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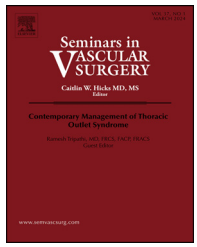

Review article

Systematic review of intermediate and long-term results of thoracic outlet decompression

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ABSTRACT

Thoracic outlet syndrome (TOS) consists of a group of disorders resulting from compression of the neurovascular bundle exiting through the thoracic outlet. TOS can be classified as follows based on the etiology of the pathophysiology: neurogenic TOS, venous TOS, arterial TOS, and mixed TOS. The constellation of symptoms a patient may experience varies, depending on the structures involved. Due to the wide range of etiologies and presenting symptoms, treatments for TOS also differ. Furthermore, most studies focus on the perioperative and short-term outcomes after surgical decompression for TOS. This systematic review aimed to provide a pooled analysis of studies to better understand the intermediate and long-term outcomes of surgical decompression for TOS. We conducted a systematic literature search in the Ovid MEDLINE, Embase, and Google Scholar databases for studies that analyzed long-term outcomes after surgical decompression for TOS. The inclusion period was from January 2015 to May 2023. The primary outcome was postoperative QuickDASH Outcome Measure scores. A total of 16 studies were included in the final analysis. The differences between postoperative and preoperative QuickDASH Outcome Measure scores were calculated, when possible, and there was a mean overall difference of 33.5 points (95% CI, 25.2–41.8; $P = .001$) after surgical decompression. There was a higher proportion of excellent outcomes reported for patients undergoing intervention for arterial and mixed TOS etiologies, whereas those with venous and neurogenic etiologies had the lowest proportion of excellent outcomes reported. Patients with neurogenic TOS had the highest proportion of poor outcomes reported. In conclusion, surgical decompression for TOS has favorable long-term outcomes, especially in patients with arterial and mixed etiologies.

1. Introduction

Thoracic outlet syndrome (TOS) constitutes a group of disorders resulting from compression of the neurovascular bundle exiting through the thoracic outlet. The vessels from the chest and the nerves from the spinal column pass between the scalene muscles above the rim of the superior thoracic aperture. They then go on to pass through the triangle formed by the first rib, clavicle, and scapula and run underneath the coracoid process to the brachium. Along this route, there are three spaces within the thoracic outlet that can cause compression of the neurovascular structures, which include the scalene triangle, costoclavicular space, and subcoracoid space [1].

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TOS can be classified as follows based on the etiology of the pathophysiology: neurogenic (nTOS), venous (vTOS), arterial (aTOS), and mixed TOS (mTOS). These can be further subdivided on the basis of congenital, traumatic, or functionally acquired cause. The constellation of symptoms a patient may experience varies, depending on the structures involved. Most commonly, these symptoms include paresthesia, pain, weakness, muscle atrophy, pallor, or swelling [2].

The diagnosis of TOS requires a thorough physical examination in addition to other adjuncts. The physical examination should focus on the upper extremity and cervical spine, while making comparisons between the affected and unaffected extremities. There are certain characteristic findings, depending on the etiology of TOS [3]. For example, aTOS can have large differences in blood pressure readings, and vTOS can present with edema, discoloration, and chest wall varicosities (if chronic). nTOS, when severe, can present with muscular atrophy of the hand and forearm. Duplex, computed tomography, and magnetic resonance imaging can assist with the diagnosis of aTOS and vTOS, which may reveal arterial or venous stenosis or thrombus. Diagnostic angiography can also be helpful with the use of intraoperative provocative maneuvers. Nerve conduction and electromyography studies are indicated for patients suspected of having nTOS. Although most patients will have normal or negative results, electrophysiological evaluation can help rule out cervical radiculopathy and myopathies [2].

Due to the wide range of etiologies and presenting symptoms, treatments for TOS also differ. Management options for TOS can include lifestyle modifications, physical therapy, pain management, anticoagulation, and surgery. Surgical options can also differ, depending on the etiology of the TOS [2]. For example, the presence of a cervical rib will require removal, or arterial reconstruction may be needed in the setting of aTOS. Most of the literature published on surgical decompression for TOS focuses on perioperative and short-term outcomes. This systematic review aimed to provide a pooled analysis of studies to better understand the intermediate and long-term outcomes of surgical decompression for TOS.

2. Methods

Institutional Review Board approval was not required for this study because all of the data were publicly available online [4–6].

2.1. *Eligibility criteria, literature search, and study selection*

We conducted a systematic literature search in the Ovid MEDLINE, Embase, and Google Scholar databases for studies that had analyzed long-term outcomes after surgical decompression for TOS. The inclusion period for studies was from January 2015 to May 2023. Studies were excluded if they were not in English or if the follow-up period was less than 2 years. Studies starting in 2015 were selected because the application of robotic technology to thoracic outlet decompression was first described in 2012 by Gharagozloo et al [7], marking the most modern era of TOS treatment. Given that this study focused on intermediate and long-term outcomes of surgical decompression for TOS, studies starting in 2015 and later were included. The search terms used were *surgery*, *decompression*, *thoracic outlet syndrome*, and *long-term*. The searches were performed in June 2023. Two of the authors (M.K.K., M.A.T.) were independently involved in the screening of titles, abstracts, and full-text reports. A third author (A.D.) was available to resolve any disagreements. The comprehensive search strategy and detailed inclusion and exclusion criteria are described in the Supplementary Methods. The outcomes of interest for this study were QuickDASH Outcome Measure (qDASH) scores and symptom relief.

2.2. *Data extraction*

The collected variables included first author, year of study, study design, data source, number of patients, number of cases, age, type of TOS, presence of cervical ribs, surgical approach, patency of intervention (if revascularization was performed), and functional outcomes (ie, qDASH score and symptom improvement). Studies were stratified on the basis of whether they focused on a TOS etiology (ie, neurogenic, venous, or arterial) or on multiple etiologies. Individual patients were stratified if they had neurogenic, venous, arterial, or mixed etiologies for their TOS. There was heterogeneity within studies regarding the reporting of symptom relief. Symptom relief was subsequently categorized as excellent, good, fair, or poor, on the basis of composite descriptions among the various studies, which are outlined in Supplementary Table 1. The baseline characteristics are reported as the mean ± SD. Egger's test of bias (precision regression plot) was used to assess publication bias.

3. Results

3.1. *Study characteristics*

We identified 230 studies through our search of Ovid MEDLINE (n = 67), EMBASE (n = 107), and Google Scholar (n = 56). Of these, 191 studies remained after duplicates had been removed. After title and abstract screening, 97 studies remained for full-text assessment. We included 16 studies in our final analysis (Fig. 1). A summary of the included studies stratified according to the type of study is provided in Table 1 [8–23]. There are 4 studies that contained neurological data only, 3 studies that contained venous data only, 1 study that contained arterial data, and none that contain multisymptom cases only. The rest of the studies contained a mixture of etiologies, and demographic data that are reported on average for all of the etiologies cannot be separated for further study. Nonetheless, this resulted in a total of 649 venous cases, 113 arterial, 501 neurogenic, and 86 mixed TOS etiologies for further study. Pooled estimates for long-term follow-up revealed a mean of 54 months of follow-up among all of the studies. Among those with data regarding surgical approaches, the proportion of transaxillary, supraclavicular, infraclavicular, and paraclavicular for the various studies are described in Table 2. Although we had a limited number of studies, we

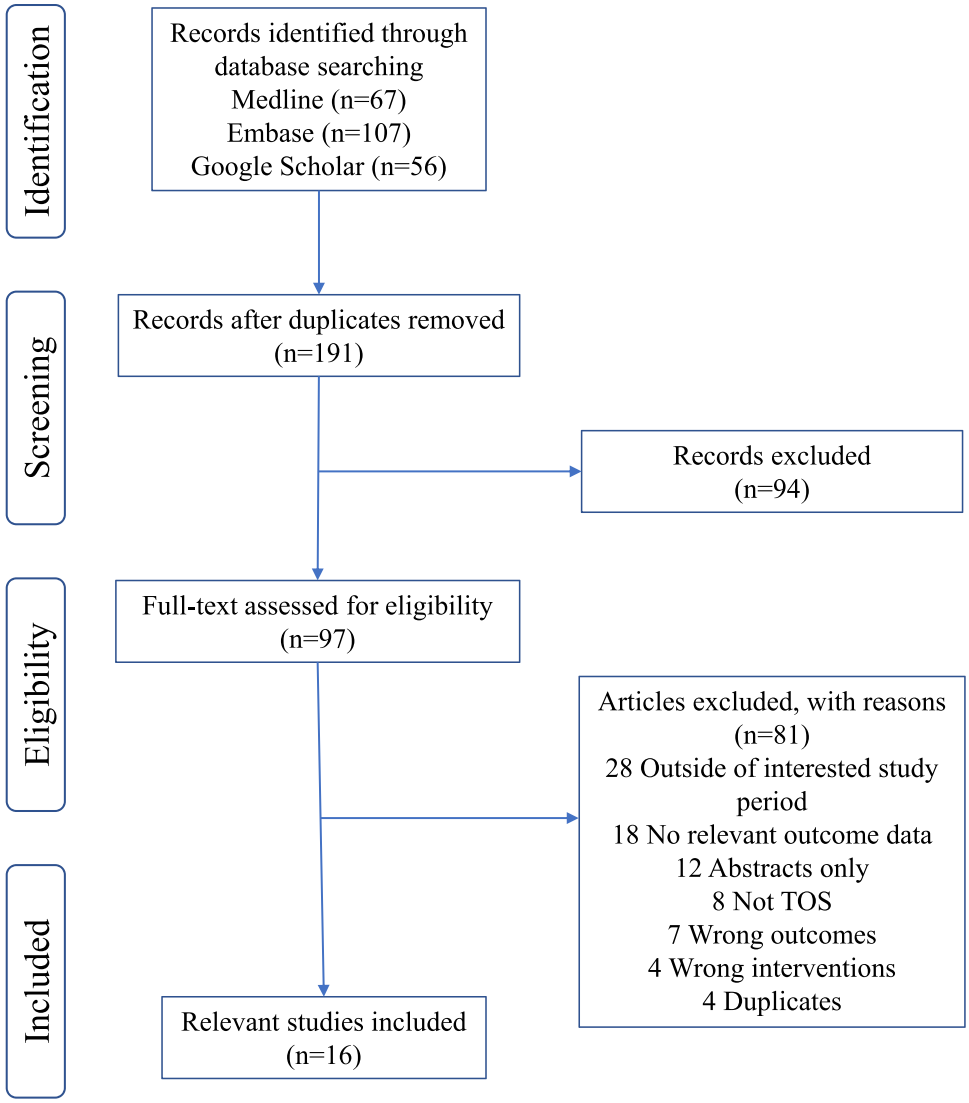

Fig. 1 – Flowchart summary of study retrieval and identification for systematic review. TOS, thoracic outlet syndrome.

performed Egger's test of bias on the primary treatment effect (postoperative qDASH score) and found a statistically significant intercept of –5.4141 (Supplementary Fig. 1), indicating that publication bias exists.

3.2. *Long-term qDASH score*

The qDASH score was recorded for some studies before the intervention and for others after the intervention. Occasionally, ranges of scores were provided and, in a few instances, the actual SD was provided, which allowed for the computation of intervals. Preoperative qDASH scores for mixed, venous, arterial, and neurogenic cases, respectively, were calculated as 45.5, 31.53, 42.6, and 62.0 with no differences among the groups (Table 2). The mean postoperative qDASH among the studies was 19.0. Postoperative qDASH scores were similar for arterial, neurological, and mixed etiologies (Table 2). We then calculated the difference in pre- and postoperative qDASH score when it was available. The mean postoperative qDASH scores were significantly lower than the preoperative qDASH scores among all of the groups ($P < .001$). The differences between postoperative and preoperative qDASH scores were calculated, when possible, and there was a mean overall difference of 33.5 points (95% CI, 25.2–41.8; $P = .001$) after surgical decompression. Data dispersion of postoperative qDASH scores is displayed in Fig. 2.

3.3. *Survey responses to symptom relief and functional outcomes*

On the basis of the responses of patients to surveys that were conducted, we categorized them as having an excellent, good, fair, or poor response to an intervention (Supplementary Table 1). We then sought to determine whether the proportion of respondents were different among the different types of TOS, as well as the different categories of response. There was a

Table 1 – Summary of the included cases.

First author	Title	Year	Thoracic outlet syndrome etiology, n			
			Venous	Arterial	Neurogenic	Mixed
Bogilone [8]	Surgical treatment of thoracic outlet syndrome in pediatrics	2022	2	3	4	0
Bozzay [9]	Infraclavicular thoracic outlet decompression compared to supraclavicular thoracic outlet decompression for the management of venous thoracic outlet syndrome	2020	30	0	0	0
Dadashzadeh [10]	Venographic classification and long-term surgical treatment outcomes for axillary-subclavian vein thrombosis due to venous thoracic outlet syndrome (Paget-Schroetter syndrome)	2023	246	0	0	20
Dua [11]	Long-term quality of life comparison between supraclavicular and infraclavicular rib resection in patients with vTOS	2020	109	0	0	0
Dua [12]	Long-term functional outcomes follow-up after 188 rib resections in patients with TOS	2020	82	4	102	0
Hoexum [13]	Long-term outcomes of nonoperative and surgical management of Paget-Schroetter syndrome	2022	92	0	0	0
Hong [14]	Long-term outcomes after surgical treatment of pediatric neurogenic thoracic outlet syndrome	2018	0	0	14	0
Jammeh [15]	Anatomically complete supraclavicular reoperation for recurrent neurogenic thoracic outlet syndrome: clinical characteristics, operative findings, and long-term outcomes	2022	0	0	90	0
Morel [16]	Functional results of cervical rib resection for thoracic outlet syndrome: impact on professional activity	2019	1	12	14	7
Moridzadeh [17]	A novel technique for transaxillary resection of fully fored cervical ribs with long-term clinical outcomes	2021	2	12	25	0
Nuutinen [18]	Long-term outcomes of transaxillary versus video-assisted first rib resection for neurogenic thoracic outlet syndrome	2022	0	0	60	0
Pantoja [19]	The evolving role of endovascular therapy in the management of arterial thoracic outlet syndrome	2022	0	50	0	0
Peek [20]	Long-term functional outcome of surgical treatment for thoracic outlet syndrome	2018	7	13	36	6
Ransom [21]	Intermediate and long-term outcomes following surgical decompression of neurogenic thoracic outlet syndrome in an adolescent patient population	2022	0	0	54	0
Al Rstum [22]	Differences in quality of life outcomes after paraclavicular decompression for thoracic outlet syndrome	2020	46	8	42	4
Stilo [23]	Thirty-year experience of transaxillary resection of first rib for thoracic outlet syndrome	2020	32	11	60	49

higher proportion of excellent outcomes reported for patients undergoing intervention for arterial and mixed TOS etiologies; whereas, those with venous and neurogenic etiologies had the lowest proportion of excellent outcomes reported (Table 3). Patients with nTOS had the highest proportion of poor outcomes reported (Table 3).

4. Discussion

Our systematic review and meta-analysis of 16 studies found that surgical decompression for TOS results in a qDASH score of approximately 19, with patients undergoing decompression for vTOS having better qDASH scores than those with arterial, neurogenic, or mixed etiologies. Patients undergoing surgical decompression for arterial and mixed TOS etiologies had better long-term functional outcomes and symptom relief; whereas those with nTOS did not experience the same long-term benefit.

Indications for surgical decompression for TOS differ on the basis of the etiology. However, nTOS is one of the most controversial entities in vascular surgery, due to the amount of disagreement regarding its etiology, diagnostic criteria, and therapeutic options [24,25]. Nonetheless, most clinicians believe that patients with nTOS should undergo rehabilitation and pharmacologic therapies for at least 4 to 6 months before

Table 2 – Demographic characteristics of patients and characteristics of the studies involved.

Characteristic	Thoracic outlet syndrome etiology				*P* value
	Mixed	Venous	Arterial	Neurogenic	
No. of studies	8	3	1	4	NA
No. of patients	690	466	48	203	0.32
Age, y, mean/median[a]	30.35	31.53	39.1	29.1	0.85
Length of follow-up, mo, mean	65.15	93.9	51.6	57.27	0.73
qDASH, mean score					
Pretreatment	45.5	31.53[a]	42.6	62.0	0.38
Post-treatment	16.67	3.05	12.6	20.8	0.14
Open surgical approach, no. of cases reported					
Transaxillary	161	91	50	30	NA
Supraclavicular	59	54	0	104	NA
Infraclavicular	59	54	0	104	NA
Paraclavicular	105	1	0	0	NA
Transthoracic (robotic)	0	0	0	30	NA
Surgical intervention, no. of cases reported					
Neurolysis	0	0	0	60	NA
Anterior scalenectomy	37	0	1	73	NA
Middle scalenectomy	0	0	0	55	NA
First rib excision	104	266	50	33	NA
Cervical rib	111	0	23	0	NA
Vein patch angioplasty	1	55	0	0	NA
Aneurysm resection	5	0	0	0	NA
Aneurysmorrhaphy	1	0	0	0	NA
Patch angioplasty	1	0	0	0	NA
Bypass	6	35	11	0	NA
Primary repair	0	0	2	0	NA
Venolysis	0	176	0	0	NA
Angioplasty	0	188	0	0	NA
Stent	24	1	8	0	NA
Lysis	80	92	0	0	NA

Abbreviations: NA, not applicable; qDASH, QuickDASH Outcome Measure.
[a] XXXXXX.

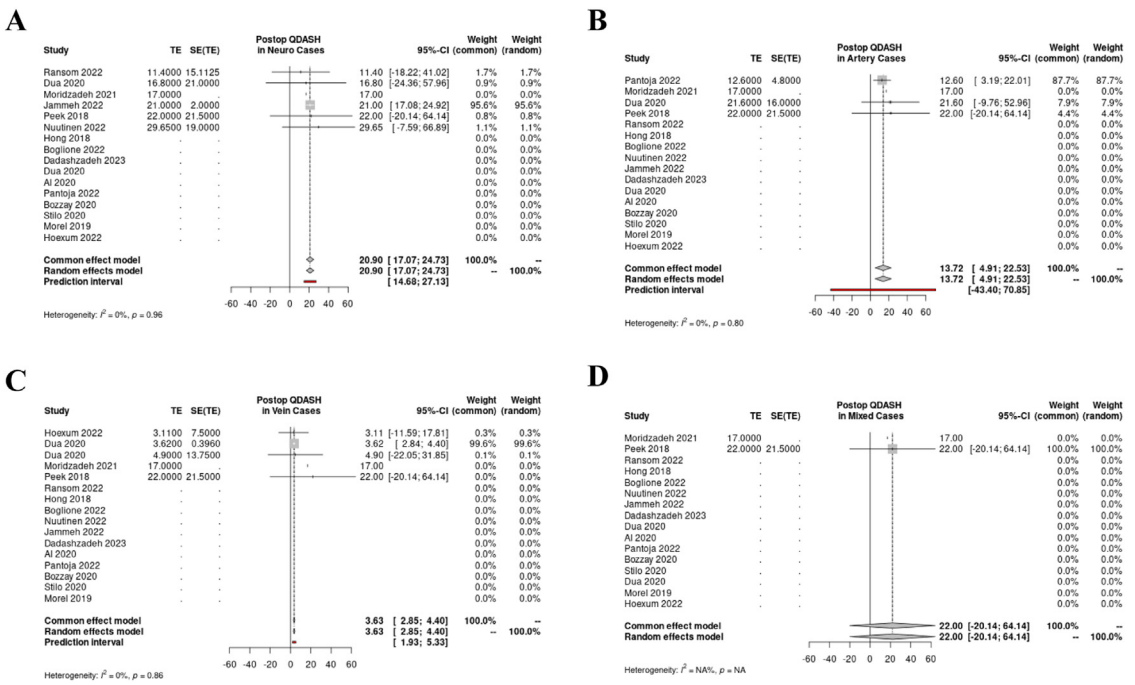

Fig. 2 – Data dispersion of postoperative QuickDASH Outcome Measure (QDASH) scores for (A) neurogenic, (B) arterial, (C) venous, and (D) mixed cases of thoracic outlet syndrome. TE, treatment effect.

Table 3 – Survey responses stratified by thoracic outlet syndrome etiology.

Etiology	Response	Proportion, %	95% CI, %
Neurogenic (n = 152)	Excellent	44.7	40.8–48.7
	Good	40.8	36.9–44.6
	Fair	7.3	6.2–8.3
	Poor	7.2	6.1–8.2
Venous (n = 47)	Excellent	44.7	37.6–51.7
	Good	31.9	25.7–38.1
	Fair	21.3	16.5–52.0
	Poor	2.1	1.5–2.7
Arterial (n = 113)	Excellent	85.0	82.6–87.3
	Good	9.7	8.1–11.4
	Fair	4.4	3.6–5.2
	Poor	0.9	0.7–1.0
Mixed (n = 165)	Excellent	84.2	82.2–86.3
	Good	15.2	13.2–17.1
	Fair	0.6	0.5–0.7
	Poor	0	0–0

surgical intervention. Rehabilitation includes physical therapy, patient education, and activity modification [26]. Pharmacologic therapies include analgesics (eg, nonsteroidal anti-inflammatory drugs and opioids), muscle relaxers, and/or antidepressants [2]. Other minimally invasive treatment strategies for nTOS include injections of anesthetic, steroids, or botulinum toxin type A into the anterior scalene and/or pectoralis muscle. Although the use of botulinum toxin A did not result in a significant clinical effect of improvement in pain, parasthesia, or function in patients with TOS [27], injection of local anesthetic into the anterior scalene muscle has been used to successfully diagnose and predict response to surgical decompression in nTOS [28].

If conservative measures fail, surgical decompression is usually offered to patients with nTOS. Goeteyn et al [29] conducted a randomized controlled trial for patients with nTOS to undergo surgery or continued conservative treatment [29]. They enrolled 25 patients in each arm and quantified the change in qDASH score at 3 months between the two groups. They found that patients undergoing surgical decompression had a significantly lower qDASH score compared with those who underwent conservative therapy (45.15 [95% CI, 38.08–52.21] *v* 64.92 [95% CI, 57.54–72.30]). All patients in the conservative treatment group eventually underwent surgery after 3 months. After the conservative treatment group underwent surgery, there were no differences between the two groups. However, the study has been criticized for the short period of conservative therapy. In addition, the study was conducted in a high-volume center that is very comfortable with the diagnosis and treatment of nTOS, which has been found to correlate with good outcomes [30]. There also appears to be a large difference between the postoperative qDASH score noted in the Goeteyn et al study (45.15) versus our study (19.7). Our study evaluated long-term outcomes, whereas Goeteyn et al evaluated short-term outcomes. It is possible that patients continue to experience symptom relief and improvements in their functional outcomes long after their surgical intervention. Nonetheless, although outcomes after surgical decompression for nTOS may not be as good as those for vTOS and aTOS; patients do experience a clear benefit after surgery and it should be considered in the treatment repertoire.

Unlike nTOS, patients with aTOS and vTOS are offered surgical decompression on diagnosis without a trial of conservative management because they are often refractory to conservative and thrombolytic therapies [31]. Surgical management of aTOS consists of two major principles: (1) relieve the compression and (2) assessment for and performing revascularization, if needed. First-rib resection and anterior scalenectomy are often performed for aTOS, but some argue that scalenectomy alone provides similar outcomes with less morbidity [32]. If the artery is compromised, this will require reconstruction via aneurysmorrhaphy or bypass grafting. First-line treatment for vTOS includes thrombolytic therapy, especially when patients present acutely with a deep vein thrombosis. However, surgical decompression is also indicated in these patients, and possibly venoplasty, depending on preoperative venography. In this review, patients with aTOS had good outcomes in regard to qDASH score and surveyed responses. However, we found a large discrepancy between long-term qDASH scores and surveyed responses in patients with vTOS. This may be explained by the fact that the qDASH score is dependent on the ability to conduct very specific activities that may not be impaired in patients with vTOS as readily as in those with nTOS and aTOS. Furthermore, residual stenosis of the subclavian-axillary vein is not uncommon after decompression due to fibrous strictures or thrombosis, which may lead to edema or varicosities that are not captured in the qDASH score [33]. Nonetheless, we found that patients with aTOS and vTOS had favorable intermediate and long-term results after surgical decompression.

4.1. *Limitations*

This review has many limitations to consider. The reported data from studies are from multiple sources and, therefore, there is potential that there was overlap across some studies. Although, we attempted to eliminate overlapping populations from the study to the best of our ability. In addition, the surveys across studies were heterogenous and we combined similar groups of responses together to provide a meaningful analysis. Therefore, the outcomes regarding survey responses in this study represent a general satisfaction with decompression surgery after TOS and one must account for this limitation when interpreting the results. Lastly, the number of modern studies available with long-term outcomes after surgical decompression for TOS is limited. Therefore, robust analyses are not able to be performed at this time.

5. Conclusions

Patients undergoing surgical decompression for aTOS and vTOS have favorable intermediate and long-term outcomes. Although patients with nTOS may not experience as favorable outcomes, patients still experience a clear benefit

after surgery and should be offered decompression when possible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1053/j.semvascsurg.2024.01.001.

CRediT authorship contribution statement

Mitri K. Khoury: Writing – review & editing, Data curation, Formal analysis, Validation. **Micah A. Thornton:** Data curation, Formal analysis, Methodology, Writing – review & editing. **Anahita Dua:** Conceptualization, Supervision, Validation, Writing – review & editing.

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