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The Feasibility of using Volumetric Phase Contrast MR Imaging (4D Flow) to assess for Transjugular Intrahepatic Portosystemic Shunt Dysfunction

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Abstract

Purpose: To demonstrate the feasibility of detecting patency, stenosis, or occlusion of transjugular intrahepatic portosystemic shunts (TIPS) with 4D Flow MR.

Materials and Methods: Sequential adult patients with TIPS were eligible for enrollment. A volumetric phase contrast sequence was used to image the TIPS. Particle tracing CINE images were used for qualitative assessment of stenosis. TIPS were segmented to generate quantitative data sets of peak velocity. Segmentation and quantitative measurement of flow throughout an entire TIPS stent defined technical success. Comparison was made to Doppler US. Venogram, when available, and 6-month clinical follow-up were used as reference standards.

Results: 4D Flow MR was performed in 23 patient encounters, and was technically successful in 16/23 encounters. Three cases demonstrated both focal turbulence and abnormal velocities (>190cm/s or <90cm/s) on 4D Flow and had venogram confirmed stenosis (true positives). Seven cases had normal velocities and no turbulence on 4D Flow and all were confirmed negative with clinical follow-up or venogram (true negatives). Six cases had discordant 4D flow results, with abnormal velocities but no turbulence, or focal turbulence but normal velocities. All six discordant cases had no evidence of dysfunction with 6-month follow-up.

Conclusion: 4D Flow MR can detect TIPS patency and stenosis, but requires further investigation before it can be used to assess for TIPS dysfunction.

Keywords

4D Flow; TIPS dysfunction; MR angiography; portal hypertension; feasibility

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Introduction:

The primary intervention for portal hypertension is the transjugular intrahepatic portosystemic shunt (TIPS). TIPS can develop stenosis, which may result in recurrent portal hypertension, ascites, hydrothorax, or even catastrophic variceal hemorrhage (1). The expected rate of dysfunction of PTFE-covered TIPS in the literature ranges from 14%–62% at 12 months (2–8). TIPS are often monitored with serial Doppler ultrasound (US) measures of angle corrected peak velocity (9), although studies have shown concordance between Doppler US and venogram to be as low as 53% (10). Despite the poor positive predictive value of Doppler US, it remains the clinical standard for non-invasive surveillance of TIPS.

The inter-user variability of Doppler US velocities may account for its high false positive rate. Doppler US is problematic in obese patients, patients with small cirrhotic livers and poor acoustic windows, and in patients with severe hepatic steatosis. If continuous surveillance of TIPS is needed, an alternative non-invasive diagnostic modality would be a welcomed addition to the clinical armamentarium. Phase contrast magnetic resonance angiography (4D Flow) provides time-resolved volumetric velocity encoded data and may provide an alternate imaging option to evaluate TIPS patency (12,13,14). Early reports of 4D Flow imaging of TIPS demonstrate the ability to image the TIPS and measure in-stent velocities (15), and further research is needed to optimize the imaging parameters and to show the feasibility of acquiring meaningful data in patients at risk for TIPS dysfunction.

This study aims to investigate the feasibility of 4D Flow to detect patency, stenosis or occlusion of TIPS stents. To evaluate the feasibility of using 4D Flow to interrogate TIPS function, a cohort of patients with TIPS were imaged with 4D Flow and Doppler US. Venography or six-month clinical follow-up used as the reference standard.

Methods:

Patients:

After institutional review board approval (IRB # 201312135), consecutive patients from January 2014 to December of 2015 were recruited for the study if they met the following criteria: (1) prior placement of a transjugular portosystemic shunt (2) no contra-indication to magnetic resonance imaging, or (3) scheduled or recently performed standard of care Doppler ultrasound for TIPS surveillance. Patients who agreed to participate underwent a non-contrast investigational MR examination, a standard of care Doppler US, and when clinically indicated, a venogram. In patients who did not proceed to venogram, clinical follow-up of at least 6 months was used to exclude stenosis.

MR image acquisition:

Patients were NPO at midnight prior to the MR. Single shot turbo spin echo and balanced steady state free precession sequences were performed for anatomic localization and registration followed by a volumetric phase contrast sequence (4D Flow). The field of view was assigned to cover the entire TIPS stent, including a portion of the suprahepatic IVC and a portion of the main portal vein. Total imaging time was 30–45 minutes, the 4D Flow sequence acquisition ranged 10–20 minutes. The 4D flow sequence acquisition time varies

based on the patients respiratory rate and cardiac rhythm. Non-contrast, free-breathing navigated, ECG-gated 4D Flow was performed on a 1.5T MAGNETOM Avanto or Espree (Siemens Healthcare, Erlangen, Germany) with the following approximate imaging parameters (Table 1): 3D transverse slab to cover the entire TIPS stent and portions of the suprahepatic IVC and portal vein, velocity encoding (VENC)= variable, segments= 3–4, TE= 3.73 msec, TR= 81.72 msec, thickness = 3 mm, Flip angle = 8° (non-contrast) 13° (post-contrast) bandwidth = 488 Hz/pixel, integrated parallel imaging technique (iPAT) acceleration factor of 2 with 24 reference lines. Initially VENC values were selected based on prior Doppler ultrasound examinations. In the process of optimizing parameters, the first 3 studies were performed using multiple VENC values. A VENC value of 225 cm/s became the default value used in all subsequent studies. The respiratory navigator sequence was set to gate from the left hemidiaphragm/spleen interface. The gating acceptance window was +/– 4 mm, balancing time of acquisition against image degradation.

Post-processing:

Siemens 4D Flow post-processing research prototype (Siemens Healthcare, Erlangen, Germany) was used for qualitative and quantitative analysis. The main portal vein and the TIPS stent were segmented. Time-resolved particle tracings were created to model flow through the stent and allow for qualitative assessment of stenosis. The main portal vein and stent segments (proximal, mid and distal) were interrogated to determine the point of peak maximum velocity for each segment. Standard quantitative values were obtained at the location of peak maximum velocity in each segment. Vector field maps were created at each point of maximum velocity to assess for artifactual values (outlier vectors).

MR 4D flow interpretation:

The MRA images were reviewed in consensus by two fellowship trained abdominal imagers and an interventional radiologist. Quantitative thresholds from Doppler US were applied to MR obtained peak through-plane velocities. Velocities <90 and >190 cm/s within the TIPS stent were considered abnormal. The images were then evaluated for the lack of flow, the non-laminar flow, and focal turbulence as a qualitative evidence of TIPS dysfunction. Concordance was assessed separately for qualitative and quantitative metrics. 4D Flow was considered technically successful if field of view and signal-to-noise ratio allowed for segmentation of the entire TIPS stent, and the phase images and particle tracing model demonstrated sufficient flow for analysis. 4D Flow imaging was defined as suboptimal when segmentation of the TIPS stent was inconsistent due to low signal to noise, or vector field maps demonstrated peripheral peak maximum velocities perpendicular or retrograde to the dominate flow (indicating noise rather than true signal). Failure of acquisition occurred when data could not be imported into the post-processing software (due to corruption of data files) or the TIPS stent could not be segmented in its entirety. Reasons for suboptimal imaging or failure were documented and adjustments to subsequent examinations made based on early experience to optimize acquisition.

Clinical Reference standards:

Doppler US: Doppler US was performed in accordance with the standard of care. Patients underwent greyscale, color Doppler and spectral wave Doppler US examination of the hepatic vasculature and the TIPS stent. Sample peak velocities were obtained from the main portal vein, the proximal, mid and distal TIPS stent, and the outflow vein. Direction of flow was determined in the right portal vein, left portal vein and outflow vein. Evidence of aliasing was recorded. The clinical radiologist's overall impression was recorded.

Stenosis on US was defined based on criteria established in the literature(16): (1) peak shunt velocity <90 or >190 cm/s, (2) change in peak shunt velocity-decrease >40 cm/s or increase >60 cm/s, (3) distal shunt velocity <90 or >220 cm/s, (4) main portal vein velocity <30 cm/s, (5) antegrade flow in the right or left portal vein, and (6) overall impression.

Clinical Follow-up: Clinical follow-up was obtained by chart review to determine if symptoms returned, repeat intervention was required, or clinical suspicion of stenosis emerged. Lack of recurrent symptoms or need for intervention was recorded at least 6 months following the MR examination to serve as a reference standard in patients who did not undergo venography. Clinical follow-up beyond 12 months was not assessed, because the development of symptoms greater 12 months after the MR, could be attributed to dysfunction that developed after the 4D Flow MR.

Venography: Venogram was performed per standard of care. Atrial pressure, portal pressure and portosystemic gradient was reported. Stenosis was defined as a focal caliber change within the stent and portosystemic gradient 12 mmHg at venogram. The lack of stenosis was defined as no focal caliber change within the stent and portosystemic gradient 12 mmHg on venogram. Patients with suspected stenosis proceeded to venogram only at the recommendation of their primary care physician, hepatologist or interventional radiologist according to current practice patterns, and not dependent on the findings of the investigational 4D Flow MR.

Results:**Patient Population:**

Twenty-three patient encounters met inclusion criteria for enrollment. Each encounter had a corresponding 4D Flow and Doppler US. Venogram was performed in 8 patients with suspected TIPS dysfunction based either on clinical presentation or ultrasound findings. Venogram confirmed TIPS dysfunction in 5 encounters. A patent functioning TIPS stent was found in 3 patients at venogram following US and MR. A 9th patient underwent venogram 9 months following US and MR, and was found to have a patent functioning TIPS stent.

4D Flow (Table 2):

Sixteen (16/23) patient encounters allowed for successful segmentation and analysis of the TIPS stent and portal vein. Table 2 shows concordance or discordance of 4D Flow imaging relative to Doppler US and the reference standards.

In 7 patient encounters, 4D Flow showed normal flow and normal velocities (Figure 1, Video 1). All 7 patients were either negative for evidence of dysfunction with 6-month clinical follow-up (true negative). In 2 of these cases US Doppler was positive (false positive).

In 3 patient encounters, 4D flow showed focal turbulence and abnormal velocities. All 3 cases had venogram confirmed stenosis, with portosystemic gradients of 18, 22, and 25 mmHg (true positive). One of these cases had a normal Doppler US (false negative) (Figure 2, Video 2).

In 2 patient encounters, 4D Flow data was positive for focal turbulence, but showed normal velocities. 1 had a normal venogram and 1 6-month clinical follow-up without evidence of dysfunction. Doppler US was positive in one case (false positive).

In 4 cases, 4D Flow detected abnormal velocities, but no focal turbulence. 4D Flow MRA found peak through-plane velocities greater than 190 cm/sec in 3 cases, and peak through plane velocity less than 90 cm/sec in 1 patient. 1 patient had a normal venogram and 3 patients had no evidence of dysfunction with 6 month clinical follow-up. Two of the cases had negative Doppler US and 2 had positive Doppler US.

Combination of Qualitative and Quantitative Metrics (Table 3):

If a test positive result is defined as both qualitative and quantitative evidence of TIPS dysfunction and a negative result is defined as either a negative qualitative or a negative quantitative result, 4D Flow MR detected stenosis in 3 TIPS, all of which were confirmed by venogram, with portosystemic gradients of 18, 22, and 25 mmHg (true positive).

Combined 4D Flow was negative in 13 cases, 2 confirmed negative by venogram, 11 without evidence of dysfunction with 6-month follow-up. In comparison, Doppler US was positive for stenosis in 7 patients. Two patients had venogram confirmed stenosis. Two patients had a negative venogram and 3 were without evidence of dysfunction with 6-month follow-up. Doppler US was negative in 9 patients. 1 patient had venogram confirmed stenosis, and 8 patients were evidence of dysfunction with 6-month follow-up.

Discussion:

The current paradigm for surveillance of TIPS function can be improved. Doppler US is a suboptimal screening examination without well-defined criteria for the diagnosis of TIPS dysfunction and most of the research supporting its use occurred prior to the use of covered stents. In a relatively recent study, the only independent predictor of shunt malfunction was diminished main portal vein peak velocity with the optimal cutoff value of 31 cm/s resulting in a sensitivity of 62.5%, specificity of 68.4%, positive predictive value of 43%, and a negative predictive value of 81%(2). Older investigations focused on absolute velocity within the stent itself, with lower limit of normal velocities of 50–60 cm/s resulting in sensitivities ranging from 78–100% for detection of stenosis(9,17,18). Others have failed to duplicate these results and suggested that a temporal change in peak velocity in the TIPS of greater than 50cm/s or reversal of flow within the hepatic vein branches, portal vein

branches, or collateral vessels are better indicators of possible shunt malfunction(19,20). One institution reported a multiparametric approach with sensitivity of 82% and specificity of 72% for detection of TIPS dysfunction, but this has not been replicated and occurred before routine use of covered stents (16).

Despite the limitations of Doppler US, many large TIPS centers perform routine Doppler US imaging for surveillance of TIPS dysfunction 4 to 6 weeks after the procedure and then every 3 months, 6 months or 1 year. A normal Doppler US is reassuring when there are no clinical symptoms. When there are clinical symptoms a Doppler US is often obtained prior to venogram, to look for clear signs of TIPS dysfunction. When a Doppler US is positive in an asymptomatic patient, clinicians may not elect to precede to venogram due to the high false positive rate of Doppler US. If 4D Flow MR is found to have a high positive predictive value it could function as a confirmatory test after a positive Doppler US in an asymptomatic patient. If 4D Flow is found to have a high negative predictive value, it could be added on to MRs performed in cirrhotic patients with TIPS to screen for TIPS dysfunction and hepatocellular carcinoma. This study shows 4D Flow MR can detect patency and stenosis of TIPS, and a multicenter prospective randomized controlled trial is needed to assess the equivalency/non-inferiority of 4D Flow and Doppler US.

Portal vein and in-stent velocity is an imperfect surrogate measure for the recurrence of portal hypertension, and this may partially account for the limitations of Doppler US. 4D Flow can provide comprehensive analysis of velocity throughout the entire TIPS stent, can model flow patterns to demonstrate turbulence, and can calculate pressure gradients to estimate the portosystemic gradient. When evaluating a TIPS stent with Doppler US, sample velocities are often obtained from the locations that are best visualized and have the best angle of insonation; the entirety of the stent is not assessed. 4D Flow creates a 3-dimensional time-resolved model of the stent that can be scrolled through in 1–3 mm increments to assess peak velocities. Flow within the stent can be modeled with vector diagrams and particle tracing CINE imaging, to allow for qualitative analysis of turbulence, non-laminar flow, aliasing, and focal increases in velocity. Abnormal areas can then be targeted for quantitative analysis. Doppler US imaging only provides peak through plane velocity from sampled locations, but 4D Flow provides multiple velocity metrics throughout the stent, including peak velocity magnitude, peak through-plane velocity, peak average through plane velocity, average through-plane velocity, peak flow rate, average net flow rate, forward/reverse volumes, and pressure gradients. Current criteria for TIPS stenosis on Doppler US, when applied to 4D Flow imaging, may not capture the best 4D Flow indicator of TIPS stenosis, and research is required to develop new criteria specifically for 4D Flow. A large prospective trial comparing Doppler US, 4D Flow and venogram may provide additional insight.

In this feasibility study, we found that 4D flow MR can measure the velocities of blood flow through TIPS stents and can detect TIPS stenosis. Our overall rate of TIPS dysfunction was 5/23 (21%). In patient encounters with a technically successful 4D Flow MR, the rate of dysfunction was 3/16 (19%). The 3 patients with venogram confirmed stenosis had both abnormal velocities on quantitative 4D Flow MR and abnormal flow (turbulence/aliasing) on qualitative 4D Flow CINE imaging. False positive 4D Flow MR occurred in 6 cases, but

only if the qualitative and quantitative results were interpreted in isolation. If the criteria for dysfunction was both abnormal velocities and turbulent flow, there were no false positives. No cases with confirmed stenosis had a normal 4D Flow MR (no false negative).

There are a number of technical issues that must be resolved to improve the utility of 4D MR imaging in this setting. Seven of 23 encounters failed to produce analyzable data (Table 4). A correctable issue was identified in most cases and often stemmed from early experience with 4D Flow MR of TIPS. Two patients had been revised with a non-nitinol stent. The non-nitinol stents caused dephasing artifact that precluded stent segmentation and analysis (Figure 3, Video 3). A FOV which did not include the distal TIPS stent was selected in 2 patients, precluding full evaluation of the stent. Improper FOV was likely due to selection of the cranio-caudal FOV on an end-inspiratory sequence, instead of end-expiratory sequence. A small FOV was selected for 1 patient, resulting in wrap-around artifact and a central band of low signal-to-noise that obscured the stent. A low VENC of 50 cm/sec was incorrectly selected for 1 patient, and result in aliasing throughout the stent. The data was corrupted for 1 encounter and would not load into the post-processing software platform. Siemens assisted with troubleshooting the data set, and concluded that the DICOM headers were corrupted during the anonymization process, which prevent the software from properly compiling the velocity data.

Additional experience and careful patient selection should mitigate most of the issues that led to unsuccessful encounters. Those with prior placement of a stainless steel stent are not good candidates for 4D Flow MRA and should be excluded from future investigations. Field of view selection is critical and should include the base of the heart to the superior mesenteric artery cranio-caudal, and at least skin to skin anterior-posterior. Cranio-caudal field of view should be selected on end-expiratory imaging or free breathing images as the respiratory navigated Siemens 4D Flow sequence captures data during end expiration. Performing 4D Flow MR on a 3T magnet, or running 4D Flow MR after the administration of intravenous gadolinium contrast may improve signal to noise and reduce artifactual aliasing. Each technical failure is addressable and with increased experience on the part of the radiologists and technologists, a high rate of optimal imaging should be achievable.

4D Flow requires the selection of a predetermined velocity encoded value (VENC), which if too low may not capture high velocities due to aliasing, or if too high may not capture slow flow due to low signal. A VENC of 225 cm/s was found to capture the range of velocities required for TIPS stent evaluation. Should velocities exceed 225 cm/sec to a degree that alias correction cannot account for the high velocity, then stenosis would be likely. A VENC of 225 cm/sec captured flow in the main portal vein with velocities in the 20 to 60 cm/sec range, so lack of signal within the stent should indicate velocities well below 90 cm/sec, an accepted threshold for TIPS dysfunction. Additional investigations are required to confirm the optimal default VENC for TIPS evaluation.

4D Flow has limitations that are impediments to wide-spread clinical implementation. It is currently not an FDA-approved sequence, restricting its use outside of clinical research. 4D Flow has an acquisition time from 10 to 20 minutes depending on the patient's heart-rate, respiratory rate, and the field of view. Respiratory gating is challenging in patients with

ascites and/or hydrothorax, which cause multiple interfaces at the diaphragm that can confuse the gating algorithms. Advances in 4D Flow are reducing imaging time with new parallel imaging techniques (21), and advances in respiratory navigation.

Many patients with TIPS stents have advanced cirrhosis and undergo MR for hepatocellular carcinoma surveillance. With additional optimization, 4D Flow could be added to a routine liver MR, adding 10–20 minutes to an already scheduled encounter, eliminating the need for a separate 1 hour Doppler US. While there may be an increased cost for the add-on MRA charge compared to Doppler US, the reduction in patient encounters and the reduction in time would improve convenience and may increase patient compliance.

This feasibility study to determine if 4D Flow MR can detect patency, stenosis or occlusion of TIPS has multiple limitations. First, there was a limited sample size with only 3 patients with venogram confirmed stenosis who underwent 4D Flow and Doppler US. Second, two reference standards were used, with only 5 patients undergoing venogram, the ideal reference standard. The use of two reference standards (venogram and 6-month clinical follow-up), is suboptimal, but reflects clinical practice. The majority of TIPS patients do not undergo venogram to evaluate for dysfunction. Even when a Doppler US is positive, clinicians commonly defer the use of venogram until there are clinical signs of dysfunction, like recurrent ascites, hydrothorax or GI bleeding. Third, there was a high rate of technical failure. The technical failures occurred early in the feasibility study and with proper training of MR technologists to select the correct field of view and VENC, and avoidance of patients with non-nitinol stents, technical failures can be reduced.

Conclusion:

4D Flow MR can detect patency, stenosis and occlusion of TIPS, but careful patient selection, technical experience and optimized protocols are important for adequate imaging evaluation. We proposed default VENC of 225 cm/s for 4D Flow MR evaluation of TIPS dysfunction. Additional investigation is required to demonstrate equivalency/non-inferiority of 4D Flow compared to Doppler US and to establish 4D Flow specific criteria for TIPS stent dysfunction.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

TIPS stent assessment: a – grayscale image from Doppler US interrogation of a TIPS stent. b – surface rendered reconstruction of a TIPS stent with centerline and 6 regions of interest for quantitative analysis (1 and 2 main portal vein; 3 proximal stent; 4 mid stent; 5 distal stent; 6 inferior vena cava). c and d – still frames from particle tracing CINE images showing uniform in-stent flow without aliasing. The white arrow indicates a region of non-turbulent flow at the upper limits of normal for velocity.

Figure 2.

Venogram proven TIPS dysfunction: a - still image from particle tracing CINE imaging of TIPS stent showing the entire stent (double sided arrow), the inferior vena cava (narrow white arrow), the portal vein (wide white arrow) and elevated velocities with aliasing at the distal TIPS stent (arrow head). b – spectral wave Doppler ultrasound interrogation of the distal TIPS showing normal velocities. c – grayscale and color Doppler ultrasound images with inadequately visualized the distal TIPS. d - digital subtraction venography showing distal TIPS stenosis (arrow head).

Figure 3.

Technically unsuccessful: a – oblique coronal MR image showing the relative lack of artifact from the proximal nitinol stent compared to the distal stainless steel stent. A,b,c – still frames from particle tracing CINE imaging of the TIPS with the junction between the nitinol and stainless steel stent well demarcated (arrowhead) by normal flow proximally, and artifact and aliasing (open arrow head) distally. Progression through the still frames taken from CINE imaging is indicated by the white arrow.

Table 1.

4D Flow Imaging Parameters.

Field of View	Velocity Encoding	Respiratory Navigation	Other Parameters
Transverse 3D slab Craniocaudal - Right atrium to superior mesenteric vein AP - At least skin to skin Slice thickness = 3 mm	All patients VENC = 225 cm/s If slow flow is expected add acquisition VENC = 75 cm/s	Spleen diaphragm interface Correction factor = 1 In the presence of ascites narrow search window and consider disabling autotracking feature Acceptance window +/-4 mm Search window +/-20mm	TE= 3.73 msec TR= 81.72 msec Bandwidth = 488 Hz/pixel Flip angle 8°(non-contrast) 13° (post-contrast) iPAT acceleration factor of 2 with 24 reference lines

Table 2.
4D Flow MR relative concordance or discordance with reference standard.

Rows shaded in gray are cases where the Doppler US, reference standards, and 4D Flow agreed. Rows in bold indicate cases where 4D Flow agreed with the reference standard, but Doppler US did not. Red indicates cases where Doppler US or 4D Flow was discordant with the reference standard.

Encounter	Doppler US	Quant MRA	Qual MRA	Venogram or clinical follow-up
1	–	–	–	– clinical
7	–	–	–	– clinical
11	–	–	–	– clinical
13	–	–	–	– clinical
15	–	–	–	– clinical
6	+	–	–	– clinical
8	+	–	–	– clinical
2	+	+	+	+ venogram
10	–	+	+	+ venogram
12	+	+	+	+ venogram
14	–	–	+	– clinical
16	+	–	+	– venogram
3	–	+	–	– clinical
9	–	+	–	– clinical
4	+	+	–	– venogram
5	+	+	–	– clinical

Table 3.
Comparison of Doppler and 4D Flow metrics.

Combined 4D Flow indicates that both qualitative and quantitative metrics were positive to determine final test positivity. If one metric was negative, the test was considered negative. Both qualitative and quantitative 4D Flow had high negative predictive value. Positive predictive value was only achieved when both the qualitative and quantitative evaluations were positive for dysfunction. Note: 7 technical failures of 4D Flow were excluded from this table.

Test		Disease Positive	Disease Negative	Positive Predictive Value	Negative Predictive Value
Qualitative 4D Flow	Test Positive	3	2	60%	100%
	Test Negative	0	11		
Quantitative 4D Flow	Test Positive	3	4	42%	100%
	Test Negative	0	9		
Combined 4D Flow	Test Positive	3	0	100%	100%
	Test Negative	0	13		
Doppler US	Test Positive	2	5	29%	89%
	Test Negative	1	8		

Table 4.

Unsuccessful examinations and potential reasons for poor quality.

Encounter	Doppler US	Venogram or clinical	Reason for poor image quality
17	Inadequate	– clinical	Stainless steel stent with dephasing
18	+	+ venogram	Stainless steel stent with dephasing
19	+	– venogram	Sm FOV; wrap artifact; central low signal-to-noise
20	–	– clinical	FOV did not include entire stent
21	Equivocal	– clinical	Corrupted data
22	–	– clinical	Low VENC relative to flow with aliasing throughout stent
23	+	+ venogram	Sm FOV; central low signal-to-noise