Endovascular treatment of type 3 and 4 thoracic central vein obstruction in hemodialysis patients

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ABSTRACT

Objective: Thoracic central vein (TCV) obstruction (TCVO) in the presence of upper extremity (UE) hemodialysis access can present as superior vena cava syndrome (SVCS) and cause vascular access dysfunction and failure. We report the techniques and results of endorevascularization of TCVO in hemodialysis patients, which allowed for long-term functioning vascular access in the UE.

Methods: From June 2009 to February 2020, 45 hemodialysis patients underwent TCV endorevascularization. The indications for surgery were TCVO or SVCS that threatened the function of a preexisting upper arm access or contraindicated placement of a new upper arm access. Conventional endovascular techniques were used when feasible. Patients with unfavorable anatomy were treated using a transseptal needle to cross difficult intrathoracic stenosis and occlusions or to facilitate an inside-out central venous access technique. The reestablishment of venous outflow was accomplished with angioplasty, stenting, and/or placement of HeRO conduits. Successful revascularization was followed by hemodialysis access revision or a new UE access placement. We recorded the risk factors and procedural outcomes, patency rates, complications, and mortality.

Results: The mean age was 53 ± 16.3 years, and 51% were women. The most common risk factors were diabetes mellitus (64.2%) and hypertension (56%). Twenty-five patients (55.5%) had symptoms of SVCS. These symptoms resolved after the TCV procedure in all cases. Crossing of the TCV lesion was successful using a conventional catheter and wire in 26 cases (57.8%) and transseptal needle in 17 cases (37.8%), including 12 using an inside-out central venous access technique. Treatment of the TCV lesion included a HeRO conduit in 20 cases (44.4%), stenting in 17 (37.7%), and transluminal balloon angioplasty alone in 7 (15.5%). Other veins were treated in 33 cases (73.3%). The overall technical success rate was 95.5%. Two intraoperative complications occurred, including one case of severe hypotension and one of fatal cardiac tamponade. Of the 16 patients with preexisting UE access, its function was preserved in all 16 (100%). In 24 of 27 patients (85.7%), new arm access was successfully created after the TCV procedure. The overall clinical success rate was 88.9%. The average follow-up was 663.4 days (median, 507 days; range, 0-2679 days). During follow-up, 26 patients had undergone 90 procedures to maintain access function, 21 had undergone repeat endovascular interventions, and 17 had undergone open procedures. Eight patients (17.8%) had developed infection, five involving HeRO conduits that required excision with loss of access. During the follow-up period, 14 patients (31%) had died of unrelated causes, and 34 patients (75.5%) maintained functional access.

Conclusions: The results of the present study have shown that endorevascularization of TCVO reconstruction is effective in maintaining function or allowing the creation of UE hemodialysis access, with acceptable complication rates. (J Vasc Surg: Venous and Lym Dis 2020;■:1-9.)

Keywords: Central venous stenosis; Endovascular treatment; Hemodialysis access; Superior vena cava obstruction; Superior vena cava syndrome

Approximately 15,000 cases of superior vena cava (SVC) syndrome (SVCS) occur annually in the United States, with increasing frequency concurrent with the increasing use of intravenous devices such as central catheters and pacemakers.[1] Such benign etiologies now comprise ≤40% to 50% of cases.[2] Of these cases, 70% will involve hemodialysis patients.[2,3] The incidence of TCV stenosis in hemodialysis patients with catheters has been estimated to range from 9.4%[4] to 24%,[5] which can be asymptomatic owing to collateral venous circulation. However, once an arteriovenous fistula is created, venous hypertension will develop, and SVCS can occur. Thoracic central vein obstruction (TCVO) can also affect adequate function of the dialysis access and can even result in the loss of the access or preclude creation of a new vascular access in the upper extremity (UE). Moreover, TCVO has

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been associated with diminished life expectancy.[3,6] The purpose of the present review was to assess the feasibility, efficacy, and clinical success of endovascular treatment of hemodialysis patients with TCVO in maintaining UE dialysis access function or allowing creation of a new one.

METHODS

We retrospectively reviewed the data of 45 hemodialysis patients with TCVO who had been treated with endovascular techniques from July 2009 to February 2020. Data were collected using a protocol approved by the institutional review board in compliance with the Health Insurance Portability and Accountability Act standards. For this type of study, specific patient consent was not required. The average patient age was 53 ± 16.3 years, 51% were women, and 55.5% had presented with SVCS. The associated risk factors included diabetes (64.2%), hypertension (56%), congestive heart failure (31.1%), and a history of stroke (18.5%). The average previous hemodialysis history was 5.8 years. The average follow-up duration was 663.4 days (median, 507 days; range, 0-2679 days).

The indications for endovascular treatment were to preserve or allow for the creation of UE access in all patients. Digital pressures were obtained before creation of a new vascular access. These evaluations did not find any patients with contraindications to vascular access placement. All patients underwent venous ultrasound imaging and venography, which was performed by puncturing the existing hemodialysis vascular access, UE vein, or femoral vein. Evaluation of TCVO was performed using the TCVO classification of the Society of the Interventional Radiology,[7] which revealed 28 patients with type 4, and 17 with type 3.

The procedures were performed percutaneously through the UE hemodialysis access and/or the femoral vein. Hydrophilic 0.0035-in. guidewires and 5F catheters (Terumo Interventional Systems, Somerset, NJ) were used to cross stenotic or occluded lesions (Fig 1). In the case of total occlusion and an inability to cross the lesion, a Brockenbrough (BRK) transseptal needle (St Jude Medical, St Paul, Minn) was used. In two cases, a suprasternal–supraclavicular puncture was used to achieve access to the SVC. In catheter-dependent patients with high-grade SVC stenosis or occlusion around the catheter, a guidewire was advanced through the catheter into the inferior vena cava. The catheter was removed, leaving the guidewire in place across the lesion. Next, percutaneous transluminal balloon angioplasty (PTA) was performed. Stenting was then performed if luminal narrowing after PTA was >50%. In cases of a residual long stenotic tract after PTA, a HeRO graft (Merit Medical Systems, Inc, South Jordan, Utah) was implanted (Fig 2).

Cases of SVC occlusion with a patent brachiocephalic vein were treated with intrathoracic vein sharp recanalization. In this technique, UE and femoral venous sheaths were used. An arm vascular access was used, if available. If not, the jugular or axillary vein was used. A 7F destination sheath (Destination Guiding Sheath; Terumo, Somerset, NJ) was placed in the brachiocephalic vein next to its junction with the SVC. The next step was to puncture the common femoral vein to place an 8F sheath (Swartz Braided SL transseptal guiding introducer sheath; St Jude Medical, St Paul, Minn) in the SVC just below the occlusion. A BRK transseptal needle was then placed in the sheath and advanced toward the brachiocephalic vein with the UE 7F destination sheath as a reference point. After successful puncture across the occlusion using the BRK transseptal needle, an 0.018-in. wire was advanced into the brachiocephalic vein. The BRK transseptal needle was removed and the wire was replaced with a 0.035-in. Amplatz Super Stiff guidewire (Boston Scientific, Marlborough, Mass). This was followed by angioplasty of the occluded tract and deployment of a self-expanding stent from the SVC to the brachiocephalic vein (Fig 3).

In the case of TCVO associated with brachiocephalic vein occlusion, access to the right supraclavicular fossa or suprasternal notch was obtained using the inside-out technique.[12] This technique involved common femoral vein placement of an 8F sheath in the SVC just below the occlusion. A BRK transseptal needle was placed in the sheath, and a sharpened 0.018-in. Connect cut wire (Abbott Hi-Torque Connect; Abbott Vascular, Santa Clara, Calif) was placed inside the needle and directed posteriorly to the head of the clavicle toward

ARTICLE HIGHLIGHTS

- **Type of Research:** A multicenter, retrospective cohort study
- **Key Findings:** We were able to perform successful revascularization of thoracic central vein obstruction using percutaneous balloon angioplasty, stenting, or HeRO graft in 95.5% of cases using advanced endovascular techniques. In 38% of cases, these procedures required sharp and inside-out recanalization. The overall success of access salvage or creation of new dialysis access was achieved in 88.9% of patients. One perioperative death occurred (2.2%). Multiple open and endovascular procedures were necessary to maintain access function.
- **Take Home Message:** Endorevascularization of thoracic central vein obstruction can be technically successful in difficult cases of complex central vein occlusion with low mortality. Almost 90% of patients will maintain function of a preexisting dialysis access or have new access created in the upper extremity. These patients require strict follow-up with multiple reinterventions to maintain access patency.

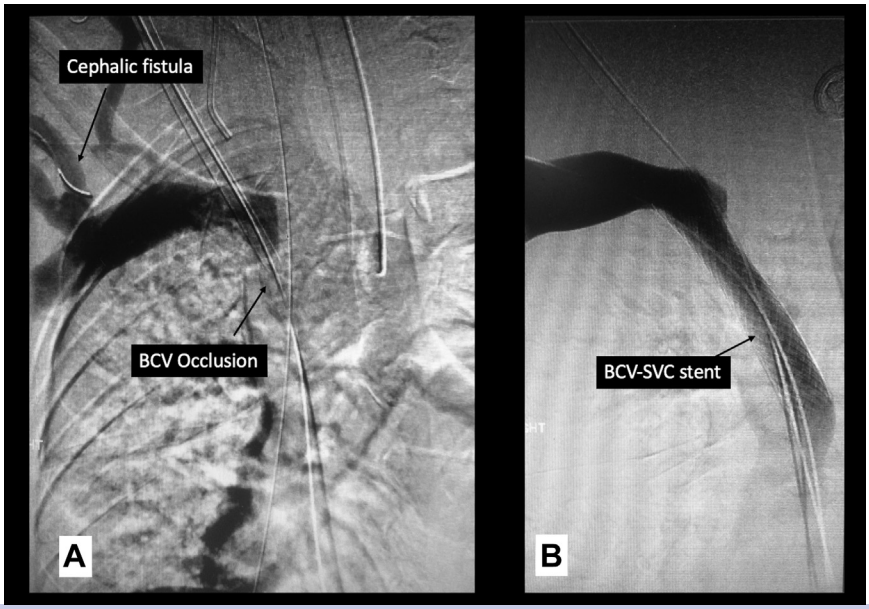

Fig 1. A, Occluded right brachiocephalic vein (*BCV*) in a patient with bilateral brachiocephalic occlusion and right cephalic fistula. **B,** Occlusion crossed with wire and Wallstent stenting.

the right supraclavicular fossa. The wire was externalized through a small open incision. The transseptal needle was removed, and the wire was replaced with a 0.035-in. Amplatz Super Stiff guidewire. A HeRO conduit was then placed in the SVC and tunneled to a right infraclavicular incision to be attached to an expanded polytetrafluoroethylene (PTFE) graft that became a new vascular access or a bridge to an existing failing access in the right UE. For left-sided cases, the inside-out device was directed to the suprasternal notch and then to the left infraclavicular area (Fig 4).

In two cases of a failing right UE fistula, a Viabahn stent graft (WL Gore and Associates, Flagstaff, Ariz) was deployed in the SVC instead of a HeRO conduit. The graft was tunneled subcutaneously and in front of the clavicle, and the lateral end was connected to an expanded PTFE graft in the lateral infraclavicular area (Fig 5).

Other central venous stenotic lesions were treated with standard angioplasty or stenting, as indicated. Most of the patients who had required dialysis access revision or a new vascular access underwent the dialysis access procedure in the same setting. All patients underwent

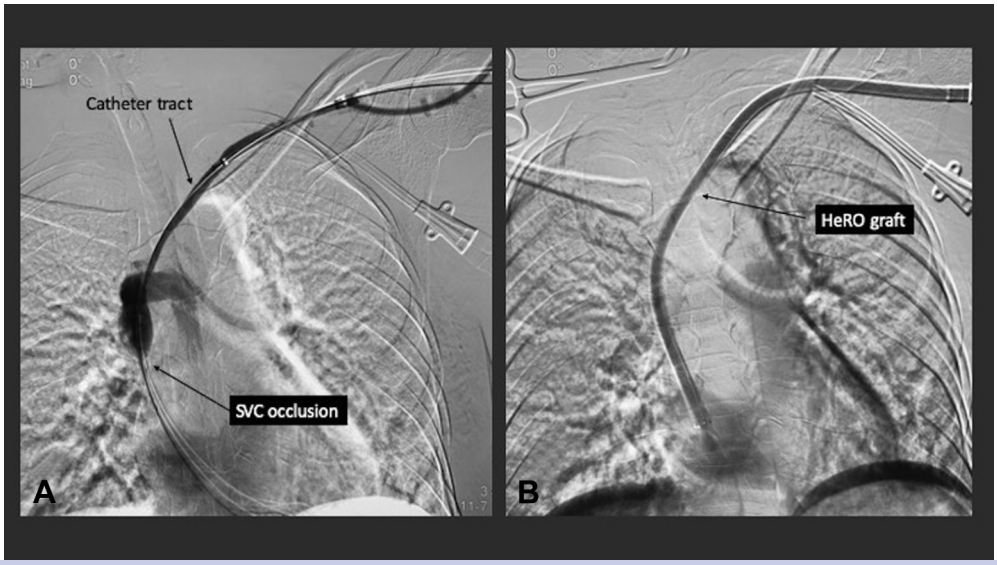

Fig 2. A, Tract after a hemodialysis catheter was removed with the wire left in place. **B,** Residual high-grade superior vena cava (*SVC*) stenosis was dilated to allow for placement of a HeRO graft.

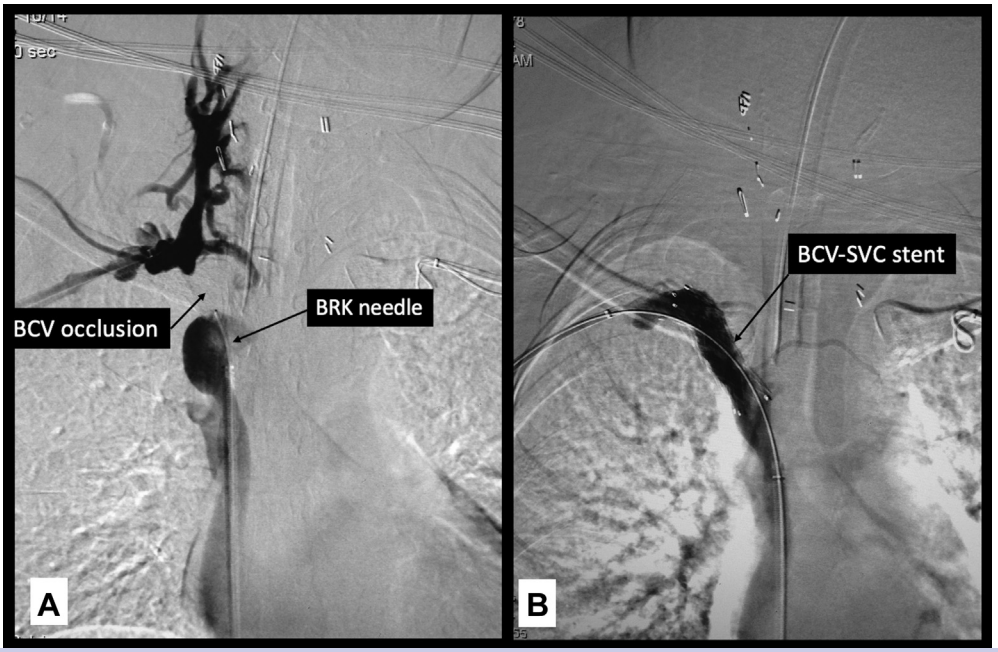

Fig 3. A, Occluded right brachiocephalic vein (*BCV*) in a patient with bilateral brachiocephalic vein occlusion. **B,** Sharp recanalization with a Brockenbrough (*BRK*) transseptal needle and stenting.

dialysis via catheter or preexisting vascular access the day after the procedure and then were discharged from the hospital. We routinely prescribed postoperative antiplatelet agents, and anticoagulation therapy was prescribed for patients with suspected hypercoagulable syndrome.

The initial postoperative evaluation in the outpatient clinic occurred 2 weeks after the procedure and every 3 months thereafter. The patients were evaluated for signs of recurring central vein stenosis. The vascular access was evaluated by physical examination and ultrasonography,

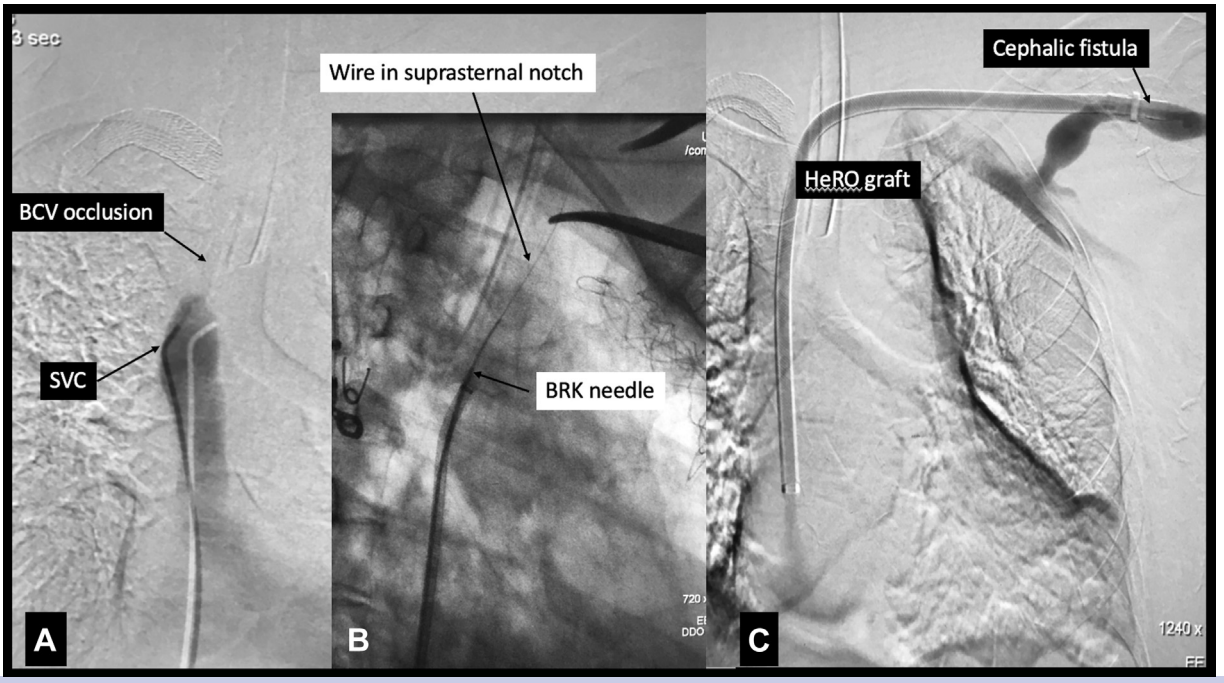

Fig 4. A, Bilateral brachiocephalic vein occlusion. **B,** Inside-out technique to suprasternal notch with Brockenbrough (*BRK*) needle. **C,** Percutaneous transluminal balloon angioplasty (PTA) of tract and superior vena cava (*SVC*), followed by HeRO graft placement to the left cephalic fistula.

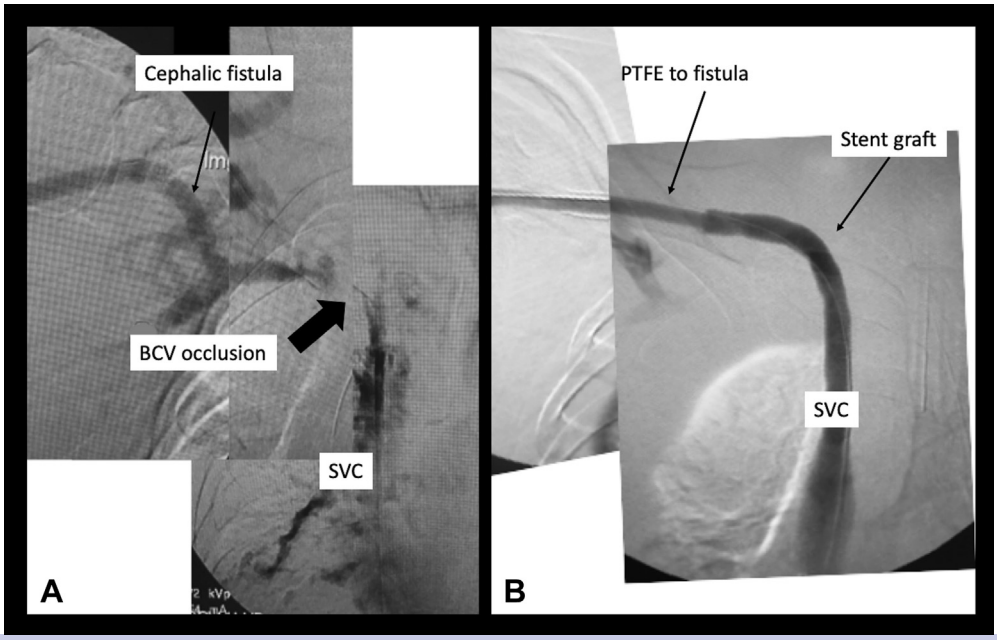

Fig 5. A, Right cephalic fistula and occluded right brachiocephalic vein (*BCV*) in a patient with bilateral brachiocephalic vein occlusion. **B,** Superior vena cava (*SVC*) stent graft over the clavicle to the polytetrafluoroethylene (*PTFE*) graft and then to the fistula.

and fistulography was scheduled if any evidence of access or venous outflow stenosis was found.

RESULTS

All patients with type 3 TCVO had had bilateral occlusion of the brachiocephalic veins. Of the patients with type 4 TCVO, 10 had presented with 100% stenosis (36%), 9 with high-grade stenosis around the dialysis catheters (32%), and 9 with 50% to 75% stenotic lesions (32%). The techniques to cross occlusive lesions included a hydrophilic guide wire alone in 26 patients (57.8%) and a BRK needle in 17 patients (37.8%), with 5 undergoing an intrathoracic vein sharp recanalization technique (all with type 4) and 12 the "inside-out" technique (all with type 3). A suprasternal–supraclavicular puncture was used in 2 patients (4.4%). Technical success was achieved in 43 patients (95.5%). The two technical failures included a fatal complication (SVC atriocaval junction tear) during the procedure in one patient and failure to cross the lesion in one patient (Supplementary Table I, online only).

After wire access, 7 patients underwent PTA alone (all type 4) and 17 underwent stenting (12 with type 4 and 5 with type 3). The stents used were Lifestar (BDPI, Tempe, Ariz) in seven patients, Luminex (BDPI) in four patients, Wallstent (Boston Scientific) in two patients, Viabahn (WL Gore and Associates) in two patients, Fluency (BDPI) in one patient, and I-Cast (Getinge, Wayne, NJ) in one patient. Most of the stents were 14 mm in diameter, and all had been post-dilated to ≥10 mm. In two cases, 10-mm stent grafts were used. The size of the stent was determined mostly by the largest diameter feasible with a minimal risk of rupture. In one case, in which the stenosis was very close to the cavoatrial junction, we chose an 8-mm I-Cast balloon expandable stent graft to avoid the risk of overdilation, rupture, and cardiac tamponade (Fig 6). Twenty patients underwent PTA and HeRO graft placement (12 patients with type 3 and 8 with type 4). In 10 patients, the occlusion was crossed using the inside-out technique[12,13] (Supplementary Fig 1, online only).

Additional concomitant endovascular PTA procedures in the other central veins included 22 procedures in the brachiocephalic vein (10 stenting), 5 in the subclavian vein (2 stenting), 4 in the internal jugular vein (2 stenting), and 2 in the axillary vein.

Of the 45 patients, 25 were catheter-dependent before the TCV procedure, all of whom were catheter free afterward, and 20 had had pre-existing hemodialysis access, 16 (75%) of whom maintained access function after the procedure. Of the remaining four patients, two had had a failing lower extremity access and had received new UE access, and two had experienced technical failure.

A total of 27 patients (25 from the catheter group and 2 with a failing leg fistula) had required new arm vascular access, which was accomplished in 24 patients (85.7%). Access was successfully created during the initial TCV procedure in 21 patients and during the first 4 postoperative weeks in 3 patients. The remaining 3 patients never scheduled the vascular access procedure. At the initial follow-up examination, 40 patients had had functional dialysis access in the UE (88.9%).

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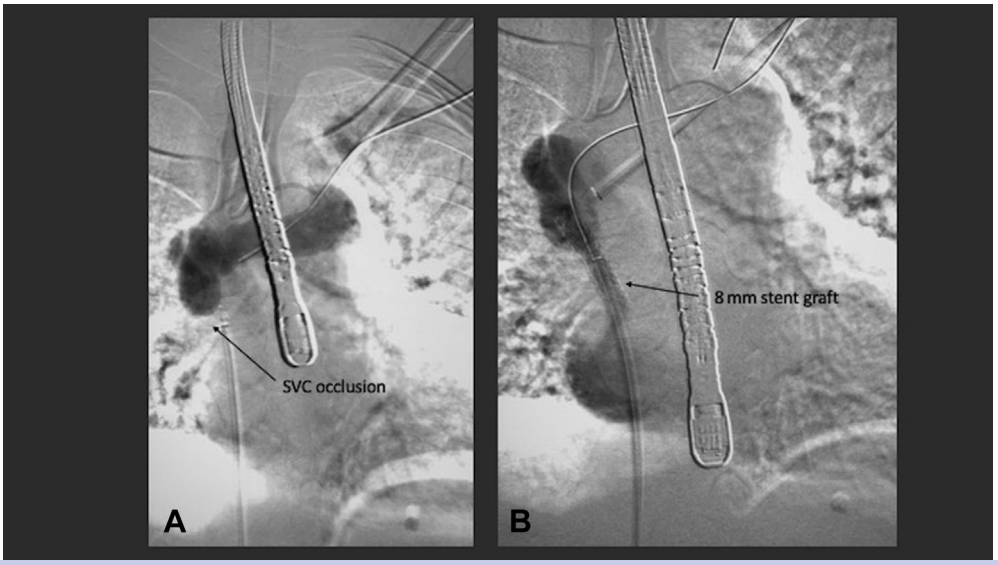

Fig 6. A, Superior vena cava (*SVC*) occlusion near the cavoatrial junction. **B,** Balloon expandable stent graft placement to treat SVC occlusion.

Two intraoperative complications had occurred. One had occurred in a 72-year-old woman with a dysfunctional right UE arteriovenous fistula and a right internal jugular catheter with SVC high-grade stenosis around the catheter. She had total occlusion of the left brachiocephalic vein and a history of severe lower extremity arterial occlusive disease that prevented new access elsewhere. We recommended SVC revascularization to achieve functional right arm access. She underwent SVC angioplasty and stenting and replacement of the dialysis catheter through the SVC stent. After stenting, she became severely hypotensive with no detectable blood pressure and required pressor support. During resuscitation maneuvers, owing to the difficulty in left lung ventilation, a left chest tube thoracostomy was placed emergently. However, no blood or air returned, suggesting endotracheal tube malposition in the right mainstem bronchus. An intraoperative transesophageal echocardiogram revealed no pericardial effusion, and an SVC venogram revealed no extravasation. In retrospect, the etiology of this hypotensive episode remains unclear.

Postoperatively, she developed a left hemothorax (likely due to chest tube insertion in the face of systemic anticoagulation), which was successfully treated with video-assisted thoracotomy and evacuation of the retained blood. The patient was discharged home and after 2 months underwent right UE arteriovenous graft placement and right brachiocephalic vein stenting. Subsequently, she required seven more endovascular procedures to maintain access function. Ultimately, she died of an unrelated cardiac event 3.5 years later with a functioning access site.

The second intraoperative complication had occurred in a 26-year-old man who had required hemodialysis for 5 years. The patient had a left upper arm graft and had presented with signs of SVCS. A preoperative venogram revealed occlusion of the SVC at the junction of the brachiocephalic vein. We placed a long sheath from the left arm graft and positioned it at the junction of the brachiocephalic vein with the SVC. We also placed a long sheath from the left femoral vein and positioned it below the SVC occlusion. Sharp recanalization with a transseptal needle was performed after attempts to cross the lesion with hydrophilic wires were unsuccessful. We placed the BRK needle inside the sheath and guided its tip toward the brachiocephalic vein, crossed the occlusion, and passed a 0.014-in. wire into the brachiocephalic vein. PTA was performed using a 3-mm balloon. Within 1 minute, the patient experienced cardiac arrest. Cardiac tamponade was suspected, and a subxiphoid pericardial window, median sternotomy, and resuscitative maneuvers were performed; however, cardiac activity could not be regained. This surgical exposure revealed that a fatal pericardial tamponade had occurred from a medial laceration of the SVC below the pericardial reflection.

During the follow-up period, 24 open surgical procedures were performed to maintain access function (10 for type 3 and 14 for type 4). These procedures included new dialysis access placement or revisions for graft thrombosis, aneurysms, infections, and steal syndrome. HeRO conduit procedures included thrombectomy, replacement, revision, and excision for infection. First rib resection and subclavian vein stenting were also performed in three cases of preexisting associated venous thoracic outlet syndrome. Two patients, who had undergone previous SVC and brachiocephalic vein stenting, were treated initially with PTA of the subclavian vein and then underwent first rib resection and subclavian

vein stenting at 16 and 20 months after SVC revascularization. The third patient had developed subclavian vein stenosis from pacemaker wires that had been removed before SVC angioplasty and had required first rib resection and subclavian vein stenting 15 months later (Supplementary Table II, online only).

In addition, 21 patients had undergone 90 access endovascular procedures (44 for type 3 and 46 for type 4), including dialysis access and central vein thrombolysis, angioplasty, and stenting, during the study follow-up period. Kaplan-Meier analysis for patency of the thoracic central vein revealed primary, primary-assisted, and secondary functional patency rates of 55.5%, 76.3%, and 90.7% at 1 year and 30.1%, 76.3%, and 81.9% at 2 years, respectively (Supplementary Fig 2, online only; Supplementary Table III, online only).

DISCUSSION

TCVO is a serious manifestation of central vein stenosis and can cause SVCS in patients with an UE dialysis access. These patients are at risk of vascular access or catheter failure. Angioplasty and stenting are currently recommended as the initial treatment for patients with TCVO and SCVS. If endovascular therapy is not successful, patients are considered for lower extremity vascular access. However, lower extremity access is associated with a significant risk of infection (18%) and steal syndrome (16%) as reported in previous studies.[8,9] Furthermore, if these patients are not candidates for open thoracic procedures or lower extremity vascular access, they will become catheter-dependent and be subject to catheter complications.[10] In our series, 25 patients (55.5%) had already had tunneled dialysis catheters preoperatively, including six in the femoral vein.

We used the TCVO classification of the Society of the Interventional Radiology to evaluate the anatomy of venous obstruction in our patients.[7] It is noteworthy that 60% of our patients had type 4 type of obstruction and 40% had type 3. Patients with these types of TCVO have been considered unsuitable anatomically for endovascular treatment in the past; and these patients have been more often undergone open surgical reconstruction.[11] However, the morbidity associated with open chest atrial bypass procedures has been greater than that with endovascular procedures and has been reported at 19% in one study.[11] We had also previously treated these types of patients with open chest atrial bypass (data not included in the present report).

In 2014, we started using more complex endovascular techniques such as using the transseptal BRK needle for intrathoracic venous recanalization or the inside-out technique to achieve access to the right supraclavicular or suprasternal area.[12,13] We also used suprasternal puncture to achieve access to the SVC. We have not used other vein crossing techniques such as laser recanalization, which have been described only recently.[14] These more advanced methods accounted for 42% of lesion crossing techniques in the present report and, in combination with HeRO graft implantation, resulted in successful endovascular treatment of patients with more complicated thoracic venous obstruction anatomy without the need for surgical venous reconstruction or lower extremity access, which we believe is inferior to UE access.

We used uncovered stents and found that intimal hyperplasia was manageable with follow-up angioplasty to maintain patency. A balloon-expanding covered stent was used in only one case of obstruction at the cavoatrial junction because we believed that prestent angioplasty would have had a high risk of injury and cardiac tamponade. In this case, we selected an 8-mm I-Cast (Getinge) to allow for controlled angioplasty under protection of the stent graft. At present, a trend exists to preferentially use covered rather than bare stents or no stents to treat central vein stenosis; and we are currently reviewing that data for future consideration.[15]

Percutaneous placement of a stent graft subcutaneously over the clavicle has been described in cases of thoracic outlet and cephalic arch occlusion.[16] We used that technique in two patients with failing right UE fistulas and occluded brachiocephalic veins, deploying a stent graft from the SVC to the infraclavicular area. We then used a PTFE graft to connect the stent graft to the right arm fistula.

Our primary and secondary patency rates of 55.5% and 90.7%, respectively, at 1 year after HeRO graft placement compared favorably with the primary patency rates reported by Katzman et al[17] (38.9%) and Gage et al[18] (48.8%). In our study, the HeRO graft cumulative patency rate was 70%.

The HeRO graft infection rate of 25% in the present study was greater than the 4.3% reported by Gage et al[18] in 164 patients and 9.5% reported by Wallace et al[19] and the bacteremia rate of 18.4% reported by Katzman et al.[17] The reasons for these differences are not clear. In our study, all HeRO grafts were implanted at TCV revascularization as a single-stage procedure, and it has been suggested that staged procedures are associated with lower early infection rates.[20] However, of the five patients in the present study with HeRO infection, only one had had an early infection at 23 days. The remaining four patients had required excision of an infected graft at an average of 362.7 days (range, 137-509 days) after the implant procedure. Therefore, our infections had most likely not been caused by an intraoperative event and, thus, would not have been influenced by performing a single, rather than staged, procedure.

Steal syndrome has been reported, with an incidence rate ranging from 1.4% to 24% after HeRO graft implantation.[18,19] A recently reported series using the inside-out central venous access technique to cross an occluded

vena cava for HeRO graft placement described a high incidence of steal syndrome necessitating access ligation in 3 of 11 patients (27.2%).[13] In the present study, only two patients developed symptoms of steal syndrome, one after HeRO graft implantation and one patient after SVC stenting. Both patients had had brachial artery inflow access and were treated with arterial inflow proximalization with improvement of symptoms. Neither patient had had preoperative evidence of arterial stenosis.

A risk of SVC injury during intrathoracic vein sharp recanalization can occur if inadvertent laceration occurs in the intrapericardial SVC, especially along the medial side, which is considered a "danger zone" of the SVC.[21] One cadaver anatomic study showed that the pericardial boundaries were consistently below the border of the carina.[22] Another anatomic study found that the median length of the intrapericardial part of the SVC was 20.5 mm on the lateral and 32.5 mm in the medial side.[23] Moreover, another study showed that the pericardium can extend high up the SVC, as much as 50 mm from the right atrium. The same study revealed that the medial aspect of the SVC adheres to the pericardium up to the level of the aortic arch.[24] Thus, intrapericardial hemorrhage from SVC perforation can occur at any location at or near the SVC.

Fatal pericardial tamponade caused by injuries in this area, such as in our one case, have been reported during crossing attempts with guidewires and after angioplasty and stenting during attempts to treat occlusive lesions close to the cavoatrial junction.[25] The mechanisms of such injury include wire perforation, rupture by angioplasty balloons and large stents, and perforation by stent struts.[25,24] It has also been suggested that venous occlusion might be associated with benign inflammatory alteration of the normal tissue planes, which might predispose to this complication.[21] The mortality of cardiac tamponade after SVC stenting for malignant SCVS has been reported as high as 42%.[24] However, one investigator reported a fatal cardiac tamponade rate of only 1.8% in 164 cases.[26] The reasons for this wide difference are not clear.

To minimize the risk of this complication, special attention should be given to maintain the guiding sheath and BRK needle in a central position toward the target, whether in the brachiocephalic vein, intrathoracic vein recanalization, or supraclavicular or suprasternal area in inside-out approaches. Lateral projections and angiography should be used to ensure that the guidewire path does not go through the atrial appendage.[13] Stenotic lesions or occlusions near the cavoatrial junction should always be considered a high-risk situation because of its location within the intrapericardial portion of the SVC where wire and catheter manipulation can cause SVC or atrial injury.[21]

Although we have relied on traditional venography to delineate the anatomy of the obstruction, other imaging modalities such as MR venography and three-dimensional computed tomography have the capability to determine the inferior extent of the occlusion and diagnose possible external compression and the relationship of the SVC with other mediastinal organs.[27] This information could be useful, especially for cases that require intrathoracic sharp vein recanalization. We, therefore, plan to consider the use of this imaging modality in the future.

Anesthesia monitoring in these cases should include at least arterial line monitoring. We try to use our cardiac anesthesia staff who are proficient with the intraoperative transesophageal echo probe in these cases. The patient should be prepared and provide consent for possible subxiphoid pericardial window or median sternotomy. Also, a "bridge" balloon catheter (Phillips, San Diego, Calif) should be available in the room to rapidly insert and gently occlude the SVC to prevent further bleeding and stabilize the patient for a surgical procedure.[28]

A variety of open surgical procedures and many endovascular procedures were necessary to maintain vascular access function. We found no differences between type 3 and type 4 patients. The average endovascular reintervention rate was 4.3 procedures per patient. These interventions were necessary to achieve a 2-year secondary patency rate of 81.9%. Our experience has confirmed that adequate patency and long-term clinical success can be obtained with regular follow-up, although at the cost of multiple secondary interventions, which has been recognized by others.[29,11]

CONCLUSIONS

In contrast to current popular belief, types 3 and 4 TCVO in hemodialysis patients can be successfully treated using advanced endovascular techniques, including sharp recanalization for intrathoracic veins and an inside-out technique combined with HeRO graft placement even for patients with anatomically complicated venous occlusion. These procedures successfully maintained function in all patients with preexisting dialysis access and allowed for the creation of new UE access in patients with preexisting catheters. These patients otherwise would have required lower extremity vascular access, thoracic venous surgical procedures, or permanent tunneled dialysis catheters. Appropriate follow-up and reinterventions are necessary to maintain satisfactory patency and vascular access function. The results of the present study also emphasize the importance of close and routine follow-up examinations and venography. These are challenging cases that require a high level of dedication, technical skills, and impeccable clinical judgment.

AUTHOR CONTRIBUTIONS

Conception and design: PU, SA
Analysis and interpretation: PU, RF, SA
Data collection: PU, JP
Writing the article: PU
Critical revision of the article: PU, RF, JP, SA
Final approval of the article: PU, RF, JP, SA
Statistical analysis: Not applicable
Obtained funding: SA
Overall responsibility: PU

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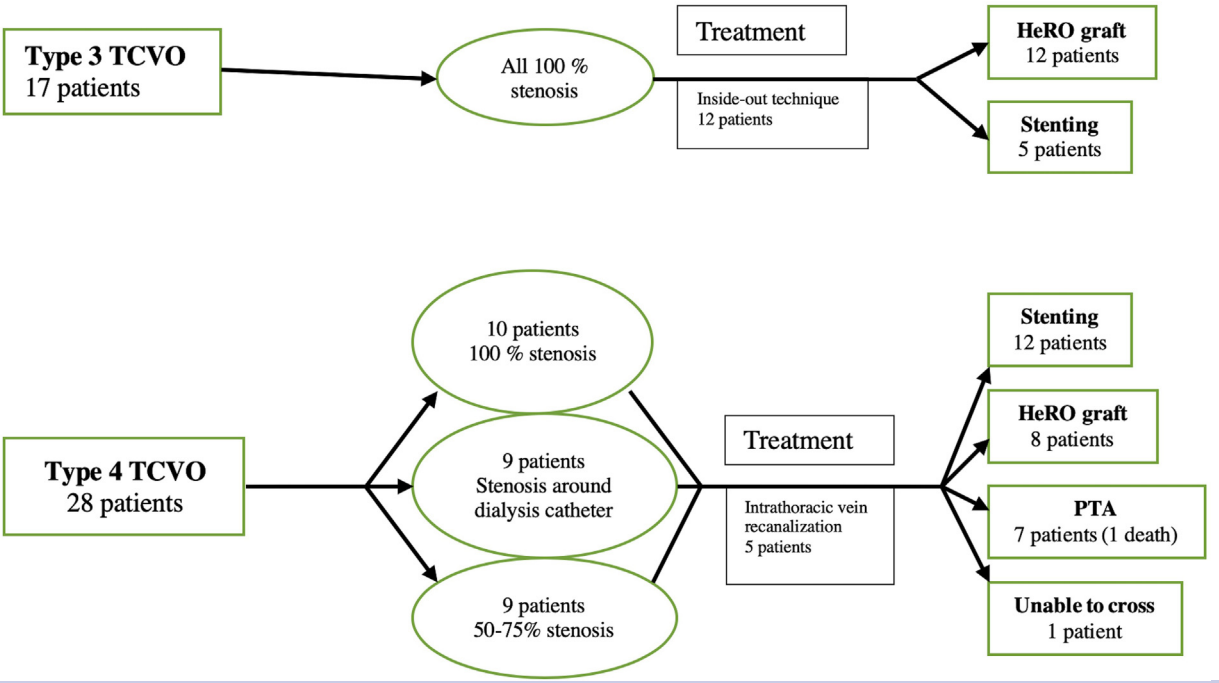
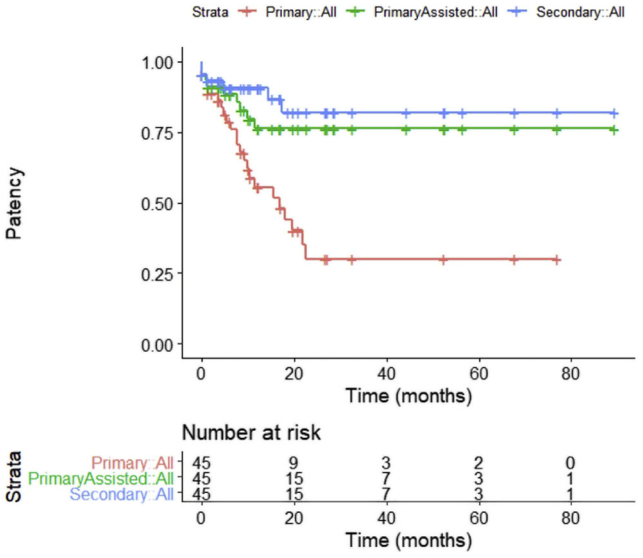


Supplementary Fig 1 (online only). Flow chart of type 3 and 4 thoracic central vein obstruction (*TCVO*) stenosis and treatment. *PTA,* Percutaneous transluminal balloon angioplasty.



Supplementary Fig 2 (online only). Kaplan-Meier analysis for patency of thoracic central vein (TCV) reconstruction.

Supplementary Table I (online only). Vein occlusion crossing techniques

Technique	Device	Patients, No. (%)	Success rate, %	Complications, No.
Conventional	Catheter and wire	26 (57.8)	100	0
Inside-out	Transseptal BRK needle	12 (26.6)	100	0
Intrathoracic sharp recanalization	Transseptal BRK needle	5 (11.1)	60 (2 not successful)	1 (fatal cardiac tamponade)
Outside-in	Micropuncture set[a]	2 (4.4)	100	0

BRK, Brockenbrough needle.
[a]Micropuncture set (Cook Medical, Bloomington, Ind).

Supplementary Table II (online only). Surgical procedures

Indication	Procedure	No.
Access aneurysm, localized infection	Access revision	8
Access failure	New access	2
HeRO dysfunction	HeRO graft revision, replacement	4
HeRO infection	HeRO graft excision	5
Steal syndrome	Proximalization arterial Inflow	2
Venous TOS	First rib resection, subclavian vein stenting	3
Total		24

TOS, Thoracic outlet syndrome.

Supplementary Table III (online only). Life-table analysis of patency rates for superior vena cava reconstruction

Patency category	Patients, No.	Failures, No.	Median patency or survival time, months	Patency. %	
				At 1 year	At 2 years
Primary	45	23	16.8	55.5	30.1
Primary assisted	45	9	NA	76.3	76.3
Secondary	45	6	NA	90.7	81.9
Survival	45	13	89.3	NA	NA

NA, Not applicable.