Management of Cavoatrial Deep Venous Thrombosis: Incorporating New Strategies

Mohamed A. Zayed, MD, PhD^{1,2} Gayan S. De Silva, MD¹ Raja S. Ramaswamy, MD³ Luis A. Sanchez, MD¹

¹ Section of Vascular Surgery, Department of Surgery, Washington University School of Medicine, St. Louis, Missouri

² Department of Surgery, Veterans Affairs St. Louis Health Care System, St. Louis, Missouri

³ Interventional Radiology Section, Washington University School of Medicine, Mallinckrodt Institute of Radiology, St. Louis, Missouri

Address for correspondence Mohamed A. Zayed, MD, PhD, Department of Surgery, Campus Box 8109, 660 South Euclid Avenue, St. Louis, MO 63110-1093 (e-mail: zayedm@wustl.edu).

Semin Intervent Radiol 2017;34:25–34

Abstract

Cavoatrial deep venous thrombosis (DVT) is diagnosed with increasing prevalence. It can be managed medically with anticoagulation or with directed interventions aimed to efficiently reduce the thrombus burden within the target venous segment. The type of management chosen depends greatly on the etiology and chronicity of the thrombosis, existing patient comorbidities, and the patient's tolerance to anticoagulants and thrombolytic agents. In addition to traditional percutaneous catheter-based pharmacomechanical thrombolysis, other catheter-based suction thrombectomy techniques have emerged in recent years. Each therapeutic modality requires operator expertise and a coordinated care paradigm to facilitate successful outcomes. Open surgical thrombectomy is alternatively reserved for specific patient conditions, including intolerance of anticoagulation, failed catheter-based interventions, or acute emergencies.

Keywords

- ▶ deep venous thrombosis
- ▶ thrombolysis
- ▶ thrombectomy

Objectives: Upon completion of this article, the reader will be able to describe the diverse therapeutic options for patients with extensive cavoatrial deep vein thrombosis.

Accreditation: This activity has been planned and implemented in accordance with the Essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of Tufts University School of Medicine (TUSM) and Thieme Medical Publishers, New York. TUSM is accredited by the ACCME to provide continuing medical education for physicians.

Credit: Tufts University School of Medicine designates this journal-based CME activity for a maximum of **1 AMA PRA Category 1 Credit™**. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Cavoatrial deep venous thrombosis (DVT) is a complex medical and surgical condition.¹ Due to a multitude of patient-specific risk factors, the prevalent use of central

venous catheters (CVCs), and the increasing rates of vena cava filter and stent implantation (–Fig. 1), both the incidence and prevalence of cavoatrial DVT have increased over recent years.¹ Accordingly, therapeutic methodologies and technologies have continued to evolve to keep up with the treatment demands of patients with cavoatrial DVT. Here, we will review the latest techniques in catheter-based interventions, as well as potential surgical options.

Types of Cavoatrial Deep Vein Thromboses

Iliocaval Deep Vein Thrombosis

Representing approximately 25% of all DVTs, iliac DVTs are defined as a thrombus involving the iliac veins with or without thrombus extension into the inferior vena cava (IVC) or common femoral veins.² Iliocaval DVTs are usually diagnosed using venous duplex; however, cross-sectional imaging or venography may be necessary if thrombus extension into the vena cava is suspected. Presenting symptoms can

Fig. 1 Cavoatrial deep venous thromboses (DVTs) resulting from indwelling or implantable devices. (a) Iliocaval DVT (solid arrow) extending from an infrarenal OptEase filter (dashed arrow). (b) Free-floating right atrial thrombus (solid arrow) extending from an indwelling catheter (dashed arrow).

vary for mild unilateral or bilateral lower extremity edema, to severe pelvic and lower extremity venous congestion leading to phlegmasia and concomitant limb ischemia.³ Postthrombotic syndrome (PTS) is a prevalent side effect of ilio caval DVTs, and results from residual venous obstruction and valvular incompetence in the previously thrombosed venous segment.³ This can lead to venous claudication, skin ulceration, and stasis dermatitis—all of which lead to significant patient morbidity and impaired physical activity.^{4,5}

Current strategies for the treatment of ilio caval DVTs include systemic anticoagulation, catheter-directed thrombolysis (CDT), and various forms of adjunct mechanical and/or suction thrombectomy.⁶ Recent studies demonstrate that in the majority of patients diagnosed with acute iliac DVT, percutaneous transcatheter thrombolysis can achieve success rates of up to 80% in venous recanalization, and more than 60% thrombosis free survival at 6 and 12 months from the index procedure.⁷ Patients with acute first-time iliac DVT who achieve complete DVT resolution with thrombolysis have a 96% extended patency rate at 1 year.^{7–9} Similarly, the Society of Interventional Radiology (SIR) also affirmed the available evidence,¹⁰ suggesting a clinical benefit for CDT in specific subgroups of patients with iliofemoral DVT including those with low bleeding risk and limb-threatening disease.¹¹

Catheter-Related Atrial Thrombus

The most frequent complication associated with tunneled and nontunneled CVC is thrombosis.¹² Despite the prevalent use of CVCs, the incidence of catheter-associated right atrial thrombus (CRAT) is not well described—with clinical patient series reporting a thrombosis rate ranging between 2 and 18%.^{12,13} Consequently, optimal management for CRAT is also not well defined, and varies based on thrombus size, burden, and patient symptoms.

The majority of studies that explore the incidence and treatment of CRAT have often regarded the size and extent of thrombus as the main indication for treatment. However, the

bulk of patients diagnosed with CRAT are typically asymptomatic, and often the thrombus is incidentally detected on cross-sectional imaging or echocardiography (►Fig. 1b). Nevertheless, existing recommendations suggest that CRAT less than 1.5 cm can be managed with catheter removal or exchange, while CRAT more than 1.5 cm can be treated with addition of therapeutic anticoagulation.¹⁴

Although there are no randomized trials exploring the efficacy of anticoagulation, thrombolysis, and surgical thrombectomy, there are a few observational studies that have explored the outcomes of these interventions in the treatment of CRAT.¹³ Stavroulopoulos et al¹³ reviewed their outcomes in 71 patients with hemodialysis CVCs who were diagnosed with CRAT. Nine patients received no treatment except catheter removal and antibiotic therapy—four of these patients died. Systemic thrombolysis was administered in eight patients, but only successful in two with pulmonary embolism (PE) and the remaining six patients required additional treatment. For the remaining patients, 37 were treated with anticoagulation alone and 23 underwent surgical thrombectomy. There was no statistical difference in mortality between anticoagulation alone versus surgical thrombectomy (16.2 vs. 13%, respectively). Patients who underwent thrombectomy tended to be younger and have a higher thrombus burden compared with patients who underwent anticoagulation alone. Patients with CRAT greater than 6 cm underwent surgical thrombectomy and survived their operations. Therefore, thrombolysis is thought to be beneficial in patients who are symptomatic or have evidence of PE, while surgical thrombectomy may be advocated for patients who have a larger thrombus burden leading to cardiac dysfunction and/or altered preload.¹³

Free-Floating Right Heart Thrombi

On the spectrum of atrial DVTs, free-floating right heart thrombosis is reported with an estimated incidence of 7 to 18% in patients with recurrent PE and/or symptoms of right

heart failure.¹⁵ Like CRAT, the majority of these are diagnosed incidentally, but unlike CRAT the thrombus tends to be elongated, highly mobile, and not associated with a foreign body (e.g., catheter). The majority of free-floating right heart thrombus can be diagnosed with good resolution using 2D or 3D echocardiography.¹⁵ Further imaging with cross-sectional CT or MR can help evaluate the extent of the thrombus, especially into the pulmonary vasculature, and determine whether the patient also has an underlying cardiac abnormality (i.e., intra-cardiac mass, valvular vegetation, etc.).¹⁶

The general prognosis for patient with free-floating right heart thrombus is poor, with a reported mortality rate of greater than 40% given their susceptibility for embolization.¹⁷ As a result, the diagnosis of free-floating thrombus in the right heart is regarded as an emergency. Traditional surgical approaches can be performed under cardiopulmonary bypass to allow for effective exploration of the right heart and pulmonary arteries, and facilitate manual thrombectomy.¹⁸ Less invasive thrombolysis procedures have also been recently proposed for treatment of free-floating right heart thrombus with variable degrees of success.¹⁹

Chartier et al reviewed their experience with 38 patients diagnosed with free-floating right heart thrombus over a period of 12 years.¹⁹ In their patient cohort, 44.7% of patients (17/38) underwent emergency surgical thrombectomy, 23.7% (9/38) underwent chemical thrombolysis using systemic intravenous tissue plasminogen activator (tPA), and 21% (8/38) underwent therapeutic anticoagulation alone (4 patients underwent interventional percutaneous techniques for thrombus removal). Successful outcomes were reported in 52.9% of patients treated surgically, and in 77.8% of patients treated with systemic intravenous tPA. Patients who were initiated on therapeutic anticoagulation had the least successful outcomes, with 50% dying soon after initiation of therapy. Of the remaining patients, the majority required additional adjunct thrombectomy procedures, and ultimately developed intractable right heart failure symptoms.¹⁹

Superior Vena Cava Thrombosis

Superior vena cava (SVC) thrombosis can occur by primary thrombus extension from the upper extremities and/or internal jugular (IJ) veins, but more commonly occurs in the setting of indwelling CVCs or pacemaker wires.^{1,20} Turbulence and vibration of these objects in the lumen of the innominate veins or SVC leads to endothelial injury, intimal hyperplasia, luminal stenosis, venous wall thickening, and ultimately thrombosis.²¹ In 20 to 40% of patients, SVC thrombosis leads to symptoms of SVC syndrome—where symptoms can range from mild facial swelling and distended neck veins to severe neck and airway edema leading to dysphagia, orthopnea, and stridor.²²

The diagnosis of a significant SVC thrombosis can be achieved with noninvasive duplex testing.²³ Confirmation with CT or MR venogram may be necessary to examine if a large central venous thrombus extends into the right atrium. This appears to be a relatively rare complication, with only a handful of case reports documented in the literature.^{23,24}

The management of SVC thrombosis is centered on achieving adequate patient symptom relief.²⁵ Therefore, if expectant management and therapy with systemic anticoagulation alone fails to improve patient symptoms, recanalization procedures aimed at restoring SVC patency may be next pursued. Pharmacomechanical thrombolysis (PCDT), with or without angioplasty and stenting, is frequently described for the treatment of SVC thrombosis with variable success rate.^{26,27} In a retrospective review of 326 patients, over an 18-year period, 56% of patients who received CDT had successful recanalization of the SVC and complete lysis of their thrombotic burden.²⁸ The study concluded that in patients with acute (<5 days) symptoms are more likely to be successfully lysed, and achieve adequate patency.

Percutaneous Catheter-Directed Thrombolysis

Overview of Management Strategy

The first-line treatment for acute DVT is systemic anticoagulant therapy. Anticoagulant therapy is highly effective in preventing further DVT extension and PE with a low risk of complications and improvement in morbidity and mortality.²⁹ However, despite the effectiveness of anticoagulation, up to 40% of patients who develop DVT (particularly in the iliofemoral and iliofemoral venous segments) may develop PTS within 2 years after DVT.² In patients with extensive thrombus burden, in particular within the IVC, CDT can achieve a quicker, more complete lysis of thrombus when compared with systemic thrombolysis and with a high safety profile.³⁰

Recent guidelines published by the Society of Interventional Radiology suggest that most patients undergoing percutaneous thrombolysis or thrombectomy for DVT should have image-proven symptomatic DVT in the IVC, iliac vein, common femoral vein, and/or femoral vein, in a recently ambulating patient with DVT symptoms for shorter than 28 days or in whom there is a strong clinical suspicion for recently formed (<28 days) DVT.^{31,32} Furthermore, the Society for Vascular Surgery also suggests percutaneous catheter-directed PCDT for early thrombus removal in patients with the following: a first episode of acute iliofemoral DVT, symptoms less than 14 days in duration, low risk of bleeding, and ambulating with good functional capacity and life expectancy.³³ Thus, percutaneous CDT/thrombectomy is recommended in the majority of patients diagnosed with acute DVT in the iliofemoral and/or iliofemoral venous systems who have a low risk of bleeding.

Patient Selection

The Society of Interventional Radiology has published practice guidelines including indications and contraindications for CDT (► **Table 1**). Patients who present with DVT require detailed workup prior to percutaneous catheter-directed intervention. Clinical severity of DVT, anatomic extent of DVT, projected risk of bleeding complications, baseline ambulatory capacity, and patient preference should all be taken into consideration prior to intervention.^{34,35}

Table 1 Patient-specific indications and contraindications for catheter-directed thrombolysis of lower extremity DVT

Indications	Relative contraindications	Absolute contraindications
1. Image proven symptomatic DVT in the following areas: <ul style="list-style-type: none"> • IVC • Iliac • Common femoral • Femoral vein With DVT symptoms for < 28 d or 2. A strong clinical suspicion for recently formed (<28 d) DVT	1. Uncontrolled hypertension (SBP > 180 mm Hg or DBP > 100 mm Hg) 2. Recent major GI bleeding (within 3 mo) 3. Severe thrombocytopenia 4. Known right-to-left cardiac or pulmonary shunt 5. Left heart thrombus 6. Renal failure 7. Bacterial endocarditis 8. Diabetic hemorrhagic retinopathy 9. Suspicion for infected venous thrombus 10. Known allergy to thrombolytics, contrast media, or anticoagulant 11. Intracranial tumor/lesion 12. Seizure disorder 13. Recent cardiopulmonary resuscitation, major surgery, obstetrical delivery, organ biopsy, trauma, cataract surgery (<7–10 d)	1. Active internal bleeding 2. Disseminated intravascular coagulation 3. Recent cerebrovascular event (TIA), neurosurgical intervention (intracranial, spinal), or recent intracranial trauma within 3 mo 4. Contraindication to anticoagulation

Abbreviations: DBP, diastolic blood pressure; DVT, deep vein thrombosis; SBP, systolic blood pressure; TIA, transient ischemic attack.
 Source: Adapted from Vedantham et al Quality Improvement Guidelines: Treatment of Lower-Extremity DVT, 2014.

Clinical severity for each patient has significant variance and can be grouped into three major categories: (1) urgent thrombolysis indicated to prevent life- or limb-threatening complications of acute DVT, (2) progressive IVC or iliofemoral venous thrombosis despite anticoagulation, and (3) prevention of PTS in patients with symptomatic proximal DVT. For the first group, aggressive therapy is warranted, whereas there is a low threshold for exclusion in groups 2 and 3. Similarly, patients with IVC thrombosis presenting with pelvic congestion, limb symptoms, or compromised visceral, renal, or hepatic drainage may benefit from thrombolysis. Those requiring thrombolytic therapy for PE usually do so due to unstable hemodynamic changes despite systemic anticoagulation therapy, or those at risk of impending death before systemic thrombolysis can become effective. Determination of anatomic extent of DVT is crucial in patient selection for catheter-directed therapy. Patients who present with extensive DVT in the IVC and/or iliofemoral region with a theoretical low risk of bleeding complications are most likely to benefit from catheter-directed interventions.

Technical Strategies for Endovascular Thrombus Removal

There are multiple percutaneous catheter-based techniques that can be used to remove intraluminal venous thrombus. Thrombus removal techniques include infusion CDT, percutaneous mechanical thrombectomy (PMT), and pharmacomechanical catheter-directed thrombolysis (PCDT).

CDT refers to pharmacologic thrombolytic agent delivery through an infusion catheter that is embedded within the thrombosed venous segment. tPA is directly infused into the thrombus via a multi-sidehole catheter. The principle behind CDT is that it achieves a higher intrathrombus drug concentration in combination with reduced systemic intravascular

dose. Access is gained into thrombosed venous segment either via a jugular or femoral approach. Catheter-directed venograms or intravascular ultrasound (IVUS) demonstrates the extent and location of the thrombus (→Fig. 2). After determining the extent and location of the thrombus, a multi-sidehole infusion catheter is placed directly into the

Fig. 2 Characterization of ilio caval deep venous thrombosis (DVT). A 56-year-old woman with prior history of left common iliac vein DVT and stenting, presented with unilateral right lower extremity edema. Right common iliac vein DVT was confirmed with venography (a) and intravascular ultrasound (b and c).

thrombus. tPA is then infused at a dose of 0.01 mg/kg/h up to a maximum of 1.0 mg/h. During thrombolytic infusion, a CBC, fibrinogen, and PTT are drawn every 6 hours. Follow-up venography is performed after infusion to identify any lesions. Clot maceration, balloon angioplasty, and stent placement may be needed to treat the offending lesion if present. Limitations of CDT include long infusion time required for complete DVT treatment which can lead to potential major bleeding and hospital resources needed to monitor the patient.³⁶

PMT provides mechanical clot debulking and helps provide early restoration of venous flow. Mechanical agitation of the clot allows for extraction and/or maceration of acute and chronic thrombus. Mechanisms of action include rheolytic/high-velocity water jets (Angiojet Rheolytic Thrombectomy System; Medrad Interventional/Possis, Warrendale, PA)³⁷ or rotational mechanical devices (Arrow-Trerotola percutaneous thrombolytic device; Arrow, Reading, PA).³⁸

PCDT combines thrombolytic agents with mechanical thrombectomy (►Fig. 3). CDT dissolves thrombus fragments that could lead to PE while PMT increases the surface area of the vessel by removing thrombus, which will accelerate thrombolysis. Therefore, theoretically the amount of infused lytic is decreased and reduces the risk of complications. There are two strategies that are typically employed with PCDT: first-generation PCDT or single-session PCDT. First-generation PCDT involves using CDT infusion followed by PMT or vice versa. The use of first-generation PCDT has been shown to result in reduced thrombolytic drug dosage, infusion time, hospital stay, and hospital costs in retrospective comparative studies.³⁵ Single-session PCDT uses a rheolytic system such as Angiojet to forcefully spray lytic into the thrombus followed by utilization of a catheter to aspirate thrombus.³⁵

Complications

Review of the literature reveals rates of major complications for endovascular thrombolytic therapy to be at approximately 3.9%. Reported rate of major bleeding when administering CDT is 2.8%, symptomatic PE is 0.5%, intracranial bleeding is less than 1%, and mortality rates are less than 1%. Risks of PMT include vessel injury or valvular injury.³⁹

Summary of Recent Data

Percutaneous CDT is able to rapidly remove thrombus and prevent PTS.^{40,41} The CaVenT trial randomized patients with femoral or iliofemoral DVT to receive CDT plus anticoagulation or anticoagulation alone. At 2-year follow-up, the relative risk of PTS was reduced by 26%.⁴² It should be mentioned, however, that nearly 60% of patients in the study had upper femoral vein thrombus, without involvement of the iliac or common femoral vein. The ATTRACT trial (Acute Venous Thrombosis: Thrombus Removal with Adjunctive Catheter-Directed Thrombolysis) is an ongoing, multicenter randomized trial. Patients enrolled in the ATTRACT trial are randomized to receive either PCDT with standard DVT therapy or standard DVT therapy alone. Standard DVT therapy comprises anticoagulant therapy and elastic compression stockings.⁴³ The results of the ATTRACT trial are pending.

Percutaneous Suction Thrombectomy

Overview of Management Strategy

Recent evolution in endovenous thrombectomy techniques has broadened the horizons for the management of patients with cavoatrial and ilio caval DVTs. Although traditional percutaneous thrombectomy and thrombolysis techniques are typically reserved for vessels that are less than 10 mm in diameter, various reports describe their extended use in the cavoatrial

Fig. 3 Catheter-directed thrombolysis for treatment of ilio caval deep venous thrombosis (DVT). A 39-year-old woman with history of factor V Leiden with previously placed inferior vena cava filter reported to the ER with bilateral lower extremity swelling. (a) CT chest with contrast demonstrates a right pulmonary artery embolus. The patient was referred for a venogram and potential thrombolysis. (b) Contrast venogram performed via the left common iliac vein demonstrates acute appearing thrombus in the inferior vena cava. Catheter-directed thrombolysis was performed, and follow-up venogram (c) demonstrated thrombus resolution in the right ilio caval segment.

system.³⁵ Varying severity and chronicity in the extent of cavoatrial thrombosis can lead to suboptimal or incomplete thrombectomy.^{42,44} Additionally, specific patient populations may have relative or definitive contraindications to thrombolytic agents, which can also greatly limit successful outcomes using conventional pharmaco-mechanical thrombolysis.

The AngioVac device (AngioDynamics, Inc., Queensbury, NY) is an Food and Drug Administration (FDA)-approved large-diameter (22F) suction device platform that is suggested as an alternative thrombectomy device for the treatment of large volume cavoatrial DVTs.^{45–47} The AngioVac system is reported to reliably remove large volume thrombi from the right atrium,⁴⁸ SVC,⁴⁵ suprarenal and infrarenal IVC, and iliac venous systems.⁴⁶ The device uses a vacuum-assisted, Nitinol reinforced, suction cannula that is attached to an extracorporeal veno-venous circuit. The circuit is spliced by a filter apparatus that removes thrombi from the venous aspirate prior to recirculation into a venous inflow cannula inserted elsewhere in the central venous system.

Preoperative Patient Screening and Selection

Appropriate patient screening is essential in facilitating informed discussions with patients who are being considered for AngioVac suction thrombectomy. At our center, patients are evaluated and screened by a multidisciplinary team of interventional radiologists and vascular surgeons. This dedicated team reviews the potential risks and benefits of the procedure based on the patient's various clinical and anatomical variables (► **Table 2**).

First, the extent of patient's symptoms is one of the main indicators of whether a patient should be considered for therapy. Patients who have symptomatic cavoatrial or ilio caval DVT, have failed anticoagulation therapy alone, and/or cannot tolerate other thrombectomy and thrombolysis interventions can be considered for AngioVac suction thrombectomy. Second, patient's age and comorbidities are often helpful in informing the general risk profile of the intervention—particularly the potential for hemodynamic fluctuations and physiological stress associated with extracorporeal circulation. Third, since patency of the extracorporeal circuit requires therapeutic anticoagulation throughout the duration of the procedure, patients who

have relative and definite contraindications to anticoagulation are not candidates for AngioVac suction thrombectomy. Lastly, effort should be made to also estimate the chronicity of the thrombus since acute and subacute DVTs are much more likely to mold into the AngioVac suction cannula compared with chronic DVT.

Specific preoperative testing is also recommended in facilitating adequate screening of potential AngioVac patient candidates. For example, cross-sectional CT or MR venogram of the occluded central venous segment of interest is vital in planning the intraoperative cannulation strategy, and the options available for safe maneuvering of the AngioVac suction cannula to the thrombosed venous segment. Attention to the morphology and location of the thrombus should be taken into consideration, as this can help determine which cannulation strategy will be associated with the least amount of risk of iatrogenic PE.

For patients with ilio caval or SVC obstruction, lower or upper extremity venous duplex, respectively, can be very helpful in determining the extent of venous inflow, the area of obstruction. In the case of successful recanalization of obstructed ilio caval systems, patent femoral venous circulation will help sustain patency to the recanalized segment. Venous duplex also can provide an accurate estimation of the size and dimensions of where the outflow and inflow cannulas are inserted in the femoral and IJ veins. Finally, a preoperative transthoracic echocardiogram (TTE) with a “bubble study” is helpful in determining whether a patient has a patent foramen ovale (PFO). Patients with a large PFO have a theoretically increased risk of intraoperative stroke from paradoxical air or thromboembolism to the brain.

Coordination of Resources

The majority of studies report the use of the AngioVac device in a controlled operating room setting.^{46,49} Similarly, in our experience we have found that a hybrid operating room suite serves as an ideal setting for performing AngioVac suction thrombectomy. This not only provides access to state-of-the-art fluoroscopy-based imaging capabilities and an array of catheter-based devices, but also affords an environment that facilitates swift dealing with unforeseen bleeding, vessel injury, or a rare need for open surgical conversion.

In the presence of a cardiovascular anesthesiologist, the procedure can also be performed under general anesthesia and constant perioperative hemodynamic monitoring.^{46,48–50} A peripheral arterial line, and an adjunct central intravenous access, is a useful adjunct to have during the procedure. Access to intraoperative transesophageal echocardiogram (TTE) can be very valuable for evaluating intraoperative gross heart function during periods of veno-venous extracorporeal circulation. TTE can also be useful in evaluating the proximal extent of the thrombus—particularly if it extends into the right atrium or parahepatic IVC.

In our practice, a dedicated group of practitioners including a vascular surgeon, interventional radiologist, cardiac anesthesiologist, and perfusionist regularly perform this procedure. This multidisciplinary group of specialists helps evaluate, screen, schedule, and coordinate perioperative

Table 2 Clinical and anatomical factors used for screening patients for AngioVac suction thrombectomy

Clinical Factors
Age
Cardiopulmonary comorbidities
Ability to tolerate therapeutic anticoagulation
Ability to tolerate chemical thrombolysis
Nature of thrombus (acute, chronic, or tumor thrombus)
Anatomical Factors
Patent foramen ovale
Extent of cavoatrial deep venous thrombosis
Internal jugular, femoral, and caval diameters
Available patent central venous cannulation sites

procedural logistics. Intraoperatively, a two-team procedural approach often helps expedite certain portions of the procedure and improve the overall execution of the case. This is especially true during initiation of the extracorporeal circuit, which may require placement of inflow and outflow cannulas in distant anatomical areas (e.g., IJ and common femoral vein). To further facilitate this, the operating room is organized to maximize efficiency of a two-team operator approach.

Technical Strategies

The suction thrombectomy strategy is determined based on the extent and region of the cavoatrial DVT. Right atrial thrombus is most accessible from a right IJ cannulation, whereas ilio caval DVTs can be accessed from either an IJ or femoral vein approach. SVC DVT is best accessed from a femoral vein approach. Depending on the placement of the suction thrombectomy outflow cannula, the inflow cannula should also be strategically placed to sustain adequate cardiac preload. For example, in a patient with ilio caval DVT where the suction thrombectomy outflow cannula is advanced from a right IJ cannulation, the inflow venous cannula should be placed through the left IJ. On the other hand, if the suction thrombectomy outflow cannula is advanced from a femoral cannulation site, it is best to place the inflow cannula through an IJ cannulation.

Recent reports demonstrate that the majority of IJ and femoral cannulations for extracorporeal circulation can be achieved via percutaneous access.^{46,50,51} However, similar to other reports, we have evolved to perform all IJ cannulations through a small oblique cut-down incision with exposure of the proximal IJ.⁴⁵ Compared with large-diameter percutaneous cannulation of the IJ, the cut-down approach facilitates adequate intraoperative mobilization of the sternocleidomastoid muscle (which provides the majority of resistance encountered during advancement of large-diameter sheaths through the IJ cannulation) and allows for a more reliable placement of a 26F sheath in which the AngioVac cannula can be advanced through.^{46,52} Placement of a sheath is particularly useful in procedures where it is anticipated that suction thrombectomy will be attempted from both an IJ and a femoral vein approach. In this situation, sheath access at both the IJ and femoral vein provides easy access to either cannulation site, and facilitate quick transfer of the inflow and outflow cannulas during the procedure.

In our practice, we have also employed various technical strategies to help alleviate the potential risk of a perioperative PE. For example, in patients with IVC thrombosis, we have often placed an IVC filter just proximal to the level of the thrombus extension in the IVC. The filter is traversed with a 26F cannulation sheath, and through the sheath the AngioVac cannula is advanced to the thrombosed region of interest (►Fig. 4). Care is taken to never traverse the newly placed filter “bare-back” with the AngioVac cannula which could lead to dislodging and proximal migration of the filter.

For more organized and dense SVC or IVC DVTs, we have observed that the use of adjunct mechanical thrombolysis devices, such as the AngioJet (Boston Scientific, Inc.) or Cleaner device (Argon Medical Devices, Inc.), may aid with efficient suction thrombectomy with AngioVac (►Fig. 5). In these

Fig. 4 AngioVac suction thrombectomy under protection of inferior vena cava (IVC) (black arrows) filter. A 52-year-old man with history of renal cell carcinoma was incidentally found to have a large volume ilio caval deep venous thrombosis (a and b). (c) An IVC filter was placed in the suprarenal (white arrow) IVC and the AngioVac suction thrombectomy catheter was advanced across the filter through a 26F sheath. The suprarenal IVC (black arrow) filter was removed at the completion of the procedure. (d) Extent of intraluminal thrombus removed.

situations, to prevent PE it is paramount to reach adequate flow rates through the AngioVac circuit (3–4 L/min) prior to initiation of mechanical thrombolysis distal to the suction cannula. Constant monitoring of the AngioVac circuit flow volumes is also critical, as a steep decline in flow volumes often indicates that the suction cannula is obstructed. When this occurs, distal mechanical thrombolysis should be temporarily halted until adequate flow volumes are restored through the extracorporeal circuit.

Summary of Recent Data

The AngioVac cannula was approved by the U.S. FDA in 2009. Since then several individual centers have reported on their experience with this suction thrombectomy technique. The largest series to date reports outcomes on 14 patients with

Fig. 5 Adjunct pharma-mechanical thrombolysis in the setting of AngioVac suction thrombectomy. A 31-year-old woman who cannot tolerate therapeutic anticoagulation received an infrarenal inferior vena cava (IVC) filter placement due to recent pulmonary embolism. The patient (white arrow) subsequently developed thrombosis of her IVC filter. (a) A suparenal vena cava filter (white arrow) was placed in preparation for AngioVac suction thrombectomy of caval thrombosis at the site of her prior IVC filter placement. (b) Adjunct pharma-mechanical thrombolysis (white arrow) was performed in the setting of AngioVac suction (black arrow) at the level of the filter thrombosis. (c) Completion venography demonstrates complete recanalization and infrarenal IVC filter removal. At the completion of the procedure, the temporary suparenal IVC filter was also removed (not shown).

DVT, involving the vena cava (73%), PE (33%), right atrial mass (73%), right ventricular mass (20%), and CRAT (13%).⁴⁵ Successful thrombus removal was achieved in 73% of patients, and 87% of patients survived on short-term follow-up. The most common complication was bleeding, with 3 of 11 bleeds occurring in the postprocedure period at one of the venous access sites. Salsamendi et al reported similar outcomes in seven patients, where the majority of thrombus (50–95%) was removed in five patients, and partial thrombus (<50%) was removed in two patients.⁴⁷ All patients survived, and the only complications reported were neck hematomas in two patients. Another study that treated seven patients for cavoatrial and ilio caval DVTs reported 100% technical success in thrombus

removal, with only one case complicated by PE of septic thrombi.⁴⁶ On the other hand, Al-Hakim et al reported limited success in treatment of acute PE.⁵³ In the five patients reviewed in this study, technical success was achieved in only two patients, and four patients ultimately died at a mean of 7.3 days following the procedure. Currently, while the retrospective data for AngioVac is promising, there are no current ongoing prospective trials evaluating the efficacy of the device

Open Surgical Thrombectomy

Overview of Management Strategy

Surgical thrombectomy is rarely performed as a first-line modality for the treatment of acute ilio caval and cavoatrial DVT. Since percutaneous endovenous therapy can be performed with low morbidity and adequate rates of patency, this has replaced surgical venous thrombectomy and bypass as the primary treatment. However, in select, usually emergency situations, open surgical intervention with or without thrombectomy may be necessary. This is particularly true in patients who present with massive or submassive PE, or lower extremity phlegmasia dolens (resulting from major thrombosis involving the deep venous system of the thigh and pelvis) and impending venous gangrene. Patients presenting with these conditions may be hemodynamically unstable, and/or have limited time prior to hemodynamic compromise. Accordingly, once the diagnosis is made, emergent surgical treatment to restore venous patency is a top priority.

Lower Extremity Thrombectomy for Phlegmasia Dolens

This procedure is also performed under general anesthesia through a groin incision over the anticipated course of the common femoral vein and its bifurcation. After adequate exposure and circumferential control of the common femoral vein, a transverse venotomy can then be made directly at the level of the bifurcation while the patient is in mild Trendelenburg position. Appropriately sized Fogarty embolectomy catheters can be advanced nonselectively or over a wire into the ilio caval system for thrombectomy. Once retrograde flow is noted, care should be taken to avoid air emboli by clamping the proximal common femoral vein. Manual thrombectomy of DVT at the common femoral vein bifurcation can also be performed, but can be challenging in the distal femoral vein due to the presence of valves. Alternatively, Esmark compression of the limb or antegrade thrombectomy from a distal cut-down at the posterior tibial vein or popliteal vein can facilitate further thrombus retrieval from the groin venotomy.

Summary of Data

Despite early efficacy of lower extremity venous thrombectomy, venographic follow-up often demonstrates evidence of rethrombosis.⁵⁴ It is reported that stent implantation after thrombectomy can help preserve longer-term patency of iliofemoral venous segments following thrombectomy.⁵⁵ Similarly, creation of a distal arteriovenous fistula is suggested to improve patency following thrombectomy. However, the prevalence of PTS following surgical thrombectomy is not well reported.

Conclusion

Cavoatrial DVTs are prevalent and can lead to significant patient morbidity. Various techniques exist in the armamentarium of vascular specialists to restore venous patency, and reduce short-term and long-term risks associated with DVT. CDT and PCDT are effective percutaneous catheter-based techniques for the treatment of ilio caval DVTs, perhaps even more so with the concomitant use of thrombolytic agents, while the AngioVac suction thrombectomy can also be used for recanalization of larger volume cavoatrial DVTs. Surgical thrombectomy should be reserved for failed catheter-based interventions or for acute select emergencies. It is anticipated that as technologies continue to evolve, the efficacy, patency, and safety profile of the treatment of patients with cavoatrial DVTs will continue to expand.

References

- Akdoglu H, Yilmaz R, Peynircioglu B, et al. A rare complication of hemodialysis catheters: superior vena cava syndrome. *Hemodial Int* 2007;11(4):385–391
- Kahn SR, Shrier I, Julian JA, et al. Determinants and time course of the postthrombotic syndrome after acute deep venous thrombosis. *Ann Intern Med* 2008;149(10):698–707
- Douketis JD, Crowther MA, Foster GA, Ginsberg JS. Does the location of thrombosis determine the risk of disease recurrence in patients with proximal deep vein thrombosis? *Am J Med* 2001;110(7):515–519
- Delis KT, Bountouroglou D, Mansfield AO. Venous claudication in iliofemoral thrombosis: long-term effects on venous hemodynamics, clinical status, and quality of life. *Ann Surg* 2004;239(1):118–126
- Akesson H, Brudin L, Dahlström JA, Eklöf B, Ohlin P, Plate G. Venous function assessed during a 5 year period after acute ilio-femoral venous thrombosis treated with anticoagulation. *Eur J Vasc Surg* 1990;4(1):43–48
- Jenkins JS, Michael P. Deep venous thrombosis: an interventionalist's approach. *Ochsner J* 2014;14(4):633–640
- Bjarnason H, Kruse JR, Asinger DA, et al. Iliofemoral deep venous thrombosis: safety and efficacy outcome during 5 years of catheter-directed thrombolytic therapy. *J Vasc Interv Radiol* 1997;8(3):405–418
- Mewissen MW, Seabrook GR, Meissner MH, Cynamon J, Labropoulos N, Houghton SH. Catheter-directed thrombolysis for lower extremity deep venous thrombosis: report of a national multicenter registry. *Radiology* 1999;211(1):39–49
- Baldwin ZK, Comerota AJ, Schwartz LB. Catheter-directed thrombolysis for deep venous thrombosis. *Vasc Endovascular Surg* 2004;38(1):1–9
- Kearon C, Kahn SR, Agnelli G, Goldhaber S, Raskob GE, Comerota AJ. Antithrombotic therapy for venous thromboembolic disease: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines (8th Edition). *Chest* 2008;133(6, Suppl):454s–545s
- Vedantham S, Millward SF, Cardella JF, et al; Society of Interventional Radiology. Society of Interventional Radiology position statement: treatment of acute iliofemoral deep vein thrombosis with use of adjunctive catheter-directed intrathrombus thrombolysis. *J Vasc Interv Radiol* 2006;17(4):613–616
- Dilek M, Kaya C, Karatas A, Ozer I, Arık N, Gülel O. Catheter-related atrial thrombus: tip of the iceberg? *Ren Fail* 2015;37(4):567–571
- Stavroulopoulos A, Aresti V, Zounis C. Right atrial thrombi complicating haemodialysis catheters. A meta-analysis of reported cases and a proposal of a management algorithm. *Nephrol Dial Transplant* 2012;27(7):2936–2944
- Shah A, Murray M, Nzerue C. Right atrial thrombi complicating use of central venous catheters in hemodialysis. *J Vasc Access* 2005;6(1):18–24
- Goldhaber SZ. Optimal strategy for diagnosis and treatment of pulmonary embolism due to right atrial thrombus. *Mayo Clin Proc* 1988;63(12):1261–1264
- Mansencal N, Attias D, Caille V, et al. Computed tomography for the detection of free-floating thrombi in the right heart in acute pulmonary embolism. *Eur Radiol* 2011;21(2):240–245
- European Working Group on Echocardiography. The European Cooperative Study on the clinical significance of right heart thrombi. *Eur Heart J* 1989;10(12):1046–1059
- Gray HH, Morgan JM, Paneth M, Miller GA. Pulmonary embolectomy for acute massive pulmonary embolism: an analysis of 71 cases. *Br Heart J* 1988;60(3):196–200
- Chartier L, Béra J, Delomez M, et al. Free-floating thrombi in the right heart: diagnosis, management, and prognostic indexes in 38 consecutive patients. *Circulation* 1999;99(21):2779–2783
- Kokotsakis J, Chaudhry UA, Tassopoulos D, et al. Surgical management of superior vena cava syndrome following pacemaker lead infection: a case report and review of the literature. *J Cardiothorac Surg* 2014;9:107
- Forauer AR, Theoharis C. Histologic changes in the human vein wall adjacent to indwelling central venous catheters. *J Vasc Interv Radiol* 2003;14(9, Pt 1):1163–1168
- Rice TW, Rodriguez RM, Light RW. The superior vena cava syndrome: clinical characteristics and evolving etiology. *Medicine (Baltimore)* 2006;85(1):37–42
- Venturini E, Becuzzi L, Magni L. Catheter-induced thrombosis of the superior vena cava. *Case Rep Vasc Med* 2012;2012:469619
- Ayuela Azcárate JM, Pérez Ojeda G, Busto Sanz P, García González A, Fernández Ratero JA, Zabalegui Pérez A. [Catheter-related central venous thrombosis in the course of an uncomplicated acute myocardial infarction: diagnostic usefulness of echocardiography]. *Rev Esp Cardiol* 2002;55(4):446–448
- Abner A. Approach to the patient who presents with superior vena cava obstruction. *Chest* 1993;103(4, Suppl):394S–397S
- Kee ST, Kinoshita L, Razavi MK, Nyman UR, Semba CP, Dake MD. Superior vena cava syndrome: treatment with catheter-directed thrombolysis and endovascular stent placement. *Radiology* 1998;206(1):187–193
- Rizvi AZ, Kalra M, Bjarnason H, Bower TC, Schleck C, Głowiczki P. Benign superior vena cava syndrome: stenting is now the first line of treatment. *J Vasc Surg* 2008;47(2):372–380
- Gray BH, Olin JW, Graor RA, Young JR, Bartholomew JR, Ruschhaupt WF. Safety and efficacy of thrombolytic therapy for superior vena cava syndrome. *Chest* 1991;99(1):54–59
- Park J, Byun Y. Recent advances in anticoagulant drug delivery. *Expert Opin Drug Deliv* 2016;13(3):421–434
- Du GC, Zhang MC, Zhao JC. Catheter-directed thrombolysis plus anticoagulation versus anticoagulation alone in the treatment of proximal deep vein thrombosis - a meta-analysis. *Vasa* 2015;44(3):195–202
- Vedantham S, Thorpe PE, Cardella JF, et al; CIRSE and SIR Standards of Practice Committees. Quality improvement guidelines for the treatment of lower extremity deep vein thrombosis with use of endovascular thrombus removal. *J Vasc Interv Radiol* 2009;20(7, Suppl):S227–S239
- Vedantham S, Sista AK, Klein SJ, et al; Society of Interventional Radiology and Cardiovascular and Interventional Radiological Society of Europe Standards of Practice Committees. Quality improvement guidelines for the treatment of lower-extremity deep vein thrombosis with use of endovascular thrombus removal. *J Vasc Interv Radiol* 2014;25(9):1317–1325
- Meissner MH, Głowiczki P, Comerota AJ, et al; Society for Vascular Surgery; American Venous Forum. Early thrombus removal strategies for acute deep venous thrombosis: clinical practice

- guidelines of the Society for Vascular Surgery and the American Venous Forum. *J Vasc Surg* 2012;55(5):1449–1462
- 34 Vedantham S. Interventional therapy for venous thromboembolism. *J Thromb Haemost* 2015;13(Suppl 1):S245–S251
 - 35 Sista AK, Vedantham S, Kaufman JA, Madoff DC. Endovascular interventions for acute and chronic lower extremity deep venous disease: state of the art. *Radiology* 2015;276(1):31–53
 - 36 O'Sullivan GJ. The role of interventional radiology in the management of deep venous thrombosis: advanced therapy. *Cardiovasc Intervent Radiol* 2011;34(3):445–461
 - 37 Kasirajan K, Gray B, Ouriel K. Percutaneous AngioJet thrombectomy in the management of extensive deep venous thrombosis. *J Vasc Interv Radiol* 2001;12(2):179–185
 - 38 Lee KH, Han H, Lee KJ, et al. Mechanical thrombectomy of acute iliofemoral deep vein thrombosis with use of an Arrow-Trerotola percutaneous thrombectomy device. *J Vasc Interv Radiol* 2006;17(3):487–495
 - 39 Valji K. *Vascular and Interventional Radiology*. 2nd ed. Philadelphia, PA: Saunders Elsevier; 2006
 - 40 Comerota AJ, Throm RC, Mathias SD, Haughton S, Mewissen M. Catheter-directed thrombolysis for iliofemoral deep venous thrombosis improves health-related quality of life. *J Vasc Surg* 2000;32(1):130–137
 - 41 AbuRahma AF, Perkins SE, Wulu JT, Ng HK. Iliofemoral deep vein thrombosis: conventional therapy versus lysis and percutaneous transluminal angioplasty and stenting. *Ann Surg* 2001;233(6):752–760
 - 42 Enden T, Haig Y, Kløw NE, et al; CaVenT Study Group. Long-term outcome after additional catheter-directed thrombolysis versus standard treatment for acute iliofemoral deep vein thrombosis (the CaVenT study): a randomised controlled trial. *Lancet* 2012;379(9810):31–38
 - 43 Vedantham S, Goldhaber SZ, Kahn SR, et al. Rationale and design of the ATTRACT Study: a multicenter randomized trial to evaluate pharmacomechanical catheter-directed thrombolysis for the prevention of postthrombotic syndrome in patients with proximal deep vein thrombosis. *Am Heart J* 2013;165(4):523–530.e3
 - 44 Kucher N, Boekstegers P, Müller OJ, et al. Randomized, controlled trial of ultrasound-assisted catheter-directed thrombolysis for acute intermediate-risk pulmonary embolism. *Circulation* 2014;129(4):479–486
 - 45 Donaldson CW, Baker JN, Narayan RL, et al. Thrombectomy using suction filtration and veno-venous bypass: single center experience with a novel device. *Catheter Cardiovasc Interv* 2015;86(2):E81–E87
 - 46 Resnick SA, O'Brien D, Strain D, et al. Single-center experience using AngioVac with extracorporeal bypass for mechanical thrombectomy of atrial and central vein thrombi. *J Vasc Interv Radiol* 2016;27(5):723–729.e1
 - 47 Salsamendi J, Doshi M, Bhatia S, et al. Single center experience with the AngioVac aspiration system. *Cardiovasc Intervent Radiol* 2015;38(4):998–1004
 - 48 Nickel B, McClure T, Moriarty J. A novel technique for endovascular removal of large volume right atrial tumor thrombus. *Cardiovasc Intervent Radiol* 2015;38(4):1021–1024
 - 49 Renew JR, Wittwer ED, Robb TM, Fritock MD. AngioVac removal of a saddle pulmonary embolus using TEE guidance and venoarterial ECMO support. *J Cardiothorac Vasc Anesth* 2016;30(3):749–752
 - 50 Grimm JC, Parsee AM, Brinker JA, et al. Utilization of AngioVac and snare for eradication of a mobile right atrial thrombus. *Ann Thorac Surg* 2015;99(2):698–700
 - 51 Johnson AM, Bjarnason H, Shields R, Shih H, McBane R, De Martino RR. Removal of floating inferior vena cava thrombus with the AngioVac device. *Vasc Med* 2015;20(2):190–192
 - 52 Smith SJ, Behrens G, Sewall LE, Sichlau MJ. Vacuum-assisted thrombectomy device (AngioVac) in the management of symptomatic ilio caval thrombosis. *J Vasc Interv Radiol* 2014;25(3):425–430
 - 53 Al-Hakim R, Park J, Bansal A, Genshaft S, Moriarty JM. Early experience with AngioVac aspiration in the pulmonary arteries. *J Vasc Interv Radiol* 2016;27(5):730–734
 - 54 Juhan CM, Alimi YS, Barthelemy PJ, Fabre DF, Riviere CS. Late results of iliofemoral venous thrombectomy. *J Vasc Surg* 1997;25(3):417–422
 - 55 Mickley V, Schwagierek R, Schütz A, Sunder-Plassmann L. [Stent implantation after thrombectomy of pelvic veins. Indications, results]. *Zentralbl Chir* 1999;124(1):12–17