

## Endovenous Management of Iliocaval Occlusion

PATRICIA E. THORPE and FRANCISCO J. OSSE

### INTRODUCTION

Endovenous reconstruction of chronic iliocaval obstruction is one of the more challenging of all major endovascular procedures. The underlying pathology is complex, as it is frequently the result of multiple episodes of deep vein thrombosis (DVT). In the mid 1980s, venous stents were successfully used to treat obstruction associated with malignancy and Budd-Chiari syndrome.<sup>1-3</sup> Although the majority of procedures are performed fluoroscopically, Zhang reported success with ultrasound-guided caval stent placement in 83 patients with Budd-Chiari related IVC obstruction.<sup>4</sup> The percutaneous approach offers an alternative to surgical bypass or prosthetic replacement of the inferior vena cava (IVC). In addition to being more invasive, deep-vein surgery often includes an arteriovenous fistula to maintain patency of the new conduit. The surgical approach provided durable clinical results in selected cases.<sup>5-8</sup> Caval thrombectomy is a relatively less invasive technique for removal of acute venous obstruction, but not organized thrombus.<sup>9,10</sup> As experience with thrombolytic agents and metallic stents evolved, the indications for percutaneous caval procedures expanded to include treatment of thromboses associated with nonmalignant conditions such as liver transplantation, Klippel-Trenaunay, and hypercoagulability.<sup>11-13</sup> The majority of patients have been treated for acute thrombotic complications. Percutaneous treatment of chronic IVC and iliocaval obstruction has been reported in relatively few individuals.<sup>13-16</sup>

The IVC syndrome is secondary to central vein obstruction and inadequate collateral flow and/or recanalization of occluded segments. This leaves the patient with a critical mass of poorly compensated obstructing thrombus that causes venous hypertension. The endovascular alleviation of

the obstruction requires interventional skills with percutaneous techniques, familiarity with thrombolytic infusions, and experienced judgment in selection and placement of metallic stents. Moreover, the interventionalist may need an entire team to manage the demands of serial visits to the angio suite, complicated infusion systems with high maintenance monitoring schedules on the ward. Some reconstructions are less complex. The wire may traverse the obstruction without need of thrombolysis, making it possible to position stents during the initial encounter. Other patients may require patience for thrombolytic infusions and sequential repositioning of catheters and wires.

The length of the obstruction can include bilateral iliofemoral segments in addition to the infrarenal cava. Manipulation of wires and balloons in the long-occluded cava bears the burden of preventing any misstep that could precipitate a retroperitoneal bleed in a fully anticoagulated and lytic patient. Therefore, the iliocaval procedure is likened to the climbing of a mountain, replete with false summits, where the interventionalist must take every step with great care and purpose, knowing that the tedious sequence of maneuvers will enable the safe passage of guidewires from below the inguinal ligament to above the renal veins. Ultimate success requires determination to solve each patient's vascular puzzle, by constructing a new endovenous pathway to reconnect inflow with a patent venous segment beyond the obstruction.

### EVOLUTION OF ENDOVENOUS THERAPY

The primary tools of endovenous surgery can be separated into sheaths, catheters and wires, balloons and stents, and thrombolytic therapy. The imaging equipment includes

duplex ultrasound, handheld ultrasound, computed tomography, magnetic resonance imaging, and digital fluoroscopy. The selection of wires and catheters might vary with the physician, and we state our preferences in the technique section. However, the history and concept of balloon angioplasty, stents, and thrombolysis form the basic armamentarium of the interventionalist treating acute and chronic ilio caval obstruction with a minimally invasive approach.

### ANGIOPLASTY

As a general principal, balloon angioplasty, alone, is not very effective in treating venous stenosis. Rather than effecting remodeling of a purposefully injured arterial wall, in occluded veins, there is some “give” as intimal hyperplasia is compressed, but the recoil is significant. Therefore, although the balloon can be inflated, there is little permanent effect from expanding the site. However, prior to stents, balloon dilatation became an option in the treatment of Budd-Chiari syndrome caused by membranous obstruction of the IVC and/or hepatic veins.<sup>17</sup> Use of the double-balloon technique on the membrane showed a high degree of technical success and resulted in regression of symptoms. Good initial results were reported in patients with segmental, nonmembranous obstruction of the IVC as well. But, as in Budd-Chiari syndrome, relief of venous narrowing was only temporary and the restenosis required repeated dilation. Balloon angioplasty became an adjunct to stent deployment in the early 1990s. In anticipation of stent placement, dilatation may be necessary to permit passage of the stent delivery system through the lesion. When the 5F end-hole catheter will not advance, it may be helpful to dilate the tract with a 3 to 4mm balloon. Following stent deployment, the balloon fully expands the self-expanding metallic prosthesis and apposes the struts against the irregular vein wall.

### METALLIC STENTS

The pioneers of venous stenting were Cesar Gianturco and his colleagues in Houston who designed and tested stents in the venous system as early as 1969.<sup>18</sup> It was almost 15 years later when initial reports of caval stenting for treatment of malignant obstructions appeared in the literature.<sup>19,20</sup> The stainless steel Gianturco Z stent™ (Cook, Bloomington, IN) was used to treat Budd-Chiari–related hepatic and IVC obstruction with good technical success rates but with a notable incidence of intimal hyperplasia and stent migration.<sup>21</sup> Axial force was decreased and hook modifications

were made to address these issues. The self-expanding woven stents do not have hooks. Whereas overlapped diamond cut Nitinol stents will lock struts, the smooth Wallstents™ will slip on each other. If there is not good apposition to the wall, or the cava expands with valsalva, migration can occur. For this reason, it is important not to place stents in normal vein segments that might expand. The displacement of a stent to the right atrium or pulmonary artery can be life threatening.<sup>22</sup> Pericardial tamponade can occur from atrial perforation. It is necessary to emergently snare the displaced stent via a jugular access and address the pericardial effusion appropriately.

Stents now have been placed in the lower extremity venous system for 20 years. However, there is very little longitudinal follow-up of stent patency. Stainless steel Gianturco stents were initially used to treat malignant conditions and the patients were palliated in their short survivals. However, now we are placing stents in chronically damaged veins of young individuals who expect a normal life span. Standards for managing and monitoring patients are not established. In our practice, we follow patients with annual duplex exams to document patency. The long-term assisted patency for iliac stents reported by Neglén and Raju was 92%.<sup>23</sup> Restenosis occurred more often in patients with thrombotic disease, and in those with thrombophilia, whose stents extended into the femoral vein. Restenosis is suspected when edema or venous claudication recur. It can be seen with intravascular ultrasound and is effectively treated with balloon dilatation.<sup>23</sup>

The advantage of the Z-stent remains the availability of large diameter stents for treating wide vessels such as the superior and inferior vena cavae. However, for treatment of venous stenosis and occlusion in medium size vessels, such as the iliofemoral segments as well as the chronically occluded IVC, the smaller profile, self-expanding metallic stents are preferred. They have longitudinal flexibility and a lower profile suitable for percutaneous entry at the popliteal site. We find the Wallstent™ (Boston Scientific, Natick, MA) serves as an excellent conduit and maintains a high degree of patency in the IVC and large veins of the pelvis and thigh. The commonly used diameters are 12–14 mm, but the stent also is made in 16 and 18 mm widths. The larger stents require an 11 F sheath and are more difficult to deploy. We prefer stents that pass through a 7–9F size sheath that includes 10–14 mm. Stent size and length are estimated with the help of balloons. If a fully inflated 12 mm balloon is tight in the vein, then a 12 mm diameter stent will extend to the wall when deployed. Dilate the balloon and try to move it up and down. If it slips easily, the stent diameter should be larger than the balloon. IVC stents are deployed in a parallel cross-over configuration that provides an individualized outflow system for each limb (see Figure 61.6). Stents are placed in tandem, with larger stents more proximal. Overlap

should be at least 1–2 cm to prevent separation with foreshortening. A number of self expanding Nitinol stents are available in 8–14 mm diameter with length ranging from 4–10 cm. Although they do not have the issue of foreshortening like the Wallstent™, they remain more difficult to see under fluoroscopy. This may be a disadvantage in the ilio caval region. Balloon expandable stents are not advocated for the venous system, since longitudinal flexibility is desirable when stenting long vessel segments. The majority of venous stents placed in the lower extremities have been positioned in the iliac segments. Approximately 10% of iliofemoral thromboses extend into the IVC.<sup>24</sup> If the distal IVC is occluded, extension of the stents above the occlusion is necessary.

### THROMBOLYTIC THERAPY

The immediate objectives of acute thrombus removal include prevention of pulmonary embolus, restoration of venous flow, and preservation of venous valves in the affected extremity. Minimally invasive technique utilizes percutaneous access with coaxial delivery systems for interventions. Ideally, the lowest effective concentration of lytic agent, delivered at a rate and volume designed for the amount of thrombus involved, will be infused through a multislit or side-hole catheter embedded in the occlusion. The goal is to use the least amount of drug that provides the best result in the shortest time without bleeding complications. Best result may mean total lysis in acute thrombosis and guidewire passage in the chronic case. The discovery of chronic stenosis associated with acute thrombosis is common. When streptokinase was introduced in the 1970s, the hope was that enzymatic dissolution of thrombus would be effective, safe, and less traumatic than surgery. Although effective, the early use of peripheral vascular thrombolysis was associated with bleeding complications, in part due to application of the agent via open access to the vessel. Since that time, we have seen an evolution of both thrombectomy and thrombolytic therapy for use in acute deep vein thrombosis.

The main principle in thrombolytic therapy is effective and efficient delivery of an agent to the thrombosed vascular segment(s). As early as 1957, Fontaine and Mahorner et al. used anticoagulants postoperatively to prevent the rethrombosis after thrombectomy. In 1983, Greenwood et al. reported on a patient with Budd-Chiari syndrome following viral myocarditis. Urokinase (UK) was given through an IVC catheter as a local infusion in large doses. The loading dose was 308,000 IU (4,400 IU/kg), followed by 4,400 IU/hr as continuous infusion. After 55 hours of infusion, there was marked improvement in the flow in the IVC. The patient's pain, ascites, and edema rapidly resolved.

Thrombolytic treatment of acute deep vein thrombosis was reported by European colleagues in the 1970s and 1980s.<sup>25,26</sup> It was clear that the complications related to systemic streptokinase and heparin partially annulled demonstration of the benefits of thrombolysis. Their immediate results showed improved thrombus resolution with thrombolysis compared to heparin. Unfortunately, fear of bleeding complications prevented widespread adoption of thrombolysis. In the United States, important technical modifications were made to reduce the incidence of major bleeding. Urokinase became the preferred lytic agent and catheter-directed methods were borrowed from the successful arterial application.<sup>27,28</sup>

Between 1980 and 1999, peripheral vascular thrombolysis was largely performed with urokinase (Abbokinase, Abbott Laboratories, Chicago, IL). This agent was preferred over streptokinase for the safety margin relative to bleeding complications.<sup>27</sup> Reconstruction of manufacturing facilities led to the unavailability of urokinase between 1999 and 2001. Alternative lytic agents such as alteplase (Activase, Genentech, Inc. South San Francisco, CA) and reteplase (Retavase, Centocor, Inc. Malvern, PA) were used in peripheral interventions, despite a shared experience of an increase in bleeding complications, compared to urokinase.<sup>29,30</sup> After dose adjustments for concomitant heparin, interventionalists became more familiar with t-PA, and achieved similar immediate and long-term results with lysis. However, the popularity of catheter-directed thrombolysis for DVT faded after urokinase left the market. When UK returned in 2002, physicians no longer felt compelled to readopt the traditionally favored drug since they had collectively discovered the merits of the less expensive synthetic drug t-PA.<sup>31</sup>

Since 1999, second and third generation tissue plasminogen activators, including alteplase and tenecteplase, have become the most commonly used agents. Newer, more direct-acting agents are being developed. Most recently, alfineprase trials have been reported and it appears to be a fast and safe lytic agent capable of shorter, more effective infusions.<sup>32</sup>

In larger axial veins, effective thrombolysis is best achieved with catheter delivery utilizing multisidehole infusion catheters and wires.<sup>33</sup> Acute thrombus, less than 14 days duration, dissolves rapidly with catheter embedded infusions of urokinase or alteplase. Chronic obstructions respond more slowly, and the thrombus does not resolve. Rather the lytic infusion serves to soften the organized thrombus and make fenestrated thrombus and synechiae more amenable to guidewire and catheter traversal, thus permitting the interventionalist to perform a sequence of dilatation and stent placement. Analysis of National Venous Registry (NVR) data suggested thrombolysis of chronic thrombus was unsuccessful.<sup>24</sup> In truth, images of distal veins often look as

abnormal after lytic infusion as they do before. Whereas comparison images show dramatic difference when lysing acute DVT, the phlebographic appearance of chronic venous obstruction changes less, even though the venous flow can improve significantly. Interpretation of static contrast images fails to explain the clinical improvement in patients after thrombolytic infusion for chronic obstruction. Reducing venous resistance, by augmenting small and medium size venous channels, does not dramatically alter the post-infusion images, but it is an important adjunct to stenting larger veins. Reestablishing continuity of deep/venous flow from the foot to the cava, has proven to give the best hemodynamic and clinical results.

Physicians attempting to recanalize chronic thrombus may fail to advance the wire or stay intraluminal if they do not infuse a thrombolytic agent prior to and during the wire recanalization phase. Only short, subtotal occlusions can be readily treated without lytic therapy. In treating chronic occlusions, we have the impression that a thrombolytic infusion can “soften” more organized thrombus and thereby facilitate passage of wires and catheters. Although catheter-directed thrombolytic therapy has been shown to be most successful in removing acute thrombus, in chronic conditions, clinical improvement observed after thrombolytic infusion is often greater than any image would suggest. That is because improvement of venous flow, particularly in the calf, depends on the cumulative effect of many unnamed veins remaining patent. Restoring flow in these small conduits can make a significant clinical difference. Real-time phlebography with digital or video recording can demonstrate a clear difference in rate of flow by comparing the rate of contrast clearance before and after thrombolytic infusion. Vascular physiology and fluid dynamics studies show how flow in a tubular conduit is proportional to  $r^4$ , where  $r$  represents the radius. If we apply this concept to venous flow, we see that augmenting multiple occluded or tiny lumens from  $<1$  mm to  $>2$ – $3$  mm significantly increases venous flow despite minimal change on radiographic images. According to this principle, Pousseille’s Law, delivery of thrombolytic agents to the extremity via catheter or flow-directed techniques can promote flow by enlarging the residual lumen. Although not restored to original caliber, lysing acute and subacute thrombus, superimposed upon chronic organized thrombus, increases the luminal diameter. This may not produce a dramatic change on x-ray images, but the increase in flow can be documented with duplex and correlated with post-treatment clinical improvement. Ambulatory venous pressure, as indirectly measured with air plethysmography, should decrease as resistance to flow decreases. However, in our exams, the numbers often do not reflect the degree of clinical improvement. Reasons for this are complex and most likely involve the effects of long-standing obstruction on valves and the calf muscle pump.

## MECHANICAL THROMBECTOMY

Thrombectomy refers to physical removal of soft, fresh thrombus. The idea of doing this with a small, percutaneously inserted device is that it atraumatically “vacuums” the thrombus out of the vessel. Such a device would offer the speed of surgical intervention with the advantage of minimally invasive therapy. The Fogarty balloon, a standard tool for rapid thrombus debulking, requires a surgical incision.<sup>35</sup> A number of new devices have emerged, and their design benefits and limitations are discussed in several review articles.<sup>36–39</sup> The objective of the newer designs is thrombus removal with a small-profile, over-the-wire device that can be introduced percutaneously. Most devices provide a small pilot lumen that leaves a substantial amount of residual thrombus. The debulking ability varies according to the device as well as the thrombus composition; the devices do not perform well with organized thrombus.<sup>40</sup> The devices are geared to vessels less than 10 mm in diameter. Both over-the-wire and wireless versions are available. They are not steerable. Residual mural thrombus persists in most vessels, particularly larger veins such as the iliac and cava. The endothelium can be injured and result in rethrombosis as well as intimal hyperplasia. The potential for valve damage has been studied in animals but it is hard to determine in humans.<sup>41</sup>

In general, the debulking seems most appropriate in patients who cannot receive thrombolytics. However, many of these patients, such as elderly post-op patients, cannot receive heparin either. Without anticoagulation, rethrombosis occurs rapidly. In our experience, the debulking process rarely decreases the overall time of the procedure, since additional thrombolysis is necessary to remove residual thrombus for optimal results.

Some devices combine mechanical and pharmaceutical properties to accelerate restoration of flow. The Trellis™ (Bacchus, Menlo Park, CA) device is a combination of balloon, infusion catheter, and wire. The thrombolytic agent is delivered between the occluding balloons. The perfused thrombus is then subjected to gentle mechanical disruption by an oscillating sinusoidal wire positioned between the balloons. This allows contained thrombolysis, thus limiting systemic exposure to the lytic agent. The device allows rapid aspiration of lysed thrombus, through the dual lumen design, but anticoagulation is still necessary. The power pulse-spray concept of the Angiojet™ (Possis, Inc., Minneapolis, MN) is also a combination of powerful delivery of a lytic agent with a thrombectomy catheter.<sup>42</sup>

Despite the reported speed of mechanical thrombectomy, we have used all available devices and most of the time we find there is still a need for overnight thrombolysis. The devices are expensive and require set-up time and technologist familiarity with each design. The use of mechanical thrombectomy may shorten the time until flow is restored,

but they may not lessen the overall time to completion, especially if catheter-directed thrombolysis is needed after the debulking process. But the concept is so appealing, we continue to look for the ideal instrument. The main categories of devices are:

- Balloons, available from 5- to 14Fr sizes, can be used with or without guidewires as a relatively inexpensive thrombectomy tool. Positive features include speed and cost-effectiveness, and negative features include a higher incidence of incomplete thrombectomy and distal embolization.
- Wire baskets, mostly represented by the Arrow PTD (percutaneous thrombectomy device), the Bacchus Solera, Rex Medical Cleaner, and MTI Castaneda Brush, all use a rotating basket or a fixed one with an inner rotational structure to fragment the thrombus at higher speeds.
- The hydrodynamic Microvena ATD (Amplatz Thrombectomy Device) uses a negative pressure created by a recirculating vortex coming from antegrade high-pressure fluid jets along the shaft and retrograde negative pressure at the tip of the catheter.
- Flow-based devices explore the Venturi/Bernoulli effect, which is based on fast-flowing positive pressure fluid jets that are directed to a negative pressure exhaustion lumen of the catheter. The resulting negative gradient pressure aspirates and causes fragmentation of thrombus. This category is represented by the Boston Scientific Oasis, the Possis AngioJet and Expedior, and the Cordis Hydrolyser.

Again, most devices provide only a small pilot lumen that leaves a substantial amount of residual thrombus. They do not perform well within organized thrombus; however, patients with multisegmental acute venous obstruction, with contraindications to lysis and surgery, now have the option of mechanical restoration of venous outflow, minimizing complications and leaving an opportunity for optimal venous reconstruction with adjunctive angioplasty and stent deployment.

### CLINICAL ASPECTS OF ILIOCAVAL OBSTRUCTION

The clinical presentation of inferior vena cava occlusion comprises a wide spectrum of signs and symptoms of venous hypertension. The recruitment of collateral pathways may be adequate, as well as occult, and some individuals will remain symptom free. Symptomatic individuals present with edema and a variety of signs and symptoms of venous hypertension. The severity of symptoms implies inadequate collateral inflow in the face of poorly recanalized, multisegmental obstruction. Although not as common as isolated iliofemoral

thrombosis, patients with iliocaval involvement represented between 1 and 10% in the reported series.<sup>15</sup>

Acute caval thrombosis commonly presents with bilateral lower limb edema, unexplained recent weight gain, and in some, back pain. The lack of collateral flow causes lower limb edema, discoloration, and discomfort. Patients have no difficulty recognizing the seriousness of this condition, even though it may have been a gradual change. Once the critical mass of thrombus interrupts caval flow, acute venous hypertension progresses rapidly. Alternatively, chronic caval occlusion is sometimes difficult to diagnose. Occult central venous problems can be indicated in duplex waveform analysis, where the loss of phasicity can provide a clue to more proximal obstruction. (See Figure 61.4)

IVC occlusion often results in bilateral lower limb edema, but occasionally, a single limb is most affected and the discovery of caval occlusion is a surprise. Prominent collateral veins may be seen on the lower anterior abdominal wall or in the region of the pubic symphysis (see Figure 61.1). Unilateral or bilateral lower limb varicosities may be present. Advanced skin changes including hyperpigmentation, lipodermatosclerosis, and ulceration are common with IVC syndrome (see Figure 61.2). In two of our patients, venous stasis changes led to below-the-knee amputation years before the caval obstruction was identified. Patients often report that leg elevation does little to alleviate edema. Prolonged sitting can cause a vague inguinal ache often described as a constant sensation of fullness in the groin area, which becomes

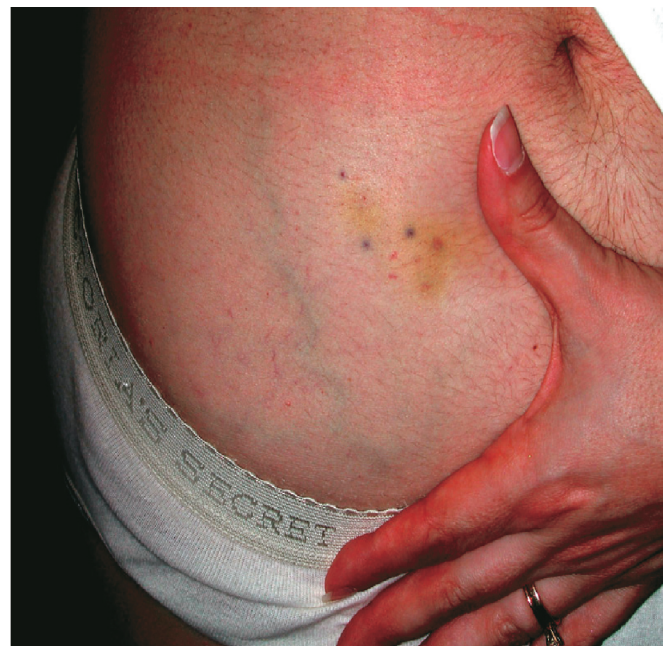


**FIGURE 61.1** Prominent lower anterior abdominal wall veins seen on a young woman with iliocaval obstruction for 2 years are a pathognomonic sign of IVC obstruction. The collateral veins become unapparent after endovenous correction of caval occlusion.



**FIGURE 61.2** Twenty-two-year-old male with long-standing ilio caval obstruction, suspected to have occurred shortly after birth. Within two years of his initial episode left femoral-popliteal thrombosis, at age 20, he had a recurrent DVT and developed a stasis ulcer on the medial anterior calf. Evidence of varicosities in his teenage years was an additional sign suspicious for central venous obstruction.

worse with stair climbing. Patients frequently report dyspnea on exertion, even in the absence of any history of pulmonary embolus or respiratory ailments. They may have been told they have asthma. One patient presented with hematuria due to bladder varicosities. In two young patients, presenting at age 17 and 21 years, caval occlusion probably occurred near birth, since each had a single left kidney with compensatory hypertrophy. The common use of central lines in premature and young infants has created a juvenile population with the sequela of central venous thrombosis. The incidence of catheter-related deep vein thrombosis is estimated to be 3.5 per 10,000 hospital admissions, whereas the IVC is affected in approximately 10% of pediatric DVT cases.<sup>43</sup> In a longitudinal study, 40 children, diagnosed with IVC thrombosis between birth and 13 years of age, were followed for up to 20 years after recognition of an early thrombotic event.<sup>44</sup> Among the patients, 21 were identified with extensive IVC thrombosis. During follow-up, complete resolution was seen in four cases; one underwent thrombolysis, two surgeries, and one spontaneous lysis. Obstructive IVC thrombus persisted in the ilio caval segments in 17 children, including six who received thrombolytic therapy. Varicose veins were present in 12/17 (71%) and post-thrombotic syndrome in 7/17 (41%). Analysis suggested that 30% of children with unresolved caval obstruction will develop post-thrombotic syndrome within 10 years of the initial thrombosis. In the

young patients we treated, they were asymptomatic until the acute thrombosis of the left iliofemoral segments at ages 21 and 17, respectively. In one patient, this happened after sliding into base playing softball and in the other, after a summer job where he leaned over a large bin husking corn. As in many patients, the investigation of an acute lower limb deep vein thrombosis led to the discovery of previously compensated underlying caval obstruction of indeterminate age.

The majority of patients with long-standing venous insufficiency, secondary to obstruction, are seen by primary care physicians long before they are referred to a vascular specialist. Patients commonly report that they have been told there is not much available for treatment of PTS other than compression. They may have a remote history of iliofemoral DVT and no suspicion of central venous obstruction. Alternatively, they may have a prior diagnosis of ilio caval occlusion, or have been told that the IVC is absent after phlebography or if cross-sectional imaging with CT or MRV have been performed. Large collaterals, seen on computed tomography (CT), have even been interpreted as lymphadenopathy and led to a search for malignancy.

## THE ENDOVENOUS PROCEDURE FOR ILIOCAVAL RECONSTRUCTION

### Patient Referrals

Acute inferior vena caval thrombosis is almost invariably associated with underlying vascular pathology that went undetected until a set of circumstances resulted in thrombotic obstruction. The combination of hypercoagulability, immobilization, surgery, and remote trauma often play a role in caval thrombosis in younger patients, whereas malignancy may be more common in older patients. Acute IVC thrombosis patients are generally in the hospital, admitted to the medicine service. The vascular specialist is consulted along with the hematologist. Alternatively, the patient with a post-thrombotic syndrome has previously received standard therapy for deep vein thrombosis and has failed to respond. The majority of these patients ultimately are referred to a vascular surgeon for evaluation of disabling venous hypertension and/or stasis ulcer care. Although we have noted a number of patients have a thrombosed caval filter, the filter, per se, cannot be implicated since longitudinal studies have shown a low incidence of caval occlusion with filters.<sup>45</sup>

### Initial Evaluation

The procedure for ilio caval reconstruction is, in many ways, similar to preparation for major surgery. The main difference is that the endovenous operation is the series of

interventions that take place in the angio suite over several days, rather than a single procedure occurring, over several hours on one day, in the operating room. The interventional process we have developed over 15 years is best divided into three chronological stages; the workup, the hospitalization and intervention, and the follow-up monitoring. Within the hospitalization phase, there is a sequence of events including the acquisition of baseline contrast studies, the positioning of sheaths and catheters, the initiation of thrombolysis, securing wire access to the portion of the cava above the obstruction, the venous angioplasty needed in preparation for the ultimate positioning of stents to reconstruct the endovenous conduit from patent distal deep veins to the supra-renal IVC. The conversion to oral anticoagulation and mobilization of the patient following removal of the working sheaths proceeds according to protocol. The follow-up phase for a patient with endovenous reconstruction is life-long, but we have found that signs and symptoms of restenosis are most likely to occur within the first 24 months after stent placement.

The clinical severity score as well as a clinical classification is recorded according to published recommendations.<sup>46,47</sup> If a hypercoagulability work-up has not been performed elsewhere, tests for Factor V Leiden and prothrombin gene mutation are acquired. Baseline and calf, thigh, and ankle measurements are obtained as well as anterior and posterior digital photographs. Baseline levels are established for hemoglobin, platelets, white blood cell, creatinine, BUN, protime, prothrombin time, and INR. For patients over 50 years, a baseline EKG is obtained.

A very important aspect of the initial meeting is an explanation of the patient's condition, in language the patient understands, with drawings of the venous pattern (see Figure 61.3). Discussion of the options for reconstructing the venous system involve an explanation of the risks and benefits of thrombolytic therapy, a demonstration of stents, and a discussion about the need for monitoring and anticoagulation after the reconstruction. This mental preparation is not unlike a process that transplant candidates undergo. The intervention implies a major commitment on the part of the surgical team as well as the patient and their family to maintain the desired clinical results long term. This requires carefully monitored INR levels, interval ultrasound evaluation and regular contact with a physician familiar with venous stents. It is important to screen patients for their motivation and ability to work with the medical team. Patients who will not get regular INR tests or who might have limited access to medical care will have a difficult time being monitored adequately. Compliance with anticoagulation and compression are important clinical adjuncts, since, as with many vascular procedures, reconstitution of the deep venous system is palliative. Clinical improvement after restoration of deep vein patency is, in part sustained by compliance with warfarin, for prevention of rethrombosis, and use

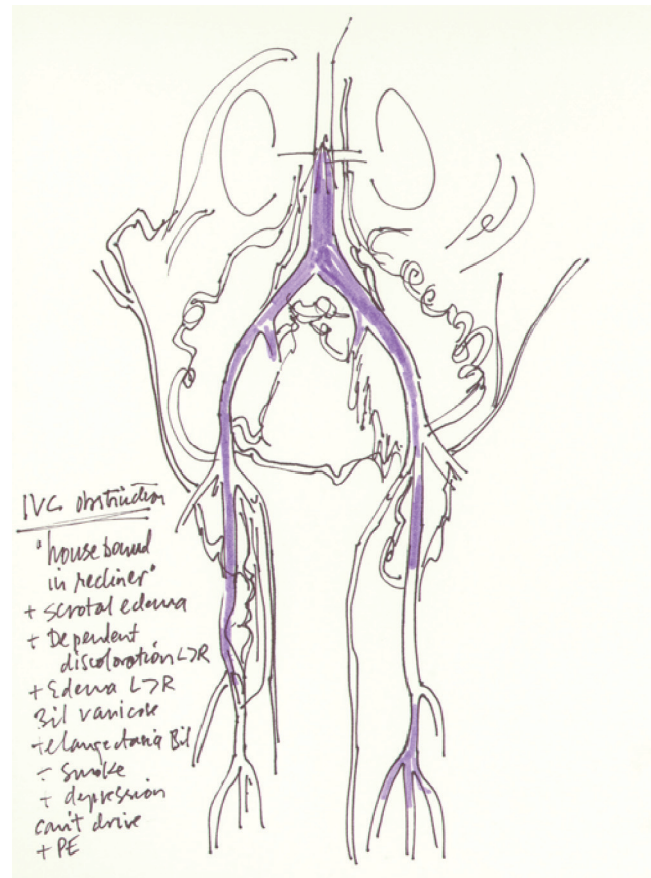


**FIGURE 61.3** A drawing of iliofemoral obstruction used to discuss the abnormal venous flow pattern and the plan for endovenous reconstruction with the patient and family. Drawings are easier for patients and nurses to understand the procedure. They also facilitate understanding of the radiographic images during the case.

of compression to compensate for the valvular incompetence, which plays a role in venous hypertension associated with DVT.

### Diagnostic Workup

Patients referred with symptomatic chronic post-thrombotic syndrome undergo a diagnostic workup. This consists of a one-hour meeting to obtain a history and physical exam and to discuss the findings of any available imaging studies. We have modified for venous obstruction patients to include attention to the difference of segmental flow velocities, as well as the wave forms. This information can provide clues to proximal venous obstruction (see Figure 61.4). Common iliac occlusion and distal IVC obstruction are suggested by loss of phasicity and relatively low velocity at the femoral level. However, flow velocity may be deceptive if there are large collaterals or a prominent internal iliac system, but the waveform will still show little or no phasicity. An ascending phlebogram is obtained preoperatively or

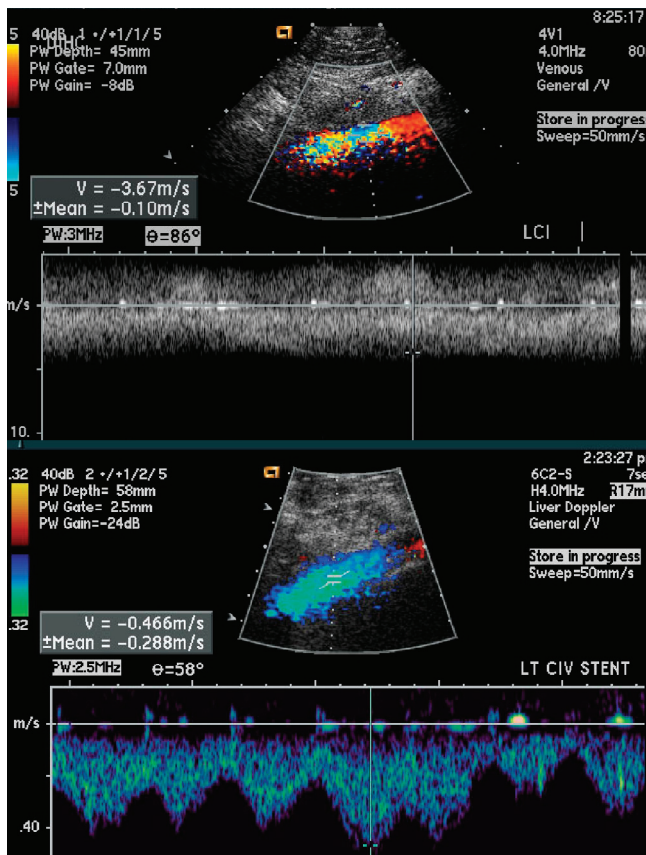


**FIGURE 61.4** Duplex images comparing the waveform obtained in the common iliac vein (CIV) segment before and after stent placement. The upper image shows a relatively flat wave, with loss of phasicity, which indicates proximal obstruction. This pattern is also seen in large collaterals near a high-grade CIV stenosis in the May-Thurner syndrome. The inferior tracing shows a phasic waveform with higher velocities. This indicates good return to normal venous flow pattern after stent placement.

as a part of the first-day interventional procedure. It is acquired by manual injection of low-osmolar, nonionic contrast through a 22 g Jelco™ pedal IV placed in a dorsal pedal vein; it is secured with extension tubing combined with a distal-end three-way stopcock. Using 60cc syringes, contrast is injected into the vein, closely observing for extravasation. This can be difficult, due to high venous pressures, and slow clearance of contrast characterizes the initial exam. It becomes easier as the venous resistance decreases. More detailed pelvic images are obtained once catheter access is obtained via the popliteal sheath.

Three dimensional CT reconstructions and MRV can provide information about pelvic vein and iliac compression. Magnetic resonance venography (MRV) has been compared with contrast venography and ultrasound in detection of DVT. All thrombi detected by contrast phlebograms were also detected with duplex and MRV. There was 98% correspondence in diagnosis of DVT with these modalities.<sup>48</sup> Insurance certification should be reviewed as an initial issue.

The therapy is expensive and insurance coverage needs to be authorized with clear revelation of potential codes and costs.

### The Endovenous Technique

After review of the imaging studies and evaluation, a patient is scheduled for admission and intervention. A patient with chronic ilio-caval occlusion, which involves both extremities, requires the “full-court press” bilateral popliteal approach. This begins with bilateral placement of pedal intravenous access when feasible. We often use contrast injection to check popliteal anatomy and puncture level. With the patient in a prone position, the popliteal area is prepped and draped. Sterile technique is used with the handheld ultrasound transducer used to identify the popliteal vein or lesser saphenous. The transducer guide will accommodate the 21 g needle from the micropuncture kit that also includes a coaxial 3/5 F short dilator and an 80 cm .018” wire. We prefer an 80 cm Nitinol for initial access through the needle. A one-wall puncture is essential. If an inadvertent arterial puncture occurs, leave a small caliber dilator in place if thrombolysis is intended. A 5–6 F 15 cm sheath is then positioned. The sheath is secured with tape or suture. Keep in mind that any puncture can cause incessant oozing when using thrombolysis. Navigation of the occluded femoral, iliac, and caval segments is performed with 4–5 F straight and angled hydrophilic catheters combined with the angled Glide wire (Boston Scientific) or Head Hunter wire (Cook). These hydrophilic tips are lumen seeking. The catheter is advanced as permitted. Stronger 035” exchange wires may secure the tract for catheter positioning, but these are dangerous wires for probing. Advancing an Amplatz wire into organized thrombus may result in perforation. Whereas this can be tolerated when chronic fibrosis is present, it is best avoided. Smaller .018” wires are useful for tracking a 2–4 mm balloon that can help augment the pilot lumen when a 5 F catheter will not track over the hydrophilic wire. Keeping in mind that balloon dilatation can also obliterate a tract, never lose access during the guidewire exchange process. A common sequence is initial attempt with 4–5 F combination, where the wire goes far beyond where the catheter will advance. A .018” wire can allow dilation with a 2–3 mm × 4 cm small vessel balloon. The 5 F catheter can then be advanced a bit more cephalad. With this sometimes tedious sequence of dilate-and-advance, one can ultimately move a wire from below the obstruction to the patent segment above the lesion. Great care must be taken in the area of the caval bifurcation. Many collaterals track parallel to the cava in anterior or posterior planes (see Figure 61.5). Angulation of the image intensifier is necessary to avoid being faked out. Perforations in this region carry the risk of retroperitoneal bleeding, so serial computed tomography may be indicated to monitor for any abnormal accumulation

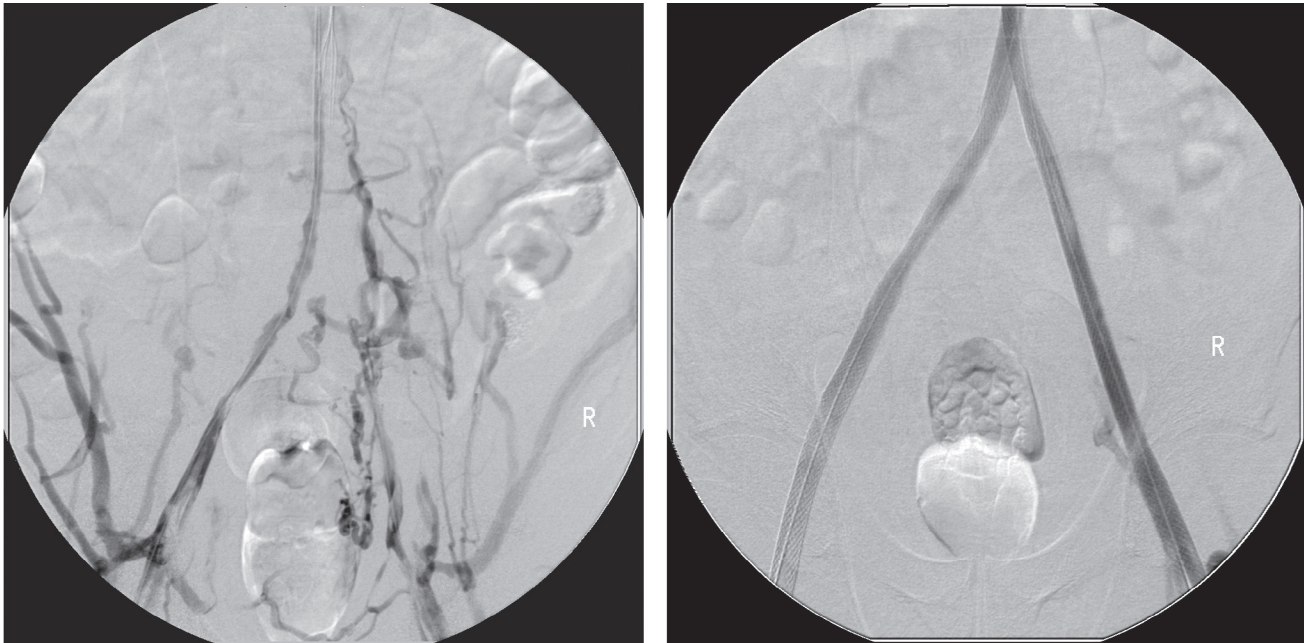


**FIGURE 61.5** Digital images show pelvic veins before and after reconstruction of totally occluded IVC and bilateral iliac segments in a 38-years-old patient. Note the prominent circumflex iliac vein as well as internal iliac tributaries that serve as alternate pathways for external and common iliac obstruction. The true lumen, leading from the common femoral level, frequently is seen as a tiny wisp of contrast medial to the iliac circumflex. The second image shows completion phlebogram after placement of bilateral Wallstents™.

of fluid or contrast. Anticoagulation is maintained during all catheter manipulations. We often “park” a catheter at the highest position achieved without force. Forcing a catheter or wire has a high probability of causing perforation. We find that overnight infusion of a dilute lytic agent (10mg alteplase/liter normal saline) at 50–75 cc/hr can change the venous terrain enough to facilitate progress toward the goal of safely passing an intraluminal wire through the total occlusion.

Once the 100cm 5F straight or angled end-hole catheter can be positioned in the open cava, usually above the renal veins, an exchange length 035” Amplatz wire is positioned. In the event that the hydrophilic wire will not traverse the lesion from below, it may be useful to advance a wire/catheter from above. This will require an internal jugular approach. It is hard to do, in the middle of the case, since the patient is prone. The popliteal sites have to be secured and the patient turned supine. Working from below is a challenge. If the wire passes from above, it may enter a catheter and exit the popliteal sheath. If the wire passes from below, a 5 to 10mm gooseneck snare can be used to snare the wire tip in the cava and pull the wire through the jugular sheath. This much traction may be necessary to balloon tight caval and iliac lesions without having the balloon slip out of position. After the working wire has been placed from each direction, serial balloon dilatation can proceed. Start

with smaller 8 mm × 40mm balloons. A single 8 × 14mm balloon can dilate the IVC area. It may be difficult to advance a larger, high-profile balloon through the pilot lumen.

Following sequential dilatation of the cava and bilateral iliac and femoral segments, it is time to select stents. A principle guides stent placement. One must reestablish deep venous flow from a point of good flow below the obstruction to a point of good out-flow, above the obstruction. In an optimal situation, the femoral veins are normal and the lesions involve the iliac segments and the infrarenal cava. We start the stent deployment in the infrarenal cava. Placement of stents in the intrahepatic cava requires great precision and avoidance of extension into the right atrium. We only stent this area if it is clearly diseased and narrowed. This can be deceiving, since decreased inflow causes collapse of the cava and it may appear stenotic when it is merely underfilled. A good way to test this is to inflate large balloons, to see if they are mobile when inflated. If they are easily moved within the lumen, the cava is not that narrow.

Stents are deployed from proximal to distal. An exception would be a very tall patient in whom the delivery system would not reach that level from the popliteal entry. We use the Wallstent or self-expanding Nitinol stent. We have had success with the high extension of cross-over parallel systems coming from left and right (Figures 61.6 and 61.9).

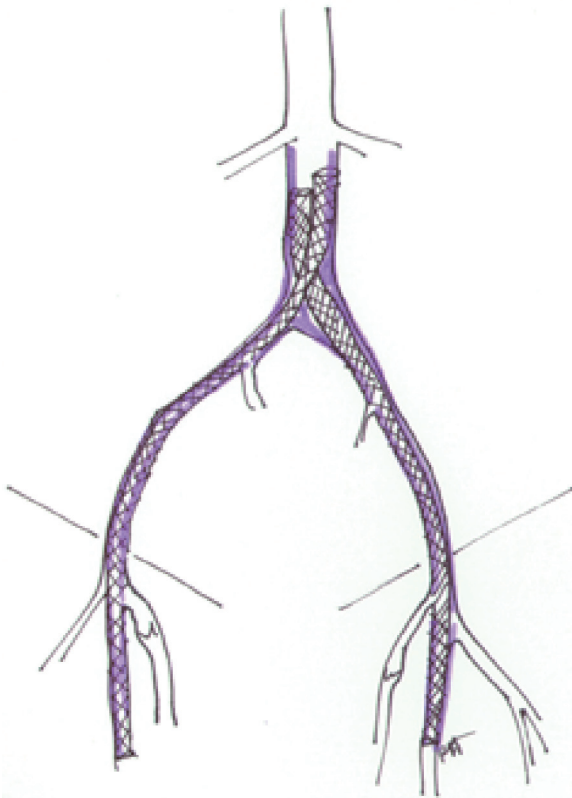


**FIGURE 61.6** Drawing shows two parallel stent systems that cross to the opposite side at the bifurcation. This dual column, cross-over configuration is our preferred stent pattern for iliofemoral reconstruction.

An alternative is the “Y” configuration (see Figure 61.10a). The large diameter stent is extended to the bifurcation and the iliac stent is positioned at an angle, but may not extend into the caval stent. A modification of this pattern would be extension of unilateral or bilateral iliac stents into the single distal caval stent (see Figure 61.10b). Often, the symmetry is not maintained after the balloons are removed. One side can be partially collapsed by the force of the other stent. It is for this reason that we evolved the high-extension, cross-over system. In the average-size patient, a parallel series of three overlapped Wallstents™, 12 mm × 90 mm, 12 mm × 60 mm, 12 mm × 90 mm, extend from the renal vein level to the upper thigh. The sequence is intended to have the distal margin of the second stent placed above the inguinal ligament. The extension of the third stent results in a gentle curve of connected stents from the cava to just below the common femoral level. If necessary for flow without stasis, we recommend dilatation and stenting of the femoral vein to a point of spontaneous flow. Spontaneous flow is indicated by contrast clearance from unforced in-flow of unopacified blood. If contrast “sits” in the vein, there is either poor in-flow or out-flow. If the out-flow is stented open, then in-flow may be blocked by the sheath or residual thrombus or both. Pull-back pressure measurements and IVUS can help determine

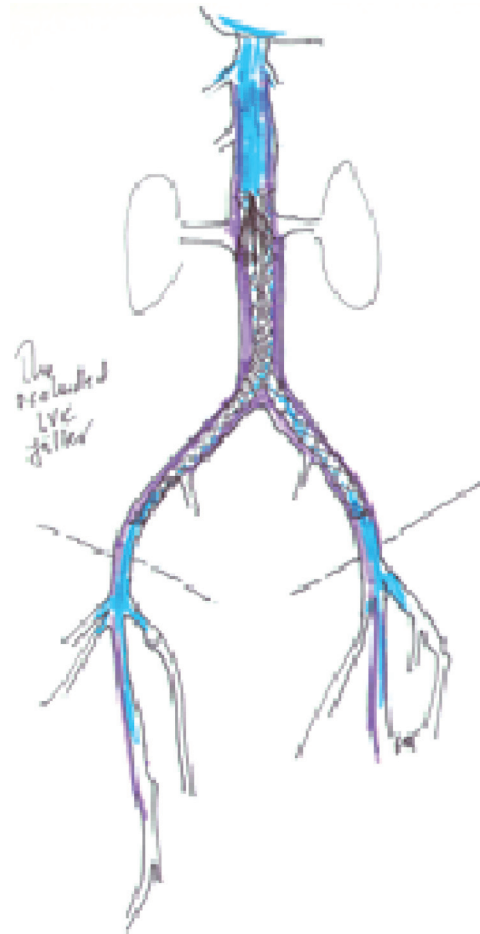


**FIGURE 61.7** Drawing depicts cross-over stent system passing through a totally occluded Greenfield filter. Note the upper margin of the stent column is at the level of the filter cone.

the significance of nonocclusive irregularities. More than 3-mm Hg pressure differential may be important, but there are no good data to confirm this observation. Keep in mind the adage, good flow through a “funny looking” vein is better than bad flow through a perfect stent. The endpoint of stenting is restoration of deep system flow. It is achieved when there is no visualization of collaterals or stasis of contrast with completion venograms. The very large pelvic collaterals may fill slightly, but the main flow pattern is returned to the newly opened stent conduit. Another parameter is duplex velocity; the measurement at the common femoral level returns to 20–40 cm/sec.

Stenting through an occluded caval filter is a special challenge. Careful positioning of the guidewire, through the struts, can be followed by serial balloon dilatation. Note that the wire does not go around the filter but through the struts. There is usually chronic, undissolved thrombus within the filter. It is “stuck” there, but care is taken to do as little manipulation as possible. Self-expanding stents are deployed

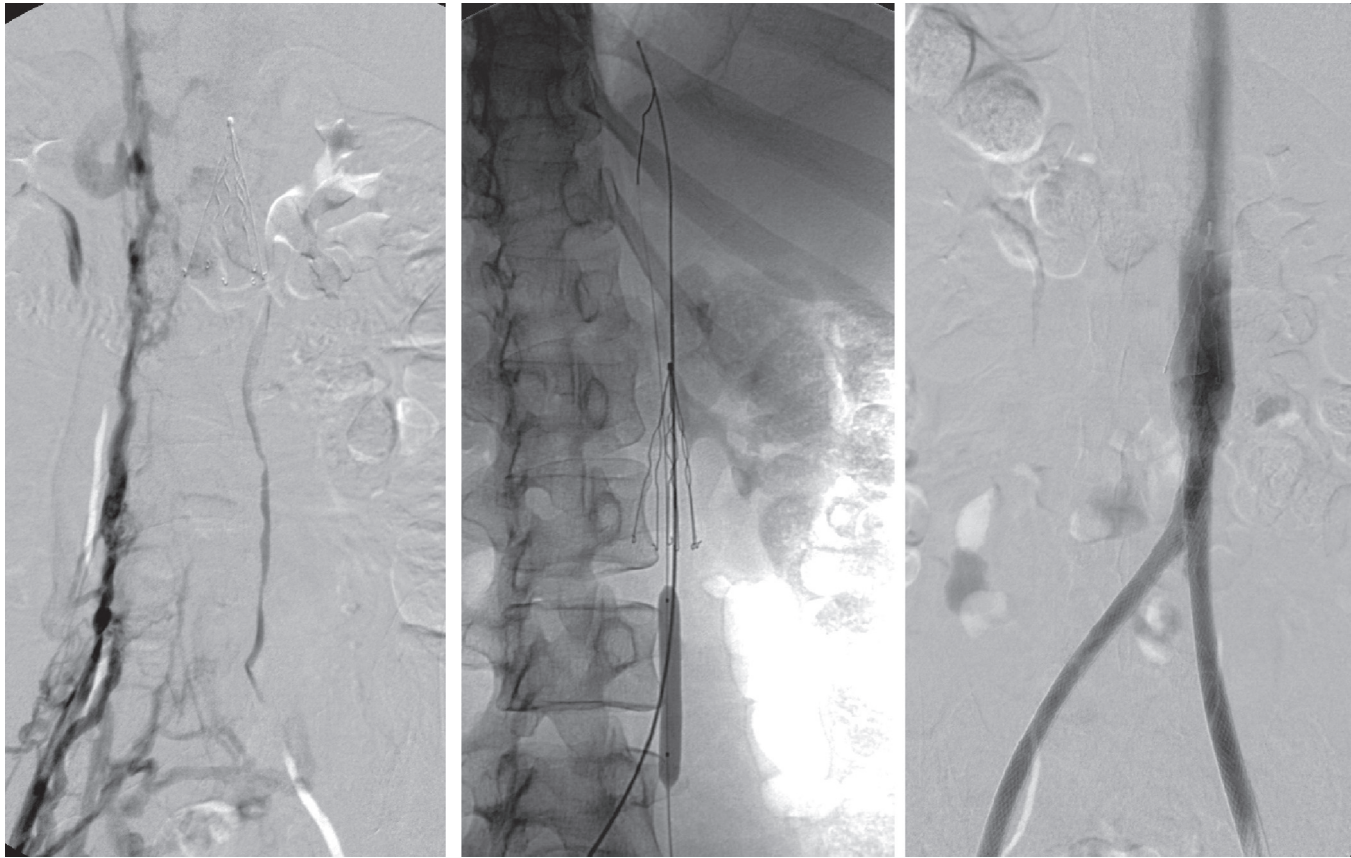


**FIGURE 61.8** This 38-year-old female patient had a two year history of ilio-caval obstruction with an occluded Greenfield filter. The first image shows peri-caval collateral with no flow in the IVC. In the middle image, guidewires can be seen traversing the filter. An 8 mm × 4 cm balloon is seen inflated in the distal cava. In order to stent the chronically thrombosed cava, the double crossover tandem Wallstents™ were extended though the filter.

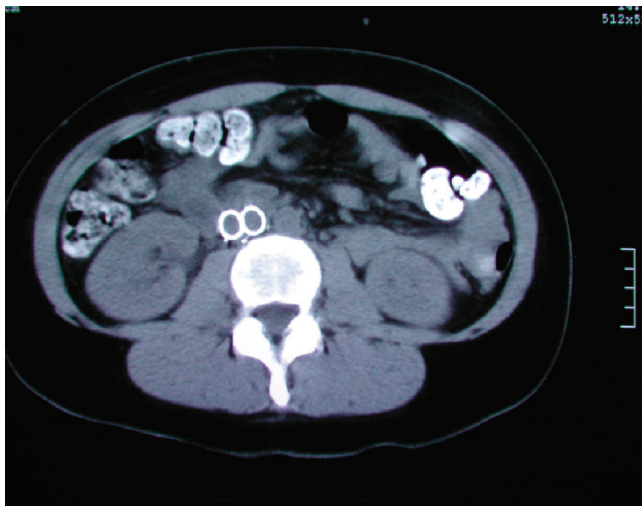


**FIGURE 61.9** Cross-sectional abdominal CT of image of patient in Figure 61.8. See the 2 stent lumens, side by side.

simultaneously, assuring that the superior margin is at least 1 cm above the filter strut (see Figure 61.11).

We keep the patient therapeutically anticoagulated with unfractionated heparin. Low molecular weight heparin (LMWH) has not been tested in this scenario and there are anecdotal cases of abrupt rethrombosis when this was attempted. Warfarin and clopidogrel (Plavix) can be started within 24 hours of stenting. A stable, therapeutic INR ( $>2.0$   $< 3.0$ ) is required before heparin is discontinued. Popliteal and jugular sheaths can be pulled with the PTT ~ 50 seconds. We do not discontinue heparin. The patient is prone for popliteal sheath removal. Mild manual pressure is placed on the back-wall puncture site and sheath tract for 10 minutes followed by placement of a Coban™ wrap, pressure dressing. The patient does not ambulate for 24 hours after removal of the sheaths. This minimizes hematoma formation behind the knee. A completion duplex exam is obtained before discharge. The INR is closely monitored for six to eight weeks, in cooperation with the patient's local physician, to assure a recommended range of 2.5 to 3.5 is maintained. Annual exam and duplex documentation of stent patency are part of

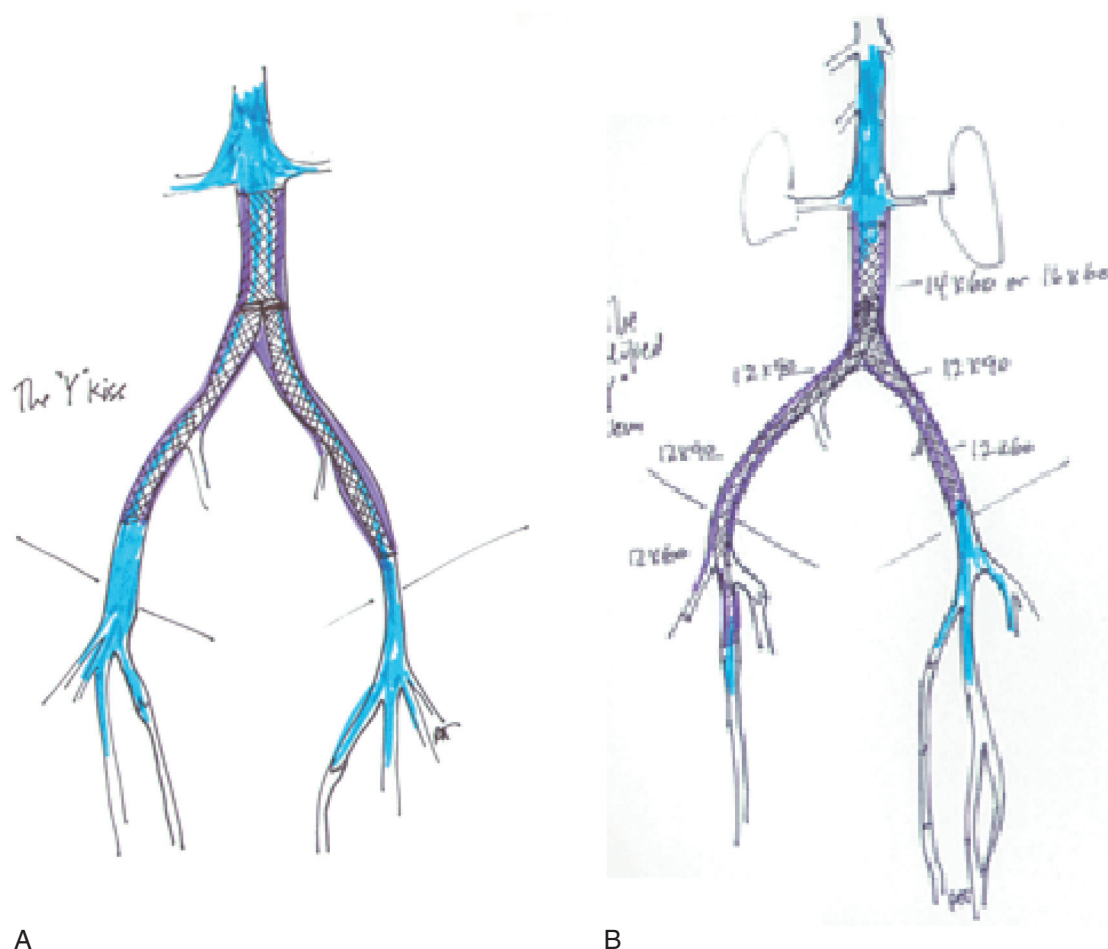


**FIGURE 61.10** Drawings depict the “Y” configuration of stents (left) and the “modified Y” pattern. When using these options, we prefer a caval stent that does not foreshorten upon deployment.

our protocol. When duplex velocities decrease, or patients have recurrence of edema or discomfort, the stents are dilated via a right internal jugular approach in an outpatient procedure.

### Clinical Experience

The first endovenous stent was placed in the IVC in 1986 by Zollikofer and colleagues.<sup>21</sup> Between 1986 and 2000, fewer than 100 IVC stent cases were documented in the literature. This included endovenous treatment of benign (67%) and malignant (33%) IVC obstruction. Most of the patients developed inferior vena cava syndrome secondary to acute thrombosis superimposed upon a focal lesion. Catheter-directed thrombolysis of acute caval thrombosis was reported to be technically and clinically feasible by Angle et al.<sup>49</sup> They restored IVC patency in 7/8 patients, and all reported no edema with mean follow-up of 11 months (range 2–24 months). In 2001, Razavi et al. reported a series of 17 consecutive patients with chronic IVC occlusion treated over a six-year period.<sup>14</sup> The mean duration of symp-

toms was 32 months. Thrombolysis and/or stents were used with technical success in 15 (88%) patients. After mean follow-up of 19 months, primary patency rate was 80% and the primary assisted rate was 87% (13/15). There were no procedure-related complications, although four patients died during the follow-up period, due to underlying disease.

Between 1996 and 1999, seven patients (6M/1F) ranging in age from 16 to 72 years (mean 45.4 years) underwent endovascular therapy at Creighton Medical Center, for symptomatic venous insufficiency involving longstanding IVC occlusion.<sup>15</sup> Mean duration of symptoms was 17 years (range 12–25 years) (see Table 61.1). CEAP classification included C4 (3), C5 (2), and C6 (2). Prior to intervention, the mean clinical score was 10.25 and the average and median disability score was 3. All patients wore compression hosiery and were on warfarin prior to treatment. Three patients had a history of pulmonary embolus (PE) treated with a filter (1), a DeWeese caval plication (1), and caval ligation (1). One patient had a prophylactic filter placed prior to back surgery, and this was occluded. Two patients had previous vascular surgery including right popliteal transpo-

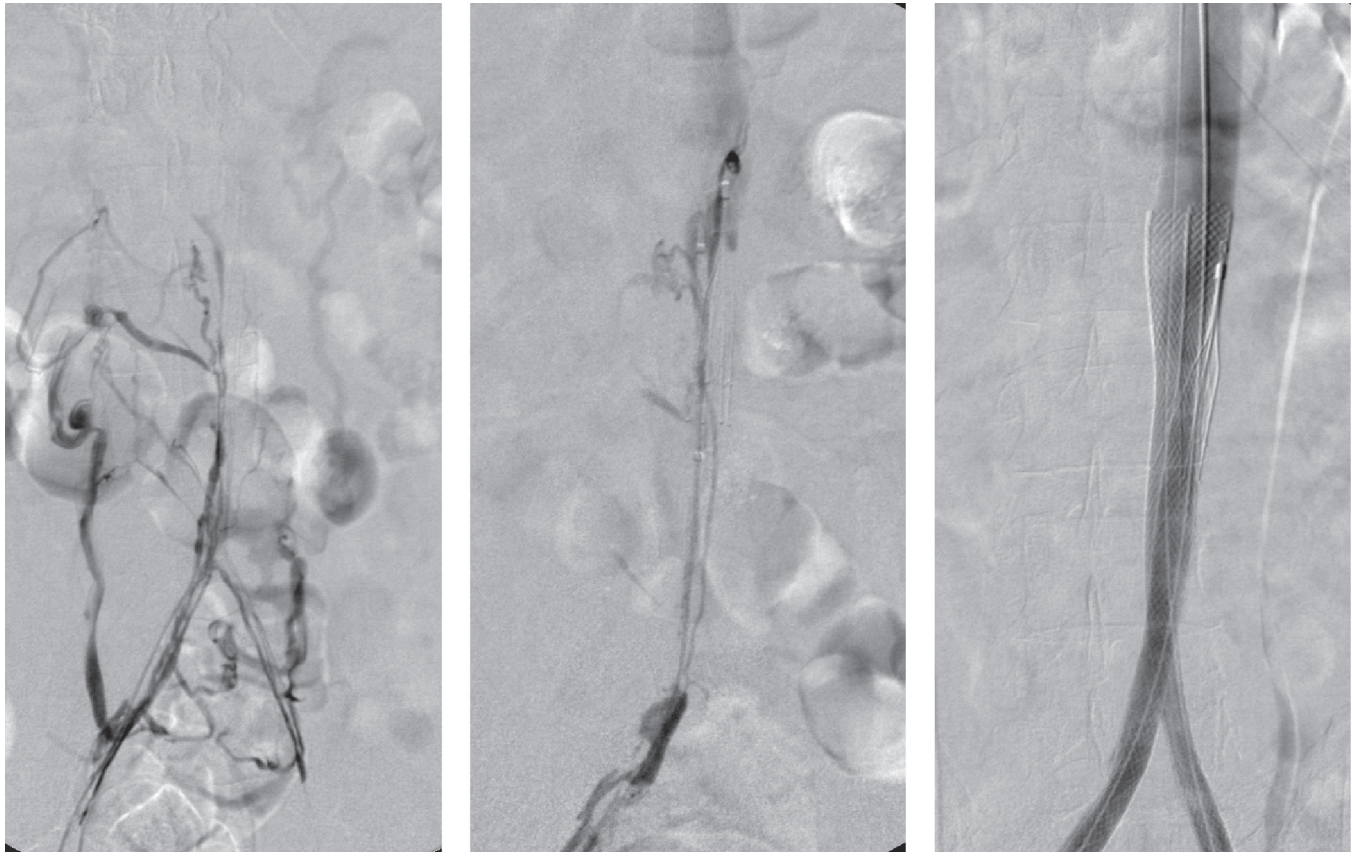


**FIGURE 61.11** This series of digital images show totally occluded IVC and iliac veins in a 50-year-old man. The Gunther Tulip™ filter was occluded. The images show the abundance of collaterals that can deceive the interventionalist before the true lumen is revealed. Wire advancement through the obscured lumen can be tedious. Note that one stent system passes through the filter whereas the other column appears to be adjacent to the contracted filter.

**TABLE 61.1** Basic Data of First Seven Patients Treated at Creighton for IVC occlusion 1995–1999 IVC Syndrome

|      |   | age  | 1 <sup>st</sup> DVT | duration |        |
|------|---|------|---------------------|----------|--------|
| 1    | m | 38   | 1977                | 20y      | Fac V  |
| 2    | m | 72   | 1984                | 12y      |        |
| 3    | f | 62   | 1977                | 20y      |        |
| 4    | m | 38   | 1981                | 17y      | AT III |
| 5    | m | 16   | 1982                | 17y      | Pro S  |
| 6    | m | 40   | 1992                | 8y       |        |
| 7    | m | 52   | 1974                | 25y      | Pro S  |
| mean |   | 45.4 |                     | 17y      |        |

sition valvuloplasty (1), and Palma-bypass, left to right (1). Although a question of congenital abnormality was raised in three patients, the etiology of caval occlusion was thought to be post-thrombotic in all patients. All patients had bilateral iliac obstruction. Chronic femoral obstruction was encountered in 10/12 (83%) limbs. Patient 5 presented with acute left DVT extending from the calf to the iliac. Chronic changes were noted in the calf and popliteal regions in

patients 5/7 (71%). Reflux was documented in 11/12 (92%) treated limbs, and in patient 6, both superficial and deep valves are incompetent. Two patients had prior below-the-knee amputation due to stasis ulcers and presented with nonhealing ulcers on the surviving limb.

Endovascular reconstruction of the occluded iliac (14) and IVC (7) segments was accomplished in all patients. The median length of stay was eight days (range 6–15 days). Urokinase was used in six patients and a combination of urokinase and rt-PA was used in patient 7. The average dose was 8.8 million IU infused over 48 to 96 hours (range 36–120 hours). The average number of stents placed was 2.8 (range 2–4). In three patients, stents extended the entire length of the IVC. Clinical improvement was noted rapidly in all patients. Long-standing thigh edema decreased over the first five days. Patients often are refitted for a different size of compression stocking. The clinical score decreased significantly after therapy ( $p < 0.001$ ). Disability decreased in six of those treated by one level and by two levels in the youngest patient. In two patients, ulcer healing occurred in <30 days, but reoccurred at 18 months in one, due to poor compliance with warfarin and a recurrent popliteal DVT.

Complications related to thrombolysis included site infection (1), UTI (1), transient hematuria (1), and retroperitoneal hematoma (1). The hematoma occurred in the patient receiving rt-PA and was associated with wire perforation, during stenting, at the site of caval ligation. However, this patient lost more blood at the groin site, where scar tissue from previous trauma and surgery caused oozing at the sheath site.

It has been 10 years since the first patient in this series was treated. Patient 2 survived four years after intervention, and death was unrelated to VTE. His IVC stents were patent by ultrasound at 44 months. Patient 3 underwent a left BKA in 2003 secondary to ischemic arterial disease and complications of diabetes. The stasis ulcer remained healed during the six years following intervention for restenosis of the distal ilio caval stents in 1997. Restenosis was identified and treated in 4/7 (57%). Among the five surviving patients, patients 4 and 5 have not required any reintervention. Their IVC/iliac stents remain patent by ultrasound at 95 and 82 months follow-up. Patient 5 was 16 years old when treated. At age 23, he remains asymptomatic and is therapeutically anticoagulated, due to Protein S deficiency. Patients 6 and 7 each had reintervention six months after stent placement. In Patient 6, the caval stents showed intimal hyperplasia at the proximal and distal aspects. Caval stents were dilated and symptoms of discomfort and associated edema resolved. A second reintervention was performed in 2002 to redilate left iliofemoral stents. The intimal hyperplasia was documented with intravascular ultrasound (IVUS). The left leg symptoms resolved. Patient 7 also experienced an increase in left leg edema at six months. A stenosis at the distal aspect of the common femoral stent was dilated. No further interventions have been indicated during the 74-month follow-up. Patient 1 has been observed for 10 years. He had suffered extreme pain from a stasis ulcer in the right medial malleolar area prior to intervention. Not only did the ulcer heal, after the series of interventions, it has remained closed since 1998. Ultrasound exams in 2005 document continued flow in the ilio-caval stents. In summary, by 2005, mean follow-up was seven years, eight months; the primary patency remained 33% with assisted patency 86% (due to one patient with rethrombosis, which was successfully reopened). Actuarial secondary patency was 100% (see Table 61.2). Clinically, two patients remain asymptomatic. Edema and variable discomfort affect the other three patients but each manages to work and remain active with compression stockings. Each patient affirms their continued clinical improvement following endovascular therapy.

Raju and Neglen reported similar experience with percutaneous recanalization of totally occluded iliac veins in 38 limbs and the occlusion extended into the infrarenal IVC in nine cases.<sup>16</sup> Two cava had an occluded filter. The median length of the occluded segment was 22 cm. The median number of 14–16 mm diameter stents used per patient was

**TABLE 61.2** Primary, Assisted, and Secondary Patency Rates Are Derived from Notation of Reintervention for Restenosis, over Time. Two Patients Have Required no Further Endovascular Treatment

|   | 6mo | 12mo | 18mo | 24mo | 3yr | 4yr | 5yr | 6yr | 7yr |
|---|-----|------|------|------|-----|-----|-----|-----|-----|
| 1 |     |      |      | X    | X   |     |     |     |     |
| 2 |     |      |      |      |     | D   |     |     |     |
| 3 | X   |      |      |      |     |     |     |     |     |
| 4 |     |      |      |      |     |     |     |     |     |
| 5 |     |      |      |      |     |     |     |     |     |
| 6 |     | X    |      |      |     | X   |     |     |     |
| 7 |     | X    |      |      |     |     |     |     |     |

three. Diffuse distal chronic venous changes were noted in 88% of treated limbs. The chronic, nonocclusive DVT involved femoral, popliteal, and tibial segments in 62% versus a single segment in 9%. However, distal segmental occlusions were noted in 52% of the limbs; the majority of such tandem occlusions were femoral. Distal femoral lesions were not stented. Mean follow-up was 24 months. He reported actuarial primary, assisted, and secondary patency rates of 49%, 62%, and 76%, respectively. Clinical improvement was gauged with the pain scale where a significant decrease from level 4 to level 0 ( $p < 0.0001$ ) was reported. Sixty-six percent of limbs showed resolution of open ulcers or stasis dermatitis at one year. Reflux was documented in 87% of treated limbs and involved both superficial and deep systems in 65% of these individuals. Perhaps the differences in the long-term ilio caval stent patency rates among separate series reflect variable treatment of distal, tandem obstructions as well as selective use of anticoagulation.

In 2004, Robbins et al. reported on two cases to demonstrate the value of endovascular correction of chronic long-segment inferior vena cava obstruction.<sup>13</sup> A young woman, with Factor V Leiden, and a three-year history of progressive right limb edema was diagnosed with caval obstruction following MRV. A series of Wallstents™ were overlapped to reconstruct the ilio caval segments without thrombolysis. The bidirectional or through-and-through access was used to facilitate balloon dilatation and stent deployment at the intrahepatic, infrarenal cava, and right iliofemoral levels. Large diameter stents, 18 mm, were used in the cava, 16–14 mm in the iliac, and 12–10 mm in the femoral. Right lower extremity edema resolved remained absent at six months. The patient was managed with warfarin and clopidogrel (Plavix) for six weeks and 81 mg daily aspirin long-term. The second case involved bilateral lower extremity edema and caval occlusion in a 72-year-old man with a three-year history of edema and venous claudication. The occluded IVC was approached through the patent right common femoral access. A sequence of Gianturco Z stents (Cook), dilated to 16 mm, was used to reconstruct the entire

IVC. The most proximal stent was placed in the intra-hepatic cava just below the right atrium. An additional left iliac lesion was treated with a single 14mm Wallstent™. The extremity edema resolved rapidly, and he was managed with warfarin and aspirin. The patient was only followed for two months due to progression of his primary liver disease.

## CONCLUSIONS

These cases demonstrate the technical feasibility of recanalization of the cava without thrombolysis. Thrombolysis is most useful when the guidewire does not easily traverse the occlusion. The option of endovenous reconstruction is a valuable addition to the vascular specialist. Each procedure may be tailored to the patient's condition. Perhaps, in the future, devices will be designed to facilitate recanalization and debulking of organized thrombus. Surely, the techniques will evolve as we share more data, and new tools are introduced. For now, some hard learned lessons can be summarized briefly. In our experience, the long-term patency of caval stents may depend upon adequate restoration of distal flow, when multisegmental occlusions are present. Establishing continuity of flow throughout the deep system appears to be important to long-term patency. However, stenting below the adductor canal level has been unsuccessful in our experience. The use of large-diameter stents (12–16mm) is favored, but it has been shown that excessive axial force is associated with intimal hyperplasia.<sup>1</sup> Finally, selective use anticoagulation may promote patency. Patients with a known hypercoagulability factor have a clear indication for long-term therapy. In addition, therapeutic warfarin levels (INR 2.0–3.0) help maintain patency in limbs with chronic residual thrombus in the deep venous system, even when larger, proximal veins are widely stented. Perhaps the most important message from reviewing the endovascular treatment of chronic venous occlusion is an appreciation for the need to aggressively treat more patients with acute DVT in hope of preventing the sequela of unresolved thrombosis.

## References

- Irving JD, Dondelinger RF, Reidy JF, Schild H, Dick R, Adam A et al. Gianturco self-expanding stents: Clinical experience in the vena cava and large veins, *Cardiovascular & Interventional Radiology*. 1992. October (5): 328.
- Hartley JW, Awrich AE, Wong J, Stevens K, Fletcher WS. Diagnosis and treatment of the inferior vena cava syndrome in advanced malignant disease, *American Journal of Surgery*. 1986. 1: 1970.
- Fletcher WS, Lakin PC, Pommier RF, Wilmarth T. Results of treatment of inferior vena cava syndrome with expandable metallic stents, *Archives of Surgery*. 1998. 9: 935.
- Zhang C, Fu L, Zhang G, Xu L, Shun H, Wang Z et al. Ultrasonically guided inferior vena cava stent placement: Experience in 83 cases, *Journal of Vascular & Interventional Radiology*. 1999. 1: 1985.
- Chan EL, Bardin JA, Bernstein EF. Inferior vena cava bypass: Experimental evaluation of externally supported grafts and initial clinical application, *Journal of Vascular Surgery*. 1984. 5: 675.
- Sarkar R, Eilber FR, Gelabert HA, Quinones-Baldrich WJ. Prosthetic replacement of the inferior vena cava for malignancy, *Journal of Vascular Surgery*. 1998. 1: 1975.
- Bower TC, Nagorney DM, Cherry KJ Jr, Toomey BJ, Hallett JW, Panneton JM et al. Replacement of the inferior vena cava for malignancy: An update, *Journal of Vascular Surgery*. 2000. 2: 270.
- Jost CJ, Gloviczki P, Cherry KJ Jr, McKusick MA, Harmsen WS, Jenkins GD et al. Surgical reconstruction of iliofemoral veins and the inferior vena cava for nonmalignant occlusive disease, *Journal of Vascular Surgery*. 2001. 2: 320.
- Neglen P, Nazzari MM, al-Hassan HK, Christenson JT, Eklof B. Surgical removal of an inferior vena cava thrombus, *European Journal of Vascular Surgery*. 1992. 1: 1978.
- Puggioni A, Kistner RL, Eklof B, Lurie F. Surgical disobliteration of postthrombotic deep veins—endophlebectomy—is feasible, *Journal of Vascular Surgery*. 2004. 5: 1048.
- Althaus SJ, Perkins JD, Soltes G, Glickerman D. Use of a Wallstent in successful treatment of IVC obstruction following liver transplantation, *Transplantation*. 1996. 4: 669.
- Stone DH, Adelman MA, Rosen RJ, Riles TS, Lamparello PJ, Jacobowitz GR et al. A unique approach in the management of vena caval thrombosis in a patient with Klippel-Trenaunay syndrome, *Journal of Vascular Surgery*. 1997. 1: 155.
- Robbins MR, Assi Z, Comerota AJ. Endovascular stenting to treat chronic long-segment inferior vena cava occlusion, *Journal of Vascular Surgery*. 2005. 1: 136.
- Razavi MK, Hansch EC, Kee ST, Sze DY, Semba CP, Dake MD. Chronically occluded inferior venae cavae: Endovascular treatment, *Radiology*. 2000. 1: 133.
- Thorpe P, Osse F, Dang H. Endovascular reconstruction for chronic iliac vein and inferior vena cava obstruction. In: Gloviczki P, Yao J, eds. *Handbook of Venous Disorders*, 2e. London: Arnold. 2001. 347–361.
- Raju S, McAllister S, Neglen P. Recanalization of totally occluded iliac and adjacent venous segments, *Journal of Vascular Surgery*. 2002. 5: 903.
- Park JH, Chung JW, Han JK, Han MC. Interventional management of benign obstruction of the hepatic inferior vena cava, *Journal of Vascular & Interventional Radiology*. 1994. 3: 403.
- Wright KC, Wallace S, Charnsangavej C, Carrasco CH, Gianturco C. Percutaneous endovascular stents: An experimental evaluation, *Radiology*. 1985. 1: 1969.
- Charnsangavej C, Carrasco CH, Wallace S, Wright KC, Ogawa K, Richli W et al. Stenosis of the vena cava: Preliminary assessment of treatment with expandable metallic stents, *Radiology*. 1986. 2: 295.
- Carrasco CH, Charnsangavej C, Wright KC, Wallace S, Gianturco C. Use of the Gianturco self-expanding stent in stenoses of the superior and inferior venae cavae, *Journal of Vascular & Interventional Radiology*. 1992. 2: 409.
- Zollikofer CL, Antonucci F, Stuckmann G, Mattias P, Salomonowitz EK. Historical overview on the development and characteristics of stents and future outlooks, *Cardiovascular & Interventional Radiology*. 1992. 5: 272.
- El FM, Soula P, Rousseau H, Chaiban F, Otal P, Joffre F et al. Endovascular retrieval of two migrated venous stents by means of balloon catheters, *Journal of Vascular Surgery*. 1998. 3: 541.
- Neglen P, Raju S. In-stent recurrent stenosis in stents placed in the lower extremity venous outflow tract, *Journal of Vascular Surgery*. 2004. 1: 181.
- 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 multi-center registry. [erratum appears in Radiology 1999 Dec; 213(3): 930], Radiology. 1999. 1: 1939.
25. Kakkar VV. Treatment of deep vein thrombosis. A comparative study of heparin, streptokinase and Arvin, *Bulletin der Schweizerischen Akademie der Medizinischen Wissenschaften*. 1973. 4: 253.
  26. Fossard DP, Friend JR, Field ES, Corrigan TP, Kakkar VV, Flute PT. Fibrinolytic activity and postoperative deep-vein thrombosis, *Lancet*. 1974. 7845: 1909.
  27. Katzen BT. Technique and results of "low-dose" infusion, *Cardiovasc Intervent Radiol*. 1988. 11: S41-S47.
  28. vanBreda A, Graor R, Katzen B, Rislus B, Gillings D. Relative cost effectiveness of urokinase versus streptokinase in the treatment of peripheral vascular disease, *JVIR*. 1991. 2: 77-87.
  29. Ouriel K, Katzen B, Mewissen M, Flick P, Clair DG, Benenati J et al. Reteplase in the treatment of peripheral arterial and venous occlusions: A pilot study, *Journal of Vascular & Interventional Radiology*. 2000-Aug. 7: 849.
  30. Ouriel K, Gray B, Clair DG, Olin J. Complications associated with the use of urokinase and recombinant tissue plasminogen activator for catheter-directed peripheral arterial and venous thrombolysis, *Journal of Vascular & Interventional Radiology*. 2000. 3: 295.
  31. Ouriel K. A history of thrombolytic therapy, *Journal of Endovascular Therapy: Official Journal of the International Society of Endovascular Specialists*. 2004. 11 (2 Suppl): 128-133.
  32. Ouriel K, Cynamon J, Weaver FA, Dardik H, Akers D, Blebea J et al. A phase I trial of alteplase for peripheral arterial thrombolysis, *Journal of Vascular & Interventional Radiology*. 2005. 8: 1075.
  33. Semba CP, Dake MD. Iliofemoral deep venous thrombosis: Aggressive therapy with catheter-directed thrombolysis, *Radiology*. 1994. 191: 487-494.
  34. Ouriel K, Green RM, Greenberg RK, Clair DG. The anatomy of deep venous thrombosis of the lower extremity, *Journal of Vascular Surgery*. 2000. 5: 895.
  35. Fogarty TJ, Krippaehne WW. Catheter technique for venous thrombectomy, *Surgery, Gynecology & Obstetrics: Gynecology-4*. 1965.
  36. Sharafuddin MJ, Hicks ME. Current status of percutaneous mechanical thrombectomy. Part I. General principles. [Review] [88 refs]. *Journal of Vascular & Interventional Radiology*. 1997-Dec. 6: 911.
  37. Sharafuddin MJ, Hicks ME. Current status of percutaneous mechanical thrombectomy. Part II. Devices and mechanisms of action. [Review] [105 refs]. *Journal of Vascular & Interventional Radiology*. 1998-Feb. 1915.
  38. Sharafuddin MJ, Hicks ME. Current status of percutaneous mechanical thrombectomy. Part III. Present and future applications. [Review] [151 refs]. *Journal of Vascular & Interventional Radiology*. 1998-Apr. 2: 209.
  39. Stainken BF. Mechanical thrombectomy: Basic principles, current devices, and future directions, *Techniques in Vascular & Interventional Radiology*. 2003. 1: 2002.
  40. Gu X, Sharafuddin MJ, Titus JL, Urness M, Cervera-Ceballos JJ, Ruth GD et al. Acute and delayed outcomes of mechanical thrombectomy with use of the steerable Amplatz thrombectomy device in a model of subacute inferior vena cava thrombosis, *Journal of Vascular & Interventional Radiology*. 1997-Dec. 6: 947.
  41. Sharafuddin MJ, Gu X, Han YM, Urness M, Gunther R, Amplatz K. Injury potential to venous valves from the Amplatz thrombectomy device, *Journal of Vascular & Interventional Radiology*. 1999. 1: 1964.
  42. Allie DE, Hebert CJ, Lirtzman MD, Wyatt CH, Keller VA, Khan MH et al. Novel simultaneous combination chemical thrombolysis/rheolytic thrombectomy therapy for acute critical limb ischemia: The power-pulse spray technique, *Catheterization & Cardiovascular Interventions*. 2004. 4: 512.
  43. Massicotte MP, Dix D, Monagle P, Adams M, Andrew M. Central venous catheter related thrombosis in children: Analysis of the Canadian Registry of Venous Thromboembolic Complications, *Journal of Pediatrics*. 1998. 6: 770.
  44. Hausler M, Hubner D, Delhaas T, Muhler EG. Long term complications of inferior vena cava thrombosis, *Archives of Disease in Childhood*. 2001. 3: 228.
  45. Greenfield LJ, Proctor MC. Twenty-year clinical experience with the Greenfield filter, *Cardiovascular Surgery*. 1995. 2: 199.
  46. Rutherford R. The CEAP classification system and assessing outcome, *Vascular Surgery*. 1997. 31(3): 221-222.
  47. Eklof B, Rutherford RB, Bergan JJ, Carpentier PH, Gloviczki P, Kistner RL et al. Revision of the CEAP classification for chronic venous disorders: Consensus statement. [Review] [10 refs]. *Journal of Vascular Surgery*. 2004. 6: 1248.
  48. Carpenter JP, Holland GA, Baum RA, Owen RS, Carpenter JT, Cope C. Magnetic resonance venography for the detection of deep venous thrombosis: Comparison with contrast venography and duplex Doppler ultrasonography, *Journal of Vascular Surgery*. 1993. 5: 734.
  49. Angle JF, Matsumoto AH, Al SM, Hagspiel KD, Spinosa DJ, Humphries JE. Transcatheter regional urokinase therapy in the management of inferior vena cava thrombosis, *Journal of Vascular & Interventional Radiology*. 1998-Dec. 6: 917.