

Surgical and endovascular central venous reconstruction combined with thoracic outlet decompression in highly symptomatic patients



Mathew Wooster, MD,^a Blake Fernandez, MD,^b Kelli L. Summers, MD,^c and Karl A. Illig, MD,^b Charleston, SC; Tampa, Fla; and New Orleans, La

ABSTRACT

Background: Subclavian vein stenosis or occlusion at the thoracic outlet is a problem associated with certain anatomic and environmental stresses (venous thoracic outlet syndrome [VTOS]), the presence of central venous catheters, and the high flows associated with arteriovenous (AV) access in the limb. We describe our experience with open and endovascular techniques for restoring patency in highly symptomatic patients.

Methods: A prospectively collected database of patients was queried for patients treated for central venous obstructive disease in the setting of highly symptomatic VTOS and ipsilateral AV access from October 2011 to August 2016.

Results: During the study period, 54 procedures were performed in 53 patients (68% male; mean age, 50.1 years). Indications for operation were venous outflow obstruction in patients with conventional VTOS (n = 19) or costoclavicular junction stenosis associated with ipsilateral dialysis access (n = 34). All patients had significant symptoms of swelling or pain. Eight patients underwent on-table pharmacomechanical thrombolysis for acute occlusion. All patients underwent costoclavicular junction decompression, 48 by infraclavicular first rib resection and 5 by claviclectomy; 6 patients underwent sternoclavicular rotation (Molina procedure) in addition to rib resection for further exposure. Surgical reconstruction of the vein was employed in 18 patients (33%); 9 underwent interposition grafting, 1 had jugular turnaround, and 8 had patch angioplasty. The one patient undergoing two procedures suffered acute occlusion after patch repair followed by jugular turnaround. Four patients underwent surgical reconstruction after thrombolysis. Endovascular procedures were performed in 36 patients (67%); 23 underwent venous angioplasty alone, and 13, all with hemodialysis access-associated stenosis, underwent stenting. Mean operative time was 135 (± 63.5) minutes, and mean estimated blood loss was 238 (± 261) mL. Median length of stay was 4 days. Perioperative complications were noted in 14 (26.4%) patients, including wound complications (n = 6), cardiac complications (n = 4), reocclusion (n = 3), and hemothorax requiring chest tube placement (n = 1) in a patient undergoing on-table thrombolysis. Mean follow-up was 13.6 (0.6-58.5) months. Initial clinical symptom relief was experienced in 100% of patients at the time of hospital discharge. During follow-up, 5 (9.4%) patients developed recurrent symptoms, 6 (11.3%) had reocclusion of the central system, and 16 (30.2%) required reintervention for restenosis, all but 2 in patients with ipsilateral hemodialysis access. Mean time to reintervention was 134 (± 285) days.

Conclusions: Given our decision-making threshold, both open and endovascular procedures are associated with relatively low morbidity and high efficacy for treatment of central venous occlusion in both symptomatic VTOS and AV access-associated subclavian vein disease. Restenosis is common in patients with a patent ipsilateral hemodialysis access. (J Vasc Surg: Venous and Lym Dis 2019;7:106-12.)

Keywords: Thoracic outlet; Rib resection; Paget Schroetter; McCleery syndrome; Effort thrombosis; Central venous stenosis

Stenosis or occlusion of the subclavian vein at the anterior portion of the thoracic outlet is a problem associated with certain anatomic and environmental factors (venous thoracic outlet syndrome [VTOS]), injury due to indwelling central venous catheters, and high venous flow created by arteriovenous (AV) access for dialysis.

This area is unusually vulnerable because of the external compression produced by the junction of the first rib and clavicle (costoclavicular junction [CCJ]).

The classic problem created by venous injury at the CCJ is VTOS from either intermittent positional obstruction (McCleery syndrome) or frank thrombosis

From the Division of Vascular Surgery, Department of Surgery, Medical University of South Carolina, Charleston^a; the Division of Vascular and Endovascular Surgery, USF Health Morsani College of Medicine, Tampa^b; and the Department of Surgery, LSU Health Sciences Center, New Orleans.^c

Author conflict of interest: none.

Presented at the Annual Spring Meeting of the Vascular and Endovascular Surgery Society, San Diego, Calif, May 31-June 3, 2017.

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

Correspondence: Mathew Wooster, MD, Medical University of South Carolina, Strom Thurmond Bldg, 114 Doughty St, BM 654E, MSC 295, Charleston, SC 29425 (e-mail: woosterm@musc.edu).

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

Copyright © 2018 by the Society for Vascular Surgery. Published by Elsevier Inc. <https://doi.org/10.1016/j.jvs.2018.07.019>

(Paget-Schroetter syndrome, effort thrombosis). Whereas this has been recognized for more than a century and a half, it is only in the past decade or so that similar lesions in the setting of ipsilateral AV access have been thought to be a form of VTOS as well.¹⁻⁴ Although the inevitable extrinsic compression caused by anatomic stress in this area is of no clinical relevance in most people, adding the high flow (a liter or more per minute) that results from AV access is believed to create a vicious circle of turbulence and intimal hyperplasia, thus re-creating the damage seen in classic VTOS. The importance of this observation lies in the fact that first rib resection is required to “cure” VTOS^{2,5-7} and thus that the same bone decompression will likely be required to “cure” subclavian vein disease at the CCJ in patients with ipsilateral AV access.

The optimal method for management of central venous disease remains to be elucidated. As such, we report our management of a cohort of patients with emphasis on the outcomes of open vs endovascular management of venous occlusive disease with combined bone decompression.

METHODS

Data were derived from a retrospective review, approved by our Institutional Review Board, of all patients whose subclavian veins were directly treated for CCJ stenosis in addition to bone decompression of the CCJ. Patients’ consent was not obtained because of the exempt status of the retrospective review. This was a review of a prospectively maintained database of all those treated from October 2011 to August 2016 at our institution, dating from the time of arrival of the senior author. All diagnoses were described according to the Society for Vascular Surgery reporting standards paper,⁸ although most patients were treated before its publication.

Two groups of patients were treated and analyzed: those with conventional VTOS and those with AV access-associated subclavian vein injury. Patients with VTOS are treated with bone decompression and thrombolytic therapy (unless contraindicated), with treatment of underlying venous lesions selectively based subjectively on degree of relief of swelling after lytic therapy alone. All AV access patients had repetitive attempts at endovascular therapy alone for access dysfunction with evidence of recurrence of stenosis at the CCJ on angiography before being referred for decompression. Patients with swelling alone were treated with arm elevation and compression therapy distal to the AV access before being deemed candidates for decompression.

All patients in this series were highly symptomatic, defined as having enough swelling or pain to interfere with daily living or dialysis access. All underwent bone decompression of the anterior portion of the thoracic outlet, with either first rib resection or claviclectomy.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study of a prospectively maintained database
- **Take Home Message:** A review was conducted of patients treated from October 2011 to August 2016 with bone resection and adjunctive open or endovascular techniques for central venous obstruction (CVO) in the setting of highly symptomatic venous thoracic outlet syndrome (VTOS) or severe swelling with an ipsilateral arteriovenous (AV) access. Fifty-four procedures, 20 for VTOS and 34 for CVO with an ipsilateral AV access performed in 53 patients, had a 100% technical success, 100% symptom relief before discharge, 1 (1.9%) death, and 14 (26.4%) perioperative complications. At a mean of 13.6 months, 9.4% developed recurrent symptoms (one central venous occlusion), and 30.2%, mostly with AV access, had reintervention.
- **Recommendation:** Bone decompression for CVO with adjunctive endovascular or open techniques is a reasonable option in patients with symptomatic VTOS or CVO with ipsilateral AV access.

First rib resection and surgical exposure of the vein, when performed, were primarily accomplished through the infraclavicular approach,^{9,10} with first interspace sternotomy and cephalad rotation of the intact sternoclavicular junction upward when needed.¹⁰⁻¹² Claviclectomy was employed in a minority of patients when it was deemed more appropriate for the given anatomy.^{2,11} Claviclectomy is primarily reserved for reoperative fields or patients in whom first rib resection is thought to be otherwise higher risk as well as in cases of primarily central exposure. Venous reconstructive technique was at the surgeon’s discretion, with endovascular intervention generally preferred and stenting reserved for >50% residual lesions after angioplasty. Open reconstructive techniques were generally reserved for those patients failing to respond to endovascular interventions or who were not candidates for endovascular techniques (ie, total occlusion unable to be crossed). Open repair techniques included interposition grafting, internal jugular turn-down, and patch angioplasty. Postoperatively, all VTOS patients were maintained on anticoagulation, given their deep venous thrombosis diagnosis. Dialysis access-associated CCJ patients were not routinely anticoagulated. Patients treated with an open reconstruction of the axillosubclavian vein with adjunctive endovascular intervention more central or more peripheral to the repair site were considered “open” for the purposes of comparison.

Follow-up was performed according to our clinical protocol. Patients are seen at 3 weeks for wound checks, then for clinical examination and ultrasound evaluation

at 3 months and approximately 6-month intervals afterward. Patency of our intervention is based on either high-quality duplex ultrasound or venography or fistulography. Technical success was defined as venous patency at completion of the procedure; clinical success was defined as improvement in swelling or access dysfunction.

Statistical analysis was performed using Microsoft Excel (Microsoft, Redmond, Wash). Categorical variables were analyzed by the χ^2 test, whereas continuous variables were compared by Student *t*-test.

RESULTS

A total of 54 procedures were performed in 53 patients (68% male; mean age, 50.1 years; Table I). Nineteen patients (20 procedures) had highly symptomatic VTOS; 34 had CCJ stenosis associated with ipsilateral dialysis access (Table II; Supplementary Table, online only).

Twelve patients, all in the VTOS group, presented with acute thrombotic occlusion. Eight underwent on-table pharmacomechanical thrombolysis for acute presentation, whereas four underwent preoperative thrombolysis followed by operation.

All patients underwent CCJ decompression, all as the initial procedure. The majority (*n* = 42) underwent infraclavicular first rib resection alone; the remainder (*n* = 11) had claviclectomy or sternoclavicular junction rotation by partial sternotomy (alone or in addition to first rib resection; Table III).

Endovascular procedures were performed in 36 cases (67%); 23 underwent venous angioplasty alone, whereas 13, all with hemodialysis access-associated stenosis, underwent stenting. Eighteen surgical reconstructions were performed in 17 patients (33%); 9 underwent interposition grafting, 8 had patch angioplasty, and 1 had jugular turn-down (after failure of patch angioplasty). Mean operative time was 135 (\pm 63.5) minutes, with mean estimated blood loss of 244 (\pm 261) mL (Table IV).

Perioperative (30-day) complications were noted in 14 (26.4%) patients, including wound complications (*n* = 6), cardiac complications (non-ST elevation myocardial infarction [*n* = 2], atrial fibrillation with rapid ventricular response [*n* = 2]), reocclusion (*n* = 3), and hemothorax requiring chest tube placement (*n* = 1) in a patient

Table I. Demographics

Patient	Total	Open	Endovascular
No.	53	18	35
Age, years, mean (range)	50.1 (15-82)	42.7 (18-70)	53.4 (15-82)
Sex, male	36 (68%)	13 (76%)	25 (64%)
Dialysis	34	6	28

There was a male predominance and an expected wide range of ages, given the disparate indications for repair.

Table II. Indication for procedure by repair type

Indication	Total (N = 54)	Open (n = 18)	Endovascular (n = 35)
VTOS	20	12	7
CCJ stenosis with HD access	34	6	28

CCJ, Costoclavicular junction; HD, hemodialysis; VTOS, venous thoracic outlet syndrome.
Nearly twice as many patients underwent endovascular vs open reconstruction, with open more common for VTOS.

undergoing on-table thrombolysis. Median length of stay was 4 (1-19) days. There was one 30-day death secondary to ischemic colitis requiring subtotal colectomy with perioperative cardiac arrest and family withdrawal of care.

Clinical symptom relief was experienced in 100% of patients before discharge. At mean follow-up of 13.4 (range, 0.6-58.5) months, 5 (9.4%) patients developed recurrent symptoms, 6 (11.3%) had reocclusion of the central system, and 16 (30.2%) required reintervention (*n* = 11 for restenosis, *n* = 5 for wound complications), all but 2 in patients with ipsilateral hemodialysis access (Fig). Mean time to reintervention was 134 (\pm 285) days (Table V).

Looking at those patients treated for classic VTOS vs those treated for AV access dysfunction (Table VI), we see that they are younger overall (mean 30.9 vs 61 years; *P* = .0001) with less male predominance (58% vs 74%; *P* = .2). Operative details were not significantly different, but treatment for VTOS was associated with a higher complication rate (42% vs 17.6%; *P* = .05), accounted for by bleeding complications (three), occlusion (three), superficial infection (one), and cardiac complications (one). The complications in those with AV access included infection (two), cardiac problems (two), occlusion (one), and ischemic colitis leading to death (one). During follow-up, the reintervention rates were similar. Reinterventions in the VTOS group, however, tended to be performed earlier after acute occlusions, whereas AV

Table III. Surgical technique

Decompression technique	Total (N = 53)	Open (n = 18)	Endovascular (n = 35)
First rib resection	42	8	34
First rib resection with SCJ rotation	5	5	0
Claviclectomy	3	2	1
First rib resection and claviclectomy	2	2	0
First rib resection with SCJ rotation and claviclectomy	1	1	0

SCJ, Sternoclavicular junction.
A majority of patients required first rib resection alone, whereas a minority required claviclectomy, SCJ rotation, or a combination thereof.

Table IV. Operative details

Operative variable	Total (N = 53)	Open (n = 18)	Endovascular (n = 35)
Operative time, minutes	135.3 (50-300)	181.5 (120-260)	117.0 (50-300)
Blood loss, mL	238.9 (10-1200)	377.6 (30-800)	173.5 (10-1200)

Values are reported as mean (range).
 Operative time and blood loss were significantly increased in the open reconstruction cohort ($P < .05$).

access patients more commonly required later reintervention for restenosis. On latest follow-up, three VTOS patients had occlusion of the central system, with one patient remaining asymptomatic and two with recurrent swelling. AV access patients suffered three access occlusions, and three patients had persistent although improved arm swelling despite that duplex ultrasound demonstrated patency (and continued to use their access on the affected arm).

DISCUSSION

It is known that the subclavian vein is prone to injury at the CCJ because of the bone compression that occurs at this point. It seems to be a reasonable hypothesis that the vein at this same location may also be prone to stenosis in patients with AV access because of the very high flow past this area, creating a positive feedback loop of turbulence and further stenosis. We view this as a form of VTOS and, as such, follow a similar treatment protocol.¹³ Traditionally accepted therapy for classic VTOS is the restoration of venous patency by means of catheter-directed thrombolytic therapy followed by bone decompression. In classic VTOS, lesser degrees of residual stenosis are believed likely to remodel,^{14,15} but if the high flow rates seen in patients with AV access are present, this may not be the case. We thus have evolved to a policy of aggressive venous reconstruction in two classes of patients: those with classic VTOS who

are highly symptomatic (including those with rethrombosis after thrombolysis within the same hospitalization) and those with AV access-associated VTOS who present with swelling or fistula dysfunction.

Open operations are typically seen as “highly invasive,” “last resort,” and reserved for those who have failed to respond to endovascular interventions. Surgical options include extra-anatomic bypass to the internal jugular vein,¹⁶⁻¹⁸ subclavian or axillary vein to right atrial bypass,^{11,19,20} and superior vena cava or innominate reconstruction using vein or prosthetic graft for more proximal obstructions.²¹ Although these procedures carry the increased risks of major surgery, the patency rates reported are far superior to endovascular treatments for central lesions, with 80% to 90% patency rates at 1 year.^{3,16-19,22} Directly comparing open reconstruction with percutaneous transluminal angioplasty (PTA), one study found that the long-term success rate was greater in the open procedure compared with a single PTA; however, in comparison with repeated angioplasty, the success rate was comparable to that of the open procedures.¹⁶ Most endovascular procedures have not included decompression of the CCJ, so theoretical success is probably underestimated. Although it is difficult to draw direct comparisons between our highly focused cohort (central stenosis with CCJ involvement) and the majority of the literature, which mixes central with more peripheral disease, the high technical success and patency rates at >1 year at a minimum suggest an important role of bone decompression as an adjunct to whatever method is used to restore central venous flow.

In this series of patients who all underwent bone decompression followed by either endovascular or open venous reconstruction, we experienced a technical success rate of 100% with associated symptom relief and low rates of reocclusion or recurrence of symptoms (9.4% and 11.3%, respectively, overall, and just one central reocclusion in the AV access subset). This is a respectable outcome compared with the current standard proposed by the National Kidney Foundation Kidney Disease Outcomes Quality Initiative guidelines of endovascular therapy alone for AV access failure, for which technical success rate of PTA ranges from 70% to 90%, with highly variable patency rates in the literature. Six-month primary and cumulative patency ranges are 23% to 63% and 29% to 100%, respectively. Twelve-month primary and cumulative patency ranges are 13% to 100%.^{13,22-28} Again, patency data in the literature are largely mixed

Complications over Follow Up

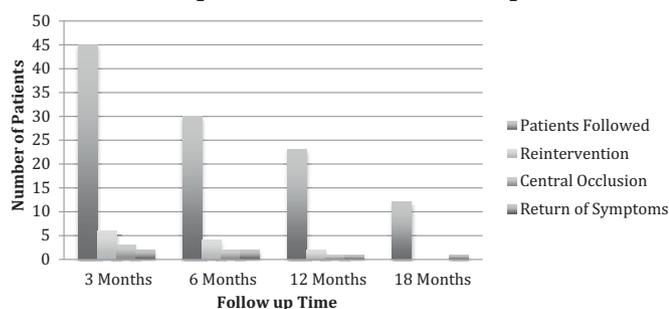


Fig. Outcomes during the course of follow-up. The number of patients remaining at risk and in follow-up at the 3-, 6-, 12-, and 18-month time points is seen along with the number of patients in each time frame experiencing return of symptoms, reintervention, or reocclusion. An additional four patients underwent reintervention at outside facilities at unspecified times and therefore are not displayed in this figure.

Table V. Postoperative outcomes by reconstruction technique

Follow-up	Total (N = 53)	Open (n = 18)	Endovascular (n = 35)
Days	408 (17-1754)	312 (29-1754)	436 (17-1455)
Symptom relief	45 (84.9)	15 (83.3)	32 (91.4)
Symptom recurrence	5 (9.4)	2 (11.1)	3 (8.6)
Central occlusion	6 (11.3)	4 (22.2)	2 (5.7)
Reintervention	16 (30.2)	8 (44.4)	8 (22.9)
Mean time to reintervention, days	133.8 ± 284.9	21.4 ± 36.9	262.3 ± 395.3

Categorical variables are presented as number (%). Continuous variables are presented as mean (range) or mean ± standard deviation. The majority of patients experienced clinical relief in long-term follow-up. Reintervention rates were similar although at different time points for open and endovascular repairs.

between truly access-related stenosis and central stenosis, making true comparison a challenge.

In this cohort of patients, we experienced a 100% level of clinical success with resolution of swelling in VTOS patients and continued or resumed use of the ipsilateral access in hemodialysis patients at time of discharge. This was not without complications, particularly with an associated increase in wound healing and bleeding complications. This may suggest a value in delayed decompression after completed thrombolysis and an initial period of thrombolysis. Importantly, there was recurrence of swelling in 9.4% of patients during the follow-up period, which is lower than the reocclusion rate, suggesting a benefit to bone decompression with or without re-establishment of venous patency.

Focusing on VTOS, these results are in line with what has previously been reported. Studies assessing anticoagulation as the sole therapy observed high rates of residual venous obstruction and persistence of symptoms⁴ and post-thrombotic syndrome in up to 75%.²⁹ Decompressing the thoracic outlet before stenting the subclavian vein is also recognized as a critical step in treatment of VTOS.³⁰⁻³² Reviewing retrospective case

series, Lugo et al³³ found that first rib resection after thrombolysis increases the likelihood of permanent symptom relief and long-term patency. A combination of thrombolysis and decompression surgery still does not address the residual intrinsic lesions and stenosis of the subclavian vein, which increases the risk of rethrombosis.^{6,34,35} Approaches to treatment include PTA, stenting, open venous reconstruction, and a combination of techniques. Although it has been previously recommended that PTA be delayed after decompression,^{5,34,36} Schneider et al⁷ demonstrated that PTA performed after decompression intraoperatively is a successful algorithm with 1-year primary and secondary patency rates of 92% and 96%, respectively. Molina et al³⁷ have also had success with vein patch angioplasty of the stenotic segment of the vein immediately after decompression. Their 97 patients had 100% patency postoperatively with a <10% reintervention rate.

CCJ stenosis in AV access does appear to function similarly to classic descriptions of VTOS. A higher rate of endovascular reintervention including the need for stent placement can be expected for AV access patients, however, presumably because of the increased flow (and turbulence) caused by the AV connection. Both cohorts of

Table VI. Postoperative outcomes by clinical indication

Patient	All	VTOS	AV access
No.	53	19	34
Age, years, mean (range)	50.1 (15-82)	30.9 (15-70)	61 (30-82)
Sex, male	68%	58%	74%
Length of surgery, minutes	135.3	145.4	129.4
Estimated blood loss, mL	239	228	245
Length of stay, median days	4	5	4
Follow-up, days	408	486	357
Reinterventions	16	5	11
Time to reintervention, days	134	20	232
Open reconstruction	18	12	6
Endovascular reconstruction	35	7	14

AV, Arteriovenous; VTOS, venous thoracic outlet syndrome.

There were no significant differences in outcomes between VTOS patients and AV access patients except for the timing of reintervention.

patients do well in the long term, and aggressive early rib resection can be performed safely with great benefit to the patient.

CONCLUSIONS

Central venous occlusion in the setting of significant symptoms in patients with and without AV access responds well to bone decompression followed by aggressive attempts at correction of the underlying subclavian vein occlusion. In patients with classic VTOS, early failures can occur but longer term outcome is excellent, whereas those with AV access-associated VTOS tend to present with later restenosis. Both open and endovascular procedures can be performed with relatively low morbidity and high efficacy for treatment of central venous occlusion.

AUTHOR CONTRIBUTIONS

Conception and design: MW, KI
Analysis and interpretation: MW, KI
Data collection: MW, BF, KS
Writing the article: MW, KS, KI
Critical revision of the article: MW, BF, KS, KI
Final approval of the article: MW, BF, KS, KI
Statistical analysis: MW, KI
Obtained funding: Not applicable
Overall responsibility: MW

REFERENCES

1. MacRae JM, Ahmed A, Johnson N, Levin A, Kiaii M. Central vein stenosis: a common problem in patients on hemodialysis. *ASAIO J* 2005;51:77-81.
2. Glass C, Dugan M, Gillespie D, Doyle A, Illig K. Costoclavicular venous decompression in patients with threatened arteriovenous hemodialysis access. *Ann Vasc Surg* 2011;25:640-5.
3. Gradman WS, Bressman P, Sernaque JD. Subclavian vein repair in patients with an ipsilateral arteriovenous fistula. *Ann Vasc Surg* 1994;8:549-56.
4. Illig KA, Gabbard W, Calero A, Bailey C, Shames M, Armstrong P, et al. Aggressive costoclavicular junction decompression in patients with threatened AV access. *Ann Vasc Surg* 2015;29:698-703.
5. Angle N, Gelabert HA, Farooq MM, Ahn SS, Caswell DR, Freischlag JA, et al. Safety and efficacy of early surgical decompression of the thoracic outlet for Paget-Schroetter syndrome. *Ann Vasc Surg* 2001;15:37-42.
6. Kreienberg PB, Chang BB, Darling RC 3rd, Roddy SP, Paty PS, Lloyd WE, et al. Long-term results in patients treated with thrombolysis, thoracic inlet decompression, and subclavian vein stenting for Paget-Schroetter syndrome. *J Vasc Surg* 2001;33(Suppl):S100-5.
7. Schneider DB, Dimuzio PJ, Martin ND, Gordon RL, Wilson MW, Laberge JM, et al. Combination treatment of venous thoracic outlet syndrome: open surgical decompression and intraoperative angioplasty. *J Vasc Surg* 2004;40:599-603.
8. Illig KA, Donahue D, Duncan A, Freischlag J, Gelabert H, Johansen K, et al. Reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome. *J Vasc Surg* 2016;64:e23-35.
9. Siracuse JJ, Johnston PC, Jones DW, Gill HL, Connolly PH, Meltzer AJ, et al. Infraclavicular first rib resection for the treatment of acute venous thoracic outlet syndrome. *J Vasc Surg Venous Lymphat Disord* 2015;3:397-400.
10. Knott AW, Cassivi SD, Gloviczki P. Open central venous reconstruction: technique, advantages, and pitfalls of partial sternotomy with infraclavicular resection of the first rib. *Perspect Vasc Surg Endovasc Ther* 2008;20:214-9.
11. Glass C, Maevsky V, Massey T, Illig K. Subclavian vein to right atrial appendage bypass without sternotomy to maintain arteriovenous access in patients with complete central vein occlusion, a new approach. *Ann Vasc Surg* 2009;23:465-8.
12. Babadjanov J, Bernstein R, Kirksey L. Surgical reconstruction of central venous obstruction in salvaging upper extremity dialysis accesses. *J Vasc Access* 2017;18:e39-41.
13. Beathard GA. Percutaneous transvenous angioplasty in the treatment of vascular access stenosis. *Kidney Int* 1992;42:1390-7.
14. Taylor JM, Telford RJ, Kinsella DC, Watkinson AF, Thompson JF. Long-term clinical and functional outcome following treatment for Paget-Schroetter syndrome. *Br J Surg* 2013;100:1459-64.
15. Guzzo JL, Chang K, Demos J, Black JH, Freischlag JA. Pre-operative thrombolysis and venoplasty affords no benefit in patency following first rib resection and scalenectomy for subacute and chronic subclavian vein thrombosis. *J Vasc Surg* 2010;52:658-62; discussion: 662-3.
16. Wisselink W, Money SR, Becker MO, Rice KL, Ramee SR, White CJ, et al. Comparison of operative reconstruction and percutaneous balloon dilatation for central venous obstruction. *Am J Surg* 1993;166:200-4; discussion: 204-5.
17. Bhatia DS, Money SR, Ochsner JL, Crockett DE, Chatman D, Dharamsey SA, et al. Comparison of surgical bypass and percutaneous balloon dilatation with primary stent placement in the treatment of central venous obstruction in the dialysis patient: one-year follow-up. *Ann Vasc Surg* 1996;10:452-5.
18. Mickley V. Stent or bypass? Treatment results in benign central venous obstruction. *Zentralbl Chir* 2001;126:445-9.
19. El-Sabroun RA, Duncan JM. Right atrial bypass grafting for central venous obstruction associated with dialysis access: another treatment option. *J Vasc Surg* 1999;29:472-8.
20. Suliman A, Greenberg JI, Angle N. Surgical bypass of symptomatic central venous obstruction for arteriovenous fistula salvage in hemodialysis patients. *Ann Vasc Surg* 2008;22:203-9.
21. Doty JR, Flores JH, Doty DB. Superior vena cava obstruction: bypass using spiral vein graft. *Ann Thorac Surg* 1999;67:1111-6.
22. Haug M, Popescu M, Vonderbank E, Kruger G. Reconstruction of mediastinal veins in same side dialysis shunt. *Zentralbl Chir* 1999;124:2-6.
23. Glanz S, Gordon DH, Lipkowitz GS, Butt KM, Hong J, Sclafani SJ. Axillary and subclavian vein stenosis: percutaneous angioplasty. *Radiology* 1988;168:371-3.
24. Kovalik EC, Newman GE, Suhocki P, Knelson M, Schwab SJ. Correction of central venous stenoses: use of angioplasty and vascular Wallstents. *Kidney Int* 1994;45:1177-81.
25. Quinn SF, Schuman ES, Demlow TA, Standage BA, Ragsdale JW, Green GS, et al. Percutaneous transluminal angioplasty versus endovascular stent placement in the treatment of venous stenoses in patients undergoing hemodialysis: intermediate results. *J Vasc Interv Radiol* 1995;6:851-5.
26. Dammers R, de Haan MW, Planken NR, van der Sande FM, Tordoir JH. Central vein obstruction in hemodialysis patients: results of radiological and surgical intervention. *Eur J Vasc Endovasc Surg* 2003;26:317-21.
27. Surowiec SM, Fegley AJ, Tanski WJ, Sivamurthy N, Illig KA, Lee DE, et al. Endovascular management of central venous

- stenoses in the hemodialysis patient: results of percutaneous therapy. *Vasc Endovascular Surg* 2004;38:349-54.
28. Bakken AM, Protack CD, Saad WE, Lee DE, Waldman DL, Davies MG. Long-term outcomes of primary angioplasty and primary stenting of central venous stenosis in hemodialysis patients. *J Vasc Surg* 2007;45:776-83.
 29. Joffe HV, Goldhaber SZ. Upper-extremity deep vein thrombosis. *Circulation* 2002;106:1874-80.
 30. Bjarnason H, Hunter DW, Crain MR, Ferral H, Miltz-Miller SE, Wegryn SA. Collapse of a Palmaz stent in the subclavian vein. *AJR Am J Roentgenol* 1993;160:1123-4.
 31. Meier GH, Pollak JS, Rosenblatt M, Dickey KW, Gusberg RJ. Initial experience with venous stents in exertional axillary-subclavian vein thrombosis. *J Vasc Surg* 1996;24:974-81; discussion: 981-3.
 32. Urschel HC, Patel AN. Paget-Schroetter syndrome therapy: failure of intravenous stents. *Ann Thorac Surg* 2003;75:1693-6; discussion: 1696.
 33. Lugo J, Tanious A, Armstrong P, Back M, Johnson B, Shames M, et al. Acute Paget-Schroetter syndrome: does the first rib routinely need to be removed after thrombolysis? *Ann Vasc Surg* 2015;29:1073-7.
 34. Machleder HI. Evaluation of a new treatment strategy for Paget-Schroetter syndrome: spontaneous thrombosis of the axillary-subclavian vein. *J Vasc Surg* 1993;17:305-15; discussion: 316-7.
 35. Rutherford RB. Primary subclavian-axillary vein thrombosis: the relative roles of thrombolysis, percutaneous angioplasty, stents, and surgery. *Semin Vasc Surg* 1998;11:91-5.
 36. Azakie A, McElhinney DB, Thompson RW, Raven RB, Messina LM, Stoney RJ. Surgical management of subclavian-vein effort thrombosis as a result of thoracic outlet compression. *J Vasc Surg* 1998;28:777-86.
 37. Molina JE, Hunter DW, Dietz CA. Paget-Schroetter syndrome treated with thrombolytics and immediate surgery. *J Vasc Surg* 2007;45:328-34.

Submitted Jan 8, 2018; accepted Jul 31, 2018.

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

Supplementary Table (online only). List of individual patients and procedures with complications and reinterventions

Patient	Indication	Procedure	Complication	Follow-up, days	Reintervention	Days from surgery to intervention
1	AV access	Right claviculectomy, innominate vein reconstruction with jugular vein, stage 1 basilic vein transposition, venography with venous stent, and right femoral artery tunneled catheter placement		160		
2	AV access	FRR, SCV stent, 14 mm		NA		
3	AV access	Claviculectomy, FRR, graft thrombectomy, SCV-innominate bypass with 12-mm PTFE	Infection, thrombosis, explantation	554	Hematoma evacuation, washout and vacuum dressing placement, eventual explantation for infection	4
4	AV access	FRR, SCV stent, 12 mm		1443		
5	AV access	FRR, innominate stent, 14 mm		392		
6	AV access	FRR, SCV stent, 14 mm		48		
7	AV access	FRR, SCV stent, 14 mm		28	PTA	28
8	AV access	Claviculectomy, SCV stent, 10 mm, stage 1 basilic vein transposition, DRIL		574		
9	VTOS	FRR, bovine patch, PTA		186		
10	AV access	FRR, SCV stent, 14 mm		734		
11	AV access	FRR, SCV stent, 10 mm, SCV bovine patch, AVF revision		NA		
12	AV access	FRR, SCV PTA, 14 mm		271	Fistula revision and SCV 10-mm stent	74
13	VTOS	FRR, vein patch with external jugular vein	Reocclusion	88	AngioJet, stenting with 8-mm stent	0
14	AV access	FRR, SCV stent, 10 mm, pacemaker lead extraction		324		
15	AV access	FRR, innominate stent, 14 mm		258	PTA	OSH
16	AV access	FRR, SCV PTA, 12 mm		307		
17	AV access	FRR, SCV PTA, 12 mm		576		
18	AV access	FRR, SCV PTA, 12 mm		126	PTA	126
19	VTOS	FRR, SCV PTA, 12 mm		505		
20	AV access	FRR, SCV PTA, 12 mm	Wound infection	54	I&D of abscess	OSH
21	AV access	FRR, innominate stent, 12 mm		NA		
22	AV access	Transaxillary FRR, SCV stent, 10 mm		456		
23	AV access	FRR, SCV PTA, 10 mm		238		
24	AV access	FRR, SCV stent, 14 mm		399		
25	AV access	FRR, innominate stent, 14 mm, Accuseal placement		301	Conversion to HeRO (Hemodialysis Reliable Outflow graft) 3/17/16	301
26	AV access	FRR, SCV PTA, 12 mm, AVG creation	Ischemic colitis, subtotal colectomy, cardiac arrest, CMO, died 7/9/15	17		

(Continued on next page)

Supplementary Table (online only). Continued.

Patient	Indication	Procedure	Complication	Follow-up, days	Reintervention	Days from surgery to intervention
27	AV access	FRR, SCV PTA, 12 mm		396	PTA × 6, additional stenting × 2	OSH
28	AV access	FRR, SCV stent, 13 mm		93		
29	AV access	FRR, SCV stent, 12 mm		123		
30	AV access	FRR/Molina procedure, SCV-SCV bypass with femoral vein	NSTEMI	95		
31	AV access	Claviclectomy, SCV-innominate bypass with panel graft made from 6-mm Artegraft		48	Wound revision	48
32	AV access	FRR, SCV PTA, 12 mm		NA		
33	AV access	FRR, claviclectomy, cephalic-SCV bypass with 6-mm PTFE		29	PTA	OSH
34	VTOS	FRR, SCV PTA, 12 mm		1455		
35	VTOS	FRR, Molina with partial sternotomy, thrombolysis, thrombectomy, GSV vein patch		1754		
36	VTOS	FRR, SCV patch with GSV		557		
37	AV access	FRR, thrombolysis, SCV PTA, 10 mm	Hematoma requiring evacuation, occlusion on POD 2, return to OR	NA		
38	VTOS	FRR, thrombolysis, SCV PTA, 10 mm		370		
39	VTOS	FRR, AngioJet, SCV PTA, 8 mm		1086		
40	AV access	FRR, SCV PTA, 10 mm, AVF revision		440		
41	VTOS	FRR, AngioJet, SCV PTA, 8 mm	Hemothorax requiring chest tube	669		
42	VTOS	FRR, SCV PTA, 8 mm		468		
43	VTOS	FRR, SCV PTA, 10 mm		473		
44	VTOS	FRR, Molina, SCV patch with bovine pericardium		385		
45	VTOS	FRR, Molina, innominate-SCV bypass with spiral vein graft with GSV, SCV PTA, 10 mm	SSI, dehiscence of sternal wound requiring reoperation with hematoma evacuation and reclosure	50	PTA/stent	5
46	VTOS	FRR, attempted thrombolysis, SCV patch with GSV	POD 2 rethrombosed	95		3
47	VTOS	FRR, jugular turndown, thrombectomy/thrombolysis	POD 2 rethrombosed	92	Takeback for venography showing occlusion	4
48	VTOS	FRR, Molina, stent removal, innominate vein patch with bovine pericardium, SCV-innominate bypass, 6-mm Artegraft	Hematoma requiring evacuation, occlusion on POD 2, return to OR	95	Takeback for SCV-innominate bypass with femoral vein	3

Supplementary Table (online only). Continued.

Patient	Indication	Procedure	Complication	Follow-up, days	Reintervention	Days from surgery to intervention
49	AV access	FRR, SCV PTA, 10 mm	Afib, NSTEMI	486		
50	VTOS	FRR, SCV PTA, 8 mm		102		
51	VTOS	FRR, SCV-innominate bypass with femoral vein	Takeback for bleeding, pneumonia with readmission 3 weeks out, right lower extremity deep venous thrombosis 5 weeks out	141	Takeback for bleeding	104
52	AV access	FRR, SCV PTA, 12 mm		1370	PTA/stenting	1040
53	VTOS	FRR, SCV patch with bovine pericardium, AngioJet	Afib with RVR	669		

Afib, Atrial fibrillation; *AV*, arteriovenous; *AVF*, arteriovenous fistula; *AVC*, arteriovenous graft; *CMO*, comfort measures only; *DRIL*, distal revascularization with interval ligation; *FRR*, first rib resection; *GSV*, great saphenous vein; *I&D*, incision and drainage; *NA*, not applicable; *NSTEMI*, non-ST elevation myocardial infarction; *OR*, operating room; *OSH*, outside hospital; *POD*, postoperative day; *PTA*, percutaneous transluminal angioplasty; *PTFE*, polytetrafluoroethylene; *RVR*, rapid ventricular response; *SCV*, subclavian vein; *SSI*, surgical site infection; *VTOS*, venous thoracic outlet syndrome.