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INTRAVASCULAR IMAGING (A.G. TRUESDELL, SECTION EDITOR)

Intravascular Ultrasound Use for Iliac Vein Interventions

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Abstract

Purpose of Review To summarize the most clinically pertinent data supporting IVUS in deep venous procedures, the basics of IVUS interpretation, technical steps of iliac vein stenting, and typical interventional case examples of acute iliofemoral deep vein thrombosis (DVT) and non-thrombotic iliac vein lesion (NIVL).

Recent Findings Intravascular ultrasound (IVUS) has a fundamental role in deep venous diagnostic and interventional procedures. Venography, although essential and complimentary to IVUS, has many limitations which render it insufficient as a stand-alone imaging modality in deep venous interventions. The diagnostic and prognostic value of IVUS is well-established in the medical literature, and its use in routine practice does not only help achieve optimal clinical results, but also prevent catastrophic complications.

Summary According to most experts in the field, IVUS is now considered to be mandatory for optimal short-term and long-term clinical outcomes of deep venous interventions.

Keywords Intravascular ultrasound (IVUS) · Iliac vein · Femoral vein · Popliteal vein · Venography · Venous stent · Venous angioplasty · Acute deep vein thrombosis (DVT) · Chronic DVT · Non-thrombotic iliac vein lesion (NIVL) · May-Thurner syndrome · Chronic iliofemoral vein occlusion · Rokitansky lesion · Post-thrombotic syndrome

Introduction

Over the last several decades, endovascular revascularization has become the preferred approach for management of venous occlusive disease [1, 2]. Balloon angioplasty, with or without stenting, is now routinely used for management of both NIVL as well as residual venous obstruction in patients with symptomatic iliofemoral DVT. Among those patients requiring adjunctive stenting, invasive venography has been the traditional approach used to guide stent placement. Nevertheless, venography has significant limitations which can lead to incomplete understanding of the lesion extent and severity, as well as the location of important anatomic landmarks such as the common iliac vein bifurcation [3, 4].

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Given the limitations of invasive venography, most operators elect to use IVUS as an adjunctive imaging modality for procedural planning and post-procedural assessment [5].

In this manuscript, we will outline the technical considerations involved in iliac vein stenting with a special focus on the role of IVUS imaging in guiding stent placement.

Diagnostic and Prognostic Role of IVUS

Incremental Value of Adjunctive IVUS Imaging over Invasive Venography Alone

The incremental value of adjunctive IVUS imaging compared with invasive venography alone has been established close to 20 years ago. IVUS is more sensitive than multiplanar venography in assessing and treating iliofemoral stenosis [3, 4].

In a 2002 publication, Neglen and colleagues performed a single-plane transfemoral venography and IVUS in 304 consecutive patients who were undergoing venous revascularization [3]. IVUS was particularly useful for the detection of left common iliac vein (CIV) compression by an overlying right common iliac artery (CIA)—a condition known as May-Thurner syndrome. Whereas IVUS clearly delineated the degree of compression, venography tended to show indirect features of an underlying compression, such as widening of the vein with central contrast lucency and the presence of trans-pelvic collaterals. These indirect venographic features of May-Thurner compression (Fig. 1) were seen in 21% of all study patients.

IVUS was also found to be more effective in detecting the presence of significant venous stenoses compared with angiography. When compared to the median stenosis severity of 50% that was seen on venography, IVUS detected a higher median stenosis of 80%. Compared to IVUS as the gold standard, venography alone also had a low sensitivity (45%) and negative predictive value (49%) for detecting stenoses with severity greater than 70%.

Subsequent work from Gagne et al. [4] compared multiplanar venography and IVUS imaging among 100 patients with suspected iliofemoral vein obstruction. Overall, venography was less sensitive than IVUS in identifying significant venous lesions (51% vs. 81%, respectively). Among patients with identifiable stenosis, venography underestimated the diameter of the most severe lesion by 11%. Given the discrepancy of the two imaging modalities, adjunctive IVUS assessment led to revision of an original treatment plan in 57% of cases, mostly related to the failure of the venogram to detect a significant lesion. A separate analysis of the VIDIO trial [6] was also undertaken to determine the optimal thresholds for stenting and residual post-intervention stenoses which predicted symptom improvement. This secondary analysis suggested that patients with a baseline area stenosis of > 54% (by IVUS), and those patients in whom baseline stenosis was reduced by > 41%, experienced significant clinical improvement. Interestingly, venographic assessment of baseline stenosis and stenosis change were not predictive.

A more recent study from Montimony et al. provides the most up-to-date comparison of venography and IVUS [7]. In their study, 152 patients (28% NIVL; 72% post-thrombotic) who were undergoing iliac vein stenting for treatment of venous occlusive disease had both venography and IVUS assessment. Venography failed to detect any degree of angiographic stenosis in 19% of cases where stenosis was present by IVUS. Within the remaining cohort, venography reported a less significant degree of mean area stenosis (52% vs. 69%, $p < 0.0001$) compared with IVUS and had poor agreement on the location of the segment with the most significant stenosis (IVUS suggested the location of maximal stenosis in 78% of all patients, whereas venography found the location of maximal stenosis in only 34% of patients).

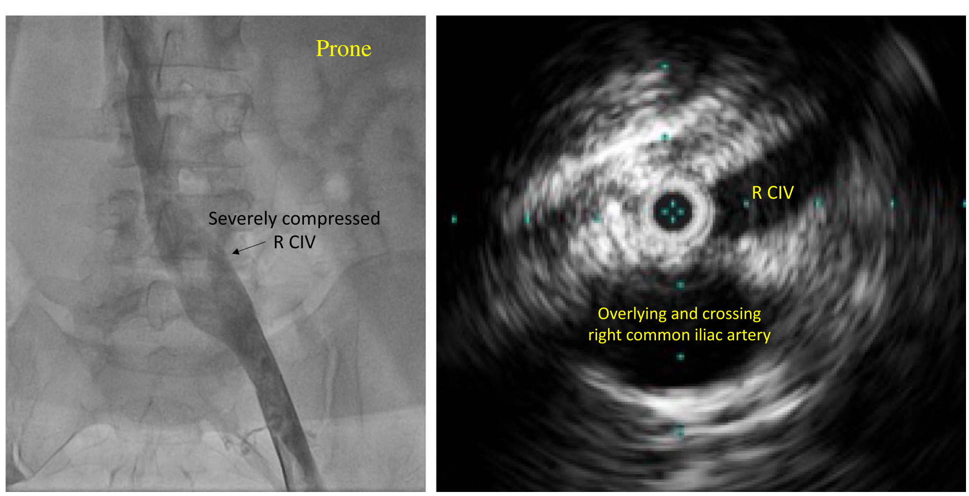


Fig. 1 Typical NIVL causing severe venous stenosis which is not identified by venography but easily detected by IVUS. Flattening or "pancaking" of the iliac vein displayed here is an indirect sign of external compression. (patient laying in a prone position here)

Another interesting finding from the study was that the agreement on the location of the iliac-caval confluence and of the distal landing zone was very poor between the two imaging modalities. IVUS found the confluence to be higher than would be suggested by venography in 74% of all patients with an average difference of one vertebral body. IVUS generally identified a lower distal landing zone (bottom of the femoral head) compared with venography (pubic ramus).

Besides its superiority in detecting venous stenosis and grading its severity relatively to a reference vessel diameter, IVUS helps identify the etiology of the lesion by displaying the abnormalities in the lumen, vessel wall, and perivascular space [6]. IVUS allows for the differentiation of acute thrombus, chronic thrombus, synechiae, webs, frozen valves, and trabeculation (Fig. 8). It detects venous wall thickening and perivascular fibrosis secondary to chronic post-thrombotic changes, also known as a Rokitansky lesion (Figs. 2C and 8C). While a tubular vein morphology could be an indirect sign of this condition, which may be difficult to detect by angiography, IVUS can easily assess and grade the severity of post-thrombotic lesions.

Furthermore, IVUS allows for the distinction between a venous stenosis and an external venous compression [3, 7]. It can also establish the mechanism of extrinsic compression: arterial crossing, masses, bone spurs, spinal hardware, etc. This is not often feasible by angiography alone.

In addition, one of the most fundamental principles of deep venous interventions consists of landing stents in a way that ensures adequate inflow and outflow, without compromising key anatomical structures, such as completely jailing the iliac vein confluence or deep femoral vein takeoff. IVUS is superior to venography, in identifying “cleaner” landing zones that ensure adequate stent inflow and outflow [8]. This has profound implications on flow, stent landing zones, and interventional outcomes [4].

Not only does the use of IVUS ensure adequate coverage of the diseased venous segment, but it also allows the operator to diagnose stent under-expansion, which correlates with stent restenosis and thrombosis [9].

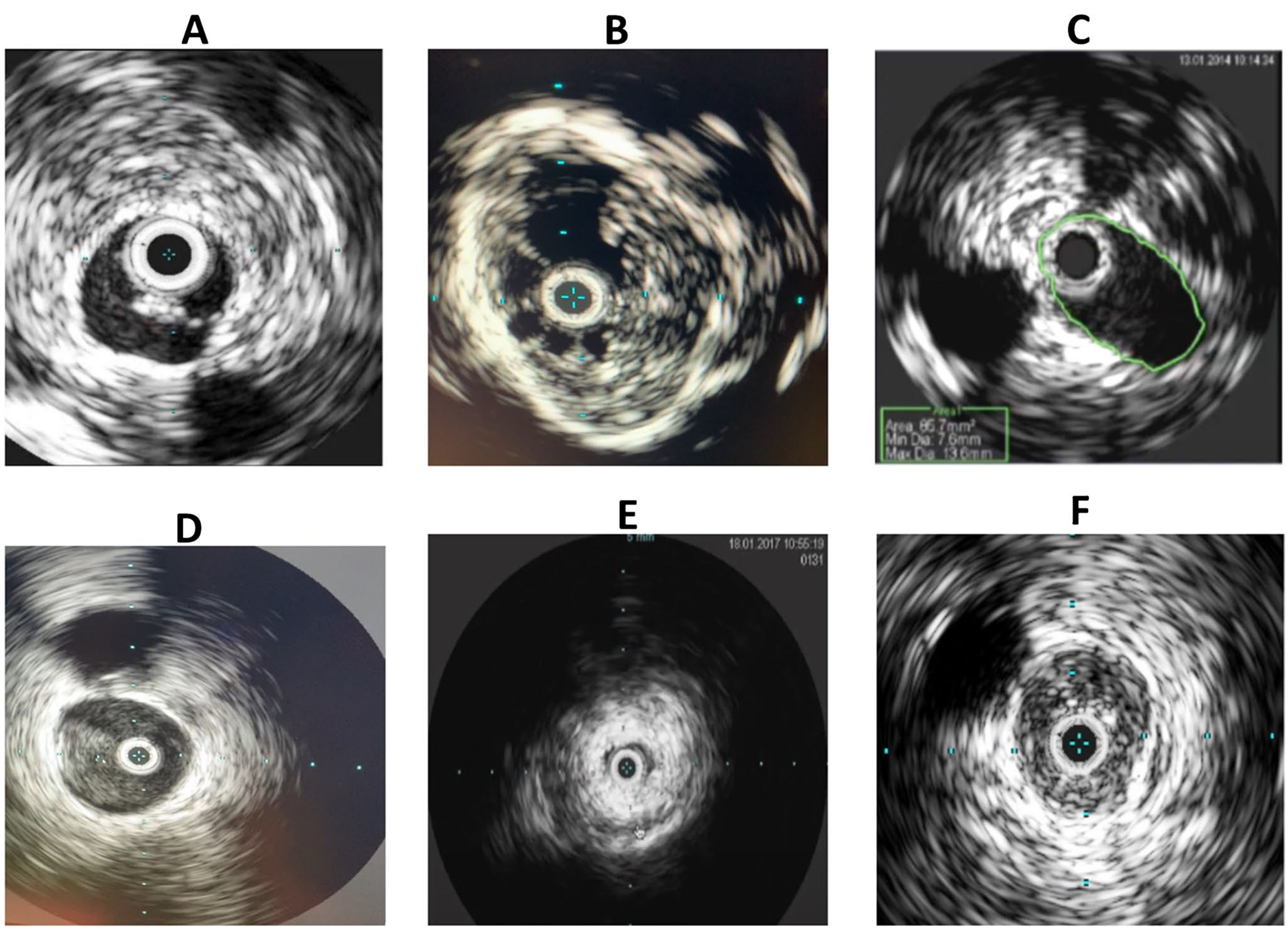


Fig. 2 IVUS findings of **A** and **B** common femoral venous web/synechiae. **C** Rokitansky lesion: Diffuse tubular venous stenosis with significant thickening of the venous wall and peri-venous tissue often related to chronic post-thrombotic changes. **D** Acute thrombus within the common iliac vein. **E** and **F** Chronic thrombus with fibrosis

IVUS helps the reduction of complications in the following scenarios:

1) By more clearly sizing iliac veins during a Valsalva maneuver, it helps to prevent stent under-sizing, reducing the potential for stent embolization.
2) It also helps to minimize the risk of oversizing which can result in disabling chronic back pain.
3) It helps to decrease the risk of pulmonary embolism by assessing the size and extension of the clot burden into the IVC, more accurately than angiography alone. This improves embolic risk stratification and the selection of cases requiring retrievable IVC filters.
4) It may identify a wire coursing into a collateral vein or small branch (Fig. 5B) which prevents perforations related to the use of large balloons in these segments.

On a cautionary note, venography should not be dismissed from deep venous procedures. Angiography identifies aspects of deep venous interventions that are not properly assessed by IVUS. This includes venous flow direction, speed, reflux severity, collateral flow analysis, and extravasation. Hence, IVUS and venography are complementary and not mutually exclusive. We propose that both should be part of every venous diagnostic and interventional procedure.

Long-term Outcomes of IVUS-Guided Endovenous Revascularization

The safety and efficacy of IVUS-guided endovascular venous revascularization has been well-established. An early manuscript [1] from Neglen et al. described their consecutive experience with endovascular management of NIVL (43.9%) and post-thrombotic (PTS—56.1%) vein obstruction in 139 lower extremities; May-Thurner syndrome accounted for 77% of all cases in the NIVL group. All of the patients underwent IVUS-guided stenting.

During follow-up venography at 2 years, patency rates in the PTS group were as follows: primary patency of 52%, primary-assisted patency of 88%, and secondary cumulative patency of 90%. In the NIVL group, primary patency was 60%, primary-assisted patency was 100%, and secondary cumulative patency was 100%. The overall rate of restenosis was 17% with a late stent occlusion rate of 3%. The majority of patients experienced significant symptom relief, and half of all patients with active venous ulcers experienced ulcer healing after undergoing revascularization.

In their follow-up study published in 2007, Neglen and colleagues reported on the longer term outcomes of 870 patients who underwent iliofemoral and/or iliocaval IVUS-guided stenting [2]. There was no short-term (< 30 days) mortality; 47 total thrombotic events (5% of all cases) were observed during the follow-up period. The patency rates were assessed at 72 months for patients with NIVL and with PTS were as follows: primary patency (79% vs. 57%), primary-assisted patency (100% vs. 80%), and secondary cumulative patency (86% vs. 100%) for NIVL and PTS, respectively. From the clinical standpoint, there was a significant reduction in the proportion of patients with severe pain symptoms (from 41 to 11%). Ulceration healed in 101/158 limbs and subsequently recurred in 8 patients during the mean follow-up period of 23 months. Finally, there was a significant improvement in the quality of life (using the CIVIQ score) following revascularization.

Although IVUS-guided stenting appears to be safe and effective, the currently published studies have only reported results of patients who underwent endovascular revascularization and have not included a comparison arm of patients treated with conservative therapy alone. The ongoing randomized NIH-funded C-TRACT (Chronic Venous Thrombosis: Relief with Adjunctive Catheter-Directed Therapy) trial [10] is looking to enroll 374 patients with moderate-to-severe PTS and > 50% stenosis on venous imaging and randomize them to either imaging-guided iliac vein stenting or optimal PTS therapy (medical and compression therapy, lifestyle interventions, and venous ulcer care) [8]. Furthermore, prior studies have not randomized patients undergoing iliac vein stenting to either venography-guided or IVUS-guided revascularization; therefore, a randomized comparison of venography and IVUS is lacking at this time.

Basics of Iliofemoral IVUS Interpretation

Figure 2 demonstrates many examples of frequently encountered deep venous abnormalities by IVUS. The use of minimal luminal area (MLA) is the cornerstone of deep venous assessment by IVUS. A significant venous stenosis is defined as a loss of more than 50% of the reference luminal area [1, 11] (Fig. 3). Table 1 demonstrates the various normal sizes of the lower extremity venous structures that are most commonly assessed with IVUS [1, 11, 12].

Currently, the most appropriate IVUS catheters for the deep venous system are 8 French (F) compatible 0.035″ catheters, Philips Volcano catheters, or Boston Scientific Opticross 35 catheters, with frequencies of 10 and 15 MHz, respectively, which allow for deep penetration of the ultrasound waves. The studied field of view can be large, nearly equaling 60 mm. It is vital to use the correct catheter, because large venous segments like the inferior vena cava (IVC) cannot be thoroughly captured by the field of view of smaller/higher frequency IVUS catheters. Imaging is able to yield both axial and longitudinal assessment of the target vessel.

The fundamental principle that deep veins run alongside their corresponding arteries should always be taken into account in the IVUS image interpretation. What differentiates the arteries from their satellite veins by IVUS is pulsation and

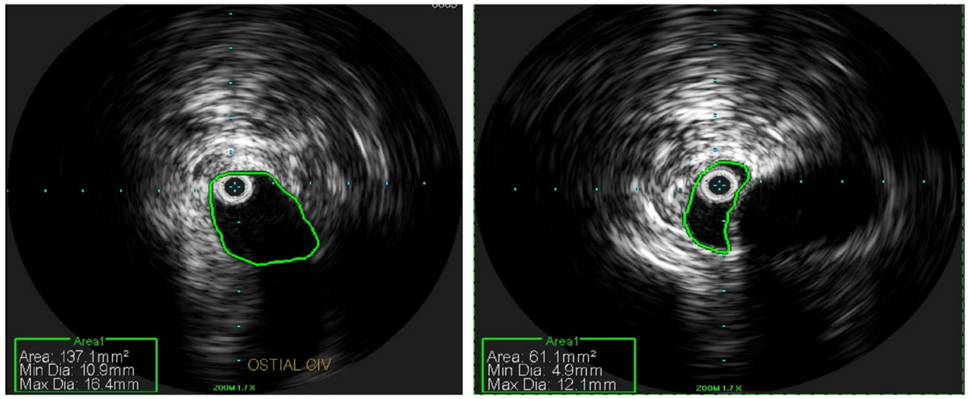


Fig. 3 Common iliac compression of greater than 50%. Note the percent stenosis is derived from the use of the minimal luminal area. This lesion was subsequently stented, relieving the obstruction

the lack of size changes with respiration/Valsalva maneuver (Fig. 4).

Another essential element in the interpretation of IVUS includes the confirmation of the wire course through the architecture of the iliac veins, which are frequently negatively remodeled in chronic post-thrombotic occlusions. Occasionally, the operator could be tricked by venography into thinking that a large well-developed collateral is the proper iliac vein, which can have disastrous consequences after large balloon angioplasty, if not appropriately identified by IVUS (Fig. 5). IVUS also helps when rerouting the wire into the iliac vein architecture, when the previous scenario occurs and the wire has traversed collaterals.

The correlation between IVUS landmarks and fluoroscopy is also mandatory for the fluoroscopic identification of accurate stent landing zones (Fig. 6). Still images of these landmarks should be saved during the IVUS catheter pullback and associated with the appropriate IVUS bookmarks.

Figure 7 outlines one of the most frequent findings in NIVL, where the proximal aspect of the common iliac vein is compressed by the contralateral or ipsilateral iliac artery. It also shows the significant improvement in venous compression after stenting. Figure 8 shows a few examples of frequently encountered findings in deep venous pathology.

Iliac Vein Stenting Technique Step-by-step

1- Access site: If the status of the common femoral vein is not certain based on noninvasive imaging, it is recommended to access the proximal femoral vein in the upper thigh (Fig. 9) with a micro-puncture needle under ultrasound guidance. An alternative access site is the popliteal vein, preferably accessed in a prone position, if the femoral vein inflow is suspected to be abnormal. If either of these scenarios is not suspected, then accessing the distal common femoral vein or proximal greater saphenous vein would be reasonable. Some operators may choose to pre-close the access site with a Perclose Proglide (Abbott Vascular, North Plymouth, MN) device prior to exchanging for an 8F sheath. Other operators choose to place a purse-string or figure of eight suture around the access site that can be cinched down at the time of sheath pull to help achieve manual hemostasis.

2- Setup for venography under digital subtraction angiography mode with roadmap imaging if possible.

a. Venography (performed with iodinated contrast or CO_2 gas depending on the patient's renal function) is mandatory in deep venous intervention, since it provides complimentary information to IVUS. This includes information about flow speed, flow changes with Valsalva and other maneuvers, reflux, extravasation, and collateral flow status/direction. IVUS does not replace angiography, and vice versa. Information obtained from both imaging modalities are complementary and both mandatory in most cases.

b. Field of view should include the femoral head from the lesser trochanter at the bottom of the screen and L3/L4 intervertebral space on top of the screen which usually corresponds to the distal infrarenal IVC. The table is set at a reasonably workable height which balances field of view and radiation scatter. Fluoroscopy is set at a relatively low magnification and at 7.5 FPS to minimize radiation exposure. The table is then locked in place. This roadmap will

Table 1 Deep vein sizes

Vessel	Average Diameter (mm)	Average Area (mm^2)
Common femoral vein	12	125
External iliac vein	14	150
Common iliac vein	16	200
Inferior vena cava	18-24	300-400

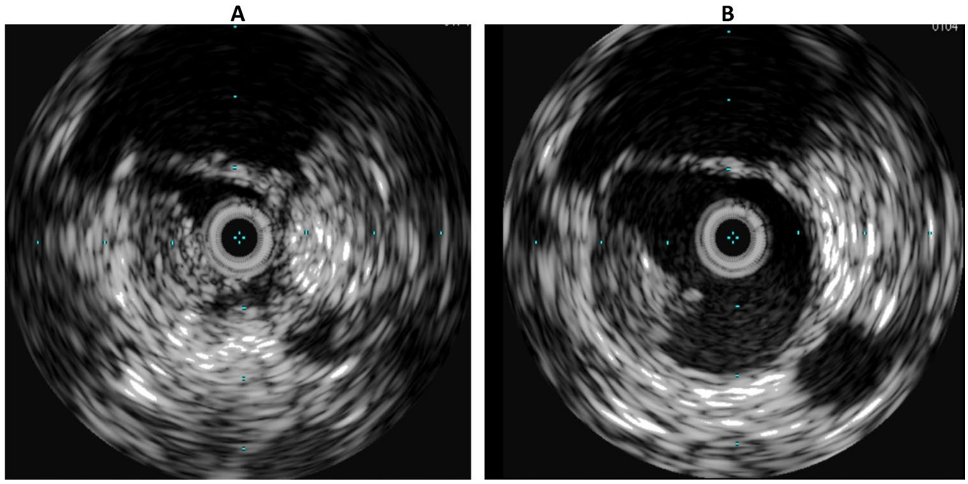


Fig. 4 **A** Expiration at the level of the common femoral vein with visible acute on chronic thrombus seen. **B** Inspiration at the level of the common femoral vein with acute on chronic thrombus seen. Note the increase in venous size with inspiration

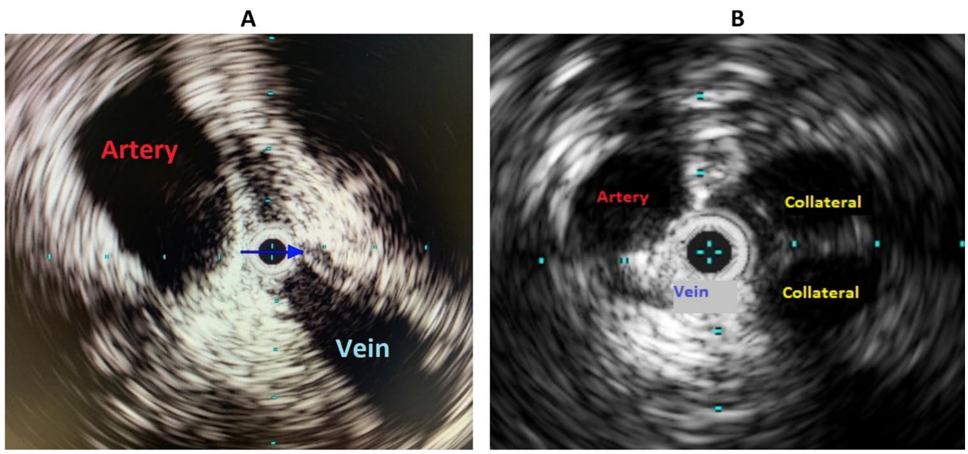


Fig. 5 **A** Deep vein in proximity to the corresponding artery. **B** Deep vein in proximity to the corresponding artery. Note the well-developed collaterals around the occluded vein that do not course parallel to the artery

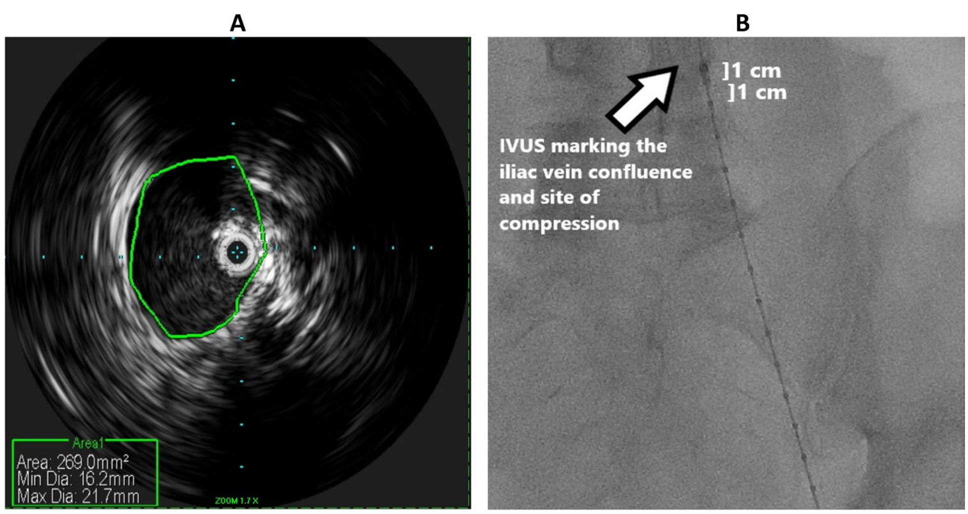


Fig. 6 **A** IVUS imaging of the left common iliac vein with basic measurements made (maximal diameter, minimal diameter, and area). **B** Fluoroscopy of IVUS catheter with markers demonstrating 1-cm segments used for measurements during intervention

serve as framework for the majority of the iliac vein intervention.

c. Except for a few clinical scenarios, it is usually preferred to have a simultaneous bilateral iliac venography to clearly outline the confluence for precise stent positioning, since most interventions will likely involve venous outflow localization. This could be obviously achieved with bilateral femoropopliteal access but preferably with single ipsilateral femoropopliteal access if the probabil-

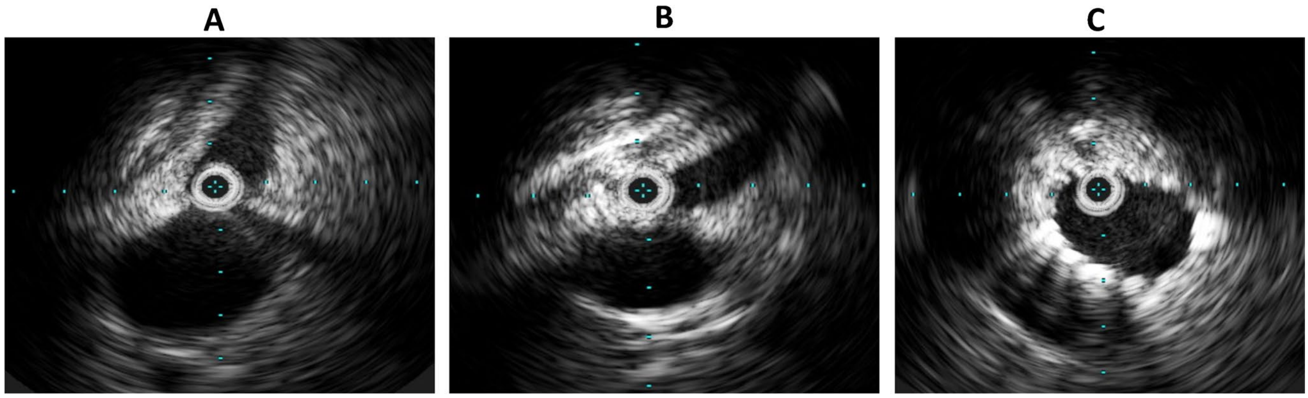


Fig. 7 **A** IVUS of the left common iliac vein at the level of the confluence. **B** IVUS demonstrating compression of the left iliac vein due to compression from the overlying artery. **C** Successful IVUS-guided stenting of the ostial left iliac vein. Special attention paid to avoid completely jailing the contralateral iliac vein

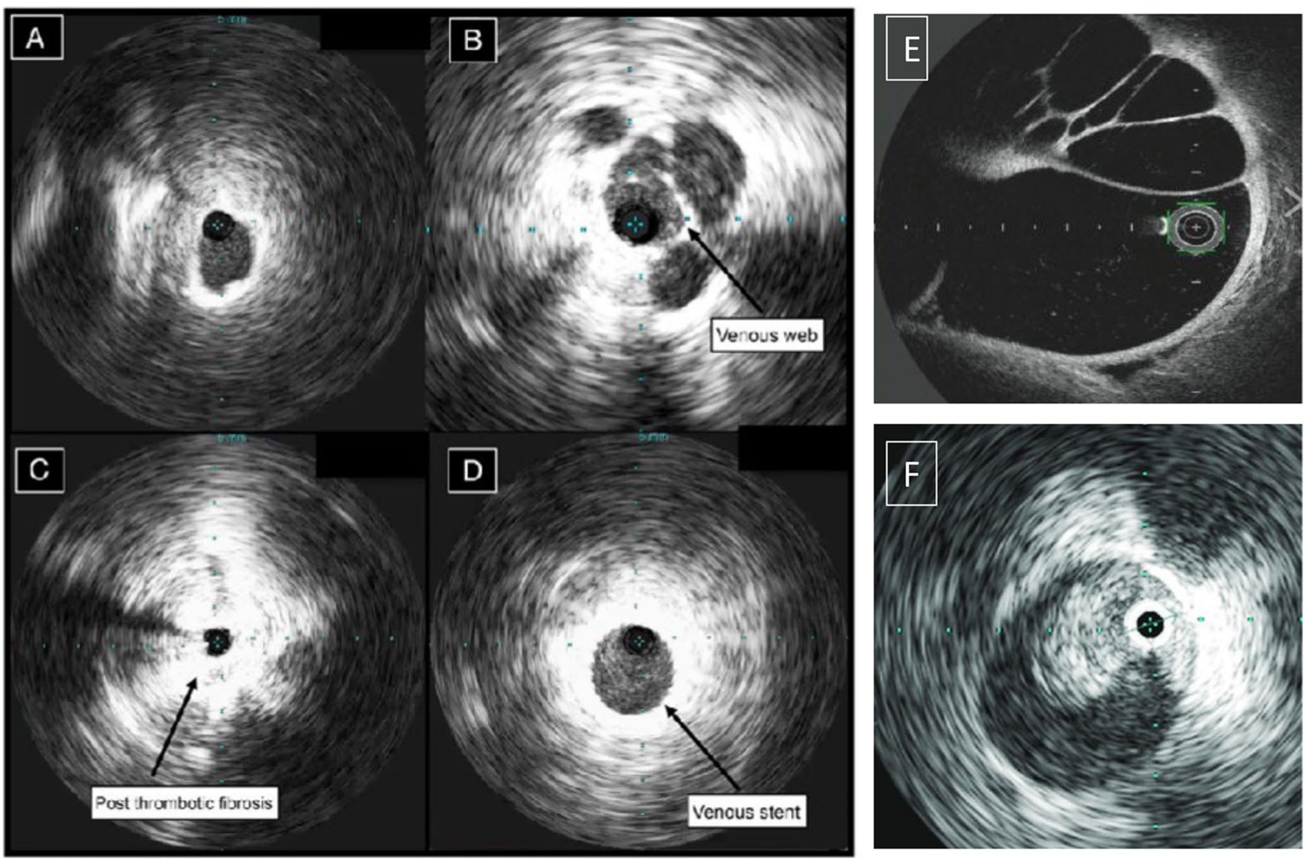


Fig. 8 IVUS. **A** Appearance of normal vein, **B** appearance of "webs" in a post-thrombotic vein, **C** occluded post-thrombotic venous segment, and **D** appearance of a venous stent in a previously occluded segment. **E** Venous trabeculations proximal to a chronic total occlusion of a CIV and **F** appearance of a chronic thrombus [13–16]

ity of a unilateral intervention is high. The status of bilateral iliac veins is needed for an ipsilateral intervention for multiple reasons: exact landmarking of the iliac confluence, direction of collateral flow, contralateral iliac vein sizing for reference, and the presence or absence of post-thrombotic abnormalities which affect overall stenting strategies, even if the contralateral limb is asymptomatic. Simultane-

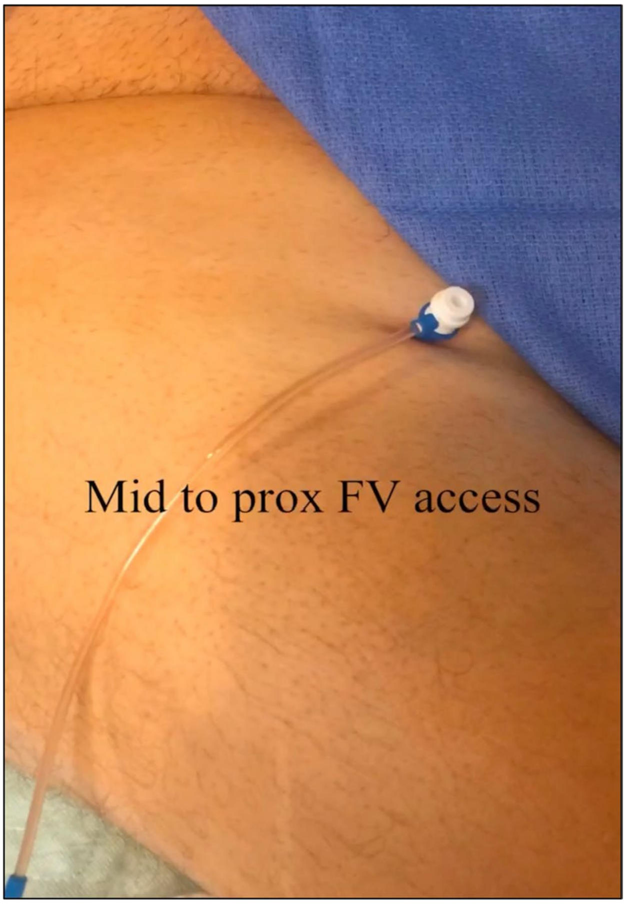


Fig. 9 If no significant disease is expected in the popliteal or femoral vein (FV), it is preferable to access the proximal FV rather than the CFV, in order to preserve the ability to extend a potential stent to the distal CFV above the venotomy site

ous bilateral venography is achieved from a single access by placing a smaller size (at least 5F) up-and-over catheter (Omni, Contra, or pigtail) across the iliac vein confluence, through a large bore ipsilateral sheath (at least 8F; Fig. 9). The injection rate should be 7–10 ml per s for a total of at least 20 ml on each side. If CO2 gas is being used, 25 ml should be injected on each side, over 2 s.

3- Perform bilateral baseline IVUS (8F Philips Volcano) over a 0.035″ wire. Since wire tips are usually out of the field of view, it is recommended to use J tipped non-polymer jacketed stiff wires (i.e., Amplatz extra-Stiff) to minimize the risk of wire-related perforations.

   a. If bilateral venous sheaths are in place, wire both iliac veins into the IVC and perform IVUS from each access site.
   b. If a single venous access is in place, exchange the up-and-over catheter over a stiff wire for an IVUS catheter. Pull back and record from the contralateral femoro-popliteal vein to the common iliac vein. It is important to know that the shape of the contralateral iliac veins and especially the venous confluence are significantly affected by the stiff wire bias. This needs to be taken into account in the interpretation of the sizing data. Based on the findings, the operator should make the decision whether to access the contralateral femoral or popliteal veins depending on the interventional strategy. Regardless, the up-and-over wire is pulled back and advanced into the IVC after imaging.

4- Major safety issue: Wire course. One must be extremely attentive to wire courses, especially after crossing chronic total occlusions. The wire may exit into small branches or collateral channels. Dilation of these vessels up to the estimated iliac vein size may result in a life-threatening catastrophic bleeding (one of the very rare complications of this procedure). This can be avoided by adequate interpretation of the IVUS findings but, in cases of significant negative architectural iliac vein remodeling, careful examination of the wire course along the expected iliac vasculature, by anteroposterior and lateral fluoroscopy, helps the identification of these situations (Fig. 10).

5- Distal wire tip position: It is recommended to place the distal tip in the innominate or subclavian veins. This not only minimizes wire-related ectopic heart beats or arrhythmias, but also preserves the ability to endovascularly salvage the rare case of stent embolization to the cardiac structures.

6- Important venous segment sizing by IVUS includes the most stenotic and reference surface areas. Of note, a significant stenosis in the deep veins is equal or above 50%. Venography is notoriously misleading with regard to the estimation of iliac vein stenosis (Fig. 1). Hemodynamic measurements are not reliable since hemodynamic significance can be as small as 2–3 mmHg and may change throughout the respiratory cycle.

7- IVUS advantages over venography include [7]: High sensitivity in detecting significant venous stenosis, very accurate venous sizing at rest and with Valsalva maneuver, clear evaluation of venous wall post-thrombotic and/or sclerotic changes, appropriate identification of stent landing zones, identification of the surrounding compressive anatomical structures, qualitative evaluation of the overall stent shape (circular vs. ovaloid) and areas of under-expansion, precise identification of the iliac vein confluence site and the takeoff of important branches like the deep femoral vein, adequate estimation of the extent of the initial and residual thrombotic burden which determines the possible need for retrievable IVC filter placement.

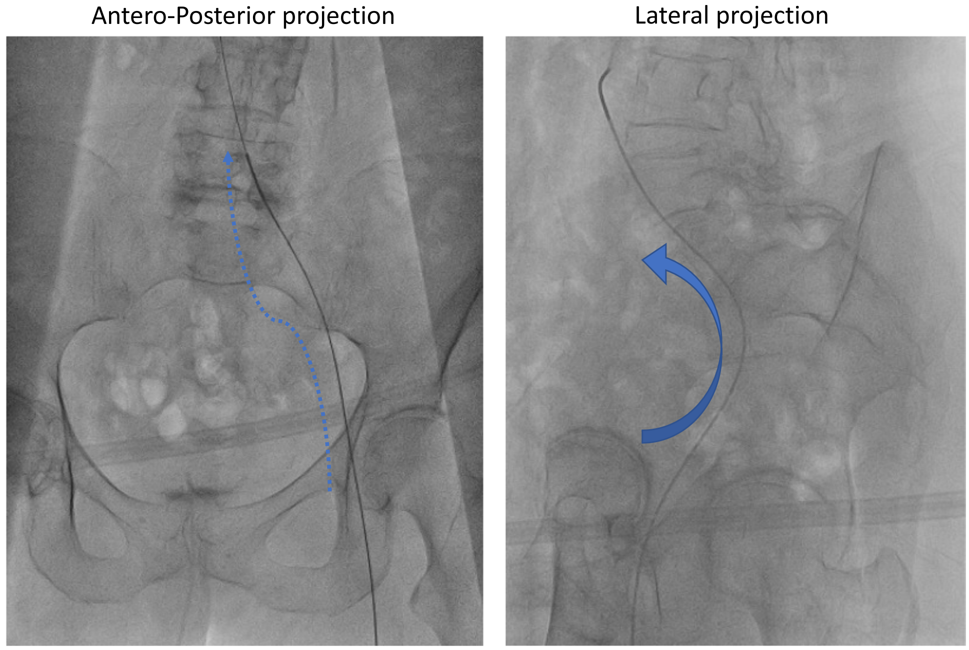
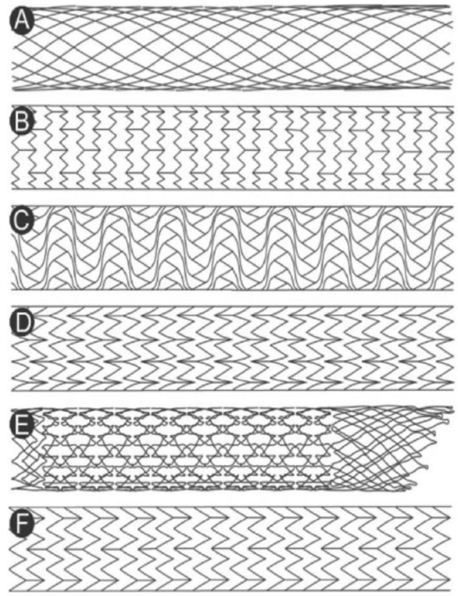


Fig. 10 When a chronic iliac venous occlusion is crossed and is too negatively remodeled and fibrosed to be distinguished from a collateral or lumbar branch, fluoroscopic evaluation of wire or catheter course in the lateral projection is important. A typical external iliac vein course dives into the pelvis. Alternative courses should make the operator re-evaluate the structures crossed by the wire

8- Pre-dilation with non-compliant balloons (i.e., BD Atlas), sized one to one to the average diameter of the reference iliac segment, is almost always necessary to ensure adequate expansion of the iliac vein before committing to metallic scaffold(s). Finding out about the lack of expansion of a stent at high pressure, after deployment, is a major technical mistake and should be avoided. Three specific situations are frequently encountered that require an alternative sizing strategy:

   a. Significant pre-stenotic ectasia: This is a frequent situation encountered in NIVL. Sizing stents according to this reference often result in significant stent oversizing which can result in severe chronic back pain and suboptimal slow flow dynamics leading to a conceptual predisposition to stent thrombosis. This would be a very difficult scenario, where there are no long-term therapeutic endovascular options available and which requires open surgical stent extraction.
   b. Venous size changes with Valsalva maneuver: If NIVL is diagnosed relatively early when venous compliance is still preserved, the iliac vein size can significantly increase with Valsalva maneuver. If this is not taken into account in the reasonable sizing of an iliac vein stent, it may lead to a catastrophic stent embolization to the heart. One should target sizing the stent to an average diameter of the iliac vein at baseline and with Valsalva maneuver. In intubated patients, this can be achieved with a transient increase in peak end-expiratory pressure PEEP up to 10 cm H2O.
   c. Diffuse post-thrombotic changes (Rokitansky lesions) (Fig. 2C) and negative remodeling in chronic total occlusions: There is no "normal" reference segment throughout the venous segment. Adequate estimation of original venous size would take into account adjacent iliac vein segments, if they are spared from similar post-thrombotic changes, or contralateral venous segments. One should also factor the patient's size into the decision-making process, as stent under- or over-sizing definitely has long-term consequences on the patient's outcomes and quality of life.

9- The choice of a dedicated venous stent depends on the treated iliac vein segment and the physical characteristics of the stent [12, 17] (Figs. 11 and 12). The clinical focus should be on crush resistance and radial force in the common iliac vein, on flexibility in the external iliac vein, and on stent fracture rate in the common femoral vein. Practically speaking, one must make decisions based on what is available on the shelf. The off label use of the Wall stent (Boston Scientific, Marlborough, MA) is still considered to be a good option in rare anatomical subsets: Large IVC (22 and 24 mm) or large differences in diameters of the proximal and distal stent landing zones. The absence of dedicated venous stents on the shelf could also be another reason to use wall stents. On a cautionary note, two dedicated venous stents have been recently recalled (VENOVO—BD, Franklin Lakes, NJ and Vici—Boston Scientific, Marlborough, MA) and technical issues are being addressed.



(A) Boston Scientific Wallstent (woven-mesh, closed cell, elgiloy i.e. like stainless steel)

(B) Cook Zilver Vena (open cell, laser cut nitinol)

(C) Boston Scientific Veniti Vici (closed cell, laser cut nitinol)

(D) Bard Venovo (open cell, laser cut nitinol)

(E) Optimed Sinus-Obliquus (hybrid: cephalad oblique, closed cell; caudal straight, open cell, laser cut nitinol)

(F) Medtronic Abre (open cell, laser cut nitinol)

Fig. 11 Venous stent schematic diagrams [12]

Venous stent	Radial force	Flexibility	Crush resistance	Accurate placement without foreshortening	Approval (EU/FDA)	Other comments
Boston Scientific Wallstent	++	++	++	Up to 40% foreshorting[24]	FDA	Braided construction A number of limitations:[24] – It may form a narrowed cone shape – It can migrate
Cook Zilver Vena	+	++	–	++ (accurate)	EU/FDA	–
Boston Scientific Veniti Vici	++	+	+	+	EU/FDA	–
Optimed Sinus Venous	++	++	–	+	EU	Independent ring system and flash links providing power and flexibility
Optimed Sinus XL Flex	++	+	–	++	EU	Available from 16 to 36 mm in diameter and from 3 to 10 cm in length so, can be used in IVC and SVC
Optimed Sinus Obliquus	+++[23]	++	–	+	EU	Hybrid design and bevelled cephalad end for the IVC confluence, to reduce protrusion into IVC
Bard Venovo	+	++	–	+ (minimal)	EU	–
Medtronic Abre	+	++	–	++	EU	Longest available stent currently on the market, up to 150 cm

CIV: common iliac vein; EU: European Union approval through the European Medicines Agency; FDA: Food and Drug Administration approval in the United States; IVC: inferior vena cava; SVC: superior vena cava; +++: severe; ++: moderate; +: mild; –: none.

Fig. 12 Physical characteristic of most venous stents [17]

10- Advantages of dedicated iliac vein stents include precise deployment and negligible foreshortening, which overcome the major downsides of the wall stent. This allows for minimal stent protrusion in the IVC and prevents jailing of the contralateral common iliac vein, which is associated with a higher risk of contralateral DVT [18]. However, they lack the ability to be “re-captured” in their delivery systems in order to be re-deployed (whereas the wall stent can be re-captured before reaching the distal stent marker which indicates the “point of no return” for re-sheathing the stent).

Fig. 13 Bilateral iliac venography from bilateral popliteal vein access sites. Note the complete flattening of the right CIV behind the spinal hardware (black arrows) and the bilateral severe angiographic stenoses throughout both CIV and EIV due to post-thrombotic changes

stent from the least diseased inflow to the least diseased outflow, in order to optimize flow dynamics and long-term stent outcomes. In the majority of cases, this is achieved by landing stents above the common femoral vein bifurcation; however, if the femoral vein is severely diseased and the inflow cannot be optimized with balloon angioplasty, it may be necessary to extend the stent into the proximal deep femoral vein [13].

Case Example 1: Severely Symptomatic Non-thrombotic Iliac Vein Lesion

A 42-year-old woman presented with severe lifestyle limiting venous claudication symptoms which had progressively worsened after lumbar spine surgery and had not improved with conservative therapy. She had CEAP 4 venous insufficiency signs bilaterally and clear signs of venous hypertension from the thighs down. An infrainguinal duplex venous ultrasound ruled out DVT and significant superficial venous reflux. Figure 13 shows bilateral iliac venography from bilateral popliteal vein access sites. Figure 14 shows the IVUS findings of both common iliac veins.

The choice of VENOVO nitinol stent sizes was made based on the following data: The reference right CIV segment measured 12.5 × 20.1 mm with an average diameter of 16.3 mm and the reference left CIV measured 10.9 × 15.2 mm with an average of 13 mm. Taking into account the size of the IVC (17.9 × 10.3 mm), and the fact

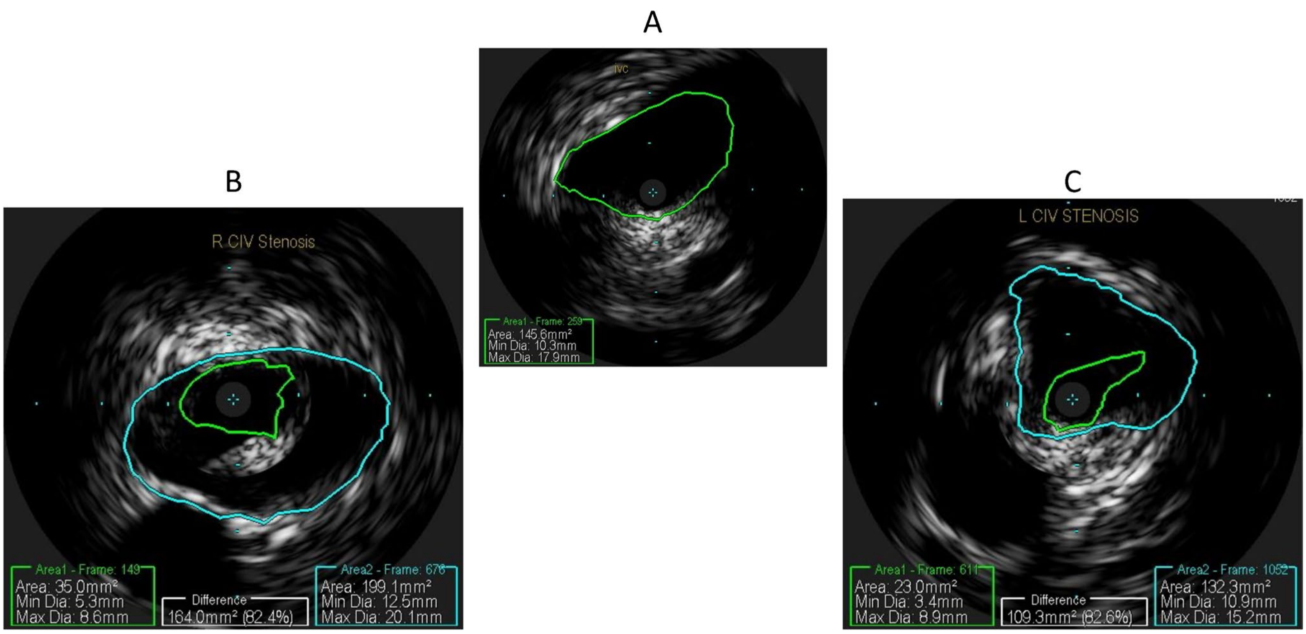


Fig. 14 IVUS of the IVC in which dimensions are taken into account in the choice of stent sizes to reconstruct the iliac vein confluence (**A**), right CIV stenosis relative to reference segment (**B**), and left CIV stenosis relative to reference segment (**C**)

From a procedural standpoint, it is important to save fluoroscopic landmarks corresponding to adequate IVUS landing zones in order to ensure complete coverage of the diseased area in order to minimize the risk of stent restenosis and thrombosis. It is also absolutely necessary to

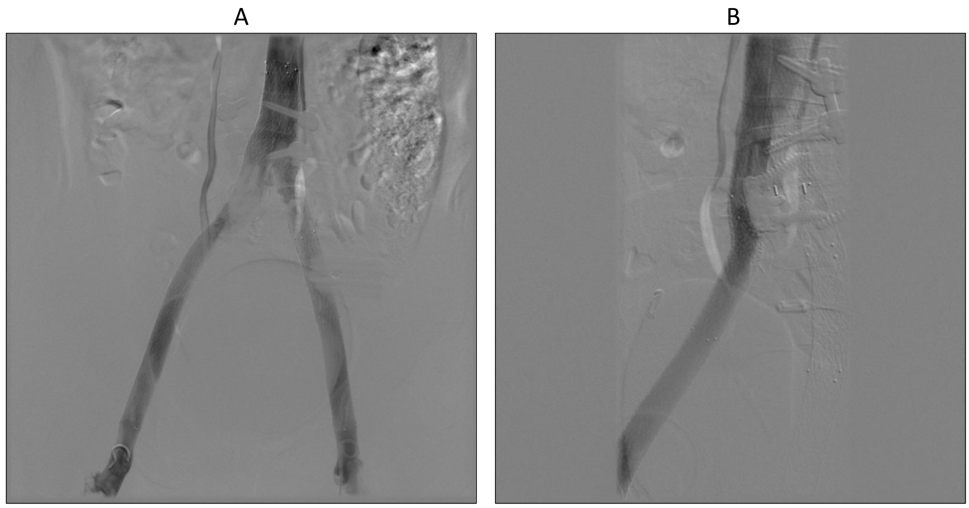


Fig. 15 **A** Venography after iliofemoral stenting reconstruction of the iliac vein confluence. **B** Extreme right anterior oblique projection to overcome the imaging artifact caused by the plate in the spinal hardware

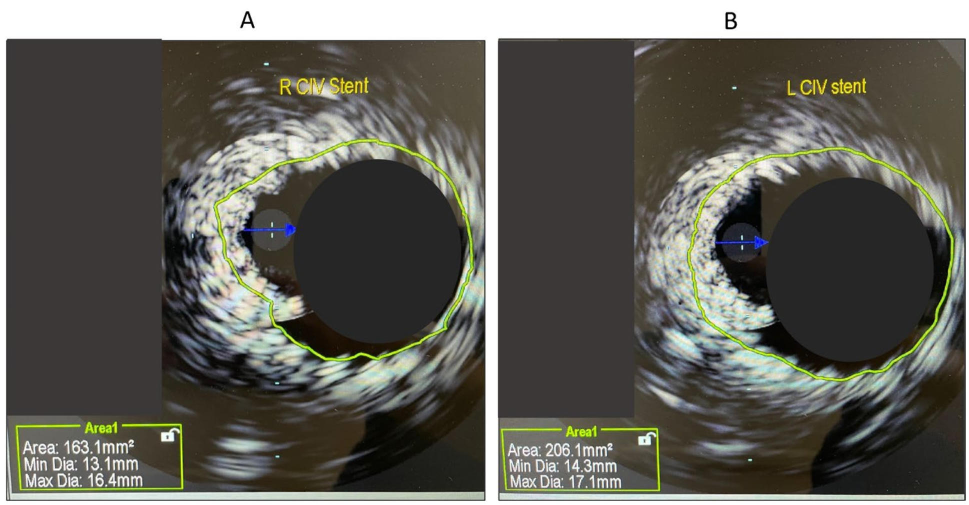


Fig. 16 IVUS of both CIV stents after dilation

that this was a small woman who already struggles from chronic back pain, the presence of 3-mm flairs on the edges of the VENOVO stent and the fact that the stents would be placed in a double barrel configuration, a 16-mm stent was found to be appropriate for the right CIV and a 14-mm stent in the L CIV with a very low overall risk of stent embolization. The lengths of both stents were 160 mm, since the stenosis and post-thrombotic abnormalities extended throughout both EIV(s) and CFV(s). Both stents were deployed slowly and simultaneously to avoid mutual stent compression. This was followed by a kissing balloon angioplasty with a 16 × 40-mm non-compliant Atlas balloon in the right CIV and a 14 × 40-mm Atlas balloon in the left CIV.

Since the right EIV was diffusely severely diseased without a relatively normal surface area and since the landing zone in the right CFV measured 8.3 × 16.9 mm with an average of 12.6 mm, we chose a 14-mm stent which overlapped the CIV stent by 20 mm. Based on the IVUS catheter markers, we estimated that the distance from stent edge to the caudal landing zone above the profunda vein takeoff was 100 mm. As such, we picked a 14 × 120-mm VENOVO stent which was deployed from the proximal right EIV to the mid-right CFV and then post-dilated the stent with a 14 × 40-mm Atlas balloon.

The left EIV had a diffuse severe stenosis without an adequate reference area but the landing zone in the left CFV measured 10.8 × 21 mm (15.9 mm average). These data in addition to the patient's small size, female gender, the necessity to overlap with a 14-mm stent in the CIV, and the presence of 3-mm edge flairs on the VENOVO stent led us to pick a 14-mm-diameter stent for the left EIV and CFV with a length of 160 mm based on the correlation of IVUS landing zones and IVUS catheter markers.

Fig. 15A shows bilateral venography after bilateral iliofemoral vein reconstruction. Figure 15B shows an extreme right anterior oblique projection to show the venous segment behind the spinal plate causing an artifact obscuring the vein behind it on the anteroposterior projection.

Figure 16 shows IVUS images of both CIV stents after post-dilation.

Case Example 2: Subacute Iliofemoral DVT Presenting with Phlegmasia Cerulea Dolens

A 62-year-old female presented with subacute disabling right leg swelling and pain starting the last 11 days. Her exam revealed typical findings of phlegmasia cerulea dolens. Duplex venous ultrasound revealed acute/subacute extensive occlusive thrombosis of the entire infrainguinal right lower extremity deep venous system. She also had chronic renal insufficiency with a creatinine of 3.3.

Due to the high thrombotic burden and severe comorbidities including low cardio-pulmonary reserve, a retrievable IVC filter (Cook Celect) was placed from a left CFV access, in a supine position, with the guidance of CO2 gas venography and IVUS (Fig. 17).

The patient was then placed in a prone position, and right popliteal venous access (11F sheath) was obtained. We decided to proceed with pharmaco-mechanical thrombectomy after CO2 venography revealed an occlusion of the supra-popliteal deep venous system (Fig. 18). An 0.035-in. stiff angled glide wire was used to cross into the IVC, and a 40-cm 4F infusion catheter was placed in the right iliofemoral segment. Eight milligrams of Alteplase was injected at high manual pressure and was left to disseminate in the clot for 20 min. We then proceeded with iliofemoral mechanical aspiration thrombectomy (CAT12-Penumbra) (Fig. 19).

IVUS was then performed for adequate balloon/stent sizing (Fig. 20) and for fluoroscopic correlation of stent landing zones (Fig. 21). Based on these measurements, the femoropopliteal segments were pre-dilated with a 12×40 semi-compliant balloon (Mustang—Boston Scientific). The Iliac veins and CFV were pre-dilated with a 16×40-mm non-compliant balloon (Atlas—BD) with good expansion.

Since a 160-mm stent was picked to cover the entirety of the diseased segments and the landing zone in the right CFV measured 14.8×17.9 mm (16.35 mm), we chose a 16-mm stent, taking into consideration that this is a woman with small body habitus and the VENOVO stent (BD) had a 3-mm edge flair which allows for one to one sizing with a lower theoretical risk of stent embolization. This 16×160-mm stent was overlapped caudally with a 16×80-mm VENOVO stent with a 30-mm overlap that was precisely landed above the deep femoral vein takeoff as identified by IVUS (Fig. 22). Final IVUS (Fig. 23) and CO2 venography (Fig. 24) revealed a good result with fast runoff and adequate stent expansion, shape, and surface areas.

No iodinated contrast was used during the procedure which preserved the patient's renal function. The patient was able to walk on the same day and recovered well with complete resolution of the pain and severe swelling within 1 week.

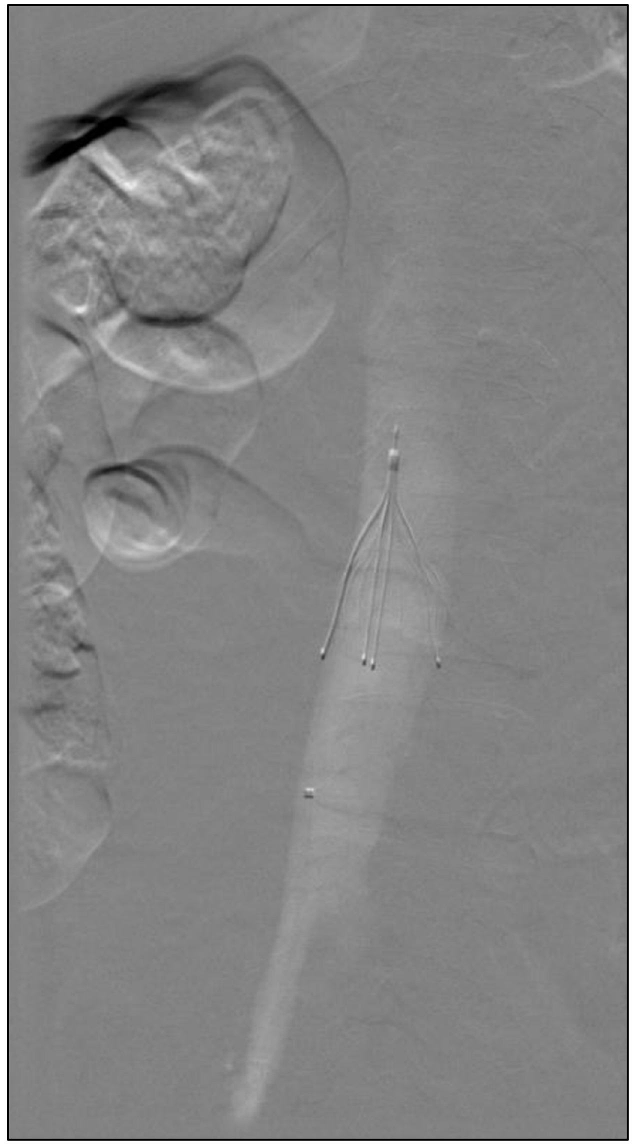


Fig. 17 IVC venography with CO2 gas after placement of a retrievable IVC filter (Cook Celect) due to the very high thrombotic burden and low cardio-pulmonary reserve of the patient

Conclusion

According to the most contemporary practices and data [6, 7], we posit that IVUS should be mandatory in deep venous diagnostic and/or interventional procedures. Venography easily misses major anatomical abnormalities and frequently underestimates iliac vein sizing; however, venography must still be routinely performed (with either iodinated contrast or CO2) in deep venous interventions due to the complimentary information that it provides regarding flow characteristics, not detectable by IVUS. In summary, IVUS and venography are complimentary and not mutually exclusive.

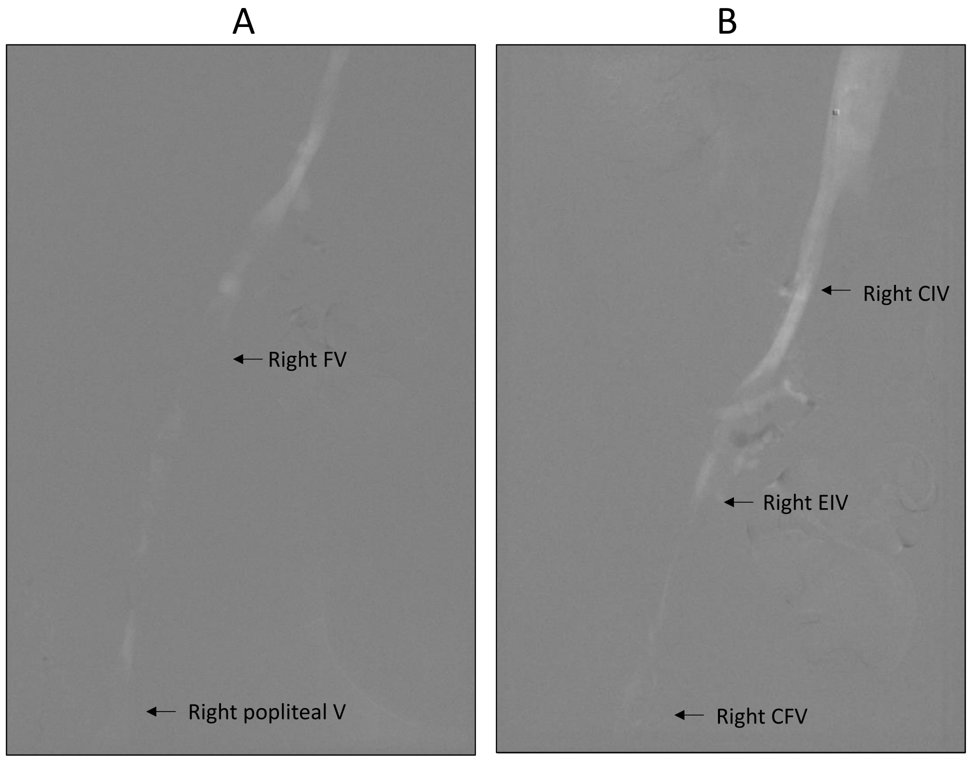


Fig. 18 CO2 venography showing the very large occlusive thrombotic burden extending throughout the entire supra-popliteal deep venous system

Fig. 19 Mechanical aspiration thrombectomy with Penumbra CAT12 device from the right popliteal vein up to the right EIV/CIV

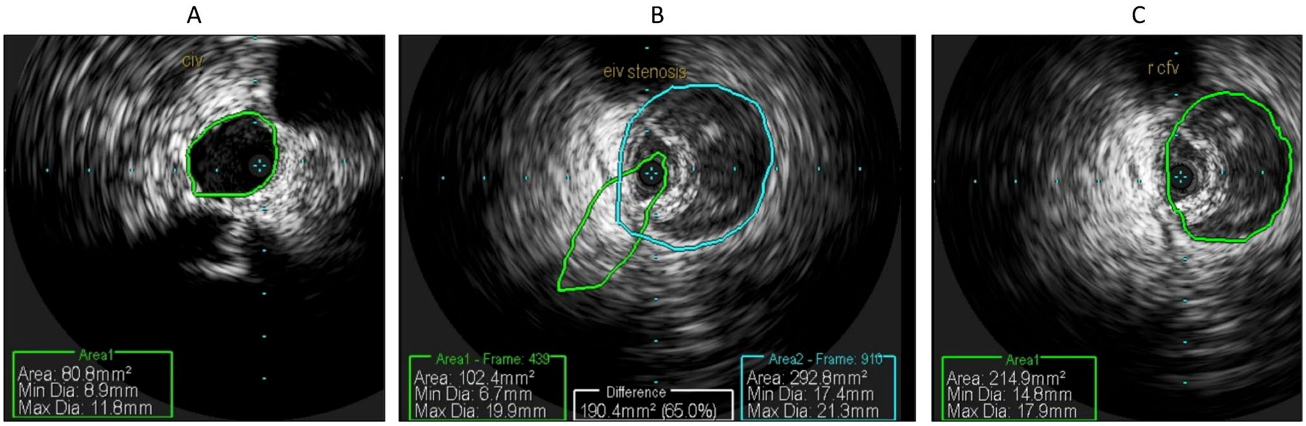


Fig. 20 **A** Right CIV IVUS findings before treatment, showing a typical Rokitansky lesion. **B** Severe right EIV stenosis. **C** Large occlusive thrombotic burden in the right CFV

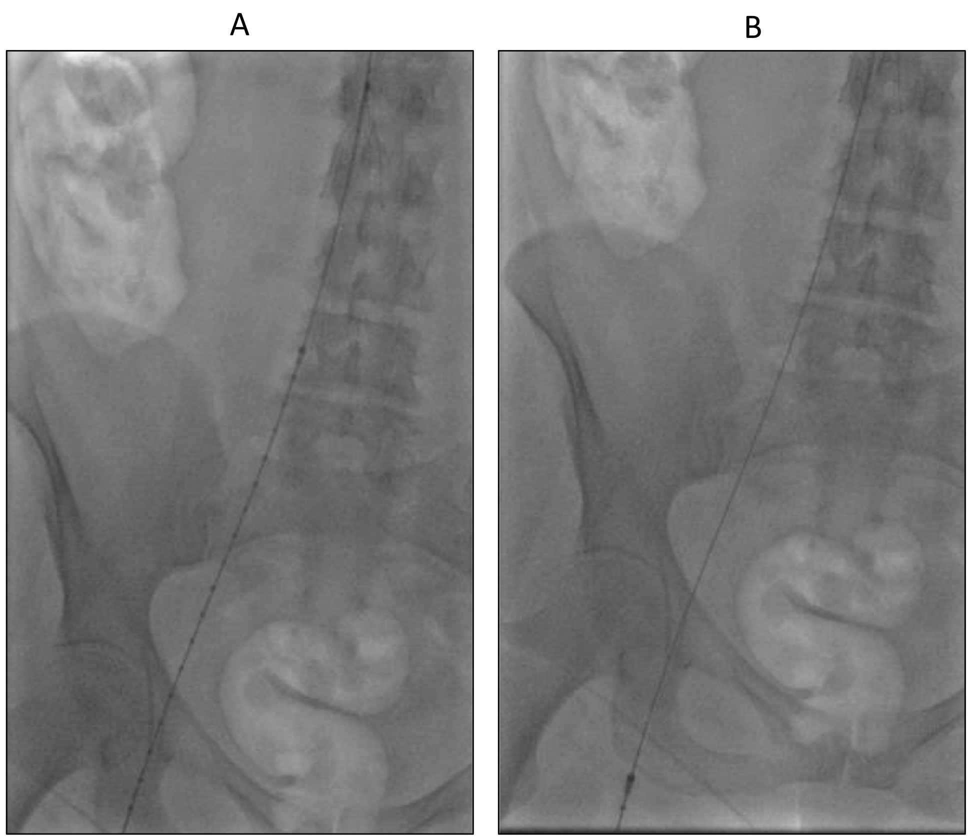


Fig. 21 Fluoroscopic landmarks of landing zones at the inflow (**A**) and outflow (**B**) based on correlation with live IVUS findings

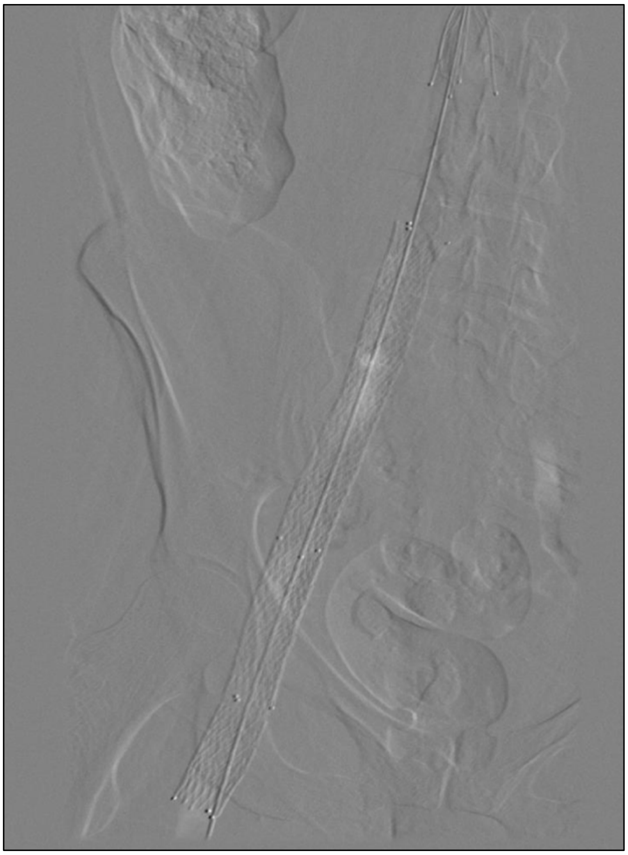


Fig. 22 Dry fluoroscopy outlining the layout of the CFV, EIV, and CIV stents with appropriate overlap

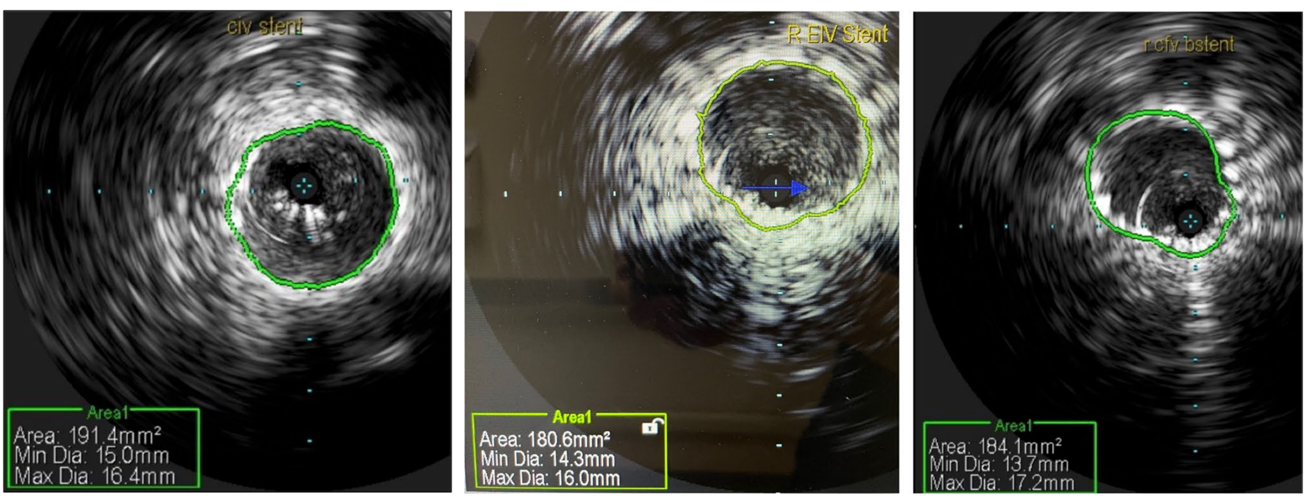


Fig. 23 Satisfactory IVUS findings of CIV, EIV, and CFV stents after high pressure dilation

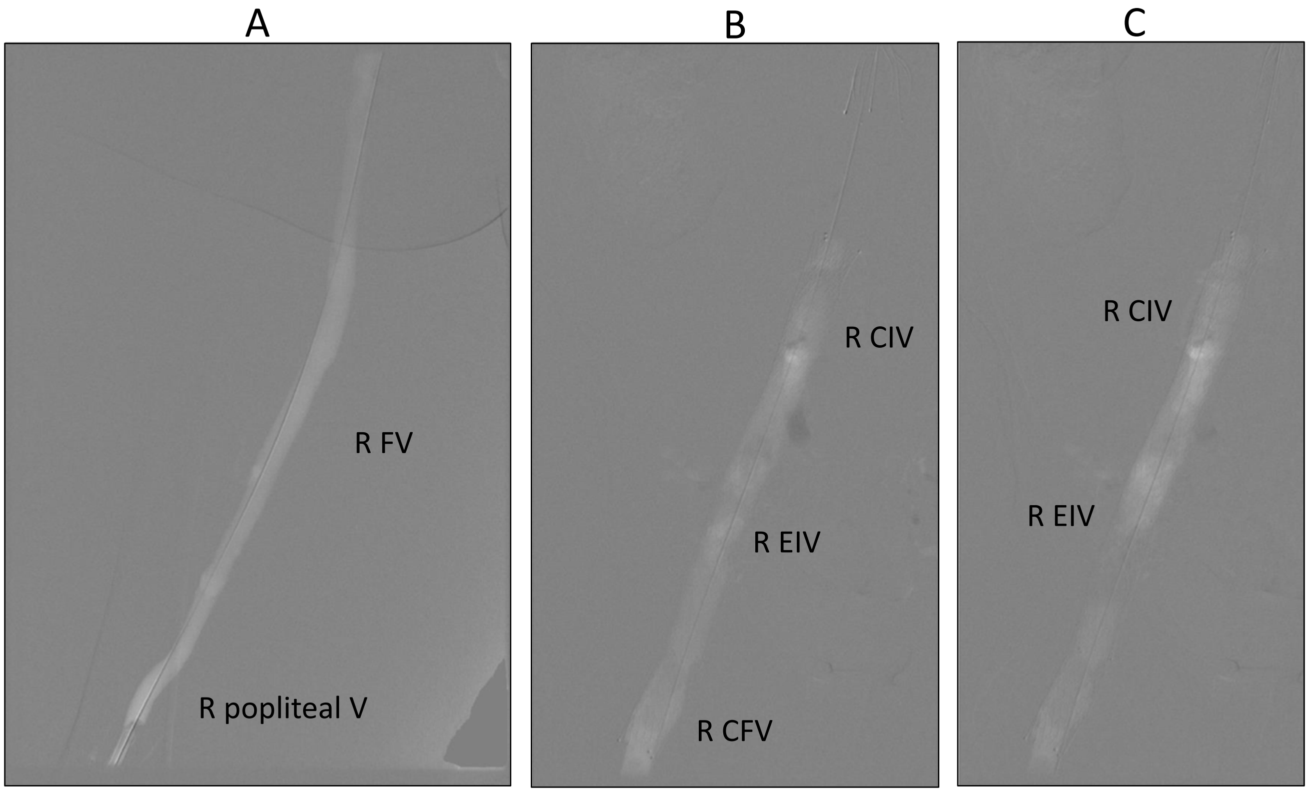


Fig. 24 Final CO2 venography of the inflow and outflow showing good angiographic results and proving that a complex lower extremity deep venous intervention can be performed with zero contrast medium

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