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Esmaeel Reza Dadashzadeh

J. Westley Ohman

Pavan K. Kavali

Karen M. Henderson

Danita M. Goestenkors

*See next page for additional authors*

## Authors

Esmaeel Reza Dadashzadeh, J. Westley Ohman, Pavan K. Kavali, Karen M. Henderson, Danita M. Goestenkors, and Robert W. Thompson

From the Midwestern Vascular Surgical Society



# Venographic classification and long-term surgical treatment outcomes for axillary-subclavian vein thrombosis due to venous thoracic outlet syndrome (Paget-Schroetter syndrome)

Esmaeel Reza Dadashzadeh, MD, MS,[a] J. Westley Ohman, MD,[a] Pavan K. Kavali, MD,[b] Karen M. Henderson, RN,[a] Danita M. Goestenkors, RMA,[a] *and* Robert W. Thompson, MD,[a,b] *St. Louis, MO*

## ABSTRACT

**Objective:** We assessed the clinical presentation, operative findings, and surgical treatment outcomes for axillary-subclavian vein (AxSCV) thrombosis due to venous thoracic outlet syndrome (VTOS).

**Methods:** We performed a retrospective, single-center review of 266 patients who had undergone primary surgical treatment of VTOS between 2016 and 2022. The clinical outcomes were compared between the patients in four treatment groups determined by intraoperative venography.

**Results:** Of the 266 patients, 132 were male and 134 were female. All patients had a history of spontaneous arm swelling and idiopathic AxSCV thrombosis, including 25 (9%) with proven pulmonary embolism, at a mean age of 32.1 ± 0.8 years (range, 12-66 years). The timing of clinical presentation was acute (<15 days) for 132 patients (50%), subacute (15-90 days) for 71 (27%), and chronic (>90 days) for 63 patients (24%). Venography with catheter-directed thrombolysis or thrombectomy (CDT) and/or balloon angioplasty had been performed in 188 patients (71%). The median interval between symptom onset and surgery was 78 days. After paraclavicular thoracic outlet decompression and external venolysis, intraoperative venography showed a widely patent AxSCV in 150 patients (56%). However, 26 (10%) had a long chronic AxSCV occlusion with axillary vein inflow insufficient for bypass reconstruction. Patch angioplasty was performed for focal AxSCV stenosis in 55 patients (21%) and bypass graft reconstruction for segmental AxSCV occlusion in 35 (13%). The patients who underwent external venolysis alone (patent or occluded AxSCV; n = 176) had a shorter mean operative time, shorter postoperative length of stay and fewer reoperations and late reinterventions compared with those who underwent AxSCV reconstruction (patch or bypass; n = 90), with no differences in the incidence of overall complications or 30-day readmissions. At a median clinical follow-up of 38.7 months, 246 patients (93%) had no arm swelling, and only 17 (6%) were receiving anticoagulation treatment; 95% of those with a patent AxSCV at the end of surgery were free of arm swelling vs 69% of those with a long chronic AxSCV occlusion ($P < .001$). The patients who had undergone CDT at the initial diagnosis were 32% less likely to need AxSCV reconstruction at surgery (30% vs 44%; $P = .034$) and 60% less likely to have arm swelling at follow-up (5% vs 13%; $P < .05$) vs those who had not undergone CDT.

**Conclusions:** Paraclavicular decompression, external venolysis, and selective AxSCV reconstruction determined by intraoperative venography findings can provide successful and durable treatment for >90% of all patients with VTOS. Further work is needed to achieve earlier recognition of AxSCV thrombosis, prompt usage of CDT, and even more effective surgical treatment. (J Vasc Surg 2023;77:879-89.)

**Keywords:** Catheter-directed thrombolysis; Deep vein thrombosis; Outcomes; Surgical treatment; Upper extremity; Paget-Schroetter syndrome

From the Center for Thoracic Outlet Syndrome, Section of Vascular Surgery, Department of Surgery[a]; and the Section of Vascular Interventional Radiology, Department of Radiology, Washington University School of Medicine.[b]

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Correspondence: Robert W. Thompson, MD, Center for Thoracic Outlet Syndrome, Section of Vascular Surgery, Department of Surgery, Washington University School of Medicine, Campus Box 8109, St. Louis, MO 63110 (e-mail: rwthompson@wustl.edu).

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Primary upper extremity deep vein thrombosis (DVT) is most frequently due to extrinsic compression of the axillary-subclavian vein (AxSCV) at the level of the first rib and costoclavicular space, also termed venous thoracic outlet syndrome (VTOS), which leads to the AxSCV "effort thrombosis" (or Paget-Schroetter) syndrome.[1-5] VTOS should be suspected with the presentation of any otherwise young healthy person with abrupt spontaneous arm swelling, with or without cyanotic discoloration, in the absence of a known central venous catheter, pacemaker, recent arm injury, malignancy, thromboembolic disorder, or history of DVT.[3-8] Prompt diagnosis of VTOS is important to direct initial anticoagulation therapy and early venography, which will permit the use of catheter-directed thrombolysis or thrombectomy (CDT) and/or balloon angioplasty as an intermediate step toward definitive surgical treatment.[7-14]

Surgical treatment of VTOS centers around first rib resection, which can be accomplished by various approaches, with each protocol having its own advantages and disadvantages.[3-5,9,14-27] The practice in our medical center has been to favor a single operative procedure using the paraclavicular approach (supraclavicular and infraclavicular incisions). Our previous studies have focused on the surgical technique and early postoperative results.[6,7,19] The purpose of the present study was to assess the clinical presentation, operative findings, and long-term treatment results for a large series of patients who had undergone surgical treatment of AxSCV thrombosis due to VTOS using the paraclavicular approach.

## ARTICLE HIGHLIGHTS

- **Type of Research:** A single-center, retrospective cohort study
- **Key Findings:** Of 266 patients with venous thoracic outlet syndrome treated by paraclavicular decompression, venography demonstrated a patent axillary-subclavian vein (AxSCV) in 150 (56%), a long chronic occlusion in 26 (10%), high-grade stenosis amenable to patch angioplasty in 55 (21%), and segmental occlusion amenable to bypass in 35 (13%) patients. At a median follow-up of 38.7 months, 246 (93%) had not experienced arm swelling, with poorer results for those with long chronic occlusions (69%).
- **Take Home Message:** Paraclavicular decompression and selective AxSCV reconstruction provided successful treatment for >90% of all patients with venous thoracic outlet syndrome. Patients with long chronic occlusions were more likely to have experienced arm swelling during long-term follow-up than were those with a patent AxSCV or bypass. Venographic intervention at the initial diagnosis was also associated with the less frequent need for AxSCV reconstruction and less frequent arm swelling.

## METHODS

The study population was derived from patients who had been referred to the Washington University Center for Thoracic Outlet Syndrome at Barnes-Jewish Hospital (St. Louis, MO) for evaluation and surgical treatment of AxSCV thrombosis and VTOS between January 1, 2016 and December 31, 2021. In accordance with the Society for Vascular Surgery reporting standards, patients with the neurogenic or arterial forms of TOS and patients with VTOS who had undergone reoperative procedures or surgery for threatened hemodialysis access were excluded from the present review.[28] Detailed information for each patient was obtained from a prospectively maintained database and summarized from the medical records. The human research protection office at Washington University (St. Louis, MO) approved the study protocol and the included patients provided written informed consent.

Data were collected regarding the initial symptoms and clinical presentation of each patient. The timing, findings, and results of diagnostic imaging, such as venography, and any intervention, were determined. The patient evaluation for surgical treatment included physical examination and a review of the most recent venography studies. Surgery was generally recommended within 4 to 6 weeks after CDT to allow time for resolution of acute perivenous inflammation and to minimize the risk of repeat thrombosis, as described previously.[29] No further hematologic testing was conducted, and oral anticoagulation therapy was continued up to 3 days before surgery, followed by subcutaneous heparin.

All the patients underwent standardized paraclavicular thoracic outlet decompression, including complete anterior and middle scalenectomy, mobilization of the brachial plexus nerve roots, subclavius muscle resection, and complete first rib resection.[6,7,29-31] Exposure through the infraclavicular incision was used to initiate circumferential external venolysis of the AxSCV, which was then continued through the supraclavicular incision to the junction of the subclavian vein (SCV) with the internal jugular and innominate veins. Postdecompression intraoperative venography was used to assess the AxSCV, with patients classified into one of four groups:

Group 1. A widely patent AxSCV after decompression and external venolysis alone, with rapid central venous flow and no collateral vein filling
Group 2. Long-segment chronic occlusion of the AxSCV with an upper basilic or axillary inflow vein unsuitable (<1.0 cm diameter) for bypass reconstruction
Group 3. A patent AxSCV with high-grade focal stenosis amenable to patch angioplasty

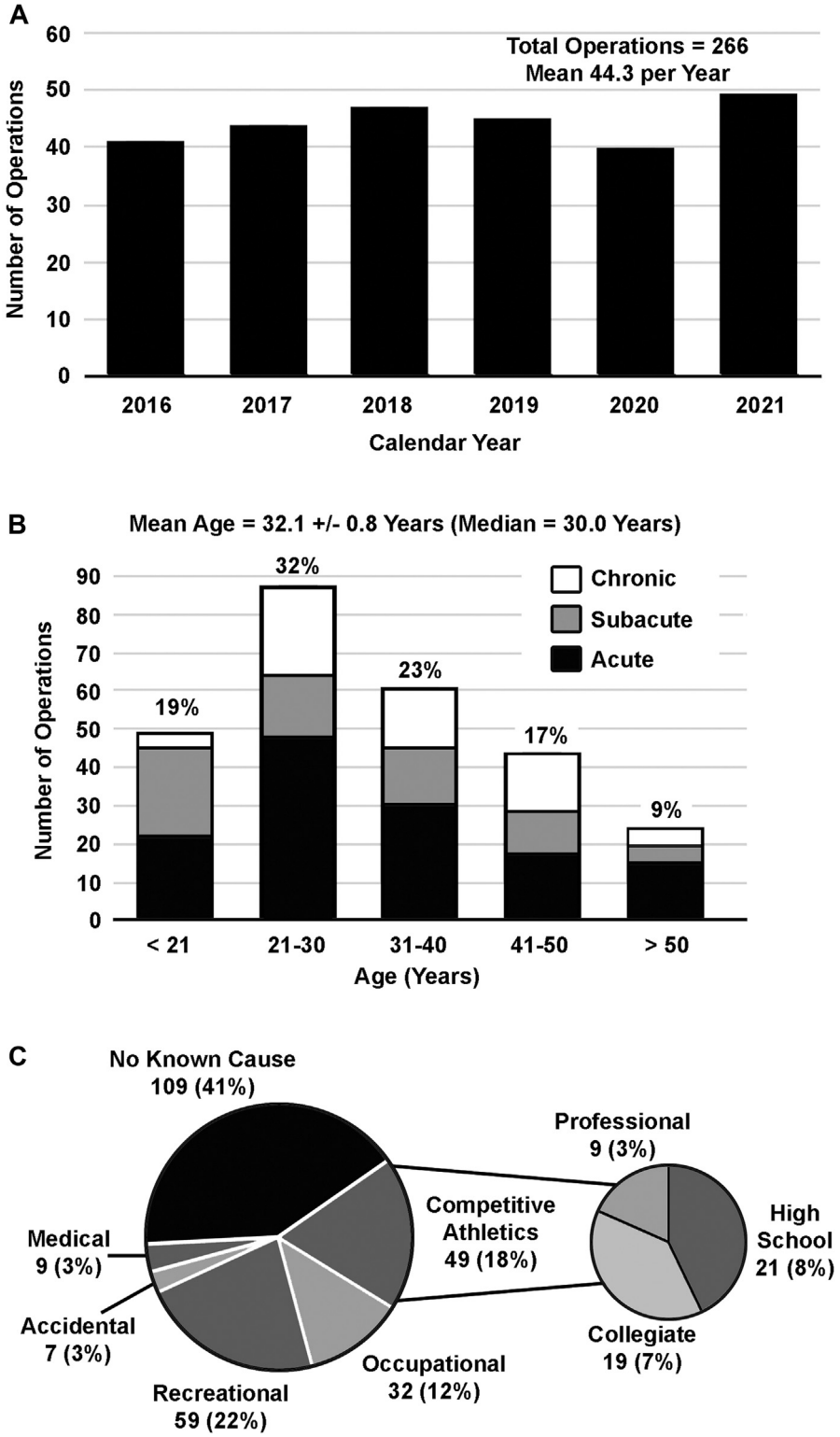


**Fig 1.** Operative volume and age distribution for patients with venous thoracic outlet syndrome (VTOS). **A,** Bar graph showing annual number of primary operations for VTOS from 2016 to 2021. **B,** Bar graph demonstrating age distribution of study population and timing of clinical presentation as either acute (venography or office visit within 14 days after symptom onset), subacute (venography or office visit 15-90 days after symptom onset), and chronic (venography or office visit >90 days after symptom onset). **C,** Pie chart showing number of patients and frequency and percentage of various causes to which axillary-subclavian vein (AxSCV) thrombosis could be attributed in patients who had undergone surgical treatment of VTOS. The secondary pie chart shows the proportion of competitive athletes participating at the high school, collegiate, and professional levels.

Group 4. Segmental chronic occlusion of the AxSCV with a suitable axillary inflow vein (>1.0-cm diameter) amenable to bypass graft reconstruction

For groups 1 and 2, no further venous interventions were performed. For group 3, direct AxSCV reconstruction was performed using patch angioplasty, with either bovine pericardium or a cryopreserved femoral vein. For group 4, axillary-innominate vein bypass was performed using cryopreserved femoral vein graft, with concomitant pectoralis minor tenotomy for occlusions extending into the distal axillary vein. During exposure of the subclavian jugular innominate vein junction for vein reconstruction in groups 3 and 4, no patient required division of the sternocleidomastoid muscle, partial resection of the clavicle, disruption of the sternoclavicular joint, or transmanubrial extension of the exposure.[6,7,29-31] Postoperative management was performed as described previously.[32]

The descriptive group data are presented as the mean ± standard error or frequencies and percent incidence. Comparisons between groups were performed using two-way analysis of variance for data with continuous variables or the $\chi^2$ test for categorical data. A life-table analysis was conducted using the log-rank test, with the presence or absence of arm swelling during long-term follow-up as the outcomes end point. Univariate analysis was performed using Pearson correlation tests, and multivariate analysis was performed by multiple logistic regression. All statistical tests were performed using Prism, version 9.4.1 (GraphPad Software Inc, San Diego, CA), with $P < .05$ considered significant.

## RESULTS

**Patient characteristics.** The study population consisted of 266 patients with AxSCV thrombosis who had undergone primary surgery for VTOS between January 1, 2016 and December 31, 2021 (Fig 1, *A*). Of the 266 patients, 132 were male and 134 were female, with a mean age of 32.1 ± 0.8 years (median, 30.0 years; range, 12-66 years; Table I). The age distribution of patients included 44 patients (19%) aged <21 years. The timing of the clinical presentation was characterized as acute (<15 days) for 132 patients (50%), subacute (15-90 days) for 71 patients (27%), and chronic (>90 days) for 63 patients (24%; Fig 1, *B*).

The frequency of documented pulmonary embolism was 9.4%, and 20 patients (7.5%) had concomitant symptoms of neurogenic TOS. The development of VTOS was associated with medical, accidental, occupational, or recreational injuries in 107 patients (40%), and 49 patients (18%) had been involved in various levels of competitive athletics (Fig 1, *C*).

**Initial management and referral.** Contrast venography had been performed for 243 patients (91%), with a median interval from symptoms to venography of 14 days (mean, 79 ± 14 days; Table I; Supplementary Table I, online only). A total of 188 patients (71%) had undergone CDT and/or balloon angioplasty, 55 (21%) had undergone no intervention, and only 1 patient (0.4%) had undergone placement of a subclavian vein stent. Patients with an acute clinical presentation had had a significantly higher frequency of CDT (94%) than those with subacute (68%) or chronic (25%) clinical presentations ($P < .001$ for all comparisons; Supplementary Fig, *A*, online only).

The median interval between the onset of arm swelling symptoms and the first TOS center referral visit was 42 days (mean, 183 ± 33 days), with 151 (57%) having an office visit within 60 days of symptom onset (Supplementary Table I, online only). The median interval from symptom onset to the office visit was significantly shorter for the patients who had undergone venography and CDT at the initial diagnosis (31 days vs 127 days; $P < .001$; Supplementary Fig, *B*, online only). All patients continued maintenance anticoagulation therapy, with restrictions on use of the affected arm after the diagnosis and any initial CDT.

**Operative findings and treatment groups.** Each patient underwent paraclavicular thoracic outlet decompression with complete resection of the first rib and circumferential external venolysis of the AxSCV. The findings at surgery included bony abnormalities in 127 (48%), such as osteophytic changes and occult first rib fractures, which were more prevalent with increasing age, as previously described (Supplementary Table II, online only).[33]

After decompression, external venolysis, and intraoperative venography, 150 patients (56%) had a widely patent AxSCV and required no further treatment (group 1), and 26 patients (10%) had a long chronic AxSCV occlusion and insufficient axillary vein inflow for bypass reconstruction (group 2). Group 3 included 55 patients (21%) with focal AxSCV stenosis for which patch angioplasty was performed, and group 4 included 35 patients (13%) with segmental AxSCV occlusion amenable to bypass graft reconstruction. No significant differences were found between age groups or in the timing of clinical presentation and the proportion of patients in each of the four treatment groups (Supplementary Table III, online only). The patients who had undergone prompt CDT at the initial diagnosis were 32% less likely to have required AxSCV reconstruction (patch angioplasty or bypass graft reconstruction) than were those who had not undergone initial CDT (30% vs 44%; $P = .034$; Supplementary Fig, *C*, online only).

**Perioperative care.** The overall mean operative time was 242 ± 5 minutes, with no intraoperative complications (Table II). The mean postoperative hospital length of stay was 5.1 ± 0.1 days; 13 patients (5%) required an early reoperation and 17 (6%) required early AxSCV reintervention. The overall rate of any complication was 11%,

**Table I.** Presenting characteristics and initial management

| Variable | No. (%) or mean ± SE |
|---|---|
| Patients | 266 (100) |
| Age, years | 32.1 ± 0.8 |
| Female gender | 134 (51) |
| White race | 246 (92) |
| Right side affected | 171 (65) |
| Bilateral VTOS symptoms | 7 (3) |
| Referral | |
| Local metropolitan area | 79 (30) |
| Regional (<200 miles) | 69 (26) |
| Distant (>200 miles) | 115 (43) |
| International | 3 (1) |
| Presentation | |
| Acute (venography or office visit <15 days) | 132 (50) |
| Subacute (venography or office visit <15-90 days) | 71 (27) |
| Chronic (venography or office visit >90 days) | 63 (24) |
| Proven pulmonary embolism | 25 (9.4) |
| Coexisting ipsilateral neurogenic symptoms | 20 (7.5) |
| Contrast venography | 243 (91) |
| Venography within 8 weeks of symptoms | 182 (68) |
| Interval from symptom onset to venography, days | |
| Median | 14 |
| Mean | 79 ± 14 |
| Thrombolysis/thrombectomy alone | 31 (12) |
| Balloon angioplasty alone | 29 (11) |
| Thrombolysis/thrombectomy and balloon angioplasty | 128 (48) |
| Contrast venography without intervention | 55 (21) |
| Stent placement | 1 (0.4) |

*SE*, Standard error; *VTOS*, venous thoracic outlet syndrome.

and the 30-day readmission rate was 3%. The patients who had undergone external venolysis alone (patent or occluded AxSCV; n = 176) had a shorter mean operative time and postoperative length of stay and a lower incidence of reoperation and late reintervention compared with those who had undergone AxSCV reconstruction (patch or bypass; n = 90). No differences were found in the incidence of overall complications or 30-day readmissions. Postoperative physical therapy was started at the 1-month office visit, with a gradual return to unrestricted activity. All the patients received direct-acting oral anticoagulant therapy for 3 months after surgery, which was discontinued in the absence of ongoing arm swelling or any need for reintervention.

**Clinical follow-up outcomes.** At a median clinical follow-up of 38.7 months (mean, 38.9 ± 1.3 months; range, 1.3-75.9 months), 246 patients (93%) had not experienced arm swelling and only 17 (6%) were receiving anticoagulation treatment. Also, 95% of those with a patent AxSCV at the end of surgery were free of arm swelling compared with 69% of those with a non-reconstructable AxSCV occlusion ($P < .0002$; Table III; Fig 2). The patients who had undergone AxSCV bypass maintained a significant reduction in arm swelling at follow-up compared with those with long chronic AxSCV occlusions (89% vs 69%; $P < .05$; Fig 2). Univariate correlation testing with 34 different clinical variables revealed 11 variables that were significantly associated with the occurrence of arm swelling (Fig 3). These included venographic intervention at the initial diagnosis, with those who had undergone CDT having a 60% lower incidence of arm swelling at follow-up compared with those who had not undergone CDT (5% vs 13%; $P < .05$, $\chi^2$ test). Multiple logistic regression revealed no specific factors that were significantly associated with the presence or absence of arm swelling at long-term follow-up, with a large number of collinear-associated variables.

## DISCUSSION

The management of upper extremity DVT associated with VTOS ranges widely, from long-term anticoagulation therapy alone (with or without CDT) to protocols involving early venography, CDT with or without balloon angioplasty, and prompt surgical treatment based on first rib resection.[3-6,9,14-27,29-33] In the present study, we examined the clinical presentation, operative findings, and long-term outcomes after surgical treatment for a large case series of patients with AxSCV thrombosis due to VTOS. The most important findings were as follows. First, paraclavicular decompression, external venolysis, and selective AxSCV reconstruction based on intraoperative venography can provide safe, successful, and durable treatment for >90% of all patients with VTOS, regardless of previous treatment or the timing of the clinical presentation. Second, patients with long chronic AxSCV occlusions were more likely to have arm swelling during long-term follow-up than were those in whom a patent AxSCV had been achieved at surgery, even if AxSCV bypass had been necessary. Finally, CDT at the initial diagnosis was associated with a less frequent need for AxSCV reconstruction at surgery and less frequent arm swelling during follow-up.

To the best of our knowledge, the present study represents nearly the largest clinical series reported to date for the treatment of VTOS. An important element of our protocol was the treatment of essentially all patients referred with VTOS, with no exclusions because of age,

**Table II.** Perioperative care stratified by operative treatment of axillary-subclavian vein (AxSCV)

| Variable | Venolysis alone | | Vein reconstruction | | Total |
|---|---|---|---|---|---|
| | Widely patent[a] | Chronic occlusion[b] | Patch angioplasty[c] | Bypass graft[d] | |
| Patients | 150 (56) | 26 (10) | 55 (21) | 35 (13) | 266 (100) |
| Operative time,[e] minutes | 196 ± 3 | 223 ± 9 | 299 ± 7 | 360 ± 8 | 242 ± 5 |
| Hospital stay,[e] days | 4.7 ± 0.2 | 5.0 ± 0.5 | 5.5 ± 0.3 | 5.9 ± 0.6 | 5.1 ± 0.1 |
| Hospital stay >6 days | 21 (14) | 6 (23) | 16 (29) | 11(31) | 54 (20) |
| Early reoperation[f] | 3 (2) | 0 (0) | 3 (5) | 7 (20) | 13 (5) |
| Hematoma | 0 (0) | 0 (0) | 2 (4) | 1 (3) | 3 (1) |
| Hemothorax | 2 (1) | 0 (0) | 1 (2) | 3 (9) | 6 (2) |
| Bypass graft revision | 1 (1) | 0 (0) | 0 (0) | 2 (6) | 3 (1) |
| Early reintervention | 12 (8) | 1 (4) | 3 (5) | 1 (3) | 17 (6) |
| Suction thrombectomy | 0 (0) | 0 (0) | 1 (2) | 0 (0) | 1 (0) |
| Balloon angioplasty | 6 (4) | 0 (0) | 1 (2) | 1 (3) | 8 (3) |
| Stent placement | 0 (0) | 0 (0) | 1 (2) | 0 (0) | 1 (0) |
| Chest tube placement | 4 (3) | 1 (4) | 1 (2) | 0 (0) | 6 (2) |
| Lymph embolization | 2 (1) | 0 (0) | 0 (0) | 0 (0) | 2 (1) |
| Any complication | 15 (10) | 1 (4) | 6 (11) | 8 (23) | 30 (11) |
| 30-Day readmission | 3 (2) | 0 (0) | 2 (4) | 2 (6) | 7 (3) |

Data presented as number (%) or mean ± standard error.
[a]Widely patent AxSCV after external venolysis alone.
[b]Long chronic AxSCV occlusion with inadequate venous inflow to support bypass graft reconstruction.
[c]Patent AxSCV with focal stenosis amenable to patch angioplasty reconstruction.
[d]Segmental AxSCV occlusion treated with AxSCV bypass graft reconstruction using a cryopreserved femoral vein.
[e]$P < .05$, two-way analysis of variance.
[f]$P < .05$, $\chi^2$ test.

previous treatment, timing of the clinical presentation, or preliminary venographic findings. The standardized protocol we used also afforded a high level of consistency in assessing the interventions performed and the outcomes achieved. The patient population in the present study was, therefore, typical and representative of the overall population of those with primary AxSCV thrombosis.

The reported outcomes of surgery for VTOS have varied owing to the heterogeneity in clinical presentation, variations in the initial treatment and operative findings, differences in patient selection, and the specific operations or management protocols used. The classification of our patients into four distinct groups according to the immediate venography findings after decompression (intraoperative) was not particularly novel, but provides a useful method to characterize the relevant subgroups of patients with VTOS for whom various treatment approaches could be used. This classification approach will also be generally applicable to all cases of VTOS. We, therefore, propose that the wider use of a postdecompression venographic classification could improve the outcomes assessment and reporting of results for VTOS by offering more rigorous stratification of the different patient subgroups.

The valuable role of CDT in the initial management of AxSCV thrombosis is well known and seemingly established, in contrast to the ongoing debate concerning the value of CDT for patients with lower extremity DVT.[3-14,34-38] Nonetheless, the 71% rate of initial CDT in the present study was still too low for satisfaction. The absence of early intervention resulted in the extension of symptoms and the initial duration of anticoagulation therapy for many patients and a prolonged delay to referral for definitive management. We have also provided evidence that patients who had undergone initial CDT and/or balloon angioplasty had better outcomes, with a 32% lower need for AxSCV reconstruction at surgery and a 60% lower incidence of chronic arm swelling at long-term follow-up. Much of the delay in the use of venography and CDT appeared likely to be related to unfamiliarity or uncertainty about the differences in optimal treatment between upper and lower extremity DVT, indicating that a great need exists for primary care providers, emergency room physicians, and hematology specialists to better understand the current standards for AxSCV thrombosis.

The perioperative outcomes were excellent for the patients with a widely patent AxSCV after external venolysis alone, similar to that reported for patients who have undergone surgical treatment with a transaxillary or an infraclavicular approach to VTOS. The patients who had undergone direct vein repair by patch angioplasty or AxSCV bypass had a higher rate of secondary procedures and reoperations during the index hospitalization,

**Table III.** Clinical follow-up stratified by operative treatment of axillary-subclavian vein (AxSCV)

| Variable | Venolysis alone | | Vein reconstruction | | Total |
|---|---|---|---|---|---|
| | Widely patent[a] | Chronic occlusion[b] | Patch angioplasty[c] | Bypass graft[d] | |
| Patients | 150 (56) | 26 (10) | 55 (21) | 35 (13) | 266 (100) |
| Follow-up,[e] months | | | | | |
| Median | 34.3 | 42.8 | 44.5 | 48.2 | 38.7 |
| Mean ± SE | 36.0 ± 1.7 | 39.1 ± 4.2 | 43.7 ± 2.8 | 43.4 ± 4.2 | 38.9 ± 1.3 |
| Late reintervention[f] | 6 (4) | 2 (8) | 9 (16) | 5 (14) | 22 (8) |
| Suction thrombectomy | 0 (0) | 2 (8) | 0 (0) | 0 (0) | 2 (1) |
| Balloon angioplasty | 5 (3) | 0 (0) | 5 (9) | 2 (6) | 12 (5) |
| Stent placement | 1 (1) | 0 (0) | 2 (4) | 2 (6) | 5 (2) |
| Reocclusion, no Rx | 0 (0) | 0 (0) | 2 (4) | 1 (3) | 3 (1) |
| No arm swelling[f] | 145 (97) | 18 (69) | 52 (94) | 31 (89) | 246 (93) |
| Anticoagulation Rx[f] | 3 (2) | 7 (27) | 4 (7) | 3 (9) | 17 (6) |

*Rx*, treatment; *SE*, standard error.
[a]Widely patent AxSCV after external venolysis alone.
[b]Long chronic AxSCV occlusion with inadequate venous inflow to support bypass graft reconstruction.
[c]Patent AxSCV with focal stenosis amenable to patch angioplasty reconstruction.
[d]Segmental AxSCV occlusion treated with AxSCV bypass graft reconstruction using a cryopreserved femoral vein.
[e]Follow-up intervals determined from date of surgery to last recorded office visit or telephone interview.
[f] $P < .05$, $\chi^2$ test.

consistent with more extensive procedures, an elevated potential for bleeding, and the need for early follow-up venography. Many of the secondary endovascular procedures performed to ensure the patency of AxSCV repairs were planned procedures, performed several days after surgery when it was more feasible to use full therapeutic anticoagulation. This was facilitated by maintaining the basilic vein access catheter placed at the index operation for several days during the immediate postoperative period, a routine aspect of our treatment protocol. Unplanned reoperations were undertaken for postoperative hematomas or hemothorax for only nine patients (2%), reflecting the challenges in managing postoperative anticoagulation as a balance between the risks of early venous thrombosis and the potential for bleeding complications.[32,39] Overall, the patients who had undergone venolysis alone (patent or occluded AxSCV) had a shorter mean operative time and postoperative length of hospital stay and a lower incidence of reoperations and later reinterventions compared with those who had AxSCV reconstruction (patch or bypass). However, no differences were found in the incidence of overall complications and 30-day readmissions.

The group of patients with focal AxSCV stenosis, for which we performed patch angioplasty at the index operation, was analogous to patients with post-decompression AxSCV stenosis after transaxillary or infraclavicular first rib resection who will typically be treated by postoperative balloon angioplasty and possible stent placement.[16-18,24-27,40-44] We have preferred to use patch angioplasty at paraclavicular decompression because the requisite operative exposure has already been obtained and aggressive balloon angioplasty could injure the exposed vein. We believe the use of patch angioplasty is more definitive and durable, and that the dependence on later endovascular procedures might not always achieve a widely patent AxSCV. Those using postoperative venography at later intervals after transaxillary first rib resection have reported that approximately 20% of patients will have AxSCV occlusions that cannot be crossed with a guidewire, leaving no immediate management options other than prolonged anticoagulation treatment.[6] Our preferred approach has also been informed by considerable experience with reoperations for recurrent VTOS, following procedures other than paraclavicular decompression and AxSCV reconstruction.[45]

An important aspect of the present study was the management of patients with persistent AxSCV occlusion despite thorough decompression. The ability to perform bypass reconstruction is an advantage of the paraclavicular approach, because it allows for definitive treatment to achieve a patent AxSCV for patients who, via other approaches, would likely require long-term anticoagulation therapy. In the present study, the long-term outcomes for patients with AxSCV bypass were not significantly different from those with a patent AxSCV after venolysis alone or patch angioplasty (absence of arm swelling for 89%, 97%, and 94%, respectively; $P = .139$). The outcomes for the bypass group were also distinctly better than were those for the patients with long AxSCV occlusions for whom bypass reconstruction could not be performed owing to an inadequate axillary vein caliber (absence of arm swelling at follow-up, 89% vs 69%). Also, although AxSCV patency is preferred, we still found surgical treatment to be of value for patients with long chronic venous occlusions, likely because complete decompression can

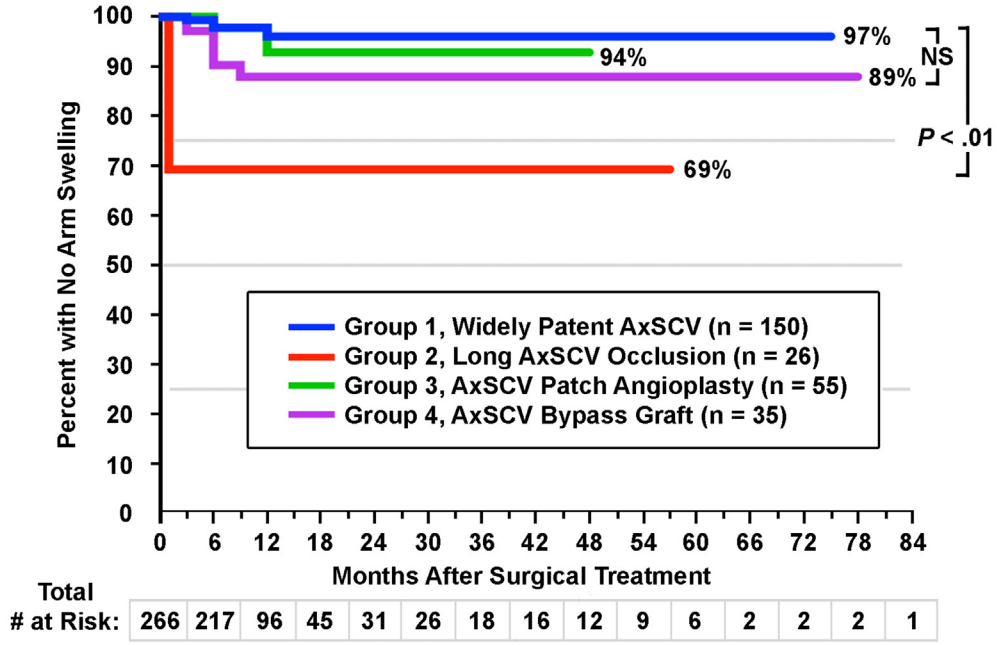


**Fig 2.** Graph showing absence of arm swelling during long-term follow-up after surgery. Life table plot demonstrating the absence of arm swelling during follow-up for 266 patients with venous thoracic outlet syndrome (VTOS) who had undergone paraclavicular thoracic outlet decompression, external venolysis, and one of four treatment methods for axillary-subclavian vein (AxSCV) according to the intraoperative venographic findings: (1) widely patent AxSCV after external venolysis alone; (2) long chronic AxSCV occlusion with inadequate venous inflow to support bypass graft reconstruction, (3) patent AxSCV with focal stenosis amenable to patch angioplasty reconstruction, and (4) segmental AxSCV occlusion treated with AxSCV bypass graft reconstruction using a cryopreserved femoral vein. The total number of patients at risk at each follow-up interval is shown. No significant differences (NS) were found between patients with patent AxSCV, patch angioplasty, or bypass at the end of surgery (groups 1, 3, and 4) vs those with long chronic AxSCV occlusions (group 2). *$P < .01$; log-rank test.

improve expansion of the venous collateral vessels that transit the thoracic outlet compared with the collaterals present before operative intervention. Similar findings have been reported for patients with chronic AxSCV occlusions for whom endovascular or open surgical bypass reconstruction could not be performed after transaxillary first rib resection.[40,41,46]

Treatment of idiopathic upper extremity DVT using anticoagulation alone, with protocols extrapolated from regimens for lower extremity DVT, does not consider the mechanical (surgically correctable) pathophysiology underlying VTOS.[34-36,47-49] Studies of such treatment have consistently demonstrated suboptimal outcomes compared with prompt CDT and definitive surgical treatment.[47-49] In the absence of surgery for VTOS, we have generally recommended restrictions on upper extremity activity with lifelong anticoagulation therapy. We have previously shown that the clinical outcomes for treatment of VTOS are diminished for patients with false-negative duplex ultrasound findings at the initial diagnostic evaluation.[29] In the present study, we have more clearly shown that those who had not undergone initial venography and intervention also have less favorable outcomes, with delayed referral, a higher frequency of long chronic AxSCV thrombosis precluding bypass, a more frequent need for AxSCV bypass reconstruction, and a greater incidence of arm swelling during follow-up vs patients who had undergone CDT and/or balloon angioplasty at the initial diagnosis. We would, thereby, recommend that the overall management of VTOS should be aimed at minimizing the number of patients with chronic long-segment occlusions. Thus, prompt recognition of AxSCV thrombosis is crucial toward directing patients to early CDT.

One of the main strengths of the present study was that all patients underwent treatment with a well-established standardized protocol involving complete thoracic outlet decompression and selective AxSCV reconstruction in accordance with the operative and venographic findings. We also had a large number of patients for a relatively uncommon condition, with particularly long-term follow-up. The limitations of the present study were the retrospective study design and the singleinstitution experience at a specialized center that focuses on the management of TOS. Thus, our findings might not easily translate into clinical practice at other medical centers. Another limitation might be that the long-term follow-up assessment was based solely on the clinical

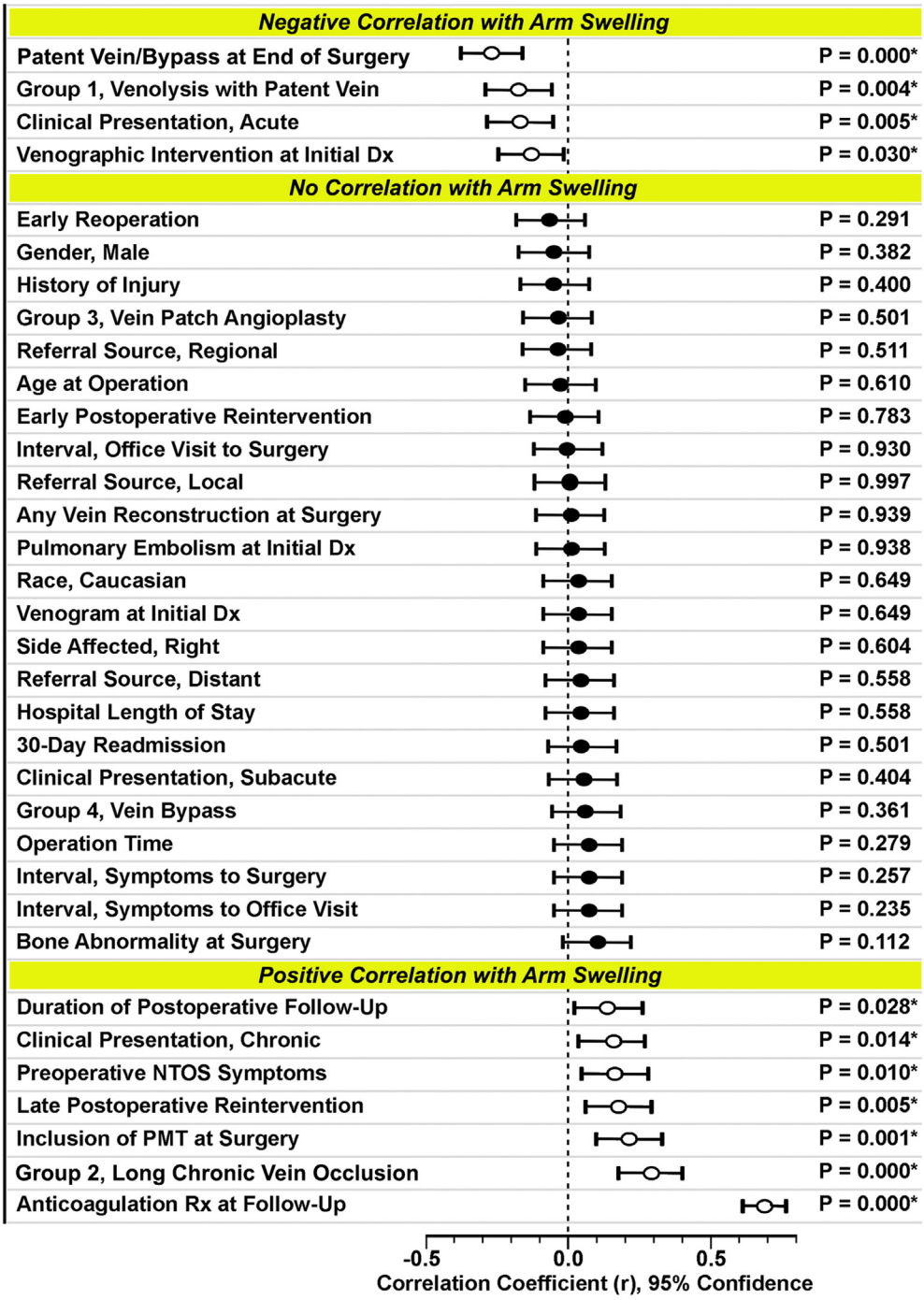


**Fig 3.** Correlation between clinical variables and arm swelling during follow-up. For 266 patients who had undergone primary paraclavicular operations for venous thoracic outlet syndrome (VTOS) from January 1, 2016 to December 31, 2021, 34 different clinical variables were tested for correlation with the presence of arm swelling at long-term follow-up. For each variable tested, the data shown indicate the Pearson correlation coefficient (*r*), 95% confidence interval, and two-tailed *P* value. Of the 34 variables, 23 had no significant correlation (*closed circles*) and 11 had significant correlation (*open circles*), including 4 with a negative and 7 with a positive association with arm swelling. *$P < .05$. *Dx*, Diagnosis; *NTOS*, neurogenic thoracic outlet syndrome; *PMT*, pectoralis minor tenotomy; *Rx*, treatment.

evaluation of arm swelling rather than arm circumference measurements, formal measures of disability, or routine imaging studies. We agree with others that the use of duplex ultrasound is insufficient to monitor AxSCV patency and that contrast venography would be more accurate.[29,50] Finally, in the present study population,

the initial clinical presentation and diagnosis of AxSCV thrombosis and the suspicion of VTOS occurred at diverse locations and practice settings and by a variety of different physicians.

## CONCLUSIONS

In the present single-center, retrospective study of 266 patients, paraclavicular decompression, external venolysis, and selective AxSCV reconstruction using intraoperative venography provided successful and durable treatment for >90% of all patients with VTOS, regardless of age, previous treatment, or the timing of the clinical presentation. Patients with long chronic venous occlusion were more likely to have arm swelling during long-term follow-up than those with a patent AxSCV or bypass achieved at surgery. Venography and CDT at the initial diagnosis were also associated with a less frequent need for AxSCV reconstruction at surgery and less frequent arm swelling during follow-up. Further work is needed to achieve earlier recognition of AxSCV thrombosis, prompt use of CDT, and even more effective surgical treatment.

## AUTHOR CONTRIBUTIONS

Conception and design: ED, JO, KH, DG, RT
Analysis and interpretation: ED, JO, PK, RT
Data collection: ED, JO, KH, DG, RT
Writing the article: ED, RT
Critical revision of the article: ED, JO, PK, KH, DG, RT
Final approval of the article: ED, JO, PK, KH, DG, RT
Statistical analysis: ED, RT
Obtained funding: RT
Overall responsibility: RT

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*Additional material for this article may be found online at www.jvascsurg.org.*

**Supplementary Table I (online only).** Referral of patients with venous thoracic outlet syndrome (VTOS)

| Variable | Value |
|---|---|
| Patients | 266 (100) |
| Office visit ≤60 days of symptom onset | 151 (57) |
| Interval from symptom onset to office visit, days | |
| Median | 42 |
| Mean ± SE | 183 ± 33 |
| Surgery ≤60 days of office visit | 227 (85) |
| Interval from office visit to surgery, days | |
| Median | 29 |
| Mean ± SE | 49 ± 5 |
| Surgery ≤90 days of symptom onset | 145 (55) |
| Interval from symptom onset to surgery, days | |
| Median | 78 |
| Mean ± SE | 229 ± 35 |

*SE*, Standard error.
Data presented as number (%), unless noted otherwise.

**Supplementary Table II (online only).** Age-related osseous findings at surgery

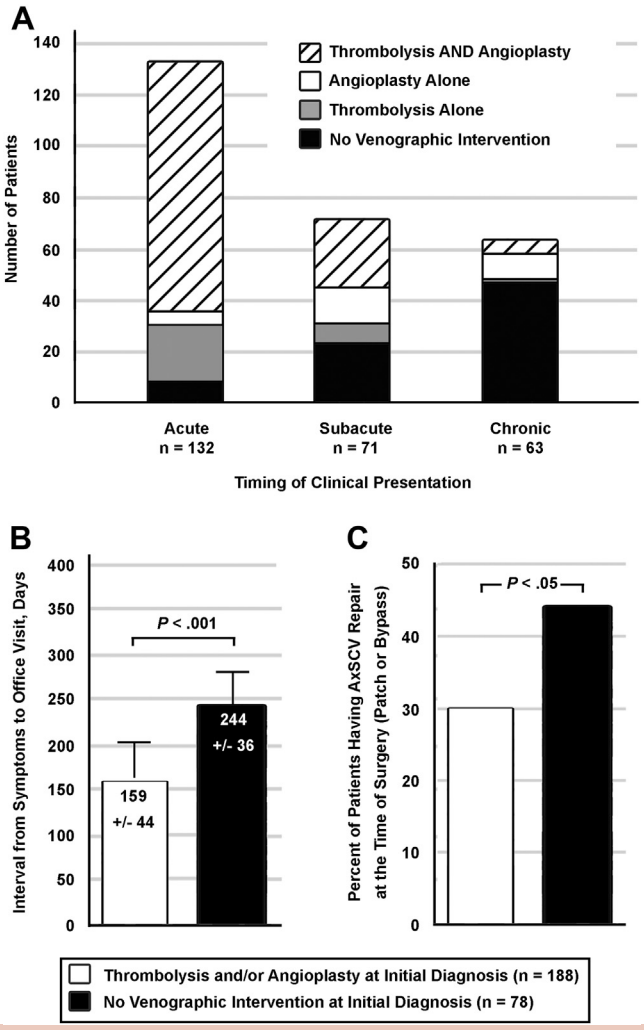
| Variable | Age group, years | | | | | Total |
|---|---|---|---|---|---|---|
| | <21 | 21-30 | 31-40 | 41-50 | >50 | |
| Patients, No. | 49 (18.4) | 88 (33.0) | 61 (23.0) | 44 (16.5) | 24 (9.0) | 266 (100) |
| Normal FR[a] | 47 (96) | 64 (73) | 20 (33) | 5 (11) | 3 (12) | 139 (52) |
| Occult FR Fx[a,b] | 0 (0) | 21 (24) | 41 (67) | 38 (86) | 21 (88) | 121 (45) |
| CR/FR anomaly | 2 (4) | 3 (3) | 0 (0) | 1 (2) | 0 (0) | 6 (2) |

*CR*, Cervical rib; *FR*, first rib; *Fx*, fracture.
Data presented as number (%).
[a] $P < .0001$, $\chi^2$ test.
[b] Osteophytic changes and occult first rib fracture.

**Supplementary Table III (online only).** Operative treatment of axillary-subclavian vein (AxSCV)

| Variable | Age group, years | | | | | Total |
|---|---|---|---|---|---|---|
| | <21 | 21-30 | 31-40 | 41-50 | >50 | |
| Patients | 49 (18.4) | 88 (33.0) | 61 (23.0) | 44 (16.5) | 24 (9.0) | 266 (100) |
| Venolysis alone[a] | 22 (45) | 54 (61) | 32 (52) | 28 (64) | 14 (58) | 150 (56) |
| Occluded AxSCV[b] | 9 (18) | 2 (2) | 6 (10) | 5 (11) | 4 (17) | 26 (10) |
| AxSCV patch[c] | 12 (24) | 22 (25) | 11 (18) | 7 (16) | 3 (12) | 55 (21) |
| AxSCV bypass[d] | 6 (12) | 10 (11) | 12 (20) | 4 (9) | 3 (12) | 35 (13) |

Data presented as number (%).
[a] Widely patent AxSCV after external venolysis alone.
[b] Long chronic AxSCV occlusion with inadequate venous inflow to support bypass graft reconstruction.
[c] Patent AxSCV with focal stenosis amenable to patch angioplasty reconstruction.
[d] Segmental AxSCV occlusion treated with AxSCV bypass graft reconstruction and cryopreserved femoral vein.




**Supplementary Fig (online only).** Preoperative care and surgical treatment of patients with venous thoracic outlet syndrome (VTOS). **A,** Bar graph demonstrating frequency of endovascular interventions (catheter-directed thrombolysis or thrombectomy [CDT] and/or balloon angioplasty) at initial contrast venography for patients with VTOS stratified by timing of clinical presentation (acute, subacute, chronic). The frequency of no venographic intervention at the initial diagnosis was significantly different between all three clinical presentation groups (*$P < .0001$ for all comparisons; $\chi^2$ test). **B,** Bar graph depicting mean ± standard error for interval between symptom onset and first referral office visit comparing patients who had undergone initial venography and intervention (CDT and/or balloon angioplasty; n = 188) and those who had not (n = 78; $P < .001$, Mann-Whitney *U* test). **C,** Bar graph depicting percentage of patients requiring axillary-subclavian vein (AxSCV) reconstruction (patch angioplasty or bypass) at surgery for VTOS stratified by initial venography and intervention (CDT and/or balloon angioplasty) at the initial diagnosis ($P < .05$, $\chi^2$ test).