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ABSTRACT

Objective: Venous thoracic outlet syndrome (VTOS) is considered chronic when symptoms and venous stenosis or occlusion are present for >3 months after the initial primary upper extremity deep vein thrombosis event. Many of patients with chronic VTOS receive conservative treatment. However, a subset of these patients will have persistent post-thrombotic syndrome symptoms because of underlying causative anatomy. We present the results of a same admission treatment consisting of transaxillary thoracic outlet decompression (TA-TOD), external venolysis, and, if necessary, treatment of residual intraluminal lesions with percutaneous transluminal angioplasty (PTA) for chronic VTOS.

Methods: All patients presenting from January 2015 to December 2019 with chronic VTOS and post-thrombotic syndrome complaints were evaluated. Patients with some degree of patency on venography or a chronic occlusion that could be recanalized using PTA preoperatively underwent TA-TOD, external venolysis, and immediate venography. Low-pressure diagnostic balloon inflation after first rib resection was used to identify residual lesions not evident by venography. If found, PTA was performed. Stent placement was reserved for patients with recurrent complaints due to residual lesions that had not been effectively treated by PTA.

Results: A total of 40 patients with chronic VTOS were evaluated, of whom 36 were included and treated according to the protocol. The remaining four patients had had a chronic occlusion that could not be recanalized preoperatively and these patients were, therefore, excluded. After TA-TOD, immediate venography showed patent vessels with residual stenosis in 31 patients. Of the five patients who had appeared to have no significant stenosis on venography, two showed narrowing with diagnostic balloon inflation of the subclavian vein, for a total of 33 patients (92%) with residual stenosis after TA-TOD. All 33 patients underwent formal venous PTA. Complications occurred in five patients. At a mean follow-up of 24 months, 30 of the 36 patients (83%) were free of symptoms. The mean thoracic outlet syndrome disability scale score was 1.97 ± 1.9. The mean Disability of the Arm Shoulder and Hand scale score was 16.16 ± 17.4. The median VEINES (venous insufficiency epidemiologic and economic study)-symptoms score was 53.90 (interquartile range, 10.54). The median VEINES-quality of life (QOL) score was 54.22 (interquartile range, 13.93). Finally, the mean 12-item short-form physical QOL component scale score was 47.97 ± 9.02. The thoracic outlet syndrome disability scale and Disability of the Arm Shoulder and Hand scale scores had significantly decreased ($P < .01$), and the 12-item short-form physical QOL component scale score had significantly improved ($P < .01$) compared with the baseline scores. A return to daily activities was achieved by 93% of the patients.

Conclusions: The treatment of patients with chronic VTOS using a same admission treatment algorithm consisting of TA-TOD, external venolysis, and PTA is effective. Intermediate follow-up showed a high return to daily activity and significant improvement in functional outcome and physical QOL. (J Vasc Surg Venous Lymphat Disord 2021;9:1159-67.)

Keywords: Post-thrombotic syndrome; Residual lesions; Upper extremity deep vein thrombosis; Subclavian vein; Venous thoracic outlet syndrome

Venous thoracic outlet syndrome (VTOS) is caused by compression of the subclavian vein (SCV) at the costoclavicular junction. In most cases, VTOS will present as symptomatic acute primary upper extremity deep vein thrombosis (pUEDVT). However, if not initially recognized or if conservatively treated, this persistent VTOS will create a variety of symptoms known as post-thrombotic syndrome (PTS). These symptoms include

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Author conflict of interest: none.

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

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The editors and reviewers of this article have no relevant financial relationships to disclose per the Journal policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

2213-333X

https://doi.org/10.1016/j.jvsv.2020.12.079

swelling, heaviness, edema, varicosities, and pain exacerbated by use or abduction. Patients with these PTS symptoms for >3 months after the index pUEDVT event are considered to have chronic VTOS.[1]

A recent set of guidelines have advised the use of anticoagulation alone as the preferred therapy for pUEDVT.[2-4] However, the proper duration of anticoagulation therapy for these patients is unknown.[5] More importantly, because these guidelines refer to spontaneous clot formation and were generally based on guidelines for lower extremity venous disease, they do not address the extrinsic compression of the vein at the thoracic outlet/inlet. Because many clinicians follow these guidelines, most patients with pUEDVT will be treated with anticoagulation alone for a significant period. However, this has been associated with an incidence of PTS ranging from 6% to 37%.[6-9] Thus, patients have been presenting to our outpatient thoracic outlet syndrome (TOS) clinic with persistent symptoms months after their index event and well after the window of opportunity for thrombolysis has passed.[10]

Because thrombolysis is not technically possible late after the index event and data to guide the treatment of chronic VTOS are sparse, most clinicians will recommend conservative therapy with anticoagulation and/or a compression sleeve.[3,11] Data on the surgical management of chronic VTOS are limited to several studies that have described thoracic outlet decompression (TOD), sometimes combined with subclavian vein percutaneous transluminal angioplasty (PTA) and stenting, patch venoplasty, or venous bypass of the SCV to reconstruct blood flow to the thoracic inlet.[7,12,13] The use of these more aggressive reconstruction methods also depends on the status of the SCV (occluded or partially patent) and the patient's symptoms.

Most of the patients in our series had presented with some degree of luminal patency found on venography. Some patients had presented with a chronic occlusion that could be recanalized preoperatively. If some degree of SCV patency is present or obtained as evidenced on venography, and passage of the stenosis by a guidewire is possible, our treatment algorithm consists of transaxillary first rib resection for TOD (TA-TOD), external venolysis, and intraoperative venography, followed by percutaneous low-pressure diagnostic balloon inflation, in a single setting. Formal PTA was performed in the case of residual lesions. Chronic occlusions that could not be recanalized with a guidewire were excluded from the present series. The aim of the present study was to report the outcomes of the use of our same admission treatment algorithm for patients with chronic VTOS.

ARTICLE HIGHLIGHTS

- **Type of Research:** A retrospective analysis of prospectively collected data
- **Key Findings:** At a mean follow-up of 24.0 months, 83% of patients with chronic venous thoracic outlet syndrome were free of symptoms after using the proposed protocol. The functional outcome measures and quality of life had all improved significantly ($P < .01$). A return to daily activities was achieved by 93% of the patients.
- **Take Home Message:** The treatment of patients with chronic venous thoracic outlet syndrome using a same admission treatment algorithm consisting of transaxillary thoracic outlet decompression, external venolysis, and percutaneous transluminal angioplasty is effective and leads to significant improvement in functional outcome and physical quality of life.

METHODS

Study design and participants. All patients referred from January 2015 to December 2019 to our institution (Thoracic Outlet Syndrome Center, Department of Vascular Surgery, Catharina Hospital, Eindhoven, The Netherlands) with suspicion of VTOS were evaluated. The patients were classified using the Society for Vascular Surgery (SVS) 2016 reporting standards for TOS: acute, symptom duration or clotting event of <14 days; subacute, presentation 14 days to 3 months after the index event; and chronic, presentation >3 months after the index event.[1] The patients diagnosed and treated for chronic VTOS were identified from a prospectively maintained database. The local ethics committee approved the present study, and all included patients provided written informed consent.

The preoperative data collected included medical history, demographics, previous trauma to the chest, clavicle, shoulder, and/or ribs, clotting disorders, dominant hand, symptom laterality, interval between the index event and presentation, daily limitations, and physical examination findings. All patients had been clinically evaluated by a TOS surgeon (J.T., M.S.) at first presentation. The physical examination consisted of mobility testing of the shoulder joint and inspection of the arm for PTS symptoms at rest and in stress positions. Complaints, including pain, cramps, heaviness, pruritus, and/or paresthesia, with signs of edema, redness, tenderness, and/or prominent veins on the arm, shoulder, or anterior chest wall, were used to define PTS. The standardized elevated arm stress test,[14] upper limb tension test, Tinel's sign, and palpation for point tenderness at the scalene triangle and pectoral minor insertion site were performed to identify any coexisting complaints of neurogenic thoracic outlet syndrome.

All patients underwent preoperative venography, with images obtained with the arm at rest and in adduction, abduction, and military attitude position to assess all possible venous compression scenarios and to acquire

information of existing collateral veins. A lumen decrease of ≥50% or preferred flow over existing collateral veins in one or more positions on venography was considered a significant lesion. If chronic occlusion was seen, preoperative recanalization and 5- to 6-mm PTA was used to obtain patency of the SCV. Only patients with some degree of luminal patency, as evidenced on venography and/or by wire passage of the stenosis, were included in the present study. Patients with a chronic occlusion that could not be recanalized preoperatively and patients with complaints or signs of active thrombus suggestive of a recent pUEDVT event were excluded from the present study.

Beginning in January 2017, the TOS disability scale, Dutch language version of the Disability of the Arm Shoulder and Hand (DLV-DASH), and short-form 12-item health survey (SF-12) were administered at first presentation.[1,15,16]

Intervention. TA-TOD was performed in all symptomatic patients with VTOS and a patent SCV, which had sometimes been acquired by preoperative PTA. TA-TOD consisted of complete transaxillary first rib resection from the costochondral junction to the articulation with the vertebral body's transverse process, partial anterior and medial scalenectomy (15-20 mm of the lower part), removal of the medial 3 to 4 cm of the subclavian muscle, and thorough, circumferential venolysis of the axillosubclavian vein.

Directly after TA-TOD, the patient was placed in the supine position and the drapes were replaced for venography of the SCV, which was performed through the basilic or brachial vein. Next, a hydrophilic wire (Glidewire; Terumo Medical Corp, Somerset, NJ) was inserted and positioned beyond the level of the costoclavicular junction. If no obvious stenosis was found on venography, subsequent low-pressure balloon inflation (Passeo-35; Biotronik, Berlin, Germany) was used as a diagnostic test to reveal occult stenosis and to visualize the extent of stenosis.

If stenosis was found by venography or low-pressure balloon inflation, formal PTA with a balloon suitable to the geometry of the vein was performed. The diameter of the balloon was determined in a graduated manner until the target size for optimal PTA of the vein was reached (generally at 8-12 mm). Preferably, stents were not used in the initial procedure, because the risk of in-stent restenosis, even in the decompressed thoracic outlet, is significant.[17] Postoperative anticoagulation therapy consisted of rivaroxaban 20 mg once daily (Xarelto; Bayer, Leverkusen, Germany) for 6 weeks. The patients who had received venous stents were also treated with rivaroxaban 20 mg once daily for 6 weeks.

Outcome measures and follow-up. The vascular surgeon evaluated all patients at 6 weeks and 1 year after intervention. In the absence of complaints, further follow-up was performed annually by telephone. Routine duplex ultrasonography or venography was not performed during follow-up. Venography was only performed for patients with clinical symptoms or if any abnormality during the physical examination was observed. Follow-up tests, including the TOS disability score, DLV-DASH, SF-12, VEINES (venous insufficiency epidemiologic and economic study)-quality of life (QOL)/VEINES-symptoms (SYM), and return to work and daily activities questionnaires were administered to all patients. The Derkash score was determined according to the complaints, daily limitations, and return to work at each visit (Table I).[18] The latest Derkash classification was used for analysis.

Statistical analysis. Statistical analyses were performed using SPSS, version 25 (IBM Corp, Armonk, NY). The data are presented as the mean ± standard deviation with the 95% confidence intervals or the median and interquartile range as measures of variance. Differences between the mean values were tested using two-tailed paired *t* tests. An overall *P* value of <.05 was considered statistically significant. The VEINES-QOL/SYM was calculated using the extrinsic method, allowing for comparisons between other cohorts with VEINES-QOL/SYM scores available.[19]

RESULTS

From January 2015 to December 2019, 40 patients were evaluated for chronic VTOS complaints. Of these 40 patients, 32 had had some degree of patency found on venography. Another four patients had presented with a chronic occlusion that could be recanalized using PTA preoperatively. These 36 patients with some degree of SCV patency were treated for chronic VTOS and included in the present analysis. The remaining four patients with chronic occlusion that could not be recanalized were excluded from the present study.

All 36 included patients had presented with persistent PTS symptoms. Of these 36 patients, 30 had initially been treated with anticoagulant therapy alone, 4 had undergone thrombolysis at another institution followed by anticoagulation, and 2 had received no therapy despite the documented presence of SCV thrombosis. The mean interval between the initial pUEDVT event and presentation to our institute was 88 weeks (range, 13-520 weeks). Seven patients (19%) had experienced more episodes of UEDVT, and a pulmonary embolism had been found between the initial pUEDVT and presentation at our clinic in two patients (6%). All baseline characteristics were recorded in accordance with the SVS reporting standards TOS and are summarized in Table II.

Venous duplex ultrasonography had been performed before their presentation to our clinic in 33 patients, with abnormalities found in 29 (88%). Preoperative

Table I. Derkash score after a mean follow-up of 24 months (n = 36; 100%)

Score	Complaint	Return to work	Daily activities	Patients, no. (%)
Excellent	None	No limitations	No limitations	16 (44.4)
Good	Some	No limitations, minor sequelae	No limitations, minor sequelae	14 (38.9)
Fair	Evident	Limitations	Limitations	5 (13.9)
Poor	Severe	No return	Severely limited	1 (2.8)

venography in our institution was performed for all patients and documented post-thrombotic changes at rest in 35 of the 36 patients (97%; Supplementary Fig 1, online only). In one patient who had undergone thrombolysis at another institution, reduced patency of the SCV was only seen in the stress positions. In four patients, a short segment chronic occlusion was seen, which was opened by 5- to 6-mm PTA preoperatively. No thrombus, suggesting a recent pUEDVT event, was seen on venography.

TA-TOD with external venolysis was performed in all patients. After TA-TOD, immediate venography was performed, which showed residual stenosis and post-thrombotic changes in 31 patients (86%; Fig 1). Subsequent low-pressure balloon inflation was performed in these 31 patients (86%), which revealed an otherwise unrecognized stenosis in 2 patients and an underestimated stenosis in 3 patients (Fig 2). PTA (Powerflex; Cordis, Miami, Fla) was performed in all 33 patients (92%) with residual stenosis (Table III), which resulted in a patent SCV after surgery in all 33 patients (Supplementary Fig 2, online only).

Complications occurred in five patients. In one patient, a small vein rupture with contrast extravasation had occurred during post-TOD PTA with an 8-mm balloon. The PTA procedure was stopped without the need for additional intervention (eg, balloon inflation, stenting, or open repair). The patient underwent venography combined with low-pressure balloon inflation 8 weeks later, with no residual stenosis found. Three postoperative hematomas had developed that required reoperation. In one of these three patients, active bleeding from an intercostal artery was found and controlled. No active bleeding was found in the other two patients, and only removal of the hematoma was performed. One of these patients had developed a transient Horner syndrome. In one patient, permanent phrenic nerve injury was identified. No other complications occurred. The overall length of stay was 1.9 days (range, 1-6 days). The surgical data are summarized in Table III.

At a mean follow-up of 24.0 months (range, 5-62 months), 30 patients (83%) were asymptomatic, 3 had reported minor complaints of PTS during exercise, and 3 had experienced persisting symptoms of PTS. During follow-up, eight patients had experienced recurrent symptoms of PTS. Venography was performed in all these patients, and seven were found to have a patent, but restenotic, SCV. Central occlusion of the SCV with extensive collateralization was found in the eighth patient. The patient was offered endophlebectomy with vein patch placement but chose to not undergo treatment. Of the seven patients with a restenotic SCV, three had undergone repeat PTA with good results. However, in three patients, despite repeated PTA, the stenosis persisted. These three were treated with venous stents (OptiMed GmbH, Ettlingen, Germany). The seventh patient had a stenotic segment that could not be passed with a guidewire. Despite unsuccessful repeat PTA, the patient had experienced fewer PTS symptoms after the procedure; thus, additional procedures were not performed given the minor complaints.

A total of five patients were treated with venous stents, two immediately after TA-TOD and three during follow-up. At the last follow-up visit, two patients were asymptomatic (imaging studies revealed an open stent) and three patients had reported persistent pain and mild swelling with exercise. In these three patients, imaging studies had revealed an occluded stent with collateralization in two patients identified 104 and 177 days after placement. One patient had an open, but stenotic, stent, identified 313 days after placement. Evidence of stent fracture was seen in one patient on venography. An overview of the study is presented in Fig 3.

After a mean follow-up of 24.0 months (range, 5-62 months), the presumed primary patency in the present study was 78%, the presumed primary-assisted patency was 92%, and the presumed secondary patency was 94% based on the absence of PTS complaints at the 6-week and 1-year evaluation by the vascular surgeon and the absence of PTS complaints reported on the follow-up questionnaires, or found, if performed, on follow-up venography. A total of 21 patients had presented after 2017 and had completed the baseline questionnaires. Of the 36 patients, 28 (78%) had completed at least one follow-up questionnaire. For 16 patients with baseline and follow-up questionnaires available, a statistically significant improvement in the DLV-DASH score (-14.97 ± 16.8; $P < .01$) and TOS disability scale (-2.2 ± 2.2; $P < .01$) between the baseline (initial presentation) and final follow-up scores was seen. The SF-12 physical QOL score had significantly improved (7.73 ± 7.21 points; $P < .01$; Supplementary Fig 3, online only). The SF-12 mental QOL score had improved by 4.50 points, although we found no statistically significant difference between

Table II. Baseline characteristics (n = 36; 100%)

Characteristic	Value
Female gender, no. (%)	20 (56)
Age, years (range)	33 (16-57)
Symptom laterality, no. (%)	
Right side (dominant, 11/19)	19 (53)
Left side (dominant, 1/15)	15 (42)
Both sides	2 (6)
Dominant side unknown	14 (39)
Symptom, no. (%)	
Swelling	27 (75)
Discoloration	17 (47)
Visible collateralization	7 (19)
Pain during exercise	25 (69)
Effort-induced complaints	9 (25)
Severe limitations in daily activities (work/sports)	29 (81)
Mean interval between pUEDVT and presentation, weeks (range)	88 (13-520)
Referred from another hospital	32 (89)
Hypercoagulability	0 (0)
Multiple episodes of pUEDVT	7 (19)
Profession/sports as provoking factor for pUEDVT	12 (33)
Coexisting symptoms of NTOS	9 (25)
Cervical rib on radiograph	2 (6)
Elongated C7 transverse process on radiograph	3 (8)
Imaging study, no. (%)	
Deviations on duplex ultrasonography (n = 33)	29 (88)
Deviations on venography	36 (100)
Collateralization visible	35 (97)
Baseline score, mean ± SD	
TOS disability scale	4.56 ± 2.46
DLV-DASH	33.34 ± 19.38
SF-12 physical component QOL score	38.17 ± 5.88
SF-12 mental component QOL score	43.45 ± 11.18

DLV-DASH, Dutch language version of the Disability of the Arm Shoulder and Hand; *NTOS,* neurogenic thoracic outlet syndrome; *pUEDVT,* primary upper extremity deep vein thrombosis; *QOL,* quality of life; *SF-12,* short-form 12-item health survey; *TOS,* thoracic outlet syndrome.

the baseline and follow-up scores ($P = .084$). The DLV-DASH score had improved between baseline and 12 months by 22.70 ± 13.58 points ($P < .01$; n = 10). Overall, the TOS disability scale score was 1.97 ± 1.9 and the DLV-DASH score was 16.16 ± 17.4, suggesting the presence of minor disabilities in the arm. Patients' QOL was measured using the adapted VEINES-SYM, VEINES-QOL, and SF-12. The median VEINES-SYM score was 53.90 (interquartile range, 10.54), the median VEINES-QOL score was 54.22 (interquartile range, 13.93), the mean SF-12 mental score was 48.70 ± 10.82, and the mean SF-12 physical score was 47.97 ± 9.02.

Of the 36 patients who had undergone TA-TOD combined with PTA, 83% had reported excellent or good results after >3 months of follow-up using the Derkash method (Table I). Preoperatively, 29 patients (81%) had been limited in their daily life activities (eg, work, sports) because of PTS complaints. After treatment, 27 of these patients (93%) had returned to daily life activities, with 4 of these 27 patients (15%) reporting PTS sequelae during these activities. For two patients, the presence of PTS complaints had limited their normal daily life activities despite surgery. All seven patients without severe limitations preoperatively had returned to daily life activities after surgery.

DISCUSSION

For patients presenting with VTOS symptoms of >3 months' duration, the first step should be to differentiate between McCleery syndrome (stenosis without a history of thrombus) and chronic VTOS due to thrombotic obstruction that had been missed or conservatively treated with anticoagulation. If chronic VTOS is present, essentially two situations are possible: the SCV is totally occluded or the SCV is partially patent but stenotic. In the first situation, contrast venography will show a complete stoppage of flow and extensive collateralization will often be present. Guidelines, which have generally been derived from those for lower extremity venous disease, have recommended conservative treatment for such cases.[3] Some have pursued a policy of TOD and believe that many of these chronically occluded veins will recanalize over time once the extrinsic compression has been relieved.[10,12,20,21] Others have recommended aggressive reconstruction of the occluded SCV in highly symptomatic patients using vein patch placement or venous bypass.[13,22,23] For patients with chronic obstruction, we have preferred paraclavicular TOD surgery with autologous deep venous bypass (superficial femoral vein) of the SCV.

In patients with a partially patent SCV, symptoms will persist despite some degree of luminal patency. Again, for these patients, the guidelines (also generally based on those for lower extremity venous disease) have recommended observation alone, although some clinicians will choose TOD and treatment of residual lesions.[3,13,24] In the case of luminal patency, the treatment options are expanded with endovascular alternatives available to directly treat the stenotic vein segment after TOD surgery. Our algorithm was developed for the treatment of patients with a stenotic, but patent, SCV or a short occlusion that can recanalized using PTA preoperatively. In these patients, some degree of patency of the SCV will allow for TA-TOD and immediate endovascular repair of residual lesions.

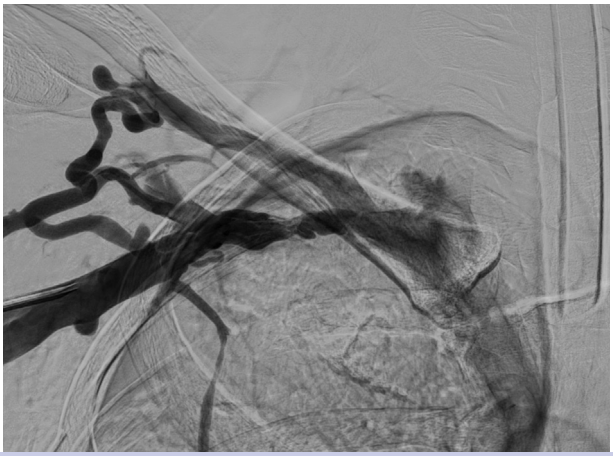

Fig 1. Venogram after transaxillary thoracic outlet decompression (TA-TOD) indicating residual stenosis due to post-thrombotic syndrome (PTS) changes to the subclavian vein (SCV) with synechiae and persistent collateralization.

Patients with chronic VTOS are often considered unsuitable for invasive treatment because of the common occurrence of extensive intravascular residual lesions and the lack of reported results and existing guidelines.[5] Our data have shown that aggressive surgical management of chronic VTOS is effective and led to good results in 83% of our patients. The primary-assisted and secondary patency rates were >90% and comparable with previous reports of treatment of chronic VTOS.[10,12,13,25] Follow-up using the DLV-DASH questionnaire showed significant improvement in the functional outcomes compared with the baseline scores. In all patients, the low DLV-DASH scores, high VEINES-QOL/SYM scores, high SF-12 scores, and high proportion of a return to work and daily activity suggested good QOL and no or minor disability of the affected arm for the vast majority of patients.

Patients with pUEDVT have a significant risk of developing chronic PTS in the presence of treatment delay, unsuccessful initial treatment, or conservative treatment with anticoagulant agents alone.[6,7,9,26,27] This can be explained by the persisting extrinsic repetitive trauma to the SCV and the development of intraluminal changes after the occurrence of pUEDVT.[28] The decreased blood flow through the SCV means the vein is vulnerable for repeat thrombosis, which can result in chronic VTOS and subsequent PTS complaints.[7,9] The causative anatomic factors in patients with VTOS, chronic injury due to thoracic outlet compression, can only be treated by TOD. Therefore, TOD surgery should be considered for all patients with PTS complaints after a history of pUEDVT.

To assess the degree of SCV patency for decision-making during treatment and follow-up, we have preferred venography over venous duplex ultrasonography for several reasons. Ultrasonography is of limited value because of the high rates of false-negative results and limited applicability for lesions or thrombus located behind the collar bone.[29] In addition, using ultrasonography, it can be more difficult to assess the significance of the stenosis, extent of collateral veins, and the exact compression points of the SCV. In our experience, venous duplex ultrasonography has been insufficient to reliably determine the need for TA-TOD and endovascular treatment of the SCV.

Venous damage will be present in most patients with chronic VTOS after TOD surgery. Some of the lesions cannot be completely identified on venography alone, and additional imaging techniques could be nescessery.[30] We perform diagnostic low-pressure balloon inflation in addition to venography to assess the extent of residual lesions directly after decompression in all patients with VTOS.[31] However, no significant residual stenosis was found after TOD surgery using venography and diagnostic balloon inflation in three patients (8%). This could indicate the limitations of the identification of significant residual stenosis using venography and diagnostic balloon inflation alone and leaves room for additional imaging techniques such as intravascular ultrasonography. Another explanation could be that the objective deviations on preoperative venography were caused by the compressive elements that had been removed during TOD surgery.

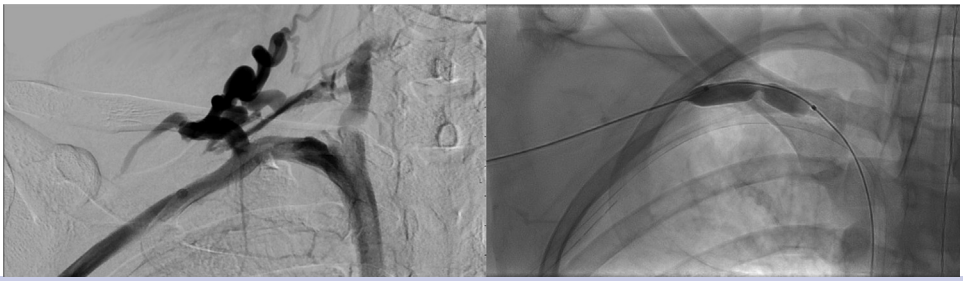

Fig 2. Venogram after transaxillary thoracic outlet decompression (TA-TOD) showing patency of the vein and the extent of residual stenosis, which was difficult to define (**Left**), and diagnostic balloon inflation showing significant residual stenosis (**Right**).

Table III. Surgical and follow-up data (n = 36; 100%)

Variable	No. (%) or mean (range)
Surgical data	
Transaxillary first rib resection performed	36 (100)
Additional pectoral minor tenotomy performed	2 (6)
Intraoperative venography	36 (100)
Significant stenosis	31 (86)
SCV without significant lumen decrease	5 (14)
Diagnostic balloon inflation performed	31 (86)
Significant stenosis (of 31 patients)	30 (97)
Intraoperative PTA successfully performed	33 (92)
8 × 40-mm balloon (of 33 patients)	8 (24)
9 × 20-mm balloon (of 33 patients)	1 (3)
10 × 40-mm balloon (of 33 patients)	16 (49)
12 × 40-mm balloon (of 33 patients)	8 (24)
Additional high-pressure PTA 7 × 20-mm balloon	1 (3)
Additional high-pressure PTA 8 × 20-mm balloon	1 (3)
PTA not performed	3 (8)
Successful repeat PTA after initial TA-TOD + PTA	7 (19)
Complications	5 (13.8)
Brachial plexus injury	0 (0)
Horner syndrome (due to hematoma)	1 (3)
Superficial infection	0 (0)
Postoperative bleeding	3 (8)
Vein rupture (during PTA; n = 33)	1 (3)
Pneumothorax	0 (0)
Scapula alata	0 (0)
Phrenic nerve injury	1 (3)
Mean operative time, minutes (range)	148 (76-244)
Mean ASA score	1.77 (1-3)
Mean time to discharge, days (range)	1.9 (1-6)
Follow-up	
Recurrent PTS symptoms requiring venography	8 (22)
Swelling	7 (88)
Discoloration	2 (25)
Visible collateralization	3 (38)
Pain during exercise	4 (50)
Effort-induced complaints	2 (25)
Severe limitations in daily activities (work/sports)	5 (63)
Mean interval to recurrence, days (range)	111 (31-318)

ASA, American Society of Anesthesiologists; *PTA*, percutaneous transluminal angioplasty; *PTS*, post-thrombotic syndrome; *SCV*, subclavian vein; *TA-TOD*, transaxillary thoracic outlet decompression.

If residual lesions are found, most clinicians will consider ≥50% residual stenosis a significant lesion that should be treated.[17,32,33] However, defining stenosis by the lumen decrease potentially excludes the flow limitation caused by synechiae and septae in a low-pressure system.[34] Future studies are needed to determine the value of the addition of diagnostic low-pressure balloon inflation after venography and to explore the definition of significant stenosis in this low-pressure system.

Residual symptoms were present in 8 of our 36 patients, all of whom were found to have residual stenosis. Three did not respond to recurrent PTA and had had long-segment sinus venous stents placed. Two of the three stents quickly occluded. Although stents placed in a nondecompressed thoracic outlet will perform poorly, the reports have been mixed for stents placed after decompression.[13,17,23,35] We are conservative toward the use of venous stents and believe that stents should only be placed in the SCV as a last resort.

The present study had some limitations. First, routine follow-up venography in symptom-free patients was not used to assess patency during follow-up. We have followed a "low-threshold" policy for venography if any residual complaints are present. For asymptomatic patients, the patency rates were determined by the absence of complaints during the clinical evaluation performed by the vascular surgeon and the absence of complaints on the follow-up questionnaires. Therefore, we have reported the "presumed patency," instead of patency, in our report. Ideally, vein patency should also be routinely determined in asymptomatic patients using venography. However, we believe that routine radiation and contrast exposure in a relatively young and asymptomatic population is unethical for performing follow-up. Second, the baseline TOS disability, DASH, and SF-12 scores were not obtained for all patients. We implemented this follow-up protocol after the publication of the SVS reporting standards for TOS. However, to the best of our knowledge, the present study is the first of chronic patients with VTOS reporting functional outcome using these questionnaires, which allows for the possibility for comparisons with future cohorts of patients with chronic VTOS. Third, as a tertiary referral center for VTOS, we treat patients for whom anticoagulant therapy was unsuccessful without knowing the proportion of patients with improvement after anticoagulant therapy alone. However, several studies have reported the clinical course (sometimes after thrombolysis) of cohorts of patients with pUEDVT treated with anticoagulation alone.[7,9,36-38] Solid evidence for surgical intervention in patients with VTOS does not yet exist, and randomized controlled trials comparing invasive treatment algorithms with anticoagulation therapy alone are needed.

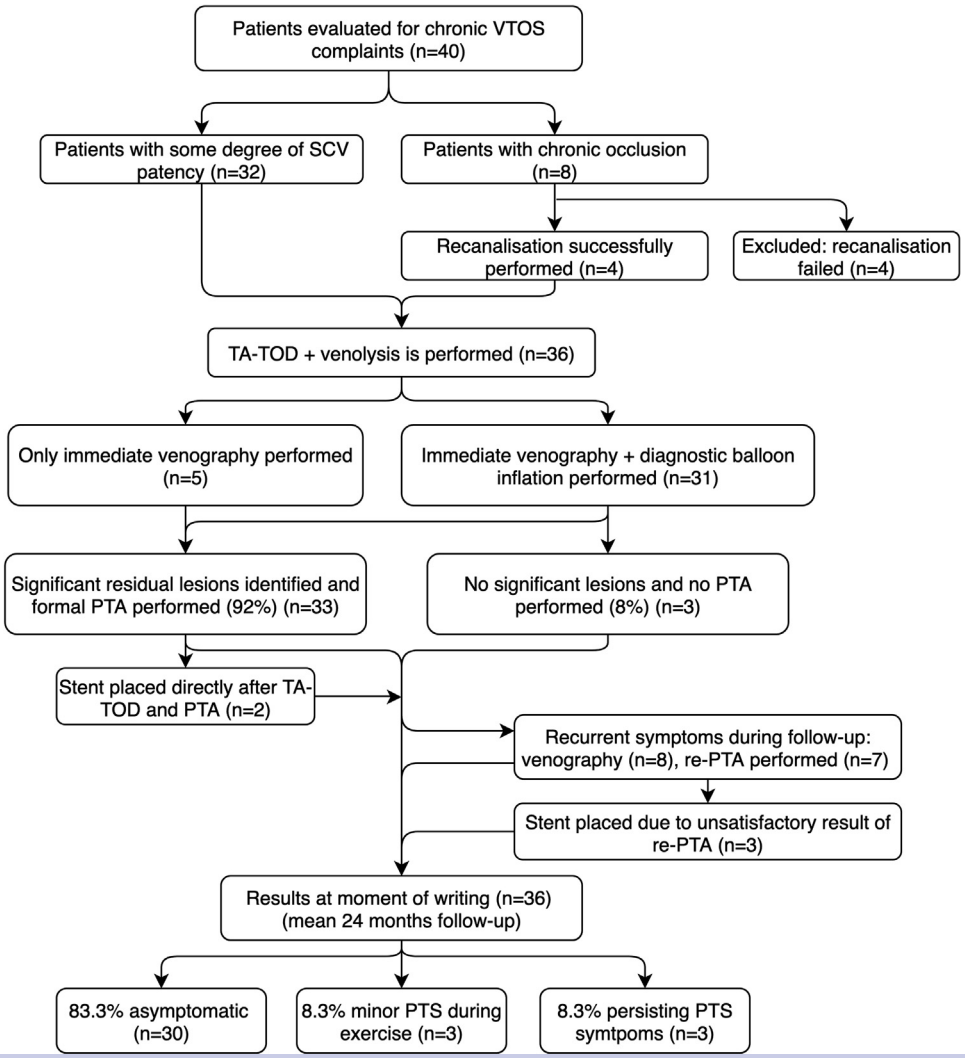

Fig 3. Flowchart of included patients with chronic venous thoracic outlet syndrome (*VTOS*) patients. *PTA,* percutaneous transluminal angioplasty; *PTS,* post-thrombotic syndrome; *SCV,* subclavian vein; *TA-TOD,* trans-axillary thoracic outlet decompression.

AUTHOR CONTRIBUTIONS

Conception and design: NP, AB, JG, JH, BN, KI, MS, JT
Analysis and interpretation: NP, AB, JT
Data collection: NP, JH
Writing the article: NP, AB, KI, JT
Critical revision of the article: NP, AB, JG, JH, BN, KI, MS, JT
Final approval of the article: NP, AB, JG, JH, BN, KI, MS, JT
Statistical analysis: NP
Obtained funding: Not applicable
Overall responsibility: NP

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Submitted Sep 23, 2020; accepted Dec 23, 2020.

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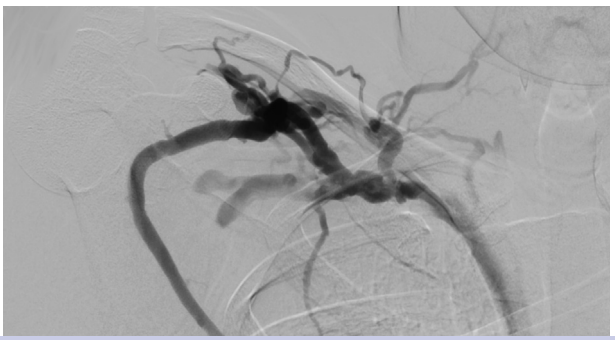
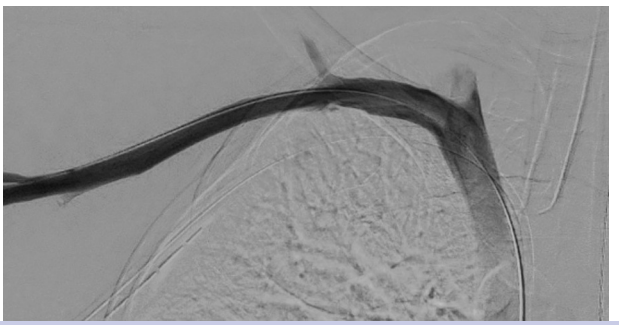
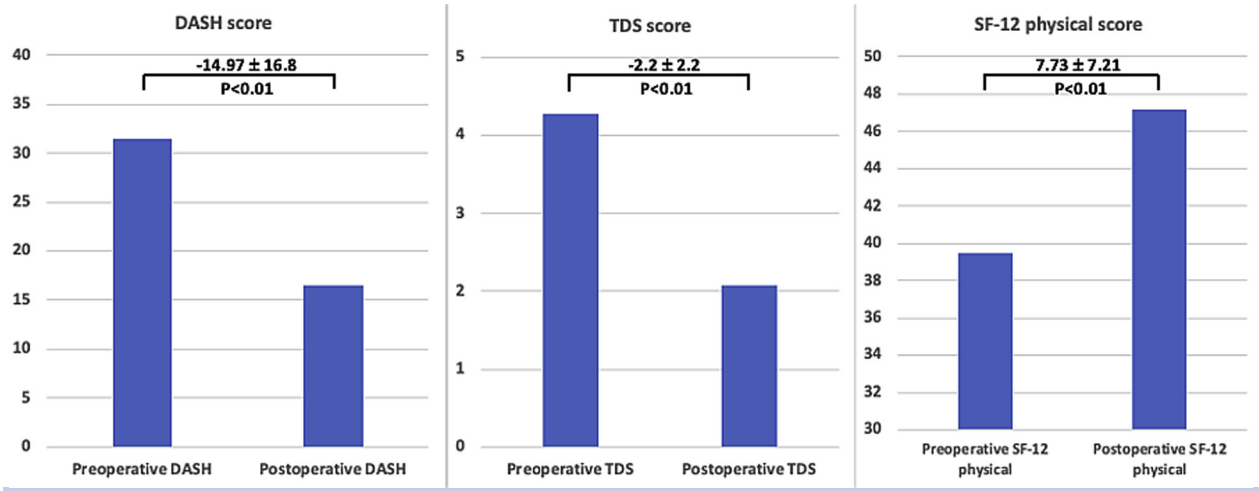


Supplementary Fig 1 (online only). Preoperative venogram showing collateral veins in a patient with chronic venous thoracic outlet syndrome patient.



Supplementary Fig 2 (online only). Venogram after transaxillary thoracic outlet decompression (TA-TOD) and percutaneous transluminal angioplasty (PTA) of the patient shown in Fig 2 showing a patent subclavian vein (SCV) without indications of significant stenosis.



Supplementary Fig 3 (online only). Follow-up scores of the Disability of the Arm Shoulder and Hand (DASH), thoracic outlet syndrome disability scale (TDS), and short-form 12-item (SF-12) physical quality of life (QOL) survey.