Supraclavicular decompression for neurogenic thoracic outlet syndrome in adolescent and adult populations

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Objective: **This study was conducted to better define clinical results and understand factors determining responsiveness to surgical treatment for neurogenic thoracic outlet syndrome (NTOS) in adolescent and adult populations.**

Methods: **A retrospective review was conducted for 189 patients with disabling NTOS who underwent primary supraclavicular decompression (scalenectomy, brachial plexus neurolysis and first rib resection, with or without pectoralis minor tenotomy) from April 2008 to December 2010. Clinical characteristics were compared between 35 adolescent patients (aged <21 years) and 154 adults (aged >21 years). Functional outcome measures were assessed before surgery and at 3- and 6-month follow-up using a composite NTOS Index combining the Disabilities of the Arm, Shoulder and Hand (DASH) survey, the Cervical-Brachial Symptom Questionnaire (CBSQ), and a 10-point visual analog scale (VAS) for pain.**

Results: **Adolescent and adult patients were not significantly different with respect to sex (overall 72.5% female), side affected (58.7% right, 60.3% dominant limb), bony anomalies (23.3%), previous injury (55.6%), coexisting pain disorders (11.1%), and positive responses to scalene muscle anesthetic blocks (95.6%). Compared with adults, adolescent patients had a significantly ($P < .05$) lower incidence of depression (11.4% vs 41.6%), motor vehicle injury (5.7% vs 20.1%), previous operations (11.4% vs 29.9%), preoperative use of opiate medications (17.1% vs 44.8%), and symptom duration >2 years (24.2% vs 50.0%). Mean preoperative NTOS Index (scale 0-100) was significantly lower in adolescent vs adult patients (46.5 ± 3.6 vs 58.5 ± 1.7; $P = .009$), and hospital length of stay was 4.4 ± 0.2 vs 4.9 ± 0.1 days ($P = .03$), but the rate of postoperative complications was no different (overall, 4.2%). Although both groups exhibited significant improvement in functional outcome measures at 3 and 6 months, adolescent patients had significantly lower NTOS Index (10.4 ± 3.1 vs 39.3 ± 3.3; $P < .001$) and use of opiate medications (11.4% vs 47.4%; $P < .001$) compared with adults.**

Conclusions: **Adolescents undergoing supraclavicular decompression for NTOS had more favorable preoperative characteristics and enhanced 3-month and 6-month functional outcomes than adults. Further study is needed to delineate the age-dependent and independent factors that promote optimal surgical outcomes for NTOS. (J Vasc Surg 2013;57: 149-57.)**

Neurogenic thoracic outlet syndrome (NTOS) is a relatively uncommon condition caused by compression and irritation of the brachial plexus within the scalene triangle or the subcoracoid space.[1,2] NTOS most frequently occurs in relatively young, active, and otherwise healthy individuals, with a clinical presentation typified by symptoms of pain, numbness, and paresthesia in the arm or hand, or both, along with reproducible exacerbation by overhead positioning of the upper extremity. Physical examination consistently reveals localized tenderness to palpation over the supraclavicular or subcoracoid space, or both, with reproduction of radiating upper extremity symptoms and exacerbation of symptoms during positional upper extremity maneuvers. NTOS is often associated with a history of neck or upper extremity injury, previous surgical and nonsurgical treatment approaches, and protracted delays in diagnosis.

The symptoms of NTOS can progress to disability in young active persons in school or the prime of working life. Conservative management based on physical therapy is the mainstay of initial treatment, along with muscle relaxants, anti-inflammatory agents, and adjustments in workplace ergonomic factors, but may not improve symptoms in patients with substantial or longstanding disability. Surgical treatment for NTOS may be recommended in this setting, but its role has often been controversial, due in part to variations in diagnosis, diversity in the populations treated, use of different surgical approaches and techniques, and

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limited application of defined outcome metrics to assess results. The factors determining outcomes for surgical treatment of NTOS therefore remain incompletely understood.

The purpose of this study was to better characterize clinical results and understand factors determining responsiveness to surgical treatment for NTOS, by examining patient characteristics and postoperative outcomes in a series of adolescent and adult patients undergoing supraclavicular decompression at a high-volume referral center.

METHODS

This study was approved by the Human Research Protection Office (HRPO) at Washington University, St Louis, Missouri.

Patients. The study population consisted of patients referred to the Washington University Center for Thoracic Outlet Syndrome at Barnes-Jewish Hospital (St. Louis, Mo) for evaluation and surgical treatment of NTOS between April 2008 and December 2010. Patients with arterial or venous forms of TOS in the absence of disabling NTOS were excluded from review, as were patients with NTOS undergoing reoperative procedures or isolated pectoralis minor tenotomy (PMT). Detailed information regarding each patient was obtained from a prospectively maintained database and summarized from office notes, hospital records, imaging studies, operative findings, and records from treating physicians and therapists.

Initial evaluation. Pretreatment assessment included the history and physical examination relevant to NTOS and review of any previous evaluations, imaging studies, and electrophysiologic tests. The diagnosis of NTOS was made predominantly by clinical criteria, as previously described.[2-4] Plain chest radiographs, magnetic resonance angiography, and computed tomography angiography studies were performed as indicated by clinical circumstances to identify bony abnormalities and to exclude vascular types of TOS but were not routinely obtained. Electrophysiologic testing was not specifically used to establish a diagnosis of NTOS but was used selectively to exclude peripheral neuropathies or cervical nerve root syndromes. Contrast-enhanced vascular imaging studies were performed in patients with NTOS who had arm swelling, a pulsatile mass in the neck, or signs of arterial insufficiency, to identify those with coexisting venous or arterial TOS.

Assessment instruments. All patients were asked to complete the Disabilities of the Arm, Shoulder and Hand (DASH) survey instrument, the Cervical-Brachial Symptom Questionnaire (CBSQ), and a 10-point visual analog scale (VAS) for pain.[5-7] The DASH is a 30-item survey scored on a 0-100 scale, designed and validated for use in a variety of upper extremity musculoskeletal disorders to quantify the degree of disability. The CBSQ is a 14-item survey scored on a 0-120 scale, developed for evaluation of patients with NTOS and related disorders to measure functional disturbances resulting from performance of certain activities. The VAS is a widely used standard method for assessment of pain. Each of these instruments provides a somewhat different measure of patient-reported symptoms and disability.

Because previous studies have demonstrated that the relationship between self-reported disability and actual functional performance varies significantly,[8-10] we hypothesized that combining scores from the DASH, CBSQ, and VAS might provide a more accurate "functional outcome" measure for patients with NTOS. The results of the three patient-reported instruments were thereby combined to calculate an "NTOS Index" as a single composite measure [NTOS Index = (DASH + {0.83 × CBSQ} + {10 × VAS})/3], which was scored on a 0-100 scale with higher numbers indicating a greater degree of disability.

Fluoroscopy-guided anterior scalene (ASM) or pectoralis minor (PM) muscle blocks, or both, with local anesthetic were frequently used to help reinforce the clinical diagnosis of NTOS and to provide additional insight into the likely responsiveness to treatment.[7,11] All patients not previously treated for NTOS and those for whom previous physical therapy did not appear to have been suitably targeted toward NTOS, underwent a 4- to 6-week course of NTOS-specific physical therapy overseen by a therapist with experience and expertise in the management of NTOS.

Surgical treatment. Surgical treatment was offered when there was a sound clinical diagnosis of NTOS, a substantial level of disability, and absence of significant improvement after a suitable course of NTOS-specific physical therapy. All patients for whom surgical treatment was recommended therefore had disabling neurogenic TOS that had been refractory to previous attempts at conservative management. The interval between initial symptoms and referral, the types and outcomes of previous treatments, or the response to ASM/PM anesthetic blocks did not preclude consideration for surgical treatment.

All patients underwent supraclavicular thoracic outlet decompression, including complete anterior and middle scalenectomy, resection of any aberrant fibromuscular bands, mobilization and external neurolysis of all five brachial plexus nerve roots, and first rib resection.[2,12] If a partial or complete cervical rib was present, it was also entirely resected. Patients that also had physical examination findings localized to the subcoracoid space underwent concomitant ipsilateral PMT through a vertical infraclavicular (deltopectoral) incision; in selected patients with bilateral symptoms, a contralateral PMT was also performed in the same operative setting.[13,14] Patients with NTOS and coexisting signs or symptoms of venous TOS had an additional infraclavicular incision to permit paraclavicular resection of the first rib and direct subclavian vein reconstruction if necessary, as previously described.[15,16] Patients with NTOS and concomitant findings of arterial TOS also underwent subclavian artery repair or distal arterial thromboembolectomy, or both, when indicated.

A closed-suction drain was placed in the neck at the end of each procedure, and the brachial plexus was wrapped with an absorbable polylactide film (SurgiWrap; Mast Biosciences Inc, MAST Biosurgery USA, San Diego, Calif) to

suppress development of perineural fibrosis. No patient required division of the sternocleidomastoid muscle, partial resection of the clavicle, disruption of the sternoclavicular joint, or transmanubrial extension of the exposure. Hospital length of stay and the occurrence of any postoperative complications requiring reoperation or a significant change in management were recorded.

Postoperative follow-up. Postoperative physical therapy was begun the day after surgical treatment to maintain neck and upper extremity range of motion. Opiate pain medications, a muscle relaxant, and an anti-inflammatory agent were routinely administered. In the absence of complications, patients were discharged from the hospital as soon as adequate pain control had been achieved solely on oral medications with no nausea or constipation accompanying opiate use, and the closed-suction drain was removed in the outpatient setting during the first week after the operation. Postoperative physical therapy was continued on a regular schedule until at least 12 weeks, when unrestricted upper extremity activity was permitted and discontinuation of opiate medications encouraged. At a minimum, clinical follow-up at 3 and 6 months after operation included physical therapy evaluation, review of medications, and completion of patient-reported functional outcome assessment instruments.

Data analysis. The principal outcomes evaluated were functional measures as assessed by the DASH, CBSQ, VAS, and NTOS Index, including proportionate changes between preoperative status and each postoperative interval and patient use and types of opiate pain medications. These end points were then evaluated in relationship to patient age and other clinical variables. Descriptive group data are presented as the mean ± standard error of the mean or the median and range of values for adolescent patients and adults. The Pearson test was used for correlation analyses, and comparisons between two groups were made using the unpaired *t*-test with Welch correction (for data with continuous variables) or Fisher exact test (for categoric data). For comparisons between more than two groups, one-way analysis of variance (ANOVA) was used with the Newman-Keuls multiple comparisons test (for data with continuous variables). All statistical tests were performed using Prism 4.0c software (GraphPad Software Inc, San Diego, Calif), with $P < .05$ considered significant.

RESULTS

Patient population and preoperative characteristics. There were 189 patients that underwent primary surgical treatment for NTOS between April 2008 and December 2010 and met the study criteria. As summarized in Table I, there were 52 men (27.5%) and 137 women (72.5%), with a mean age at the time of treatment of 35.8 ± 0.9 years (median, 37; range, 13-72 years). The age distribution of patients included 35 (18.5%) aged <21 years and 154 (81.5%) aged >21 years, with the appearance of a bimodal population distribution that distinguished adolescent (mean age, 17.3 ± 0.3; median, 17, range, 13-20 years) from adult patients (mean age, 40.0 ± 0.7; median, 40; range, 22-72 years; Fig 1, *A*).

Table I. Preoperative characteristics of the study population with thoracic outlet syndrome (*TOS*)

Variable[a]	*Adolescent*	*Adult*	P[b]
Patients	35 (18.5)	154 (81.5)	
Age, years			
Mean ± SEM	17.3 ± 0.3	40.0 ± 0.7	<.0001
Median (range)	17 (13-20)	40 (22-72)	
Female sex	26 (74.3)	111 (72.1)	>.05
Right-sided symptoms	22 (62.9)	89 (57.8)	>.05
Dominant side affected	22 (63.0)	92 (59.7)	>.05
Bony anomaly (eg, cervical rib)	5 (14.3)	39 (25.3)	>.05
Neurogenic TOS alone	31 (88.6)	136 (88.3)	>.05
+ venous TOS	4 (11.4)	8 (5.2)	>.05
+ arterial TOS	0 (0.0)	10 (6.5)	>.05
Diagnosis of			
Depression	4 (11.4)	64 (41.6)	.0007
Other pain disorder	1 (2.9)	20 (13.0)	>.05
Participation in athletics	24 (72.7)	12 (8.3)	<.0001
History of injury	22 (62.9)	83 (53.9)	>.05
Repetitive motion	11 (31.4)	23 (14.9)	.0289
Motor vehicle collision	2 (5.7)	31 (20.1)	.0482
Fall on arm	7 (20.0)	25 (16.2)	>.05
Other	2 (5.7)	13 (8.4)	>.05
Previous operations	4 (11.4)	46 (29.9)	.0324
Cervical spine	0 (0.0)	20 (13.0)	.0280
Shoulder	2 (5.7)	16 (10.4)	>.05
Cubital canal	0 (0.0)	10 (6.5)	>.05
Carpal tunnel	1 (2.9)	14 (9.1)	>.05
Other	1 (2.9)	2 (1.3)	>.05
Multiple operations	0 (0.0)	14 (9.1)	>.05
Scalene block performed	15 (42.9)	99 (64.3)	.0225
Positive scalene block	13 (86.7)	96 (97.0)	>.05

SEM, Standard error of the mean.
[a]Categoric data are shown as number (%) and continuous data as mean ± standard error of the mean or median (range).
[b]Comparison between adolescent (<21 years of age) and adult (>21 years of age) groups, unpaired two-tailed *t*-test with Welch correction (for continuous data) or Fisher exact test (for categoric data).

There were no significant differences between the adolescent and adult groups with respect to sex (overall, 72.5% female), side affected (58.7% right, 60.3% dominant limb), bony anomalies (23.3%), previous injury (55.6%), or presence of coexisting pain disorders (11.1%; Table I). Compared with adults, the adolescent patients had a significantly lower incidence of depression (11.4% vs 41.6%) and history of motor vehicle injury (5.7% vs 20.1%) and a higher incidence of repetitive motion injury (31.4% vs 14.9%) and participation in athletics (73% vs 8%). The overall frequency and extent of symptoms were similar for adolescent patients and adults as assessed for 38 different features potentially associated with NTOS, with significant differences in severity (1-to-5 point numeric scale; 1 = absent, 5 = extreme) exhibited only for hand pain (adolescent patients, 56%, 2.3 ± 0.2; adults, 79%, 2.9 ± 0.1), hand cramping (adolescent patients, 41%, 1.9 ± 0.2; adults, 63%, 2.4 ± 0.1),

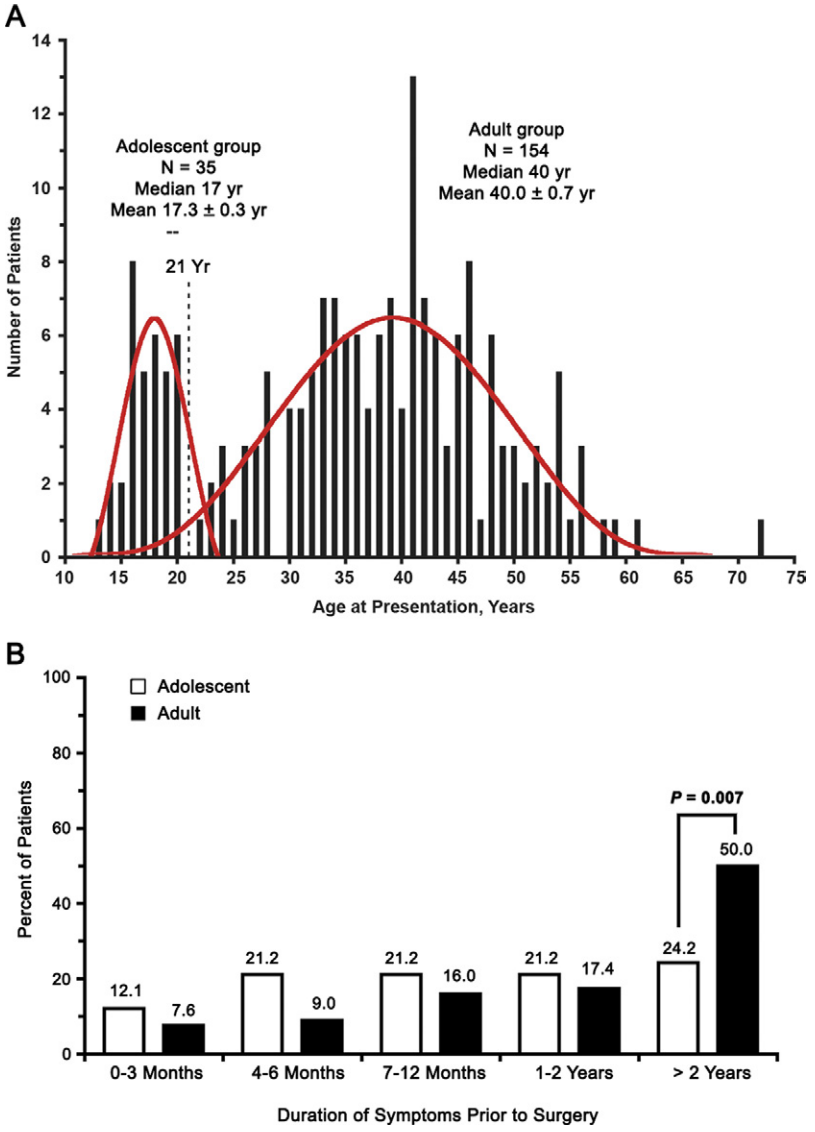

Fig 1. Age distribution and duration of symptoms. **A,** The distribution of 189 patients with neurogenic thoracic outlet syndrome is shown by age at presentation and surgical treatment. A bimodal distribution is illustrated distinguishing adolescent (age <21 years) from adult (age >21 years) patient groups. **B,** Duration of symptoms before referral evaluation for neurogenic thoracic outlet syndrome is shown in adolescent (n = 35) and adult (n = 154) patients. There was a significant difference between the percentage of adolescent vs adult patients that reported symptoms for >2 years ($P = .007$, χ^2 test), with no significant differences for the other time intervals.

and pale discoloration in the fingers (adolescent patients, 53%, 2.3 ± 0.3; adults, 38%, 1.8 ± 0.1; Table II). The overall duration of symptoms before referral was shorter for adolescent patients than for adults, with only 24.2% of adolescent patents having symptoms >2 years compared with 50% for adults (Fig 1, *B*).

Although all of the patients in this series were initially evaluated and treated for neurogenic (brachial plexus) symptoms, there were 12 (6.3%) with concomitant evidence of positional subclavian vein obstruction (venous TOS) and 10 (5.3%) with concomitant lesions of the subclavian artery (arterial TOS), with no difference in the presence of vascular obstruction between adolescent and adult patients (Table I). Adolescent patients with NTOS had undergone fewer previous operations to treat the presenting symptoms than adults (11.4% vs 29.9%), particularly with respect to previous cervical spine procedures (0.0% vs 13.0%; Table I). Although scalene muscle blocks with local anesthetic were performed less frequently in the adolescent group than in adults (42.9% vs 64.3%), there was no difference between groups in the frequency of positive responses (overall, 95.6%).

Table II. Nature of preoperative symptoms[a]

Symptom (rank order)	*Adolescent*		*Adult*		P[b]
	%	*Score*	*%*	*Score*	
Tingling/numbness, hand	84	3.4 ± 0.2	93	3.3 ± 0.1	>.05
Arm weakness	88	3.1 ± 0.2	91	3.4 ± 0.1	>.05
Shoulder pain	84	3.4 ± 0.2	90	3.4 ± 0.1	>.05
Arm pain	72	2.8 ± 0.2	89	3.3 ± 0.1	>.05
Neck pain	81	2.9 ± 0.2	87	3.2 ± 0.1	>.05
Hand weakness	78	2.8 ± 0.2	88	3.2 ± 0.1	>.05
Tingling/ numbness, arm	78	3.1 ± 0.3	86	3.0 ± 0.1	>.05
Awakening from sleep	72	2.6 ± 0.3	87	3.1 ± 0.1	>.05
Arm heaviness	71	2.5 ± 0.2	79	2.9 ± 0.1	>.05
Hand pain	56	2.3 ± 0.2	79	2.9 ± 0.1	.0118
Trouble getting to sleep	66	2.6 ± 0.3	72	2.8 ± 0.1	>.05
Back pain	75	2.6 ± 0.2	70	2.6 ± 0.1	>.05
Too sleepy during day	59	2.4 ± 0.3	72	2.6 ± 0.1	>.05
Cold feeling, hand	59	2.4 ± 0.2	66	2.4 ± 0.1	>.05
Hand cramping	41	1.9 ± 0.2	63	2.4 ± 0.1	.0451
Muscle spasm, neck	47	2.0 ± 0.2	55	2.3 ± 0.1	>.05
Cold feeling, arm	41	2.0 ± 0.2	56	2.1 ± 0.1	>.05
Headaches, occipital	41	1.8 ± 0.2	55	2.2 ± 0.1	>.05
Headaches, frontal	63	2.2 ± 0.2	48	2.0 ± 0.1	>.05
Muscle spasm, arm	44	1.8 ± 0.2	50	2.0 ± 0.1	>.05
Hand swelling	47	1.9 ± 0.2	48	1.8 ± 0.1	>.05
Dyspnea with exertion	44	1.9 ± 0.2	46	1.9 ± 0.1	>.05
Muscle spasm, back	41	1.7 ± 0.2	43	2.0 ± 0.1	>.05
Pale discoloration in fingers	53	2.3 ± 0.3	38	1.8 ± 0.1	.0315
Arm swelling	41	1.7 ± 0.2	38	1.7 ± 0.1	>.05
Side pain with exertion	41	1.8 ± 0.2	36	1.7 ± 0.1	>.05
Lump in neck	25	1.5 ± 0.2	38	1.9 ± 0.1	>.05
Cyanotic hand discoloration	47	1.9 ± 0.2	32	1.6 ± 0.1	>.05
Neck swelling	16	1.3 ± 0.1	32	1.6 ± 0.1	>.05
Vision changes	27	1.2 ± 0.1	27	1.4 ± 0.1	>.05
Excess sweating, hand	19	1.4 ± 0.2	26	1.4 ± 0.1	>.05
Enlarged veins, arm	22	1.5 ± 0.2	21	1.4 ± 0.1	>.05
Cyanotic arm discoloration	22	1.4 ± 0.2	19	1.3 ± 0.1	>.05
Dyspnea at rest	16	1.2 ± 0.1	21	1.4 ± 0.1	>.05
Excess sweating, face	13	1.3 ± 0.2	19	1.4 ± 0.1	>.05
Enlarged veins, shoulder	16	1.3 ± 0.2	17	1.3 ± 0.1	>.05
Drooping eyelid	6	1.1 ± 0.0	9	1.1 ± 0.0	>.05
Finger ulceration	3	1.0 ± 0.0	4	1.1 ± 0.0	>.05

[a]Data shown represent the percentage of patients describing each of the symptoms indicated, and the score indicates the mean ± standard error of the mean for each symptom as scored on a 1-to-5 symptom severity scale (1 = absent, 5 = extreme).
[b]Comparison between adolescent (aged <21 years) and adult (aged >21 years) groups, unpaired two-tailed *t*-test with Welch correction.

With respect to functional assessment measures, the mean preoperative DASH scores and CBSQ ratings were significantly lower in the adolescent group than in adults (DASH, 35.4 ± 2.9 vs 49.7 ± 1.7; CBSQ, 57.3 ± 5.5 vs 74.5 ± 2.4), but there was no difference in mean preoperative VAS pain scores (Table III). The mean preoperative NTOS Index (a composite of the DASH, CBSQ, and VAS scores) was also significantly lower in adolescent vs adult patients (46.5 ± 3.6 vs 58.5 ± 1.7; Table III).

Table III. Functional assessment and outcome measures

Assessment[a]	*Adolescent*	*Adult*	P[b]
DASH score (scale 0-100)			
Preoperative score	35.4 ± 2.9	49.7 ± 1.7	<.0001
3-month score	16.7 ± 4.1	41.2 ± 2.1	<.0001
6-month score	7.8 ± 3.2	37.8 ± 2.4	<.0001
CBSQ score (scale 0-120)			
Preoperative score	57.3 ± 5.5	74.5 ± 2.4	.0070
3-month score	21.2 ± 6.0	46.5 ± 3.1	.0008
6-month score	11.9 ± 4.4	49.0 ± 3.4	<.0001
VAS pain score (scale 0-10)			
Preoperative score	5.8 ± 0.4	6.3 ± 0.2	>.05
3-month score	2.3 ± 0.5	4.4 ± 0.2	.0006
6-month score	1.8 ± 0.5	4.6 ± 0.6	.0006
NTOS index (scale 0-100)			
Preoperative score	46.5 ± 3.6	58.5 ± 1.7	.0089
3-month score	18.4 ± 4.1	41.0 ± 2.3	<.0001
6-month score	10.4 ± 3.1	39.3 ± 3.3	<.0001

CBSQ, Cervical-brachial symptom questionnaire; *DASH,* disabilities of arm, shoulder and hand; *NTOS,* neurogenic thoracic outlet syndrome combined with CBSQ, DASH, and VAS; *VAS,* visual analog scale.
[a]Data shown represent the mean ± standard error off the mean.
[b]Comparison between adolescent (aged <21 years) and adult (aged >21 years) groups, unpaired two-tailed *t*-test with Welch correction.

Table IV. Use of opiate pain medications

Variable	*Adolescent No. (%)*	*Adult No. (%)*	P[a]
Initial (preoperative)			
None	29 (82.9)	85 (55.2)	.0022
Moderate[b]	4 (11.4)	38 (24.7)	>.05
Strong[c]	2 (5.7)	21 (13.6)	>.05
Moderate + strong	0 (0.0)	10 (6.5)	>.05
3-month follow-up			
None	24 (68.6)	53 (34.4)	.0003
Moderate[b]	2 (5.7)	11 (7.1)	>.05
Strong[c]	8 (22.9)	74 (48.1)	.0078
Moderate + strong	1 (2.9)	16 (10.4)	>.05
6-month follow-up			
None	31 (88.6)	81 (52.6)	<.0001
Moderate[b]	1 (2.9)	15 (9.7)	>.05
Strong[c]	3 (8.6)	48 (31.2)	.0057
Moderate + strong	0 (0.0)	10 (6.5)	>.05

[a]Comparison between adolescent (<21 years of age) and adult (>21 years of age) groups, Fisher exact test for categoric data.
[b]U.S. Drug Enforcement Administration schedules III and IV narcotic mediations.
[c]U.S. Drug Enforcement Administration schedule II narcotic medications.

As summarized in Table IV, 75 of 189 patients (39.7%) used opiate pain medications before surgical treatment, including 46 (24.3%) using moderate opiates, 27 (14.3%) using strong opiates, and nine (4.8%) using both moderate and strong opiates. There was a significant difference in overall use of opiate pain medications between the adolescent and adult groups (17.1% vs 44.8%) but no differences in the types of medications used.

Table V. Surgical treatment

Variables[a]	*Adolescent*	*Adult*	P[b]
Supraclavicular incision plus infraclavicular incision	29 (82.9)	139 (90.3)	>.05
	6 (17.1)	15 (9.7)	>.05
PMT included			
Ipsilateral	18 (51.4)	113 (73.4)	.0148
Contralateral	2 (5.7)	16 (10.4)	>.05
Hospital length of stay, days			
Mean ± SEM	4.4 ± 0.2	4.9 ± 0.1	.0330
Median (range)	4.1 (2.8-7.5)	4.4 (2.0-11.3)	
Complications	1 (2.9)	7 (4.5)	>.05
Bleeding/hematoma	0 (0.0)	1 (0.6)	>.05
Lymph leak	0 (0.0)	5 (3.2)	>.05
Wound infection	1 (2.9)	1 (0.6)	>.05

PMT, Pectoralis minor tenotomy; *SEM,* standard error of the mean.
[a]Categoric data shown as number (%), continuous data as indicated.
[b]Comparison between adolescent (aged <21 years) and adult (aged >21 years) groups, unpaired two-tailed *t*-test with Welch correction (for continuous data) or Fisher exact test (for categoric data).

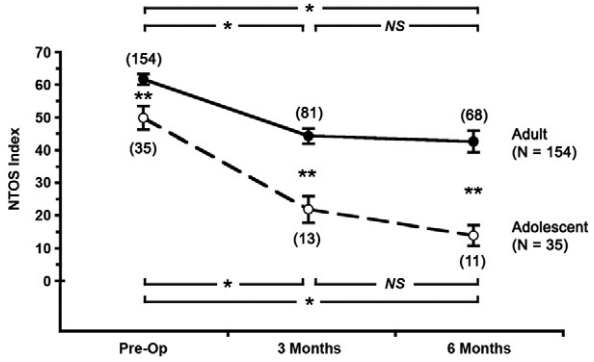

Fig 2. Neurogenic thoracic outlet syndrome (*NTOS*) index scores are shown for patients undergoing supraclavicular decompression for NTOS, comparing preoperative values with those at 3-month and 6-month follow-up intervals (data shown represent the mean ± standard error of the mean). Line graphs depicting comparison between adolescent patients and adults demonstrate a significant and progressive decline in NTOS Index scores during postoperative follow-up in both groups with a more rapid and substantial decline in adolescent patients vs adults ($P < .0001$ one-way ANOVA). *$P < .001$ (Newman-Keuls multiple comparisons test; *NS* = not significant ($P > .05$). **$P < .05$, adolescent patients vs adults at each interval, unpaired two-tailed *t*-test with Welch correction.

Surgical treatment. All patients in this series underwent supraclavicular decompression without intraoperative complications. As summarized in Table V, an additional infraclavicular incision was used in 21 patients (11.1%) to permit complete resection of the anteromedial first rib for coexisting vascular compression, with no difference between the adolescent and adult groups. Ipsilateral PMT was performed in conjunction with supraclavicular decompression in 131 patients (69.3%) and somewhat less frequently in adolescent patients than in adults (51.4% vs 73.4%). Contralateral PMT was also performed simultaneously in 18 patients (9.5%), with no difference between adolescent patients and adults.

The overall postoperative length of hospital stay was 4.8 ± 0.1 days and was significantly less in adolescent patients than in adults (4.4 ± 0.2 vs 4.9 ± 0.1 days; Table V). The overall rate of postoperative complications requiring reoperation was 4.2% (one surgical site bleeding, two infected wound fluid collections, and five persistent lymph drainage) but was not significantly different between adolescent patients (1 of 35, 2.9%) and adults (7 of 154, 4.5%; Table V).

Postoperative outcomes. Patients undergoing supraclavicular decompression for NTOS exhibited significant and progressive improvement in symptoms and functional outcome measures at the 3-month and 6-month follow-up intervals (Table III; Fig 2). By direct comparison with adults at the 3-month follow-up, adolescent patients had a significantly lower mean NTOS Index (18.4 ± 4.1 vs 41.0 ± 2.3l; Table III; Fig 2), and a significantly lower proportion were using opiate pain medications (31.4% vs 65.6%; Table IV). Adolescent patients also had a significantly lower mean NTOS Index than adults at the 6-month follow-up (10.4 ± 3.1 vs 39.3 ± 3.3; Table III; Fig 2), and there was a lower proportion using opiate pain medications (11.4% vs 47.4%; Table IV). There was a significant correlation between age and NTOS Index at the 3-month and 6-month intervals after surgical treatment (Fig 3). As shown in Fig 4 and summarized in Table VI, there was an overall extent of improvement in the four functional outcomes measures, ranging from 43.5% to 57.8% in adolescent patients and from 8.7% to 30.0% in adults at 3 months and from 63.9% to 83.4% (adolescent patients) and from 12.6% to 29.6% (adults) at 6 months. The overall percentage of patients exhibiting an improvement in outcome measure scores was from 73.3% to 88.2% (adolescent patients) and 67.0% to 79.8% (adults) at 3 months and from 86.7% to 100.0% (adolescent patients) and 68.9% to 83.8% (adults) at 6 months. By these analyses, the measured extent of improvement at each follow-up interval was consistently greater in adolescent patients than in adults, but there were no significant differences between groups in the proportion of patients exhibiting improvement (Table VI; Fig 4).

DISCUSSION

The diagnosis and management of NTOS varies widely between different physicians and institutions, and determining the most effective approach to this condition continues to elicit substantial controversy.[17] Although the pathophysiologic mechanisms underlying the development of NTOS have yet to be fully elucidated, it is clear that certain patient populations do not improve sufficiently with conservative management alone. In the present study, we demonstrate that adolescent and adult patients with disabling NTOS can both improve substantially after surgical treatment. This reinforces the notion that surgical treat-

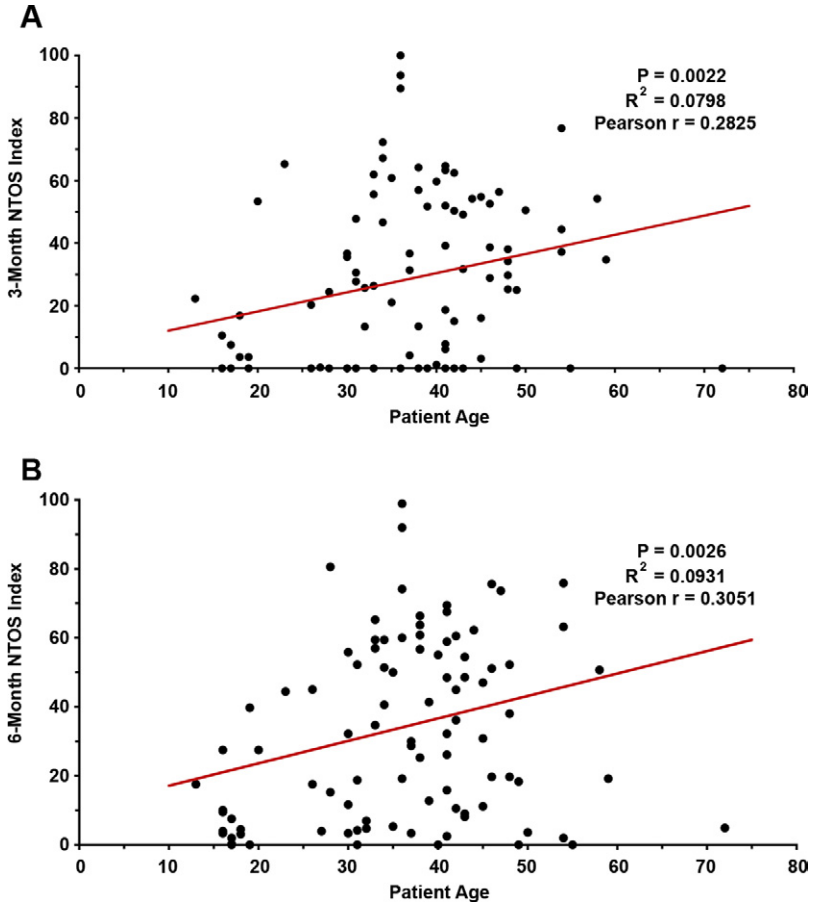

Fig 3. Age and postoperative functional outcome measures. Scatterplots depict the relationship between patient age and neurogenic thoracic outlet syndrome (*NTOS*) index scores during postoperative follow-up. **A,** Three-month postoperative follow-up. $P = .0022$, Pearson correlation test ($r = .2825$; $R^2 = .0798$). **B,** Six-month postoperative follow-up. $P = .0026$, Pearson correlation test ($r = .3051$; $R^2 = .0931$).

ment of NTOS is effective in the adolescent age group and helps to identify clinical factors that may be associated with more favorable outcomes in other patients.

Several reports have been published concerning TOS in pediatric and adolescent patients.[18-23] Although these studies have provided valuable insights, the relatively low numbers of patients with NTOS prevents meaningful conclusions to be drawn regarding optimal management of this condition in children and young adults. There appears to be an overall benefit to those patients undergoing surgical decompression, but there is inconsistency in diagnostic criteria, limited clinical follow-up, and minimal use of quantifiable outcome measures to assess management strategies. Previous studies are also confounded by the use of different surgical approaches, inclusion of primary vascular forms of TOS, and lack of comparison groups. As noted by Stansby and Lambert,[24] although comparative clinical trials on the management of TOS are somewhat unrealistic, establishment of a TOS registry to record indications, outcomes and complications, accompanied by national society guidelines, would be a worthwhile and valuable endeavor in this field.

In the present report, we assessed 189 patients who underwent supraclavicular decompression for disabling NTOS that had been refractory to conservative management. Of these patients, 35 were aged <21 years, thereby representing the largest group of pediatric or adolescent patients with NTOS described in the literature to date. Furthermore, our comparison group was a cohort of 154 adults who underwent a similar approach to surgical decompression for NTOS in the same time period. In examining the preoperative clinical characteristics between the two groups, we found that patients in the adolescent cohort had a significantly lower incidence of depression and history of motor vehicle injury, and a higher incidence of repetitive motion injury and participation in athletics. The overall duration of symptoms was shorter for adolescent patients compared with adults, and previous use of opiate pain medications was also substantially lower. These favorable clinical features in adolescent patients can thereby be ex-

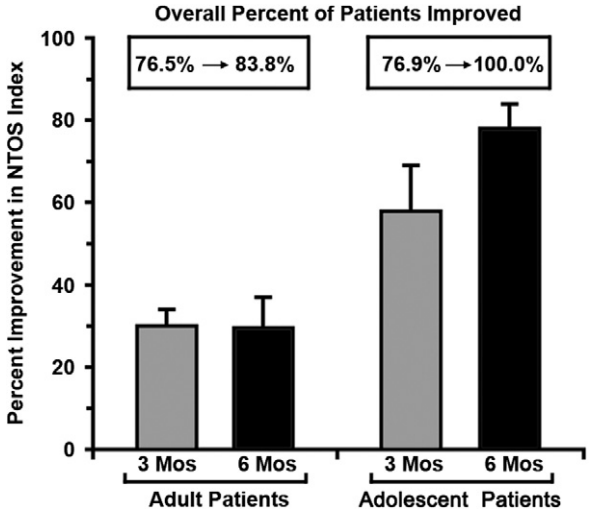

Fig 4. Postoperative improvement in functional outcome measures. The extent (percentage) of improvement in the neurogenic thoracic outlet syndrome (*NTOS*) index at 3 months and 6 months for patients undergoing supraclavicular decompression for NTOS, with data shown for adolescent patients and adults (values represent the mean ± standard error of the mean). Inset values depict the overall percentage of patients exhibiting improvement.

Table VI. Postoperative outcomes at 3 and 6 months

Outcome	*Adolescent (%)*	*Adult (%)*	P[a]
3-month follow-up			
Percent improvement			
DASH score	43.5 ± 15.5	8.7 ± 8.0	>.05
CBSQ score	56.8 ± 14.1	15.1 ± 15.0	.0475
VAS pain score	56.3 ± 11.5	20.3 ± 7.5	.0140
NTOS index	57.8 ± 11.3	30.0 ± 4.1	.0364
Percent of patients improved			
DASH score	85.0	67.0	>.05
CBSQ score	88.2	79.8	>.05
VAS pain score	73.3	69.1	>.05
NTOS index	76.9	76.5	>.05
6-month follow-up			
Percent improvement			
DASH score	79.5 ± 9.2	20.6 ± 6.4	<.0001
CBSQ score	83.4 ± 5.9	17.3 ± 17.0	.0004
VAS pain score	63.9 ± 9.6	12.6 ± 16.4	.0086
NTOS index	78.0 ± 6.0	29.6 ± 7.3	<.0001
Percent of patients improved			
DASH score	93.8	68.9	.0399
CBSQ score	100.0	82.6	>.05
VAS pain score	86.7	69.2	>.05
NTOS index	100.0	83.8	>.05

CBSQ, Cervical-Brachial Symptom Questionnaire; *DASH,* Disabilities of the Arm, Shoulder and Hand; *NTOS Index,* neurogenic thoracic outlet syndrome assessed by combined CBSQ, DASH, and VAS pain score.
[a]Comparison between adolescent (aged <21 years) and adult (aged >21 years) groups, unpaired two-tailed *t*-test with Welch correction (for continuous data) or Fisher exact test (for categoric data).

pected to predict improved outcomes after surgical treatment compared with adults.

We used several patient-reported survey instruments to assess preoperative characteristics of individuals with NTOS and to provide quantifiable outcome measures of treatment results. Prior to treatment, adolescent patients had significantly lower scores for the DASH, CBSQ, and NTOS index compared with adults (but no difference in VAS pain scores). Using these measures as well as descriptive evaluations of symptoms, adolescent and adult patients both exhibited significant improvement 3 months after supraclavicular decompression, with slightly greater (but not statistically significant) improvement at 6 months. The extent of improvement at both intervals was greater in adolescent patients than adults, with significantly lower scores for the DASH, CBSQ, and NTOS index, and adolescent patients also had lower use of opiate pain medications than adults at both the 3-month and 6-month follow-up. These findings were further reflected by a linear correlation between age and NTOS index at both 3 and 6 months of follow-up. Although these results confirm that supraclavicular decompression is successful in treating disabling NTOS, they indicate that adolescent patients tend to have greater improvement, as determined by quantitative functional outcome measures, compared with adults.

One limitation of this investigation is that during the time interval over which the study patients underwent treatment, we did not regularly use quality-of-life measures, such as those previously described in patients with TOS by Chang et al.[25] Obtaining this type of information is now included in our approach to patient assessment before and after treatment and will provide useful information in the future. In addition to a relatively large number of patients with NTOS, strengths of this study include the consistency of clinical management throughout the period of review. Thus, all patients underwent surgical treatment in a similar manner by a single surgeon, with protocol-driven care provided through the operating room, inpatient hospital stay, and postoperative phases of care.

Other limitations of this study include its retrospective nature as well as the absence of a cohort of patients managed conservatively for NTOS. Although all of the patients underwent surgery after failing to improve with appropriate TOS-specific physical therapy, we do not otherwise know the number of patients with NTOS from the same population base that might have been treated successfully with conservative measures alone.

CONCLUSIONS

We found that adolescent patients had more favorable clinical characteristics at the time of referral, which appeared to predict better outcomes than adults after surgical treatment. Further study may reveal that one or more of these clinical characteristics, alone or in various combinations, can effectively predict response to treatment in adults. However, because the duration of symptoms was also shorter in adolescent patients, we are unable to exclude the possibility that age may simply represent a surrogate for

earlier diagnosis and referral rather than a completely independent prognostic factor in determining responsiveness to treatment. Finally, the period of postoperative follow-up in the present study was limited to 6 months. Because the incidence of recurrent NTOS appears to be greatest within the first 2 years after surgical treatment, the duration of follow-up reported here may not have taken into account the potential development of recurrent NTOS or the need for reoperative procedures at later intervals.[26,27] Additional investigations will therefore be needed to further delineate the age-dependent and independent factors that promote optimal surgical outcomes for NTOS.

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AUTHOR CONTRIBUTIONS

Conception and design: FC, AW, VE, RT
Analysis and interpretation: FC, AW, CV, VE, RT
Data collection: FC, AW, CV, VE, RT
Writing the article: FC, AW, CV, RT
Critical revision of the article: FC, AW, CV, MD, JE, RR, VE, RT
Final approval of the article: FC, AW, CV, MD, JE, RR, VE, RT
Statistical analysis: FC, AW, RT
Obtained funding: RT
Overall responsibility: RT

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