Thoracic outlet syndrome: Pattern of clinical success after operative decompression

Grant G. Altobelli, Toshifumi Kudo, MD, PhD, Bradley T. Haas, Fiona A. Chandra, Jennifer L. Moy, BS, and **Samuel S. Ahn, MD,** *Los Angeles, Calif*

Objective: **To evaluate the pattern of clinical results in patients with neurogenic thoracic outlet syndrome (N-TOS) after operative decompression and longitudinal follow-up.**

Methods: **From May 1994 to December 2002, 254 operative sides in 185 patients with N-TOS were treated by the same operative protocol: (1) transaxillary first rib resection and the lower part of scalenectomy for the primary procedure with or without (2) the subsequent upper part of scalenectomy with supraclavicular approach for patients with persistent or recurrent symptoms. This retrospective cohort study included 38 men and 147 women with an age range of 19 to 80 years (mean, 40 years). Evaluated were primary success, defined as uninterrupted success with no procedure performed, and secondary success, defined as success maintained by the secondary operation after the primary failure.** *Success* **was defined as ≥50% symptomatic improvement judged by the patient using a 10-point scale, returning to preoperational work status, or both.**

Results: **Follow-up was 2 to 76 months (mean, 25 months). Eighty sides underwent a secondary operation for the primary clinical failure. No technical failures and no deaths occurred ≤30 days after the operations. The complication rate was 4% (13/334) and consisted of 7 pneumothoraxes, 3 subclavian vein injuries, 1 nerve injury, 1 internal mammary artery injury, and 1 suture granuloma. Of 254 operative sides, the primary and secondary success was 46% (118/254) and 64% (163/254). Most the primary failures (90%, 122/136) and the secondary failures (66%, 23/35) occurred ≤18 months after the respective operation.**

Conclusions: **The long-term results of operations for TOS in this study were much worse than those initially achieved, and most of the primary and secondary failures occurred ≤12 months of the respective operations. A minimum of 18-month follow-up on patients and standardized definition of the outcomes are necessary to determine the true effectiveness and outcome of operative treatment of N-TOS. (J Vasc Surg 2005;42:122-8.)**

Neurogenic thoracic outlet syndrome (N-TOS) is often confounded by related diseases such as cubital and carpal tunnel syndromes, myofascial pain syndrome, and spinal stenosis; therefore, evaluation of surgical decompression of the thoracic outlet as an effective treatment has been difficult. Previous studies[1,2] have addressed the overall long-term success, but the time course has not been well described. Additionally, no standardized criterion of success currently exists. To address this concern, we reviewed a 9-year experience of operative decompression for N-TOS using a 10-point scale evaluation of the outcomes and a standard life-table analysis to illuminate the time-scale for symptom recurrence and evaluate the need for follow-up over time.

METHODS

Patient population. From May 1994 to December 2002, 279 operative sides in 197 patients with N-TOS underwent a primary operation of the thoracic outlet decompression. Both sides were surgically decompressed in 69 patients. To minimize variables, we excluded the 25 (9%) operative sides in which a supraclavicular scalenectomy was used for the primary decompression.

The final sample was 254 operative sides in 185 patients with N-TOS, and they were included in a retrospective cohort study. The cohort consisted of 38 (21%) men and 147 (79%) women, aged 19 to 80 years (mean, 40 years) at the time of the primary operation. The same operative protocol was applied prospectively: (1) transaxillary first rib resection and lower part (1/4) of scalenectomy for the primary procedure with or without (2) subsequent upper part (3/4) of scalenectomy with supraclavicular approach for patients with persistent or recurrent symptoms (Fig 1).

The following procedures were used routinely for the diagnosis of N-TOS:

1. clinical evaluation: inspection, palpation, auscultation in the supraclavicular fossa with the arm in the neutral position and up into the abducted and externally rotated position, and muscle strength test,
2. provocative clinical tests: Tinel's sign, Adson's test, abduction and external rotation test, and elevated arm stress test
3. electrophysiologic tests: somatosensory evoked potential recording across the brachial plexus,[3]
4. anatomic studies: plain radiograph and magnetic resonance imaging,[4] and

From Gonda (Goldschmied) Vascular Center, University of California at Los Angeles.

Competition of interest: none.

Presented at the Nineteenth Annual Meeting of the Midwestern Vascular Society, Victoria, British Columbia, Canada, Sep 11–14, 2004.

Reprint requests: Samuel S. Ahn, MD, UCLA Gonda (Goldschmied) Vascular Center, 200 UCLA Medical Plaza, Ste 526, Los Angeles, CA, 90095-6958 (e-mail: sahn@mednet.ucla.edu).

0741-5214/$30.00

doi:10.1016/j.jvs.2005.03.029

5. provocative stimulation and anesthetic blocks of the anterior scalene muscle.[5,6]

In patients with a double-crush syndrome, entrapments that were more peripheral were treated first when surgical intervention was necessary. A neurologist was involved in the preoperative diagnosis and nurse practitioners were involved in the postoperative follow-up and evaluation to minimize any surgeon bias. The follow-up interval was 3 to 6 months.

The indications for reoperation were the same for the primary operation with the same diagnostic procedures as mentioned: (1) the patient had symptoms compatible with TOS that were miserable enough for surgery, (2) the neuro-vascular bundle was compressed at the thoracic outlet, and (3) the compression caused the symptoms.

This study was not designed to address which strategy (ie, transaxillary first rib resection vs supraclavicular scalenectomy) is better. The local institutional review board approved the study protocol.

Data analysis. Clinical success was evaluated as primary or secondary success, or both. The patient was considered to have had primary success when the success was uninterrupted, with no procedure performed on the operative side; whereas the secondary success could be maintained by the secondary operation even after the primary failure. *Success* was defined as ≥50% improvement on the ipsilateral side of the operation, the patient returning to preoperational work status without the need for an additional ipsilateral procedure, or both. *Improvement* was defined subjectively by the patient using a 10-point scale to answer the question "Please rate your pain on a scale of 0 to 10, with 0 being no pain and 10 being the pain you experienced before the operation."

Follow-up was obtained by standard visits with the clinician and by telephone interviews for all patients who could be reached. The surgical results were gathered and analyzed in 6-month time increments, with an additional time point at 2 months after surgery. These results were analyzed by using a standard life-table analysis to evaluate the freedom from recurrent symptoms over time.

In cases in which failure was reported at the 2- or 6-month time point but later replaced by clinical success at successive future time points, the patient was considered successful at early time points, and the perceived failure was attributed to residual surgical pain and healing. On the other hand, if a patient's records reflected an aberrant successful time point surrounded by failures, the patient was considered to have failed at the first time point of reported failure, regardless of later isolated reports of clinical success.

Statistical analysis methods. The log-rank was used to evaluate differences in stratified life tables. Statistical significance was defined as $P < .05$.

RESULTS

Of 254 operative sides, 80 underwent secondary operation for the primary failure, resulting in 334 surgeries.

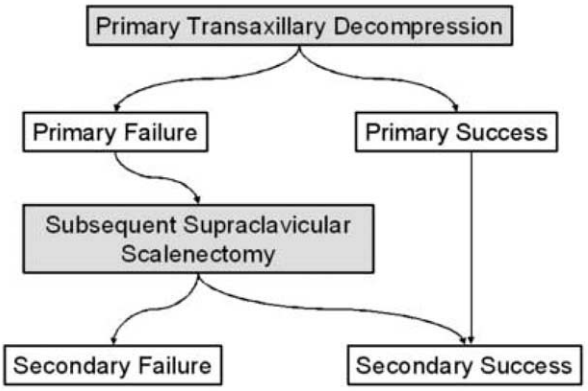


Fig 1. The algorithm of operative treatment for neurogenic thoracic outlet syndrome.

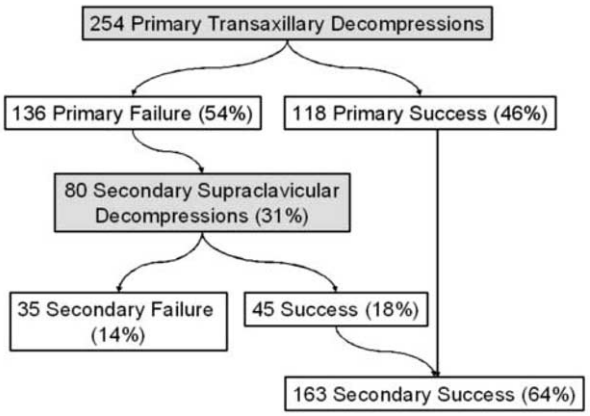


Fig 2. The primary and secondary operations and the results in all patients.

Follow-up was 2 to 76 months (mean, 25 months). During the follow-up, 118 of 254 operative sides were successes after the primary operation alone. At the last follow-up, 163 of 254 sides were successful, including success after the secondary operation. Overall, the primary and secondary success rates were 46.5% and 64.2%, respectively (Fig 2). Of 163 operative sides with primary or secondary success, the 10-point scale defined 148 (91.4%) and work status defined 14 (8.6%). Forty (24.5%) patients had fewer analgesics after surgery than before surgery.

Of the 136 primary failures, 111 failed ≤12 months of treatment (81.6%) and 122 (89.7%) had failed after 18 months (Fig 3). This characteristic pattern of deterioration is shown clearly in the life-table analysis (Fig 4 and Table I). After the 80 secondary operations, there were 35 secondary failures. They exhibited a similar but less pronounced time scale to the primary failure, with 20 sides (57.1%) failing within the first year and 23 failures (65.7%) in the first 18 months (Fig 3). The pattern of the overall secondary success is shown in Fig 4 and summarized in Table II, with gradual deterioration until 48 months and an essentially flat line thereafter.

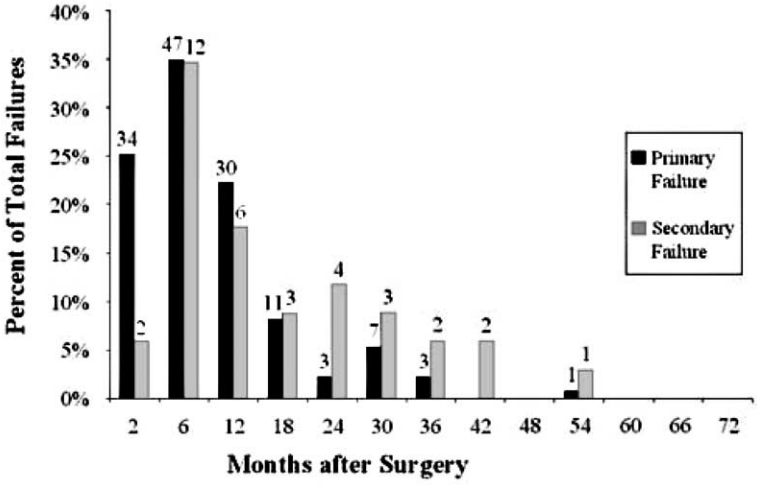
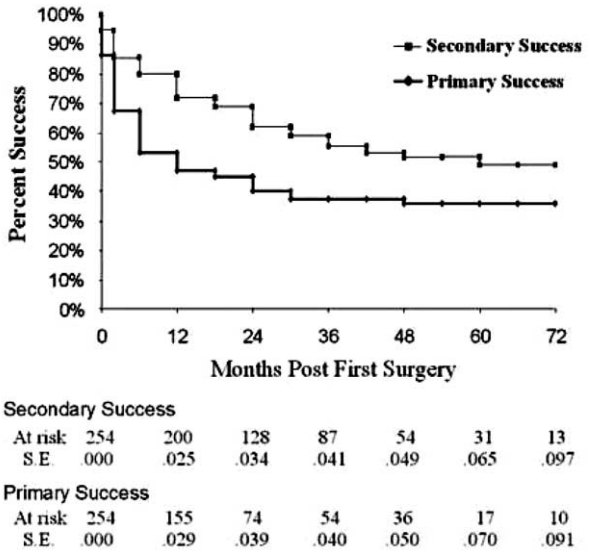


Fig 3. Percentage of the primary and secondary failures in each time interval after their respective operation. Note that 82% of the primary failures occur ≤12 months, 90% ≤18 months, and 59% of the secondary failures occur ≤12 months, 65% ≤18 months.



Secondary Success							
At risk	254	200	128	87	54	31	13
S.E.	.000	.025	.034	.041	.049	.065	.097
Primary Success							
At risk	254	155	74	54	36	17	10
S.E.	.000	.029	.039	.040	.050	.070	.091

Fig 4. Life-table analysis of the primary and secondary success rates after operative decompression for neurogenic thoracic outlet syndrome.

In the 334 operations, 13 complications (3.9%) occurred. Seven were pneumothoraxes in which six required chest tubes and an additional hospital day, and one patient required an additional surgery. Four of the remaining complications (three minor injuries to the subclavian vein, one minor injury to the long thoracic nerve) were relatively minor, having no sequelae In one instance the internal mammary artery was severed, resulting in 2,000 mL blood loss and a blood transfusion. The remaining complication was a suture granuloma that required an additional surgery. All complications were completely resolved and no fatalities occurred ≤30 days after the operations.

Three risk factors—workers' compensation, a duration of symptoms of ≥2 years, and at least one previous surgery—were used to divide 254 operative sides into three subgroups: patients with no risk factor (group A, n = 53), one or two risk factors (group B, n = 172), and all three risk factors (group C, n = 29). Stratified life-table analysis and log-rank test revealed that group B had significantly reduced primary success rates compared with group A ($P <$ .001) (Fig 5), and group C had significantly decreased secondary success rates compared with group A ($P = .01$) and group B ($P = .02$) (Fig 6). We had 116 patients with unilateral TOS (unilateral group) and 69 patients with bilateral TOS (138 operative sides). The outcomes were not significantly different between patients with unilateral and bilateral decompression operation. The primary success was 51.7% in the unilateral group and 41.3% in the bilateral group (χ^2, $P = .097$; log-rank test, $P > .5$). The secondary success was 65.5% in the unilateral group and 57.2% in the bilateral group (χ^2 test, $P = .18$; log-rank test, $P > .1$).

DISCUSSION

There are no standard criteria for evaluating the results of surgery for N-TOS. It is difficult to study the outcomes objectively, and most postoperative results are reported with a subjective grading of success. Mackinnon[7] suggested that the gold standard of pain relief would be a self-report that used a visual analogue scale. Additionally, a good result from surgery generally means improvement, not total cure. Most patients with good results experience fewer, less intense, and less frequent symptoms, but it is rare to observe complete symptom relief.[8] Finally, functional outcome, as well as a symptomatic improvement, is an important parameter. The patient's ability to return to the same job can therefore provide a good index of operative success. For all these reasons, we defined success as ≥50% symp-

Table I. Primary success rates with life-table analysis in 254 operative sides

Event time (mon)	*No. at risk*	*Withdrawn (censored)*	*No. of events*	*Failure rate*	*Cumulative primary success rates*	*SE*
0	254	0	0	0.000	100.0%	0.00%
2	254	0	34	0.134	86.6%	1.99%
6	220	18	47	0.223	67.3%	2.59%
12	155	24	30	0.210	53.2%	2.92%
18	101	16	11	0.118	46.9%	3.40%
24	74	5	3	0.042	44.9%	3.88%
30	66	5	7	0.110	40.0%	3.81%
36	54	6	3	0.059	37.6%	4.04%
42	45	9	0	0.000	37.6%	4.43%
48	36	8	0	0.000	37.6%	4.95%
54	28	10	1	0.043	36.0%	5.44%
60	17	2	0	0.000	36.0%	6.98%
66	15	5	0	0.000	36.0%	7.44%
72	10	3	0	0.000	36.0%	9.11%
73-76	7	7	0	0.000	36.0%	10.88%

Table II. Secondary success rates with life-table analysis in 254 operative sides

Event time (mon)	*No. at risk*	*Withdrawn (censored)*	*No. of events*	*Failure rate*	*Cumulative secondary success rates*	*SE*
0	254	0	0	0.000	100.0%	0.00%
2	254	0	13	0.051	94.9%	1.35%
6	241	18	23	0.099	85.5%	2.10%
12	200	24	12	0.064	80.0%	2.53%
18	164	20	16	0.104	71.7%	2.98%
24	128	16	5	0.042	68.7%	3.40%
30	107	10	10	0.098	62.0%	3.69%
36	87	13	4	0.050	58.9%	4.05%
42	70	11	4	0.062	55.2%	4.42%
48	55	10	2	0.040	53.0%	4.90%
54	43	11	1	0.027	51.6%	5.48%
60	31	4	0	0.000	51.6%	6.45%
66	27	13	1	0.049	49.1%	6.74%
72	13	3	0	0.000	49.1%	9.72%
73-76	10	10	0	0.000	49.1%	11.08%

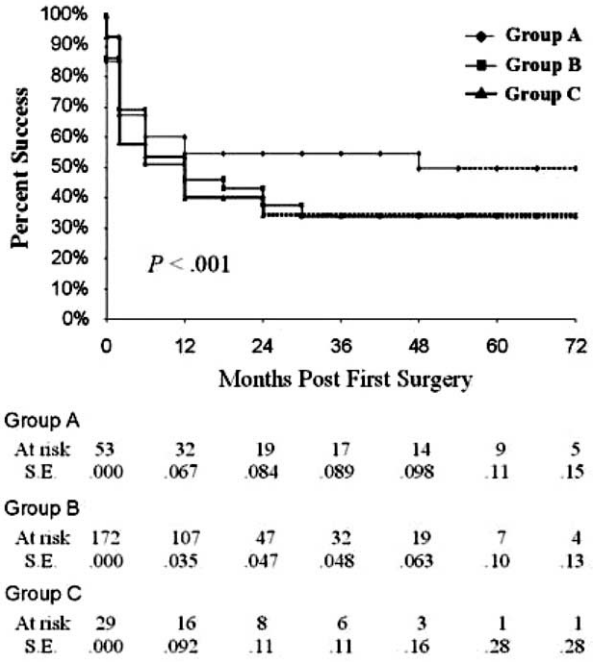
tomatic improvement on the ipsilateral side of operation using a 10-point scale or the patient returning to preoperational work status without the need for an additional ipsilateral procedure, or both.

The long-term results of N-TOS decompression surgery are still not clear; furthermore, few papers have reported how the success rates deteriorate after the surgery.[9-11] We thus evaluated the deteriorating curve by using life-table analysis and the failure rate in each time interval.

The initial success at 2 months in the current study was 87% for primary procedures. However, life-table analysis revealed that it decreased rapidly to 53% at 12 months, 45% at 24 months, and 38% at 36 months. The secondary success deteriorated less rapidly from the initial success of 95% at 2 months to 80% at 12 months, 69% at 24 months, 59% at 36 months, and 49% at 72 months. Of the 136 primary failures, 82% failed ≤12 months and 90% had failed ≤18 months.

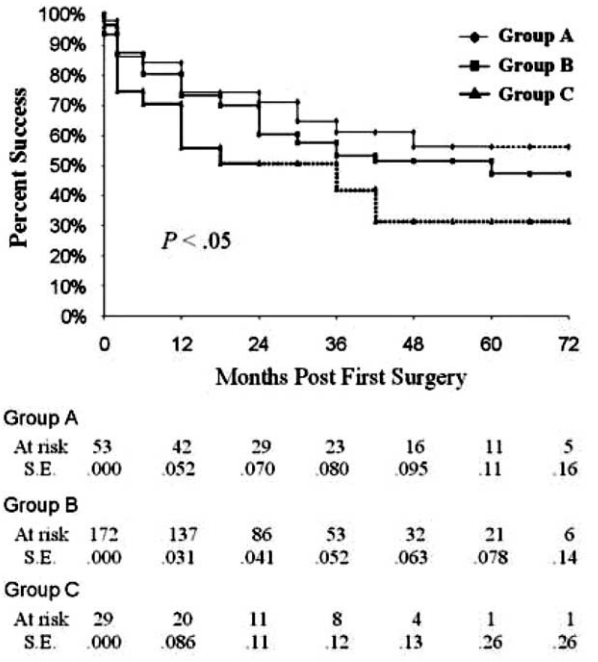
Our results with the transaxillary approach were similar to reported results in the literature. Improvement of N-TOS symptoms may be noticed shortly after surgery, sometimes immediately. The initial higher percentage of improvements generally deteriorated ≤2 years.[1,12] Compared with other approaches, the long-term results of transaxillary first rib resection were about the same compared with anterior and middle scalenectomy and supraclavicular first rib resection with scalenectomy.[9] Overall, the initial success rate of 91% to 93% at 3 months dropped to 76% to 79% at 1 to 2 years, followed by a slight fall of 69% to 72% at 5 to 10 years.[9] Similar to our results, most (81%) recurrences occurred ≤2 years of the initial operation. In evaluating these results, length of follow-up is one of crucial factors because recurrent N-TOS usually occurs ≤18 months after an initial success. Thus, reports with short-term follow-up may mask the overall success rate of the procedures performed.

Suboptimal initial surgery should be considered in patients with initial clinical success followed by recurrent symptoms. It has been reported that the presence of a long posterior first rib stump might contribute to recurrence.[10-12] Its role may be to act as a fixed, rigid anchoring



Group A							
At risk	53	32	19	17	14	9	5
S.E.	.000	.067	.084	.089	.098	.11	.15
Group B							
At risk	172	107	47	32	19	7	4
S.E.	.000	.035	.047	.048	.063	.10	.13
Group C							
At risk	29	16	8	6	3	1	1
S.E.	.000	.092	.11	.11	.16	.28	.28

Fig 5. Life-table analysis of the primary success rates of group A, group B, and group C after operative decompression for neurogenic thoracic outlet syndrome. There was a significant difference between group A and group B (log-rank test, $P < .001$). *Dashed line*, Portion of plot where standard error is >10%.



Group A							
At risk	53	42	29	23	16	11	5
S.E.	.000	.052	.070	.080	.095	.11	.16
Group B							
At risk	172	137	86	53	32	21	6
S.E.	.000	.031	.041	.052	.063	.078	.14
Group C							
At risk	29	20	11	8	4	1	1
S.E.	.000	.086	.11	.12	.13	.26	.26

Fig 6. Life-table analysis of the secondary success rates of group A, B, and C after operative decompression for neurogenic thoracic outlet syndrome. There was a significant difference between group A and group C (log-rank test, $P = .01$), and group B and group C (log-rank test, $P = .02$). *Dashed line*, Portion of plot where standard error >10%.

point to which scar tissue can attach rather than the primary factor.[10] In the current study, no patients revealed technical failure of the initial surgery because the posterior stump of the resected rib was uniformly <1 cm. All recurrent patients were therefore considered spontaneous recurrences. The precise cause of a spontaneous recurrence is unknown. However, one of the main causes of recurrence may be scar tissue formation around the brachial plexus and subclavian vessels, which follows nerve decompression operations anywhere in the body during the normal physiologic healing process.[10,13,14] This scar tissue contracts in such a way as to reproduce symptoms that are similar to preoperative symptoms. The supraclavicular approach allows complete scalenectomy and thorough removal of perineural scar around the brachial plexus.[14] Scar tissue forms regardless of which operation is performed, however.

The group of patients in whom scarring alone was considered the primary cause of recurrence may represent those who had an inherent predilection for excessive scar formation in the postoperative period. Some reports suggest that this group of patients fared worse than the group in whom residual anomalies were identified and removed[14] or whose recurrence was elicited by an injury.[10] In the former group, prevention would be more important. To minimize the effect of scar tissue and give early mobility to the brachial plexus and subclavian vessels, patients should be instructed to perform active range-of-motion exercises beginning the day after surgery and continue physical therapy indefinitely. These exercises may minimize the harmful effects of the scar formation on the neurovascular structures by stretching the scar tissue and promoting very early gliding of the brachial plexus and the subclavian artery and vein.[15]

In the current series, the primary and secondary success rates were 47% and 64%, respectively. These rates are lower than reported success rates, although one report agreed with our results.[16] Most of previous documentations regarding decompression surgery for N-TOS were reported with better results of 65% to 81% (Table III).[1,2,9,11,16-20]

Several caveats must be considered before these data can be interpreted further, however. In some reports, only secondary success rates were reported,[1,11] a small number of procedures were performed,[2,16,18-20] or "fair," as well as "good" and "excellent," were defined as success.[9,20] Our lower results might reflect a strict definition of clinical success.

In the present study, 56 of the 136 primary failed patients did not undergo the secondary surgery because ≥50% were satisfied by the improvement of their symptoms even though their evaluation was <50% on a 10-point scale. Less than 10% of the patients rejected the second surgery. If we change our criteria of success to "satisfied" or "good enough" as previously reported,[2] the primary and secondary success rates would increase significantly. The standardized uniform criteria would be clinically important

Table III. Results of operative decompression for neurogenic thoracic outlet syndrome

Authors	*Year*	*No. of procedures*	*Primary surgery*	*Mean follow-up duration (mon)*	*Definition of success*	*Success rate*
Sanders et al.[9]	1989	668	Transaxillary, scalenectomy, or combined	N/A	Improvement in some symptoms, but persistence of major ones (excellent, good, and fair)	70-73% (at 3-5 yr) 69-72% (at 5-10 yr)
Green et al.[1]	1991	136	Transaxillary	60	Would undergo surgery again	79%
Mingoli et al.[11]	1995	134	Transaxillary	99	Mild residual symptoms with return to employment	81%
Lindgren et al.[16]	1995	48	Transaxillary	96	Asymptomatic	43%
Leffert et al.[17]	1999	282	Transaxillary	55	Improvement requiring no analgesics	69%
Axelrod et al.[2]	2001	87	Supraclavicular	47	Symptoms improved, satisfied	64%
Fulford et al.[18]	2001	83	Transaxillary	48	Partially better	74%
Sharp et al.[19]	2001	27	Transaxillary	48	Relief of most major symptoms	66%
Bhattacharya et al.[20]	2003	60	Supraclavicular or transaxillary	43	Relief of some symptoms, but persistence of other symptoms (excellent, good, and fair)	90%
Present series	2005	254	Transaxillary	26	50% of improvement	46% (primary) 64% (secondary)

because it might evaluate more accurately and appropriately the effect and postoperative course of decompression surgery for N-TOS.

Our results might also reflect the characteristic factors of our patient population:

- about 50% of the patients were workers' compensation,
- the average duration of symptoms before surgery was about 3 years, and many of patients might have had chronic pain syndrome, and
- about one third had previous surgeries on the neck, shoulder, elbow, or wrist.

These factors probably have had a negative impact on the outcome as previously reported.[1,21-23]

In their study of the Washington State Workers' Compensation system, Franklin et al[21] reported that 60% of workers were still work-disabled 1 year after TOS decompression surgery. Other reports also have supported that worse outcomes occur among patients with workers' compensation compared with those without workers' compensation.[1,22,23]

In Franklin's series,[21] the significant predictors of remaining disabled were longer time between injury and TOS diagnosis, number of days on disability before surgery, and older age at injury. Green et al[1] reported that preoperative neurologic or musculoskeletal deficits had adverse affects on patients satisfaction.

We found a significantly worse rate of success in our study after the surgery in the subgroup defined as with workers' compensation, had a duration of symptoms for $\geq$2 years, and $\geq$1 previous surgery. Finally, postoperative physical therapy is an important method to decrease painful symptoms. Most investigators who have written on postoperative therapy for TOS agree that therapy has an equally important role after surgery in achieving successful outcomes.[24] However, patients in the current series did not undergo routine physical therapy postoperatively primarily because of insurance reasons.

In conclusion, with the use of transaxillary first rib resection and partial scalenectomy followed by supraclavicular scalenectomy for N-TOS and a 10-point scale postoperative evaluation, the initial surgical results were satisfactory and the secondary procedure improved the long-term outcome. Our results also indicate that clinical success deteriorates over time. A standardized definition of the outcomes is necessary to determine the effectiveness and results of this treatment. Most primary and secondary failures occurred $\leq$12 months after operation. To monitor recovery effectively, we recommend at $\geq$18 months of clinical follow-up after operative decompression for N-TOS.

REFERENCES

1. Green RM, McNamara J, Ouriel K. Long-term follow-up after thoracic outlet decompression: an analysis of factors determining outcome. J Vasc Surg 1991;14:739-46.

2. Axelrod DA, Proctor MC, Geisser ME, Roth RS, Greenfield LJ. Outcomes after surgery for thoracic outlet syndrome. J Vasc Surg 2001;33: 1220-5.
3. Machleder HI, Moll F, Nuwer M, Jordan S. Somatosensory evoked potentials in the assessment of thoracic outlet compression syndrome. J Vasc Surg 1987;6:177-84.
4. Collins JD, Shaver ML, Disher AC, Miller TQ. Compromising abnormalities of the brachial plexus as displayed by magnetic resonance imaging. Clin Anat 1995;8:1-16.
5. Jordan SE, Machleder HI. Diagnosis of thoracic outlet syndrome using electrophysiologically guided anterior scalene blocks. Ann Vasc Surg 1998:12:260-4.
6. Jordan S, Machleder HI. Electrodiagnostic evaluation of patients with painful syndromes affecting the upper extremity. In: Machleder HI, editor. Vascular disorders of the upper extremity. 3rd ed. Armonk, NY: Futura Publishing Co.; 1998. p. 137-53.
7. Mackinnon SE. Thoracic outlet syndrome. Ann Thorac Surg 1994;58: 287.
8. Sanders RJ, Cooper MA, Hammond SL, Weinstein ES. Neurogenic thoracic outlet syndrome. In: Rutherford RB, editor. Vascular surgery. 5th ed. Philadelphia: WB Saunders; 2000. p. 1184-200.
9. Sanders RJ, Pearce WH. The treatment of thoracic outlet syndrome: a comparison of different operations. J Vasc Surg 1989;10:626-34.
10. Sanders RJ, Haug CE, Pearce WH. Recurrent thoracic outlet syndrome. J Vasc Surg 1990;12:390-400.
11. Mingoli A, Feldhaus RJ, Farina C, Cavallari N, Sapienza P, di Marzo L, et al. Long-term outcome after transaxillary approach for thoracic outlet syndrome. Surgery 1995;118:840-4.
12. Urschel HC Jr, Razzuk MA. Neurovascular compression in the thoracic outlet: changing management over 50 years. Ann Surg 1998;228:609-17.
13. Atasoy E. Thoracic outlet compression syndrome. Orthop Clin North Am 1996;27:265-303.
14. Cheng SWK, Stoney RJ. Supraclavicular reoperation for neurogenic thoracic outlet syndrome. J Vasc Surg 1994;19:565-72.
15. Atasoy E. Recurrent thoracic outlet syndrome. Hand Clin 2004;20:99-105.
16. Lindgren KA, Oksala I. Long-term outcome of surgery for thoracic outlet syndrome. Am J Surg 1995;169:358-60.
17. Leffert RD, Perlmutter GS. Thoracic outlet syndrome. Results of 282 transaxillary first rib resections. Clin Orthop 1999;368:66-79.
18. Fulford PE, Baguneid MS, Ibrahim MR, Schady W, Walker MG. Outcome of transaxillary rib resection for thoracic outlet syndrome-a 10 year experience. Cardiovasc Surg 2001;9:620-4.
19. Sharp WJ, Nowak LR, Zamani T, Kresowik TF, Hoballah JJ, Ballinger BA, et al. Long-term follow-up and patient satisfaction after surgery for thoracic outlet syndrome. Ann Vasc Surg 2001;15:32-6.
20. Bhattacharya V, Hansrani M, Wyatt MG, Lambert D, Jones NA. Outcome following surgery for thoracic outlet syndrome. Eur J Vasc Endovasc Surg 2003;26:170-5.
21. Franklin GM, Fulton-Kehoe D, Bradley C, Smith-Weller T. Outcome of surgery for thoracic outlet syndrome in Washington state workers' compensation. Neurology 2000;54:1252-7.
22. Sanders RJ. Results of the surgical treatment for thoracic outlet syndrome. Semin Thorac Cardiovasc Surg 1996;8:221-8.
23. Lepantalo M, Lindgren KA, Leino E, Lindfors O, von Smitten K, Nuutinen E, et al. Long term outcome after resection of the first rib for thoracic outlet syndrome. Br J Surg 1989;76:1255-6.
24. Wishchuk JR, Dougherty CR. Therapy after thoracic outlet release. Hand Clin 2004;20:87-90.

Submitted Nov 18, 2004; accepted Mar 9, 2005.