

## Defining the utility of anteroposterior venography in the diagnosis of venous iliofemoral obstruction



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### ABSTRACT

**Background:** Intravascular ultrasound (IVUS) is the current standard for the diagnosis of obstruction in the iliac and femoral veins. However, multiple venographic findings including collaterals, pancaking, and contrast thinning have been suggested to improve the sensitivity of venography. The objective of our study was to further elucidate where and how anteroposterior venography may successfully guide the diagnosis of venous obstruction.

**Methods:** A retrospective review of patients with chronic venous insufficiency who received iliofemoral stenting by a single practitioner at a tertiary medical center between January 2014 and August 2016 was performed. Patients who had records of anteroposterior venography and IVUS were included. Patients who underwent reoperation, did not have complete records of venography and IVUS, or had preoperative acute deep vein thrombosis were excluded. All patients with a greater than 50% luminal area reduction by IVUS underwent balloon angioplasty and stent placement. The locations of stenosis, collaterals, pancaking, and contrast thinning with venography, the locations of stenosis with IVUS, and the location of each stent placed were recorded.

**Results:** There were 107 patients who underwent venous stenting guided by venography and IVUS in this study. Six patients who underwent reoperation, 1 patient who had an acute preoperative deep vein thrombosis, and 14 patients who had incomplete records were excluded. Thus, 86 patients with 77 left lower extremity and 68 right lower extremity studies were available for analysis. The sensitivity by stenosis on venography was 4% in the left common iliac vein (CIV), 44% in the left external iliac vein (EIV), and 44% in the common femoral vein (CFV). The sensitivity by stenosis on venography in the right CIV, EIV, and CFV was 21%, 46%, and 40%, respectively. Combined, pancaking and collaterals had a sensitivity of 97% in the left CIV. IVUS resulted in a change in plan in 2%, 32%, and 48% of patients in the left CIV, EIV, and CFV, and in 26%, 35%, and 48% of patients in the right CIV, EIV, and CFV, respectively.

**Conclusions:** Anteroposterior venography can indirectly diagnose obstruction of the left CIV through the identification of collaterals and pancaking. The combination of low sensitivity and a high rate of change of plan owing to IVUS precludes complete reliance on anteroposterior venography for the diagnosis of lesions in the left EIV and CFV and the right CIV, EIV, and CFV. IVUS must be used to comprehensively identify all venous iliofemoral lesions. (J Vasc Surg: Venous and Lym Dis 2019;7:514-21.)

**Keywords:** Intravascular ultrasound; Stenting; Venous; Venography; Chronic venous insufficiency

The management of chronic venous insufficiency (CVI) has undergone a complete shift over the past two decades. Historically, surgical options were limited to the Palma procedure, or cross-pubic venous bypass,

and femorocaval or iliocaval bypass.<sup>1-6</sup> In the late 1990s, select practices began to use stenting for proximal lower extremity venous outflow obstruction.<sup>7,8</sup> Since the initial reports by Forauer and Raju and Neglen in 2002, numerous groups have reported excellent clinical outcomes and patency after iliofemoral stenting.<sup>9-16</sup>

Neglen et al<sup>17</sup> in 2002 reported that stenosis on anteroposterior venography had a 45% sensitivity in the detection of lesions as compared with intravascular ultrasound (IVUS). Indeed, subsequent studies have confirmed that stenosis on venography has a sensitivity for venous obstruction ranging from 23% to 50% when compared with IVUS.<sup>18-21</sup> Interestingly, Gagne et al,<sup>18</sup> the only series in the literature to use multiplanar venography, reported a sensitivity of 53%. Raju et al<sup>22</sup> reported a sensitivity of 63% with the combination of pancaking, contrast thinning, collaterals, and stenosis on anteroposterior venography. Other studies have reported a sensitivity by collaterals on anteroposterior venography of 28%

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to 71%.<sup>17,20-22</sup> However, the aforementioned studies grouped common iliac vein (CIV), external iliac vein (EIV), and in some cases common femoral vein (CFV) lesions together. The literature suggests three concepts. First, indirect findings of venous obstruction including collaterals, pancaking, and contrast thinning yield a higher sensitivity. Second, some anatomic vein segments may have a higher sensitivity with anteroposterior venography than others. Third, using multiple obliques intraoperatively may have a limited ability to improve the sensitivity of venography. The objective of our study was to clarify the ability of anteroposterior venography with the presence of stenosis, collaterals, pancaking, and contrast thinning to diagnose obstruction in the CIV, EIV, and CFV.

## METHODS

**Patient population.** A retrospective review was performed for patients with Clinical condition, Etiology, Anatomy, Pathophysiology (CEAP) class 2 through 6 who underwent stent placement for chronic proximal venous outflow obstruction in the iliac vein and CFV from January 2014 to August 2016 by the senior author (W.T.), at a single tertiary medical center. The majority of Dr Ting's practice is dedicated to patients with CVI, and he has developed a prospectively maintained retrospective database. Although other practitioners at our institution do perform venous stenting, it comprises a small minority of their respective practices. To eliminate variability in operative technique as a limitation to our study, the decision was made to only include Dr Ting's patients. Exclusion criteria included reoperation, immediate history of an acute deep vein thrombosis (DVT), and incomplete records of IVUS or venography. Approval was obtained from the Institutional Review Board of the Icahn School of Medicine at Mount Sinai. Prospective informed consent was waived because of the retrospective nature of the analysis. Preoperative demographic data were collected and included age, gender, history of DVT, and CEAP score. Intraoperative data collected included intraoperative evidence of DVT, the location with venography of stenosis, the location with IVUS of stenosis, and the location of stent placement. Venographic evidence of DVT was an occluded vein or a diffuse rather than focal narrowing across a large proportion of a specific vein (eg, EIV).<sup>23</sup> Evidence of DVT with IVUS included a diffuse rather than focal narrowing, wall thickening, or intraluminal echogenic material.<sup>23</sup> Diameter reduction on anteroposterior venography was determined subjectively by comparing the stenosed segment with a proximal or distal normal segment. A significant stenosis was considered to be a 50% diameter reduction. Intraoperatively, the luminal area reduction was always calculated with the equation  $1 - SA/NA$  where SA was the luminal area at the stenosis and NA was the luminal area of a normal proximal or distal vein segment to determine the indication for stenting. However, these

## ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective cohort study
- **Key Findings:** In 86 patients with 77 left lower extremity and 68 right lower extremity imaging studies sensitivity of determining venous stenosis with anteroposterior venography findings of combined venous pancaking and collaterals compared with intravascular ultrasound (IVUS) was 97% for the left common iliac vein (CIV), but IVUS changed clinical plans in 2%, 32% and 48% for the left CIV, left external iliac vein (EIV), and left common femoral vein (CFV) respectively and 26%, 35% and 48% for the right CIV, EIV and CFVs.
- **Take Home Message:** The study suggests that anteroposterior venographic findings of combined pancaking and collaterals can diagnose left CIV obstruction but is insufficient for diagnosing venous obstruction in the left EIV, left CFV and in the right CIV, EIV and CFVs.

measurements were not reliably saved in the medical image record system. Thus, luminal area reduction with IVUS was determined by viewing the recording loops of IVUS and subjectively comparing the stenosed segment with a proximal or distal normal segment. A significant stenosis was considered to be a 50% luminal area reduction. The stenoses on IVUS were then confirmed with the operative report, which documented stenoses found to have a greater than 50% luminal area reduction. Locations included the CIV, EIV, internal iliac vein (IIV), and CFV. In addition, the location of indirect evidence of obstruction, including the presence of collaterals, the presence of dilation, or "pancaking," and contrast thinning was recorded (Supplementary Figs 1-3, online only). Patients with collaterals originating from the CIV, EIV, and IIV were coded as having CIV lesions. The rationale was that a CIV lesion would result in the formation of collateral flow distal to the obstruction to facilitate a path of lesser resistance to the more proximal IVC. Using the same rationale, patients with collaterals originating from the CFV were coded as having EIV lesions. Because our focus was to determine the correlation of collaterals to the location of more proximal venous lesions, data for the course of the collaterals (eg, translumbar, axial) and the number of collaterals for a given vein segment were not collected. A vein was considered to have pancaking if there was an increase in the diameter relative to either the proximal or distal normal segments of the unilateral venous outflow tract. No quantitative scoring system was used in the characterization of collaterals or pancaking.

**Clinical assessment.** Patients with a history of venous claudication—defined as lower extremity pain exacerbated with ambulation or extended periods of standing

that is relieved with elevation and rest—and with CEAP class 2 through 6 on physical examination were evaluated with lower extremity venous duplex ultrasound examination and magnetic resonance venography of the abdomen and pelvis. Ankle brachial indices were obtained when indicated by nonpalpable pedal pulses or other evidence of peripheral arterial disease.

**Indications for venography, IVUS, and stenting.** All patients received conservative management with compression stockings and elevation. While undergoing conservative management, each patient was offered venography and IVUS with possible stenting if there was failure of conservative management and evidence of deep venous disease. Stenting was performed intraoperatively when there was a greater than 50% decrease in luminal area as measured with IVUS.

**Interventional technique.** The patient was placed in the supine position and provided monitored anesthesia care. Access to the femoral, common femoral, or great saphenous vein was obtained under ultrasound guidance. Systemic anticoagulation was performed with intravenous heparin. Iliofemoral venography was performed in the anteroposterior projection with hand injections of 10 mL of full contrast through the sheath and with the table at the level position. Depending on availability, either an endovascular suite with fixed imaging or a mobile fluoroscopic unit was used. No Valsalva or other provocative maneuvers were performed routinely. Before performing venography, the sheath tip was withdrawn distally to the level of the femoral head. After venography was performed, a Volcano 9F Visions PV 0.035 IVUS catheter (Philips, San Diego, Calif) was advanced to the level of the right atrium and a recording was performed. IVUS was used to determine the proximal and distal extent of lesions and to guide Wallstent (Boston Scientific, Marlborough, Mass) placement. Men received 18-mm stents in the CIV and 16-mm stents in the EIV and CFV. Women received 16-mm stents in the CIV, EIV, and CFV. The 16-mm and 18-mm XXL balloons (Boston Scientific) were used for postplacement dilation in women and men, respectively.

**Postoperative care and anticoagulation.** Patients were prescribed anticoagulation with rivaroxaban 10 mg once daily after surgery and then transitioned to aspirin 81 mg once daily during the follow-up period. Follow-up was performed at 1, 3, 6, and 12 months and then every 6 months.

**Statistics.** The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated at each anatomic location for venographic stenosis, collaterals, pancaking, and combinations of the markers of obstruction as compared with IVUS. A true positive (TP) referred to venographic evidence of obstruction with concurrent stenosis on IVUS. A false

positive (FP) referred to venographic evidence of obstruction without concurrent stenosis on IVUS. A true negative (TN) referred to an absence of venographic evidence of obstruction with no evidence of stenosis on IVUS. A false negative (FN) referred to an absence of venographic evidence of obstruction with evidence of stenosis on IVUS. IVUS was considered to have changed the operative plan if there was a lesion demonstrated on IVUS that was not demonstrated with anteroposterior venography for a given anatomic segment that received stenting.

## RESULTS

**Patient population.** During the study period, 444 patients underwent venous stenting. We retrospectively reviewed 107 patients who received both intraoperative venography and IVUS. Six patients undergoing reoperation, 1 patient with an acute preoperative DVT, and 14 patients with incomplete records were excluded; a total of 86 patients were included in the final analysis. The demographic information including mean age, percentage of patients with post-thrombotic syndrome, and CEAP class distribution are listed in [Table I](#).

**Distributions of lesions.** There were 77 left lower extremity and 68 right lower extremity studies available for analysis ([Table II](#)). Bilateral studies were performed in 59 patients. Isolated left CIV lesions were present in 22 of the 77 patients (28%).

**Individual venographic findings in isolation.** [Supplementary Table I](#) (online only) lists the numbers of TPs, FPs, TNs, and FNs used to calculate the sensitivity, specificity, PPV, and NPV of each venographic finding in isolation. The findings of stenosis in isolation on venography are listed in [Table III](#). There were two complete occlusions discovered, both of which were in the left CIV. The findings of collaterals in isolation on venography are listed in [Table III](#). The PPV for left CIV lesions of 93% was calculated from 40 TPs and 3 FPs (40/43 [93%]). Of the 77 patients, 44 (57%) had one or more collaterals in the left

**Table I.** Demographic data (N = 86)

Variable	
Age, years	60.8 ± 1.4 [58.0, 63.8]
Female gender	64.0 (55/86)
Post-thrombotic	43.0 (37/86)
CEAP classification	
C <sub>2</sub>	2.3 (2/86)
C <sub>3</sub>	55.8 (48/86)
C <sub>4</sub>	24.4 (21/86)
C <sub>5</sub>	5.8 (5/86)
C <sub>6</sub>	11.6 (10/86)

CEAP, Clinical condition, Etiology, Anatomy, Pathophysiology.  
Data are presented as mean ± standard deviation [95% confidence interval] or percent (n/N).

**Table II.** Distribution of obstruction as characterized by intravascular ultrasound (IVUS)

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
With lesion, % (n/N)	90.9 (70/77)	67.5 (52/77)	35.1 (27/77)	55.9 (38/68)	82.4 (56/68)	39.7 (27/68)

*CIV, Common iliac vein; EIV, external iliac vein.*

CIV, IIV, EIV, and CFV. The PPV for right CIV lesions of 68% was calculated from 13 TPs and 6 FPs (13/19 [68%]). Of the 68 patients, 21 (30%) had one or more collaterals in the right CIV, IIV, EIV, and CFV. The findings of pancaking in isolation are listed in Table III. The findings of contrast thinning in isolation on venography are listed in Table III.

**Combined venographic findings.** Supplementary Table II (online only) lists the numbers of TPs, FPs, TNs, and FNs used to calculate the sensitivity, specificity, PPV, and NPV of the different combinations of venographic findings. The findings of the combination of stenosis and collaterals, the combination of stenosis and pancaking, the combination of collaterals and pancaking, and the combination of stenosis, collaterals, and pancaking are listed in Table IV.

**Intervention data.** The percentage and number of patients whose lesions were not identified with venography but were identified with IVUS and who then received stents as guided by IVUS are listed in Table V.

## DISCUSSION

The need for our study derived from the well-documented decreased sensitivity with stenosis in isolation on venography as compared with the standard of IVUS.<sup>17-22</sup> The history of this comparison began with Neglen and Raju in 2002.<sup>17</sup> These investigators first documented the eccentric mechanism of compression in venous lesions with their discovery that the actual area of venous cross-sections in a stenosis was less than the cross-sectional area calculated with the maximum diameter with IVUS in the majority of patients. With its direct visualization of the lumen, IVUS became the de facto standard for the characterization of the highly morphologically variable stenoses found in the venous outflow tract. Indeed, Gagne et al<sup>18</sup> even documented that, in the 57 patients in their trial who had the plan changed because of IVUS, 3 of those patients with significant lesions found on venography had no stent placed on the basis of IVUS. The eccentric nature of venous lesions also explains why stenosis must be measured differently

**Table III.** Venographic characterization of obstruction by stenosis, collaterals, pancaking, and thinning in isolation

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
Stenosis in isolation on venography compared with IVUS						
Sensitivity	4.29	44.2	44.4	21.1	46.4	40.7
Specificity	100.00	100.0	100.0	100.0	100.0	100.0
PPV	100.00	100.0	100.0	100.0	100.0	100.0
NPV	4.29	46.3	76.9	50.0	28.6	71.9
Collaterals in isolation on venography compared with IVUS						
Sensitivity	57.1	1.9	–	34.2	5.4	–
Specificity	57.1	100.0	–	80.0	100.0	–
PPV	93.0	100.0	–	68.4	100.0	–
NPV	11.8	32.9	–	49.0	18.5	–
Pancaking in isolation on venography compared with IVUS						
Sensitivity	87.1	11.5	3.7	36.8	1.8	11.1
Specificity	57.1	84.0	88.0	73.3	91.7	95.1
PPV	95.3	60.0	14.3	63.6	50.0	60.0
NPV	30.8	31.3	62.9	47.8	16.7	61.9
Thinning in isolation on venography compared with IVUS						
Sensitivity	92.9	65.4	50.0	81.6	55.4	51.9
Specificity	0.0	64.0	62.0	30.0	58.3	58.5
PPV	90.3	79.1	40.6	59.6	86.1	45.2
NPV	0.0	47.1	70.5	56.3	21.9	64.9

*CIV, Common iliac vein; EIV, external iliac vein; IVUS, intravascular ultrasound; NPV, negative predictive value; PPV, positive predictive value. Data are presented as percentages.*

**Table IV.** Venographic characterization of obstruction by combinations of stenosis, collaterals, and pancaking

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
Stenosis and collaterals on venography compared with IVUS						
Sensitivity	58.6	55.8	44.4	52.6	53.6	37.0
Specificity	57.1	72.0	100.0	80.0	91.7	100.0
PPV	93.2	80.6	100.0	76.9	96.8	100.0
NPV	12.1	43.9	76.9	57.1	29.7	70.7
Stenosis and pancaking on venography compared with IVUS						
Sensitivity	87.1	46.2	48.1	50.0	48.2	48.1
Specificity	57.1	88.0	76.0	73.3	91.7	78.0
PPV	95.3	88.9	52.0	70.4	96.4	59.1
NPV	30.8	44.0	73.1	53.7	27.5	69.6
Collaterals and pancaking on venography compared with IVUS						
Sensitivity	97.1	36.5	3.7	55.3	19.6	11.1
Specificity	42.9	60.0	88.0	56.7	91.7	95.1
PPV	94.4	65.5	14.3	61.8	91.7	60.0
NPV	60.0	31.3	62.9	50.0	19.6	61.9
Stenosis, collaterals, and pancaking on venography compared with IVUS						
Sensitivity	97.1	57.7	48.1	65.8	55.4	48.1
Specificity	42.9	60.0	76.0	56.7	91.7	80.5
PPV	94.4	75.0	52.0	65.8	96.9	61.9
NPV	60.0	40.5	73.1	56.7	30.6	70.2

CIV, Common iliac vein; EIV, external iliac vein; IVUS, intravascular ultrasound; NPV, negative predictive value; PPV, positive predictive value. Data are presented as percentages.

with venography and IVUS. The irregular compression of the venous lumen clearly precludes the calculation of luminal area with a venographically measured diameter. As such, stenosis must be measured with diameter reduction with venography. IVUS, with its direct visualization of the borders of the lumen and associated software, however, is well-equipped to measure luminal area. Thus, stenosis on IVUS was measured with luminal area reduction. The use of a 50% diameter reduction with venography and a 50% luminal area reduction with IVUS is well-documented, even though a 50% diameter reduction is equivalent to a 75% luminal area reduction.<sup>9,13,17-22</sup>

By analyzing the location of lesions by anatomic vein segment and by incorporating collaterals and pancaking into our analysis, we hoped to provide insight into the true value of anteroposterior venography in the diagnosis of obstruction in the venous outflow tract. Although

anteroposterior venography with the combination of stenosis, collaterals, and pancaking had a high sensitivity in the left CIV, it had poor sensitivity ranging from 48% to 65% in the left EIV and CFV and right CIV, EIV, and CFV. The mediocre sensitivities resulted in a high rate of change in plan in these anatomic areas. Our results strongly suggest that IVUS must be used during the intraoperative assessment of venous outflow obstruction to ensure the detection of all lesions. Nonetheless, we believe that venography still plays a pivotal role. First, if collaterals are present, the hemodynamic success of the intervention can be demonstrated by the disappearance of collateral flow after stenting. Second, even if collaterals are not present, contrast stagnation followed by brisk flow after intervention can also demonstrate the hemodynamic success of stenting. Finally, venography is indispensable for completely occlusive lesions.

**Table V.** Percentage of time plan changed because of intravascular ultrasound (IVUS) by anatomic area

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
Percent of patients in whom plan was changed because of IVUS <sup>a</sup>	2.9 (2/70)	32.7 (17/52)	48.1 (13/27)	26.3 (10/38)	35.7 (20/56)	48.1 (13/27)

CIV, Common iliac vein; EIV, external iliac vein.

<sup>a</sup>Number of patients in whom the plan was changed because of IVUS/number of lesions on IVUS.

The resumption of in-line flow is critical for the determination of the success of intervention. Although these more intangible benefits of venography were not specific findings of our study, they do support our belief that both venography and IVUS should be used for venous iliofemoral outflow obstruction.

The poor sensitivity with anteroposterior venography of stenosis but high sensitivity of pancaking with the left CIV in our analysis corroborates the flattening of the left CIV against the anterior surface of the lower lumbar vertebral bodies by either common iliac artery. Raju and Neglen's studies also documented pancaking as the venographic manifestation of eccentric compression of the iliac veins in the lateral plane.<sup>17,20,22,24</sup>

Our data on the correlation between collaterals on venography and the presence of lesions yielded several interesting conclusions. On the left, CIV, IIV, and EIV collaterals in isolation strongly suggested the presence of left CIV lesions. Interestingly, there were still three FPs found with left CIV, IIV, and EIV collaterals. Possible explanations include a more proximal IVC lesion or transpelvic collaterals caused by a right iliac obstruction. Given the poor NPV of 11%, the absence of left IIV, CIV, and EIV collaterals does not rule out a left CIV lesion. On the right, CIV, IIV, and EIV collaterals seemed to be an unreliable indicator of right CIV lesions. The six FPs for right CIV lesions may also have been due to more proximal IVC lesions or transpelvic collaterals caused by a left iliac obstruction. Similar to the left side, right CIV, IIV, and EIV collaterals had a poor NPV (49%) and their absence did not rule out a right CIV lesion. For both sides, there were too few CFV collaterals to make conclusions.

Although contrast thinning has been cited as a venographic adjunct for the detection of stenosis, two compromising factors became apparent during our data collection.<sup>21,22</sup> First, we used hand injections for venography and variations in the speed and volume of the injection could have inadvertently resulted in contrast thinning. Second, blood without contrast flowing into the iliofemoral segment from the IIV and the more distal CFV may have caused thinning in the absence of pathology. Consequently, we did not include thinning in our analysis of combinations of the venographic adjuncts.

Many vascular surgeons continue to diagnose and treat CVI with iliofemoral stenting without IVUS. Contemporary series of venous stenting with sole use of venography or selective use of IVUS have demonstrated a 46% decrease in pain, a 75% to 89% decrease in edema, an 82% to 89% rate of healing ulceration, a 78% to 95% primary patency, and a 91% to 95% secondary patency.<sup>9,10,12-14</sup> Interestingly, these results are comparable with studies using both venography and IVUS that have demonstrated a 77% to 85% decrease in pain, 40% to 53% decrease in edema, 54% to 76% healing of ulceration, 73% to 91% primary patency, and 91% to

100% secondary patency.<sup>19-22,25</sup> In those studies with sole use of venography, high cost and inaccessibility to technology were cited.<sup>9,13</sup> Although we do strongly believe that IVUS must be used in the intraoperative assessment of venous outflow obstruction, our study does provide a context with which to interpret stenosis, collaterals, and pancaking for providers without access to IVUS.

Our sizing protocol for stents is similar but not identical to the oversizing of stents performed by Raju,<sup>26</sup> who regularly placed 18-mm stents in the common iliac artery, 16-mm stents in the EIA, and 14-mm stents in the CFV. Similar to Raju's description, we had no incidence of rupture or embolization and maintained satisfactory luminal gain in our cases.

Our study has limitations. First, the absence of routine use of multiplanar venography is an important critique to our conclusion that IVUS must be used to ensure detection of all venous outflow lesions. The improved but still unsatisfactory sensitivity of stenosis in isolation in the left EIV and CFV and right CIV, EIV, and CFV ranging between 40% and 46% in our study suggests that multiplanar venography may have more accurately captured the variable eccentric compression in these anatomic areas. However, Gagne et al<sup>18</sup> performed a prospective clinical trial with multiplanar venography and reported a sensitivity of 53%.<sup>1</sup> As mentioned in the introduction, their study is the only series to date that routinely performed multiplanar venography. A likely explanation for the lack of studies with multiplanar venography is the concurrent use of IVUS and use of venography primarily for other findings, such as the resolution of contrast stagnation and collaterals. Given the marginal improvement in sensitivity of stenosis by approximately 10% to 15% in the study by Gagne et al compared with our data for stenosis in isolation, the benefit for the detection of stenosis with multiplanar venography is unclear. The combination in our study of stenosis, collaterals, and pancaking furnished a sensitivity in the left EIV and CFV and right CIV, EIV, and CFV ranging from 48% to 65%. Thus, even in the most optimal circumstance, sensitivity would have reached only 80% with 20% of the lesions still not detected. Although the role of multiplanar venography certainly merits further investigation, its ability to allow venography to equal IVUS in diagnostic sensitivity seems to be limited. Pursuing the best angle to reveal a stenosis also significantly increases the amount of contrast used, radiation exposure, and the time of the procedure. Second, our surgical technique did not facilitate the routine collection of adequate venographic images of the IVC, which may have helped to clarify why right and left CIV, IIV, and EIV collaterals had FPs for CIV lesions. Third, the left CIV had a high prevalence of lesions at 90% (70/77) with only seven possible TNs. Consequently, the four FPs and two FNs resulted in the poor specificity of 42% (3/7) and NPV of 60% (3/5). A study with a larger cohort and greater

number of TNs would better elucidate the true specificity and NPV of venography in the left CIV. Fourth, the determination of diameter reduction on venography and luminal area reduction on IVUS were performed subjectively. The subjective determination of a 50% luminal area reduction on anteroposterior venography could have been skewed to favor an increased sensitivity of venography. However, our results for the sensitivity with stenosis in isolation of anteroposterior venography between 4% and 46% are overall comparable with the existing literature, which ranged from 23% to 45%.<sup>17,19-22</sup> Furthermore, the possible increase in sensitivity obtained by a more objective measurement of diameter reduction would be unlikely to improve venographic sensitivity to the point of threatening our conclusion that venography is unable to successfully comprehensively diagnose venous outflow obstruction. Fifth, only 107 of the 444 patients who received stenting were included in this study because of time constraints. Our standard approach was to perform venography followed by IVUS, which was completed in the majority of patients with few exceptions. IVUS in some cases was performed in isolation because of a documented contrast allergy, renal insufficiency, or morbid obesity that obfuscated venography.

## CONCLUSIONS

IVUS is the gold standard for the identification of venous obstruction in the lower extremity outflow tract and must be used to ensure the identification of all lesions. Although it is able to indirectly identify obstruction of the left CIV with collaterals and pancaking, anteroposterior venography performed without IVUS will fail to comprehensively diagnose lesions in the left CIV and CFV and right CIV, EIV, and CFV.

## AUTHOR CONTRIBUTIONS

Conception and design: IL, WT

Analysis and interpretation: IL, CP, RT, AV, MMa, PF, WT

Data collection: IL, CP, ME, MMi, SK, WT

Writing the article: IL

Critical revision of the article: IL, CP, ME, MMi, SK, RT, AV, MMa, PF, WT

Final approval of the article: IL, CP, ME, MMi, SK, RT, AV, MMa, PF, WT

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**Supplementary Table I (online only).** Venographic characterization of obstruction by stenosis, collaterals, pancaking, and thinning in isolation with raw data

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
Stenosis in isolation on venography compared with IVUS						
TP, No.	3	23	12	8	26	11
FP, No.	0	0	0	0	0	0
TN, No.	7	25	50	30	12	41
FN, No.	67	29	15	30	30	16
Sensitivity, %	4.29	44.2	44.4	21.1	46.4	40.7
Specificity, %	100.00	100.0	100.0	100.0	100.0	100.0
PPV, %	100.00	100.0	100.0	100.0	100.0	100.0
NPV, %	4.29	46.3	76.9	50.0	28.6	71.9
Collaterals in isolation on venography compared with IVUS						
TP, No.	40	1	—	13	3	—
FP, No.	3	0	—	6	0	—
TN, No.	4	25	—	24	12	—
FN, No.	30	51	—	25	53	—
Sensitivity, %	57.1	1.9	—	34.2	5.4	—
Specificity, %	57.1	100.0	—	80.0	100.0	—
PPV, %	93.0	100.0	—	68.4	100.0	—
NPV, %	11.8	32.9	—	49.0	18.5	—
Pancaking in isolation on venography compared with IVUS						
TP, No.	61	6	1	14	1	3
FP, No.	3	4	6	8	1	2
TN, No.	4	21	44	24	11	39
FN, No.	9	46	26	25	55	24
Sensitivity, %	87.1	11.5	3.7	36.8	1.8	11.1
Specificity, %	57.1	84.0	88.0	73.3	91.7	95.1
PPV, %	95.3	60.0	14.3	63.6	50.0	60.0
NPV, %	30.8	31.3	62.9	47.8	16.7	61.9
Thinning in isolation on venography compared with IVUS						
TP, No.	65	34	13	31	31	14
FP, No.	7	9	19	21	5	17
TN, No.	0	16	31	22	7	24
FN, No.	5	18	13	24	25	13
Sensitivity, %	92.9	65.4	50.0	81.6	55.4	51.9
Specificity, %	0.0	64.0	62.0	30.0	58.3	58.5
PPV, %	90.3	79.1	40.6	59.6	86.1	45.2
NPV, %	0.0	47.1	70.5	56.3	21.9	64.9

*CIV*, Common iliac vein; *EIV*, external iliac vein; *FN*, false negative; *FP*, false positive; *IVUS*, intravascular ultrasound; *NPV*, negative predictive value; *PPV*, positive predictive values *TN*, true negative; *TP*, true positive.

**Supplementary Table II (online only).** Venographic characterization of obstruction by combinations of stenosis, collaterals, and pancaking with raw data

Location	Left			Right		
	CIV	EIV	CFV	CIV	EIV	CFV
<b>Stenosis and collaterals on venography compared with IVUS</b>						
TP, No.	41	29	12	20	30	11
FP, No.	3	7	0	6	1	0
TN, No.	4	18	50	24	11	41
FN, No.	29	23	15	18	26	16
Sensitivity, %	58.6	55.8	44.4	52.6	53.6	40.7
Specificity, %	57.1	72.0	100.0	80.0	91.7	100.0
PPV, %	93.2	80.6	100.0	76.9	96.8	100.0
NPV, %	12.1	43.9	76.9	57.1	29.7	71.9
<b>Stenosis and pancaking on venography compared with IVUS</b>						
TP, No.	61	24	13	19	27	13
FP, No.	3	3	12	8	1	9
TN, No.	4	22	38	22	11	32
FN, No.	9	28	14	19	29	14
Sensitivity, %	87.1	46.2	48.1	50.0	48.2	48.1
Specificity, %	57.1	88.0	76.0	73.3	91.7	78.0
PPV, %	95.3	88.9	52.0	70.4	96.4	59.1
NPV, %	30.8	44.0	73.1	53.7	27.5	69.6
<b>Collaterals and pancaking on venography compared with IVUS</b>						
TP, No.	68	19	1	21	11	3
FP, No.	4	10	6	13	1	2
TN, No.	3	15	44	17	11	39
FN, No.	2	33	26	17	45	24
Sensitivity, %	97.1	36.5	3.7	55.3	19.6	11.1
Specificity, %	42.9	60.0	88.0	56.7	91.7	95.1
PPV, %	94.4	65.5	14.3	61.8	91.7	60.0
NPV, %	60.0	31.3	62.9	50.0	19.6	61.9
<b>Stenosis, collaterals, and pancaking on venography compared with IVSU</b>						
TP, No.	68	30	13	25	31	13
FP, No.	4	10	12	13	1	8
TN, No.	3	15	38	17	11	33
FN, No.	2	22	14	13	25	14
Sensitivity, %	97.1	57.7	48.1	65.8	55.4	48.1
Specificity, %	42.9	60.0	76.0	56.7	91.7	80.5
PPV, %	94.4	75.0	52.0	65.8	96.9	61.9
NPV, %	60.0	40.5	73.1	56.7	30.6	70.2

*CIV*, Common iliac vein; *EIV*, external iliac vein; *FN*, false negative; *FP*, false positive; *IVUS*, intravascular ultrasound; *NPV*, negative predictive value; *PPV*, positive predictive values *TN*, true negative; *TP*, true positive.



**Supplemental Fig 1 (online only).** Collaterals on venography. **A**, A collateral originates from the left common iliac vein (CIV) and extends to the right CIV on venography. **B**, A collateral originates from the left internal iliac vein (IIV) and extends to the right external iliac vein (EIV). **C**, A collateral originates from the proximal EIV. **D**, A collateral originates from the common femoral vein (CFV).



**Supplementary Fig 2 (online only).** Pancaking on venography. **A**, Pancaking can be seen in the left common iliac vein (CIV) with concomitant contrast thinning. **B**, Pancaking can be seen in both the external iliac vein (EIV) and CIV. **C**, Pancaking can be seen in the proximal common femoral vein (CFV).



**Supplementary Fig 3 (online only).** Thinning on venography. **A**, Thinning can be seen in the common iliac vein (CIV) and the external iliac vein (EIV). **B**, Thinning can be seen in the common femoral vein (CFV).