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Author(s): Resnick; O'Brien; Strain; Malaisrie; Schimmel; Salem; Vogelzang

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Single-Center Experience Using AngioVac with Extracorporeal Bypass for Mechanical Thrombectomy of Atrial and Central Vein Thrombi

Scott A. Resnick, MD, Dan O'Brien, BS, David Strain, MD, Chris Malaisrie, MD, Daniel Schimmel, MD, Riad Salem, MD, MBA, and Robert Vogelzang, MD

ABSTRACT

The AngioVac device (AngioDynamics, Inc, Queensbury, New York), a commercially available large-diameter aspiration cannula using extracorporeal venovenous bypass, is designed to facilitate en bloc mechanical thrombectomy of massive thrombi of the central vasculature. Between February 2014 and January 2015, seven consecutive patients, each presenting with large central thrombi of the iliac veins, vena cava, right atrium, or pulmonary artery, underwent thrombectomy. Partial or complete clot abatement was achieved in all instances. All patients survived the procedure. One case was complicated by embolization of septic thrombi. At most recent follow-up, one patient had died of causes unrelated to venous thrombosis; all other patients were living (median follow-up time 8 mo). Several technical and therapeutic insights were gained from our center's early experience.

ABBREVIATIONS

CFV = common femoral vein, IJV = internal jugular vein, IVC = inferior vena cava, PA = pulmonary artery, PE = pulmonary embolus, RA = right atrium, TEE = transesophageal echocardiography, TIPS = transjugular intrahepatic portosystemic shunt

Various endovascular techniques are used to remove venous clots (1,2), although the efficacy of these techniques with respect to central vein thrombi is not well characterized. Methods that rely on thrombolysis are contraindicated for patients at elevated risk for hemorrhage and may be poorly tolerated by hemodynamically compromised patients who would benefit from rapid clot abatement. Endovascular methods for mechanical thrombectomy of central thrombi have also been described, but these approaches are technically limited, and most commercially available aspiration devices carry indications for use in vessels < 10 mm in diameter and are not effective in the central veins (3–5).

The AngioVac device (AngioDynamics, Inc, Queensbury, New York) is a large-diameter, vacuum-assisted aspiration catheter that uses a cardiopulmonary venovenous bypass circuit to facilitate removal of large, occlusive thrombi without significant blood loss during aspiration. The AngioVac system has been described in several recent case reports (6,7) and single-institution case series (8–10). The purpose of this study is to describe a single-center experience with the AngioVac device in the management of large, central venous thromboembolism.

MATERIALS AND METHODS

Patient Selection

Institutional review board approval for this study was obtained. All patients who underwent AngioVac-assisted mechanical thrombectomy at our institution were included in the retrospective series. Patients were selected to undergo thrombectomy on the basis of clinical

From the Departments of Interventional Radiology (S.A.R., D.O., D.St., R.S., R.V.), Cardiothoracic Surgery (C.M.), and Cardiology (D.Sc.), Northwestern University Feinberg School of Medicine, Chicago, Illinois. Received June 16, 2015; final revision received January 30, 2016; accepted February 7, 2016. **Address correspondence to** S.A.R., Department of Radiology, Northwestern Memorial Hospital, Feinberg Pavillion, Room 7-410X, Chicago, IL 60647; E-mail: sresnick@northwestern.edu

None of the authors have identified a conflict of interest.

Figure E1 is available online at *www.jvir.org*.

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judgment. Each patient presented with large central vein thrombi, and each either had failed thrombolysis or was precluded from thrombolysis because of a high bleeding risk or hemodynamic instability. Demographic and procedural details for each case are summarized in Table 1.

Procedure

The AngioVac device (first generation) uses a vacuum-assisted 22-F drainage cannula to achieve evacuation of large thrombi. Access to the venous circulation was achieved via standard percutaneous technique, and the device was passed through a 26-F sheath. Because of the large volume of blood (> 3 L/min) evacuated from the venous system during vacuum aspiration, aspirate was filtered extracorporeally, and autologous blood was returned through venovenous bypass. All procedures were performed under general anesthesia.

RESULTS

Seven patients were treated using the AngioVac device. Four presented with right atrial thrombi, and three presented with inferior vena cava (IVC) thrombi. Two from the latter group had distal extension of thrombi into the iliac veins bilaterally.

Case 1

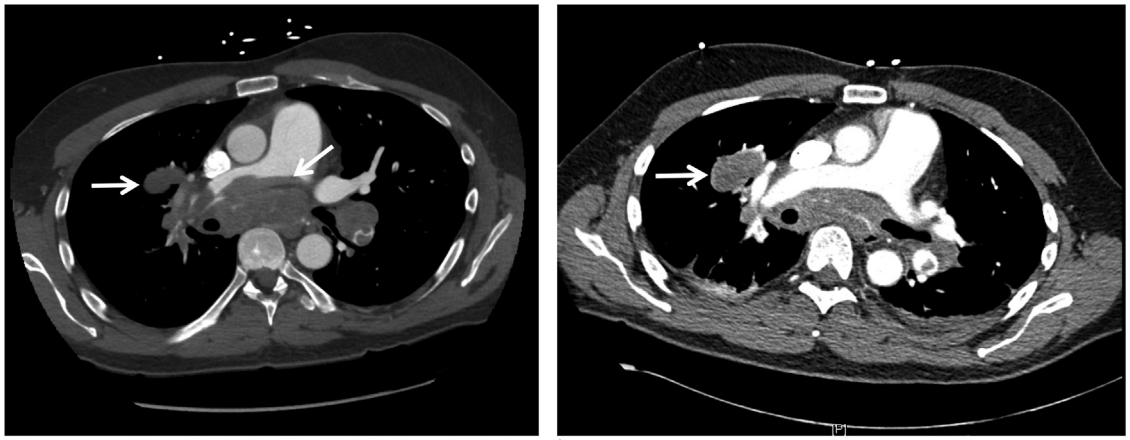
A 47-year-old man with melanoma and lung and brain metastases developed worsening dyspnea 6 days after oncologic neurosurgery. He was found to have a submassive saddle pulmonary embolus (PE) (Fig 1a). An echocardiogram revealed a thrombus measuring > 4 cm in the right atrium (RA) extending into the right ventricle with right ventricular strain.

AngioVac-assisted mechanical thrombectomy was performed. The aspiration cannula was inserted via right internal jugular vein (IJV) access through a 26-F GORE DrySeal Sheath (W.L. Gore & Associates, Inc, Flagstaff, Arizona). An 18-F return cannula was inserted via left femoral access. A third access was achieved through the right femoral vein, and a 10-F sheath for intravenous ultrasound (US) (Volcano Corporation, San Diego, California) was placed. Before insertion of the aspiration catheter, a heat gun (hair dryer) was used to modify the geometry of the distal end of the cannula creating a 30° curvature to improve maneuverability of the cannula given the anticipated difficulty of approaching intracardiac thrombus. Removal of atrial and ventricular clot was achieved under image guidance from digital subtraction angiography with concurrent intravenous US and transesophageal echocardiography (TEE). The aspiration cannula was withdrawn and again reshaped to create an additional 30° angle approximately 5 cm proximal to the initial angle to facilitate pulmonary artery (PA) access (Fig 2). A flow-directed balloon catheter (Swan-Ganz catheter; Edwards Lifesciences

Table 1. Patient Demographics and Case Summaries

Case	Age (y)/Sex	Clot Location	Aspiration Cannula Access Site	Return Cannula Access Site	Accessory Devices Used (and Access Site)	Neoplastic Tissue in Aspirate	Complications	Follow-up Time (mo)
1	47/Male	PA trunk; RA; right ventricle	Right IJV	Left femoral vein	Intravenous US; TEE	–	None	9*
2	47/Female	RA	Right IJV	Left femoral vein	Intravenous US (right femoral vein)	–	Multiple septic pulmonary emboli	10
3	73/Male	IVC	Right IJV	Left IJV	Angiography (left femoral vein)	+	None	10
4	50/Male	IVC; bilateral iliac veins	Right IJV	Left IJV	Angioplasty and stent (right IJV)	–	None	1
5	37/Male	IVC; bilateral iliac and femoral veins	Right IJV	Right femoral	Angiography and snare (right upper extremity deep vein)	–	None	17
6	39/Male	RA, cavoatrial junction	Right femoral vein	Left femoral vein	TEE; second access site for aspiration cannula (right IJV)	–	None	17
7	70/Male	RA	CFV	Left femoral vein	TEE; angioplasty balloon (left femoral vein)	+	None	11

CFV = common femoral vein; IJV = internal jugular vein; IVC = inferior vena cava; PA = pulmonary artery; RA = right atrium; TEE = transesophageal echocardiography.
*Patient deceased at most recent follow-up from metastatic carcinoma.



a. b.

Figure 1. **(a)** Case 1. CT angiogram depicting submassive saddle embolus (arrow, right) with additional filling defects in right segmental branches (arrow, left). **(b)** CT angiogram depicts reduced thrombus burden after thrombectomy; clot is still present in right segmental branches (arrow).

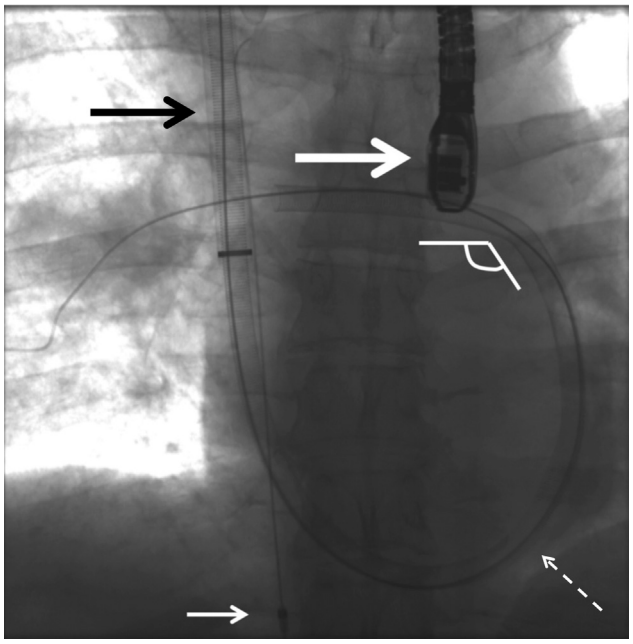


Figure 2. Case 1. AngioVac cannula (dashed arrow) through a 26-F DrySeal Sheath (black arrow). Heat-shaped cannula (before balloon inflation/tip actuation) with 30° bend 5 cm proximal to the distal cannula end with the tip positioned in the right PA. TEE probe (large white arrow) and intravenous US sheath (small white arrow) are shown.

Corporation, Irvine, California) was advanced through the GORE DrySeal Sheath and used to traverse the tricuspid and pulmonic valves to ensure wire passage through the valve lumen rather than through chordae. A stiff guide wire (Amplatz Super Stiff Guidewire; Boston Scientific, Marlborough, Massachusetts) was placed, and the cannula was reinserted through the IJV access. Under TEE guidance, thrombus was removed from the main pulmonary trunk and right PA. After removal of aspiration and return cannulas, the right IJV and left groin wounds were closed with interrupted vertical mattress sutures. TEE performed after the procedure showed improved right ventricular function. Computed tomography (CT) performed 2 months after thrombectomy showed an absence of thrombus in the IVC or PA. Small amounts of chronic clot were noted in the lower lobe segmental arteries (Fig 1b).

Case 2

A 47-year-old woman with a history of cirrhosis complicated by bleeding gastric varices had a transjugular intrahepatic portosystemic shunt (TIPS). Bleeding recurred, and a venogram demonstrated complete occlusion of the TIPS lumen with thrombus that extended proximally into the RA. A TIPS check demonstrated persistent right atrial thrombus, which prompted simultaneous AngioVac-assisted thrombectomy, TIPS revision, and balloon-occluded retrograde transvenous obliteration of varices.

AngioVac thrombectomy was performed via right IJV access after heat shaping of the catheter with complete extraction of the atrial thrombus. After TIPS revision and balloon-occluded retrograde transvenous obliteration, restoration of hepatopetal shunt flow was demonstrated. The patient became hypotensive after the procedure. Chest CT revealed multiple small, likely septic emboli. The patient remained in the hospital for 2 weeks for management of sepsis. Chest CT performed 2 weeks after thrombectomy revealed no remaining thrombus in the IVC, and liver US demonstrated phasic flow in the IVC. The patient underwent liver transplant later that year.

Case 3

A 73-year-old man had lung adenocarcinoma, small cell bladder carcinoma, and adenocarcinoma of the prostate. He was admitted for transurethral bladder tumor resection and was found to have juxtarenal IVC thrombus and bilateral PE. A pulmonary lysis catheter was placed, and a suprarenal IVC filter was deployed cephalad to the IVC thrombus bridging the renal veins. Repeat

CT performed 7 weeks later demonstrated progressive occlusive IVC thrombus extending proximally from a juxtarenal location (Fig 3). The patient presented for AngioVac-assisted mechanical thrombectomy before planned suprarenal filter removal.

Before beginning the procedure, digital subtraction angiography showed that the filter appeared tilted and deformed. The AngioVac cannula was passed through the struts of the existing filter via right IJV access (Fig 4); however, given the strut configuration, only the medial caval component could be addressed from the IJV access, resulting in subtotal clot extraction. In an attempt to remove the remaining caval thrombus, the cannula was then passed through a right common femoral vein (CFV) access, and thrombectomy was performed in posterior-to-superior fashion. During retrograde passage of the AngioVac cannula through the filter struts, the balloon tip ruptured compromising distal cannula leaflet deployment (Fig E1 [available online at *www.jvir.org*]). At the end of the procedure, a portion of thrombus remained adherent to the vessel wall. Because of tilt and deformity, the existing filter was removed and replaced. A thrombectomized specimen was sent for pathologic evaluation and was determined to consist of organizing thrombus with deposits of pancreaticobiliary tract adenocarcinoma, a new primary neoplasm. Surveillance CT performed 3 months after thrombectomy revealed reocclusion of the IVC. The cause of the obstruction (thrombus or tumor) was not investigated, and the patient ultimately entered hospice care.

Case 4

A 50-year-old man with a history of lupus anticoagulant syndrome, PE, deep vein thrombosis, and remote intracerebral hemorrhage with an IVC filter was found to have occlusion of the IVC and iliac veins bilaterally. Catheter-directed lysis was performed with minimal improvement, at which time the patient consented to AngioVac-assisted thrombectomy.

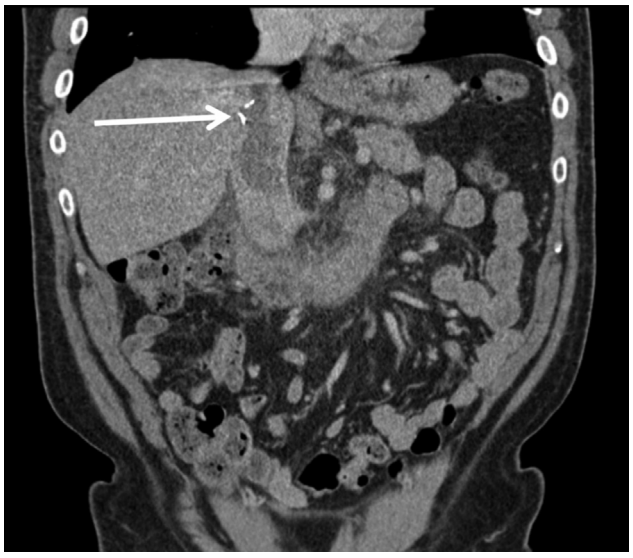


Figure 3. Case 3. Coronal CT image depicting extensive IVC thrombus surrounding the struts of a previously placed IVC filter (arrow).

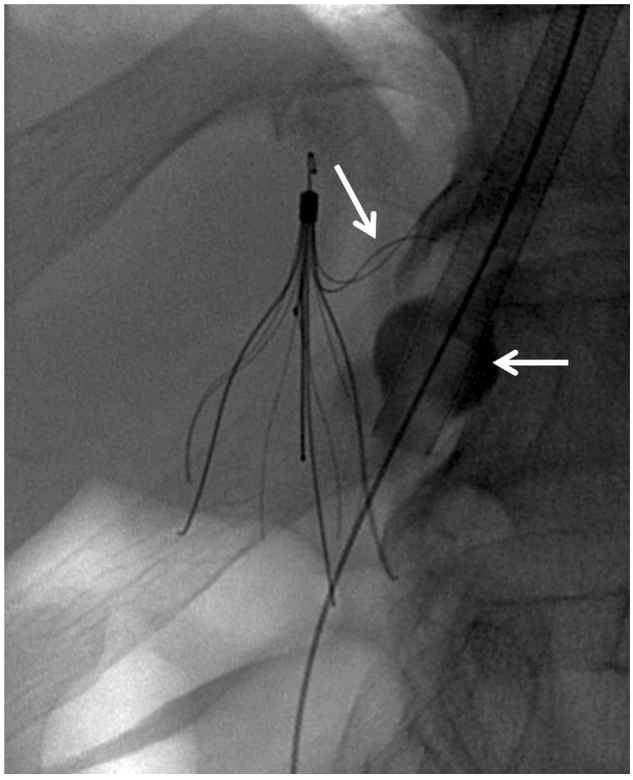


Figure 4. Case 3. AngioVac cannula passing medially through the struts of deformed IVC filter (arrow, top) during mechanical thrombectomy. Cannula (arrow, bottom) removal through filter struts resulted in balloon rupture.

Aspiration was performed via right IJV access. Given the existing clot within and caudal to the occluded filter, a tandem 10-F right jugular access was placed to allow for IVC filter removal during aspiration in an attempt to extract filter-associated thrombus dislodged during filter removal. While advancing the cannula through what seemed to be chronic clot, the balloon ruptured at its tip. At completion, some residual wall-adherent clot remained (Fig 5). Follow-up CT performed 5 weeks later revealed patent iliofemoral veins with small areas of hypoattenuation consistent with residual chronic clot.

Case 5

A 37-year-old man with suspected antithrombin III deficiency was admitted with left lower extremity pain and found to have thrombosis of the IVC and deep veins of the lower extremity. He underwent catheter-directed thrombolysis and IVC filter placement and was discharged on low-molecular-weight heparin. He developed right lower extremity pain 2 days later and was found to have acute deep vein thrombosis, again undergoing catheter-directed thrombolysis. The day after discharge, he developed bilateral lower extremity pain and dyspnea

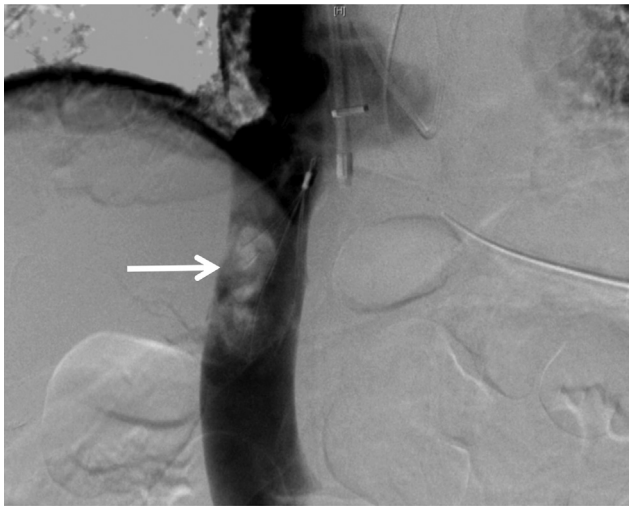


Figure 5. Case 4. Cavogram showing restored patency with some residual wall-adherent clot (arrow).

on exertion. CT showed thrombosis of the IVC and the lower extremity deep and iliofemoral veins bilaterally, PE, and heparin-induced thrombocytopenia. He was admitted to the surgical intensive care unit on a direct thrombin inhibitor and consented for iliocaval AngioVac-assisted thrombectomy.

Angiography revealed large-volume thrombus extending from the iliac veins to the infrarenal IVC filter. AngioVac thrombectomy was performed via right IJV access to the level of the IVC filter. The filter was removed through the right axillary access via a snare and sheath technique during AngioVac aspiration. Thrombectomy was resumed; however, complete iliofemoral thrombus removal was impeded by vacuum-induced vein wall coaptation in vessels with luminal diameters that approached device funnel width (Fig 6). A 7-mm angioplasty balloon (Advance 35LP; Cook, Inc, Bloomington, Indiana) was advanced into the left CFV, and sweeps were performed in an attempt to dislodge wall-adherent clot with concurrent AngioVac aspiration, although insubstantial additional thrombus was extracted (11). A cavogram revealed a patent IVC with brisk anterograde flow. A new filter was placed caudal to the renal veins. CT scan performed 5 months after thrombectomy showed no evidence of clot in the left common, external, and internal iliac veins or CFV.

Case 6

A 39-year-old man with a history of cutaneous T-cell lymphoma complicated by recurrent graft-versus-host disease after bone marrow transplantation was admitted to the intensive care unit for management of septic shock and acute respiratory failure. A troponin leak prompted transthoracic echocardiography, which identified a RA mural thrombus, and magnetic resonance imaging further identified thrombus adjacent to the tip of a tunneled IJV catheter. There was concern for embolization in a

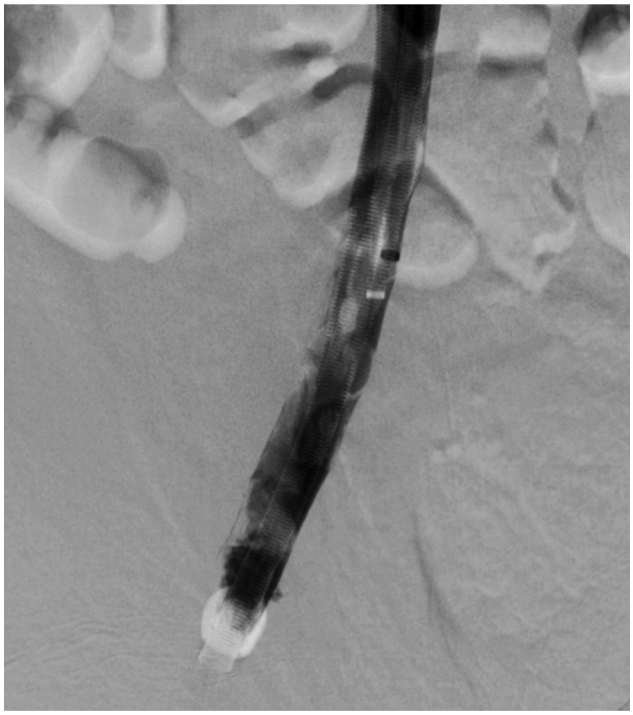


Figure 6. Case 5. AngioVac cannulation of a vein with a luminal diameter approaching the device funnel size may be complicated by vacuum-induced vessel collapse.

patient with limited pulmonary reserve, and so the patient consented to undergo AngioVac-assisted thrombectomy of the RA clot.

TEE performed during the procedure revealed a mass at the distal end of the tunneled catheter near the cavoatrial junction and a separate 3-cm mobile mass adherent to the RA wall prolapsing through the tricuspid valve during diastole. Access was achieved via the right CFV. The cannula was advanced to the RA, and the tunneled catheter was removed. Right IJV access was obtained because of poor angulation of the AngioVac cannula relative to the RA thrombus achieved with the initial CFV access. Thrombus adjacent to the tunneled catheter was completely extracted. TEE suggested that RA mural thrombus was adherent to the atrial wall in a pedunculated fashion and not prolapsing through or extending into the PA. A snare was advanced through the axillary vein into the RA and looped around the narrow base of the mural thrombus to separate it from the atrial wall. Freed clot was aspirated through the AngioVac cannula. A sessile remnant of the mural thrombus remained adherent to the atrial wall. Echocardiography and chest CT scan performed 5 and 6 months after thrombectomy, respectively, showed no evidence of intracardiac or caval thrombus.

Case 7

A 70-year-old man had a history of cirrhosis complicated by hepatocellular carcinoma with metastases to the ribs (12). He presented to the hospital with acute-on-

chronic back pain and weakness and was found to have a large psoas abscess and epidural/subdural collections. TEE performed to rule out endocarditis revealed a right atrial mass (3.3 cm × 2.1 cm) thought to be associated with an indwelling peripherally inserted central catheter, as TEE performed before placement of the peripherally inserted central catheter showed no atrial mass.

The patient underwent AngioVac-assisted thrombectomy of the atrial mass and concurrent withdrawal of the peripherally inserted central catheter. The cannula was advanced under TEE into the RA via a right CFV approach; however, the atrial mass was not readily cannulated. Via a left CFV access, an 18-mm angioplasty balloon was advanced and used to agitate mass remnant while thrombectomy was continued. After manipulation with the balloon, TEE revealed successful removal of the atrial mass. The specimen was sent for pathologic analysis and found to be neoplastic tissue consistent with hepatocellular carcinoma (gross and histologic preparations of aspirate are depicted in the article by Abboud et al [12]). The patient was discharged with scheduled oncologic follow-up but did not return.

DISCUSSION

The management of central venous thromboembolism represents a complex therapeutic dilemma. Central thrombi should be swiftly abated to spare significant morbidity. However, patients who develop such high degrees of clot burden are often critically ill and less able to tolerate traditional methods for thrombolysis or thrombectomy, many of which are ineffective in the setting of massive clot burden. The AngioVac system is designed to address some of these concerns. Case reports and single-center series describe effective use of the device for the removal of intracardiac masses, acute PE, and caval and iliocaval thrombi (8,10). Efficient thrombectomy facilitated by the large-diameter cannula is an alternative to thrombolytic methods, which often require long infusion times, are frequently contraindicated in medically complex patients, and may risk hemorrhagic complications. The use of extracorporeal bypass allows for large-volume aspiration in proportion to clot burden, while minimizing risk of embolization or exsanguination. The broad diameter of the aspiration cannula further facilitates large-volume thrombectomy and minimizes the likelihood of embolism, as clot is less likely to pass beyond the broad cannulation tip during the procedure. However, extracorporeal bypass is not available at all centers, limiting the applicability of this technique.

In all cases presented here, clot burden was reduced. Perioperative or postoperative complications were few, although one patient (case 2) experienced septic embolization to the lungs. Although the large diameter of the catheter is designed to prevent this complication, it was not avoided in all cases. In addition to providing an assessment of the efficacy of the AngioVac device in carefully selected patients, this center's experience has yielded several technical insights.

1. Supplemental venous access is needed to accommodate ancillary percutaneous devices perioperatively. All procedures in this series were augmented with the use of accessory endoluminal devices, including angioplasty balloons to dislodge adherent clot from vessel walls, snares for filter removal or the amputation of pedunculated mural thrombi (a technique described elsewhere) (6), and intravenous US. Intravenous US was used in case 1 to augment TEE of atrial thrombi, although it is unclear whether its use in this case was beneficial. Early studies of intravenous US in the setting of iliofemoral deep vein thrombosis therapy have not demonstrated a therapeutic benefit (13). The use of these accessory devices necessitated additional percutaneous access sites.
2. The AngioVac catheter can be advanced into the PA to facilitate PA thrombectomy with the assistance of a flow-directed balloon catheter. Case 1 represents an instance of successful clot abatement from the PA as well as the RA and ventricle. Advancing the large-diameter catheter through the right heart en route to the PA has the potential to result in traumatic damage to delicate cardiac structures (eg, the tricuspid and pulmonic valves as well as chordae) and cause life-threatening insufficiency. The safety and efficacy of this procedure warrant further study, although recent reports have demonstrated successful AngioVac-assisted PE removal (14,15). Should it be deemed necessary in the meantime, advancing the device over a wire positioned with the use of a flow-directed balloon catheter (allowing the balloon to traverse areas of laminar flow ensuring atraumatic passage of the wire and catheter through central, high-flow channels of the cardiac chambers and valve apertures away from chamber walls) may protect against damage to the pericardium, chordae, or valve epithelium.
3. Procedures may be assisted by the use of multiple imaging modalities. As described earlier, TEE, in addition to assisting with visualization of cardiac thrombi, allows for rapid echocardiographic assessment of atrioventricular function. Intravenous US was used in several instances to assist in visualization of thrombi but may not improve outcomes compared with TEE alone.
4. Preoperative and perioperative heat shaping of the AngioVac aspiration cannula tip can enhance device performance. The tip of the AngioVac catheter can be modified to achieve a directional shape more suited to individual anatomy. A heat gun softens the catheter allowing it to be bent to the desired geometry and fixed in cold water. When performing such modifications, the most distal end of the catheter may become

damaged, preventing optimal deployment of the funneled catheter tip, which may limit effective thrombectomy and promote embolization. Although the cannula can be removed from the endoluminal space and reinserted percutaneously elsewhere, the funnel-shaped tip of the device may accrue progressive deformation with repeated removal and reinsertion. It is important to consider whether heat shaping will be necessary before initiating thrombectomy and to select the access site carefully.

5. Thrombectomy allows for pathologic evaluation of thrombectomized specimens. In two of the cases described (cases 7 and 3), occlusive lesions were thrombectomized and, on pathologic evaluation, determined to represent previously unknown neoplastic tissue. Attempts to lyse or macerate these lesions would have been ineffective or prevented pathologic diagnosis of new or progressive neoplastic processes. Tissue can be removed more or less en masse using the large-caliber AngioVac catheter, and the ability to preserve a specimen while achieving mechanical extraction represents another potential advantage of the device. Although other methods for endovascular biopsy are available, in the presence of associated thrombus, lesion localization with forceps or other endovascular biopsy devices may be impossible. Furthermore, suspicion for a neoplastic process would have to be high to recommend biopsy before thrombectomy or thrombolysis.
6. Vessel size and vein coaptation need to be considered. Some vessels with luminal diameters that minimally exceed that of the aspiration cannula are not amenable to aspiration, as their compressible venous walls cause them to undergo vessel collapse or coaptation when submitted to the highly negative intraluminal pressures exerted by vacuum suction.
7. The cannula tip balloon may rupture. In cases 3 and 4, the AngioVac cannula tip balloon was ruptured as it was passed through the struts of an IVC filter (case 3) and through chronic clot (case 4). Safe use of the device after balloon rupture is not yet well described, and so special care should be taken when maneuvering through vascular beds compromised in this manner.

In conclusion, the AngioVac device is useful in achieving rapid clot abatement in carefully selected patients with central venous thrombosis. Because the procedure requires careful patient monitoring and the use of extracorporeal bypass, it should not be initiated without adequate consideration of risks and benefits of this intervention and its alternatives. In addition to revealing some technical considerations that may facilitate optimal device usage, results from this case series suggest that AngioVac-assisted thrombectomy may be a useful therapy in critically ill patients with large thromboses of the atria or central veins.

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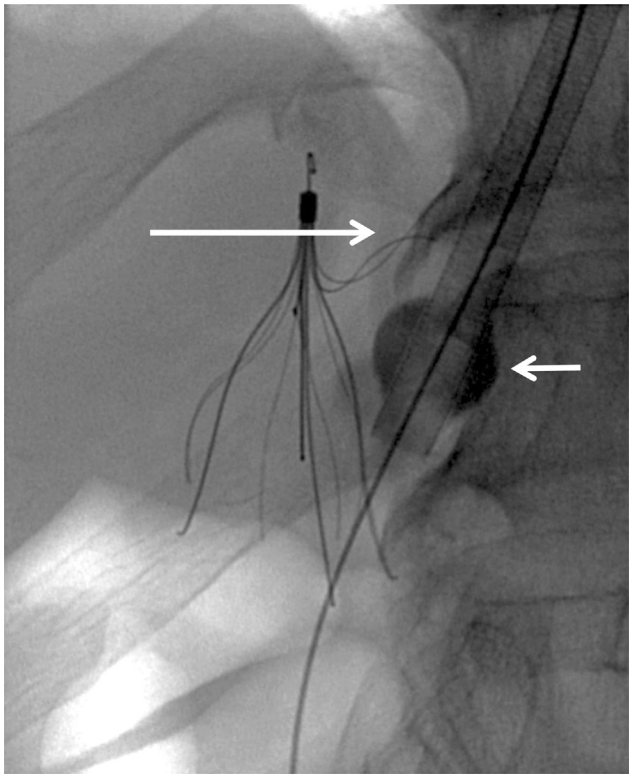

Figure E1. Case 3. AngioVac aspiration cannula with inflated balloon tip (arrow, bottom) passing retrograde through deformed struts of IVC filter (arrow, top), ultimately resulting in balloon rupture.