Rehabilitation of patients with thoracic outlet syndrome. Ann Vasc Surg 1992;6:381-9.

27. Edgelow PI. Physical therapy for NTOS. In: Illig KA, Thompson RW, Freischlag JA, Donahue DM, Jordan SE, Edgelow PI, editors. Thoracic Outlet Syndrome. London: Springer; 2013. p. 167-73.

28. Thompson RW. Supraclavicular operative approach for thoracic outlet syndrome. In: Stanley JC, Veith FJ, Wakefield TW, editors. Current Therapy in Vascular and Endovascular Surgery. 5th ed. Philadelphia: Elsevier Saunders; 2014. p. 182-6.

29. Thompson RW, Vemuri C. Neurogenic thoracic outlet syndrome exposure and decompression: supraclavicular. In: Mulholland MW, Hawn MT, Hughes SJ, Albo D, Sabel MS, Dalman RL, editors. Operative Techniques in Surgery. Philadelphia: Wolters Kluwer Health; 2015. p. 1848-61.

30. Duwayri YM, Thompson RW. Supraclavicular approach for surgical treatment of thoracic outlet syndrome. In: Chaikof EL, Cambria RP, editors. Atlas of Vascular Surgery and Endovascular Therapy. Philadelphia: Elsevier Saunders; 2014. p. 172-92.

31. Matos JM, Gonzalez L, Kfoury E, Echeverria A, Bechara CF, Lin PH. Outcomes following operative management of thoracic outlet syndrome in the pediatric patients. Vascular 2018;26:410-7.

32. Hong J, Pisapia JM, Ali ZS, Heuer AJ, Alexander E, Heuer GG, et al. Long-term outcomes after surgical treatment of pediatric neurogenic thoracic outlet syndrome. J Neurosurg Pediatr 2018;21:54-64.

33. Lum YW, Brooke BS, Likes KC, Modi M, Grunebach H, Christo PJ, et al. Impact of anterior scalene lidocaine blocks on predicting surgical success in older patients with neurogenic thoracic outlet syndrome. J Vasc Surg 2012;55:1370-5.

34. Jordan SE, Machleder HI. Diagnosis of thoracic outlet syndrome using electrophysiologically guided anterior scalene blocks. Ann Vasc Surg 1998;12:260-4.

35. Jordan SE. Scalene test blocks and interventional techniques in patients with NTOS. In: Illig KA, Thompson RW, Freischlag JA, Donahue DM, Jordan SE, Edgelow PI, editors. Thoracic Outlet Syndrome. London: Springer; 2013. p. 133-42.

36. Chandra V, Olcott C IV, Lee JT. Early results of a highly selective algorithm for surgery on patients with neurogenic thoracic outlet syndrome. J Vasc Surg 2011;54:1698-705.

37. Beaton DE, Katz JN, Fossel AH, Wright JG, Tarasuk V, Bombardier C. Measuring the whole or the parts? Validity, reliability, and responsiveness of the Disabilities of the Arm, Shoulder and Hand outcome measure in different regions of the upper extremity. J Hand Ther 2001;14:128-46.

38. Scott W, Wideman TH, Sullivan MJ. Clinically meaningful scores on pain catastrophizing before and after multidisciplinary rehabilitation: a prospective study of individuals with subacute pain after whiplash injury. Clin J Pain 2014;30:183-90.

39. Gibson E, Sabo MT. Can pain catastrophizing be changed in surgical patients? A scoping review. Can J Surg 2018;61:311-8.

40. Altobelli GG, Kudo T, Haas BT, Chandra FA, Moy JL, Ahn SS. Thoracic outlet syndrome: pattern of clinical success after operative decompression. J Vasc Surg 2005;42:122-8.

41. Thompson RW, Wittenberg AM, Caputo FJ. Directions in clinical research on NTOS. In: Illig KA, Thompson RW, Freischlag JA, Donahue DM, Jordan SE, Edgelow PI, editors. Thoracic Outlet Syndrome. London: Springer; 2013. p. 299-304.

42. Humphries MD. Creating a registry for patients with thoracic outlet syndrome. Diagnostics (Basel) 2017;17:E36.