Doppler Sonographic Criteria for the Diagnosis of Inferior Mesenteric Artery Stenosis

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Objective. The purpose of this study was to define the optimal Doppler criteria for the diagnosis of inferior mesenteric artery (IMA) stenosis in patients with suspected chronic mesenteric ischemia (CMI). ***Methods.*** A retrospective review of 205 dedicated color and pulsed Doppler sonographic studies of mesenteric arteries was performed in 205 patients. All studies were performed in patients with suspected CMI. Correlative angiography was available in 50 patients. ***Results.*** The IMA was visualized in 176 of 205 Doppler sonographic examinations (86%) and in 92% of the correlative studies. The visualization rate for the detection of a patent IMA by Doppler sonography in this series was 90%. The ranges of the peak systolic velocity (PSV), end-diastolic velocity (EDV), and mesenteric-aortic velocity ratio (MAR) in the nonstenotic IMA were 70 to 200 cm/s, 0 to 33 cm/s, and 0.7 to 3.7, respectively. The ranges of the PSV, EDV, and MAR in IMA stenosis were 200 to 485 cm/s, 0 to 177 cm/s, and 0.69 to 8.1. The threshold values for severe IMA stenosis by logistic regression analysis (n = 42) were as follows: PSV, greater than 200 cm/s; EDV, greater than 25 cm/s; and MAR, greater than 2.5, with sensitivities of 90%, 40%, and 80%; specificities of 97%, 91%, and 88%; positive predictive values (PPVs) of 90%, 57%, and 67%; negative predictive values (NPVs) of 97%, 83%, and 93%; and accuracy of 95%, 79%, and 86%, respectively. ***Conclusions.*** We found that a PSV of greater than 200 cm/s was the best criterion for the diagnosis of IMA stenosis. The sensitivity, specificity, PPV, NPV, and accuracy for the PSV were 90%, 97%, 90%, 97%, and 95%, respectively. ***Key words:*** Doppler sonography; mesenteric; stenosis; vascular.

Abbreviations
CMI, chronic mesenteric ischemia; CT, computed tomographic; CTA, computed tomographic angiography; DSA, digital subtraction arteriography; EDV, end-diastolic velocity; IMA, inferior mesenteric artery; MAR, mesenteric-aortic velocity ratio; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value; PSV, peak systolic velocity; ROC, receiver operating characteristic; SMA, superior mesenteric artery

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Mesenteric ischemia is an important cause of abdominal pain in the elderly and patients with progressive atherosclerotic disease.[1–3] Chronic mesenteric ischemia (CMI) results from severe occlusive disease of the mesenteric circulation in which the blood supply to the bowel is inadequate to support metabolic and functional demands.[4–6] Clinical signs and symptoms are usually nonspecific, and as a result, the diagnosis may be elusive. Accurate diagnosis depends on the detection of arterial occlusive changes in the major mesenteric branches: the celiac, superior mesenteric, and inferior mesenteric arteries. Detection of these changes is important to determine the appropriate treatment, when necessary, including surgical revascularization or angioplasty with stent placement. Traditional studies of the bowel, including barium gastrointestinal series and conventional computed tomographic (CT) scans of the abdomen do not detect these changes in arterial blood flow. Vascular studies, including digital sub-

traction arteriography (DSA), sonography, computed tomographic angiography (CTA), and magnetic resonance angiography (MRA), may be required for diagnosis. Many patients with underlying vascular disease may also have diabetes, renal insufficiency, or allergic conditions that may preclude evaluation with iodinated contrast material or gadolinium. Sonographic evaluation offers a safe, noninvasive alternative to contrast examinations.

Doppler sonography is recognized as a useful modality for the evaluation of severe stenosis in the mesenteric arteries.[7–10] Studies have shown that sonography is accurate for identifying stenosis and occlusion of the celiac artery and superior mesenteric artery (SMA).[9–20] The peak systolic velocity (PSV), end-diastolic velocity (EDV), and mesenteric-aortic velocity ratio (MAR) are published parameters for the detection of celiac artery and SMA stenosis. These parameters are the standard criteria for the detection of mesenteric artery disease. Because the diagnosis of CMI relies on the identification of stenosis or occlusion in at least 2 of the 3 mesenteric arteries, the inferior mesenteric artery (IMA) should be included in the evaluation of all patients with suspected CMI. The role of Doppler sonography in the identification of diseases of the IMA has not been defined in the literature. Recent studies have shown that the IMA can be seen in up to 92% of cases.[21] To our knowledge, there are no studies that have identified criteria for the diagnosis of severe stenosis of the IMA.

In this study, we determined the percentage of studies in symptomatic patients in which the IMA was visualized and the range of IMA PSVs in our study group. We also analyzed the PSV, EDV, and MAR to determine the best Doppler parameter for defining hemodynamically severe IMA stenosis.

Materials and Methods

This study was approved by our Institutional Review Board Committee. A retrospective review of consecutive mesenteric Doppler studies with correlative studies (DSA, CTA, and MRA) was performed in compliance with Health Insurance Portability and Accountability Act regulations.

All patients were evaluated for suspected CMI with Doppler sonography between January 1998 and January 2007. A total of 205 Doppler sonography cases were reviewed. There were 57 correlative angiograms: 21 DSAs, 29 contrast-enhanced MRAs, and 7 correlative CTAs; 7 patients had 2 correlative studies (5 DSA/MRA, 1 DSA/CTA, and 1 MRA/CTA). There were 19 men and 31 women aged 42 to 91 years (mean age ± SD, 69.5 ± 13.4 years). The maximum time between correlative studies was 6 months.

Color and pulsed Doppler examinations were performed with HDI 3000 or HDI 5000 (Philips Healthcare, Bothell, WA) or LOGIQ 9 (GE Healthcare, Milwaukee, WI) sonography units with color and pulsed Doppler capabilities. All studies were optimized for abdominal vascular imaging with lower-frequency (3- to 5-MHz) transducers. Color optimization included adjustment of the color gain, color wall filter, and pulse repetition frequency. Harmonic imaging was routinely used to minimize artifacts. Small (2- to 5-mm) pulsed Doppler sample volumes were used to obtain Doppler spectral information from the vessels of interest. All velocity measurements were obtained with angle correction of 60° or less. All examinations were performed after an overnight fast. No medications were given before the examinations. Postprandial Doppler studies were not performed.

The protocol for the mesenteric evaluation included examination of the abdominal aorta from the celiac axis to the level of the IMA. Gray scale, color, power, and pulsed Doppler imaging were used for the sonographic studies. The sonographic examinations were performed in the supine position, and the abdominal aorta was visualized in the sagittal and transverse projections. In the sagittal plane, the celiac artery and SMA were identified arising from the anterior aspect of the aorta, and the IMA was identified arising from the left anterolateral aspect of the aorta, below the origin of the renal arteries (Figure 1). Gray scale imaging was used to evaluate for atherosclerotic plaque or aneurysms in the aorta and proximal branch vessels. Color Doppler imaging was optimized to assess for patency and blood flow abnormalities, including aliasing, bruit artifacts, and poststenotic turbulence. Pulsed Doppler sampling was performed

in the aorta at the level of the mesenteric arteries and at the origin and proximal segments of the celiac artery, SMA, and IMA (Figures 2 and 3). Aortic PSV measurements were obtained at the level of the celiac artery and SMA for the MAR calculations. Additional aortic PSV measurements were obtained at the level of the IMA if there was evidence of aortic stenosis or an aortic aneurysm to correct for the change in the aortic diameter. Peak systolic velocity measurements were recorded in the sagittal plane with Doppler angle correction of less than 60° along the direction of blood flow. Measurements of PSV and EDV were obtained from the spectral display at the origin and proximal segments of each branch vessel. The highest angle-corrected PSV and EDV measurements were recorded for this study.

All studies were performed by credentialed sonographers and reviewed by board-certified radiologists. The data from each study were retrieved from a computer workstation, except for those examinations obtained before picture archiving and communications system installation, and were reviewed on cut film. Absence of flow was interpreted as arterial occlusion (Figure 4). Inferior mesenteric artery PSV, MAR, and EDV measurements were analyzed for each patient. The MAR was calculated as the PSV obtained from the IMA divided by the PSV obtained from the abdominal aorta at the level of the mesenteric arteries. Hemodynamically severe stenosis was defined as 50% or greater diameter reduction in the IMA on correlative imaging. With the results of correlative studies as the reference standard, Receiver operating characteristic (ROC) curve analysis using logistic regression was performed to determine threshold values for the PSV, EDV, and MAR for diagnosis of severe stenosis in the IMA. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the different diagnostic criteria were then evaluated from the statistically significant ($P < .05$) logistic model with the highest area under the ROC curve. The accuracy of Doppler sonography for identification of severe IMA stenosis was also calculated on the basis of this logistic model.

Logistic regression was used to produce ROC curves, and 2 × 2 tables were used to calculate the sensitivity, specificity, PPV, NPV, and accuracy.

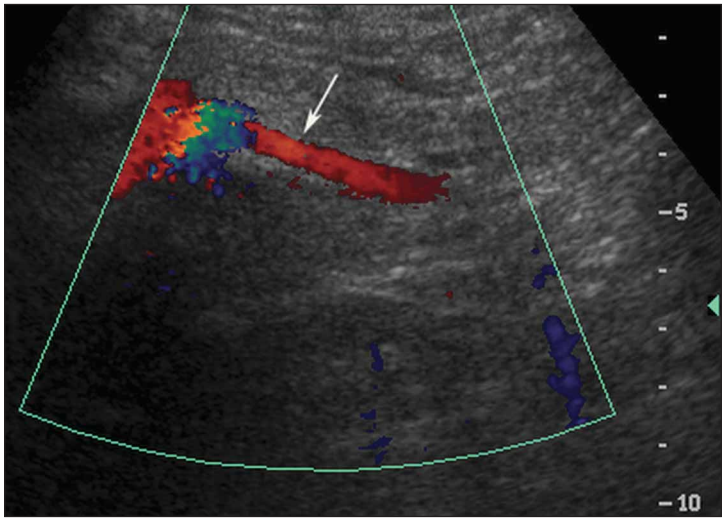
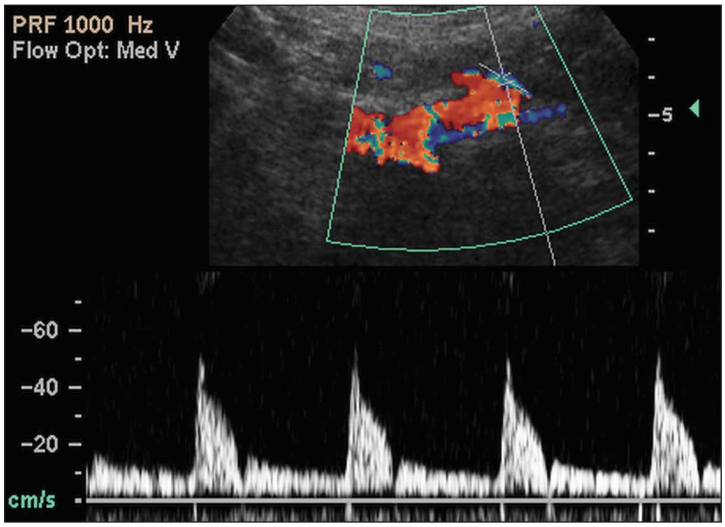


Figure 1. Color Doppler image of a normal IMA (arrow) arising from the anterior left lateral aspect of the aorta.

For each criterion, PSV, EDV, and MAR, a range of cut points was used to define the binary disease status of the independent predictor of a logistic regression model in which the binary disease status of the dependent variable or reference standard was defined from the results of the correlative studies (DSA, sonography, CTA and MRA). Each cut point produced a logistic regression model giving a *P* value of the independent predictor entered, the 2 × 2 table counts used to calculate the sensitivity and specificity, and the c

Figure 2. Color and pulsed Doppler image of a normal IMA showing a characteristic high-resistance waveform pattern.

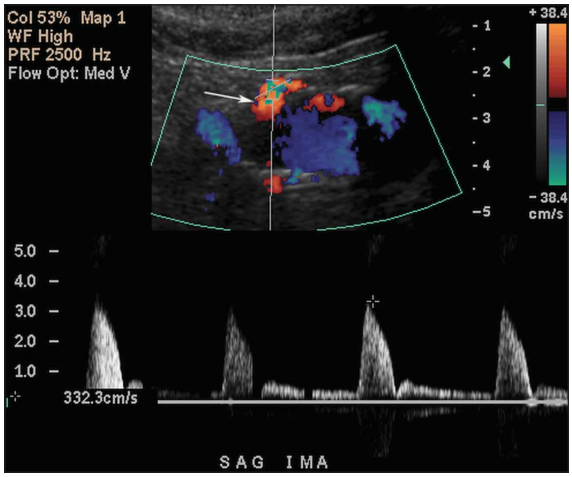


value, the area under the ROC curve produced from the model. The best cut point was chosen from the significant model ($P < .05$) with the highest values for sensitivity and specificity. Visual inspections of the ROC curves and their c values were also done to confirm the best cut point chosen, and 95% confidence intervals were calculated by the exact binomial method. A nonparametric comparison of the areas under the 3 (PSV, EDV, and MAR) ROC curves was used to test the null hypothesis of equal areas under the curves (%ROC macro; SAS Institute Inc, Cary, NC).

Results

The IMA was adequately visualized in 176 of 205 Doppler sonographic examinations (86%). The IMA was visualized in 42 of 50 Doppler studies reviewed with angiographic correlation (84%). Adequate visualization was defined by the ability to obtain color Doppler images and PSV measurements at the origin and proximal segments of the IMA. The IMA was visualized in 92% of the correlative studies; thus, the IMA was not visual-

A



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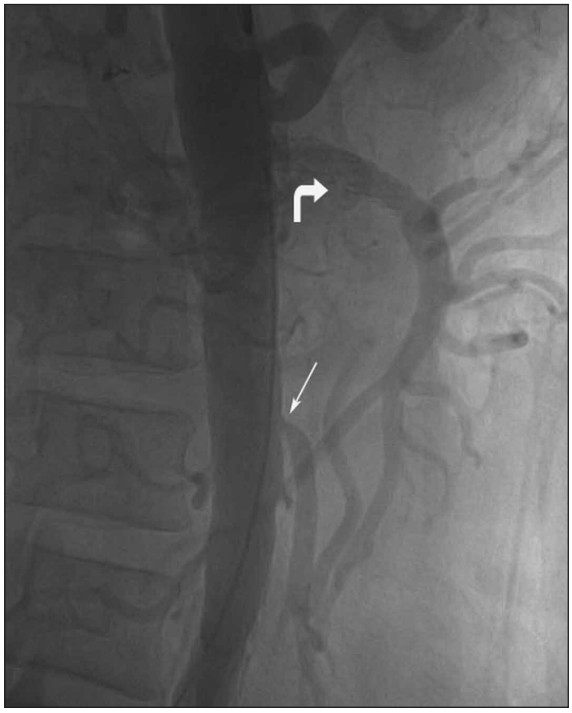

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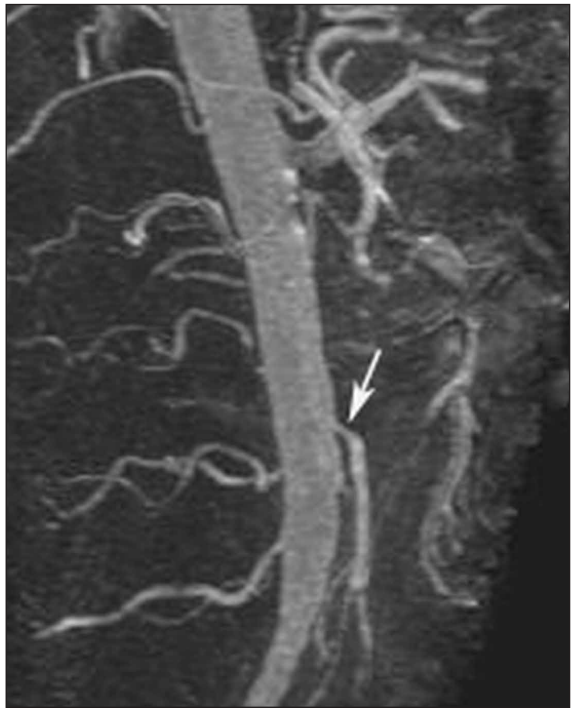


Figure 3. A, Color Doppler image showing color aliasing at the site of IMA stenosis (arrow). Pulsed Doppler sampling of the stenotic region shows elevated PSVs, consistent with hemodynamically severe stenosis. **B**, Conventional abdominal angiogram showing stenosis at the origin of the IMA (straight arrow). The SMA is identified above the IMA (curved arrow). **C**, Abdominal MRA showing stenosis at the origin and proximal segment of the IMA (arrow).

ized in 8% of the reference standard examinations. The IMA was not seen in 3 cases on either Doppler imaging or angiography, consistent with occlusion. The IMA was seen on angiography in the other 5 cases when it was not seen on Doppler imaging. The visualization rate for the detection of a patent IMA by Doppler sonography in this series was 90%.

Nine of the 50 sonographic examinations showed severe IMA stenosis on arteriography. Ranges of the PSV, EDV, and MAR were obtained in patients with nonstenotic and stenotic IMAs. The PSV, EDV, and MAR were chosen for this analysis because they are the standard criteria used in the detection of celiac artery and SMA disease. The range of PSV in the nonstenotic IMA was 70 to 200 cm/s. The range of the PSV in IMA stenosis was 200 to 485 cm/s. Receiver operating characteristic curve analysis was used to determine the threshold PSV for severe (>50%) IMA stenosis. A PSV of greater than 200 cm/s was found to be consistent with severe IMA stenosis, with sensitivity of 90%, specificity of 97%, and accuracy of 95%. The PPV was 90%, and the NPV was 97% ($P < .0001$; Table 1). There was 1 false-positive finding of stenosis that was detected at the threshold velocity of 200 cm/s. This was likely related to cardiac arrhythmia with a spurious elevation of the PSV.

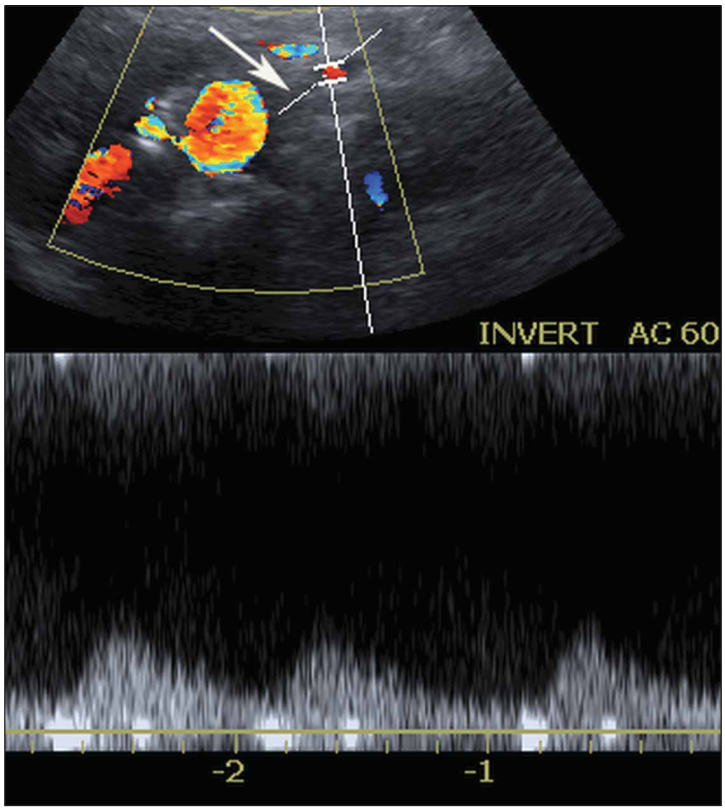
The range of the EDV in the nonstenotic IMA was 0 to 33 cm/s. The range of the EDV in IMA stenosis was 0 to 177 cm/s. Receiver operating characteristic curve analysis was used to determine the threshold EDV for severe (>50%) IMA stenosis. An EDV of greater than 25 cm/s was found to be consistent with severe IMA stenosis, with sensitivity of 40%, specificity of 91%, and accuracy of 79%. The PPV was 57%, and the NPV was 83% ($P < .0354$; Table 2).

The range of the MAR in the nonstenotic IMA was 0.7 to 3.7. The range of the MAR in IMA stenosis was 0.69 to 8.1. Receiver operating characteristic curve analysis was used to determine the threshold MAR for severe (>50%) IMA stenosis. An MAR of greater than 2.5 was found to be consistent with severe IMA stenosis, with sensitivity of 80%, specificity of 88%, and accuracy of 86%. The PPV was 67%, and the NPV was 93% ($P < .0005$; Table 3).

Logistic regression analysis of the Doppler diagnostic criteria for IMA stenosis showed that the PSV at the threshold value of 200 cm/s was the best criterion for detection of hemodynamically severe IMA stenosis, with sensitivity of 90% and specificity of 97% ($P < .0001$). Criteria based on EDV and MAR measurements showed lower sensitivity and specificity. In addition, comparisons of the areas under the 3 correlated ROC curves were found to be significantly different ($P = .0246$). Both PSV and MAR ROC curves were significantly different from the EDV ROC curve ($P < .0336$ and $< .0072$, respectively; Table 4 and Figure 5).

On the basis of the PSV criterion alone, 10 hemodynamically severe IMA stenoses were identified on Doppler sonography. Nine of these lesions were subsequently confirmed on correlative studies, with 1 false-positive result. This patient, without severe IMA stenosis on angiography, had a PSV of 200 cm/s, the cutoff point for

Figure 4. Color Doppler image showing the absence of color flow at the origin of the IMA, consistent with occlusion (arrow). Pulsed Doppler imaging reveals tardus parvus waveforms in the reconstituted distal IMA segment.



severe stenosis. Substantial cardiac arrhythmia was identified on the spectral tracings obtained during pulsed Doppler sampling, which produced marked variability in the PSV measurement and resulted in elevated velocities.

Discussion

There are few studies that attempted to identify the IMA with Doppler sonography. Denys et al[21] showed that the IMA was seen in 92% of cases in their study of 100 consecutive patients. This study was performed in fasting patients referred for routine abdominal sonography for various clinical problems and without apparent vascular disease. Criteria for exclusion from their study included clinical signs of vascular disease, signs of atherosclerosis of the aorta, celiac artery, or SMA, and a nonfasting state. The authors did not determine the normal velocity range for the IMA in their study.

Table 1. Best PSV Cut Point Found at 200 cm/s (Evaluated From 180–250 cm/s): Logistic Regression Model With $P > .0001$

	Reference Standard		
Criterion	**Positive Disease**	**Negative Disease**	**Total**
Positive disease	9	1	10
Negative disease	1	31	32
Total	10	32	42
	Exact 95% Binomial Confidence Interval		
Sensitivity, %	90	56–99	
Specificity, %	97	84–99	
PPV, %	90	56–99	
NPV, %	97	84–99	
Accuracy, %	95	84–99	

Table 2. Best EDV Cut Point Found at 25 cm/s (Evaluated From 25–55 cm/s): Logistic Regression Model With $P < .0354$

	Reference Standard		
Criterion	**Positive Disease**	**Negative Disease**	**Total**
Positive disease	4	3	7
Negative disease	6	29	35
Total	10	32	42
	Exact 95% Binomial Confidence Interval		
Sensitivity, %	40	12–74	
Specificity, %	91	75–98	
PPV, %	57	18–90	
NPV, %	83	66–93	
Accuracy, %	79	63–90	

Table 3. Best MAR Cut Point Found at 2.5 (Evaluated From 2–4.5): Logistic Regression Model With $P < .0005$

	Reference Standard		
Criterion	**Positive Disease**	**Negative Disease**	**Total**
Positive disease	8	4	12
Negative disease	2	28	30
Total	10	32	42
	Exact 95% Binomial Confidence Interval		
Sensitivity, %	80	44–98	
Specificity, %	88	71–97	
PPV, %	67	35–90	
NPV, %	93	78–99	
Accuracy, %	86	72–95	

Table 4. Receiver Operating Characteristic Curve Analysis

ROC Curve Areas and 95% Confidence Intervals				
Criterion	**ROC Area**	**SE**	**Confidence Limits**	
PSV	0.9031	0.0969	0.7132	1.0931
EDV	0.6594	0.1122	0.4395	0.8793
MAR	0.9563	0.028	0.9013	1.0112

Tests of 95% Confidence Intervals for Pair-Wise Comparisons						
Criterion	**Estimate**	**SE**	**Confidence Limits**		χ^2	$P > \chi^2$
PSV vs EDV	0.2437	0.1147	0.0189	0.4686	4.5151	.0336
PSV vs MAR	–0.0531	0.0918	–0.233	0.1268	0.3351	.5627
EDV vs MAR	–0.2969	0.1105	–0.5135	–0.0802	7.2129	.0072

Comparison Test Results		
χ^2	*df*	$P > \chi^2$
7.409	2	.0246

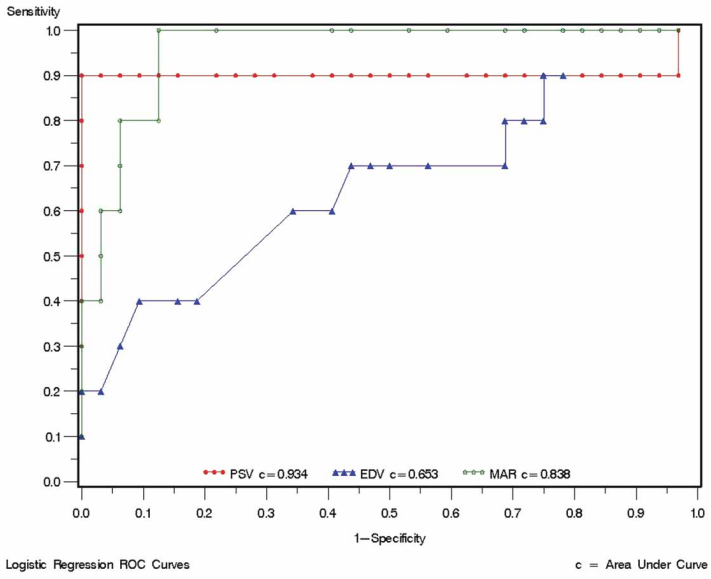
In their series of 116 patients without evident splanchnic vascular disease, Mirk et al[22] identified the IMA in 88.8% of examinations. All patients were fasting before the examinations and were referred for a variety of nonvascular reasons. Peak velocity values ± SD for the IMA were 1.41 ± 0.48 m/s. The minimal diastolic velocity was 0.1 ± 0.16 m/s. They also found a larger vessel size and increased flow volumes in patients older than 50 years.

Erden et al[23] analyzed IMA Doppler waveform changes and IMA size in patients with aortic, splanchnic, or iliac vascular disease. Thirty-three patients with documented arterial vascular disease by DSA were examined with Doppler sonography and categorized to the level of disease. The IMA was identified in 91% of cases. A high-resistance waveform was obtained in unaffected patients, with a PSV of 0.98 ± 0.3 m/s, an EDV of 0.11 ± 0.05 m/s, and a resistive index of 0.89 ± 0.06. With SMA occlusion, flow in the IMA changed to a high-velocity, low-resistance monophasic pattern with a 10-fold increase in blood flow volume. Low-velocity monophasic flow was identified in the IMA in patients with aortic occlusion. They postulated that the IMA PSV, EDV, resistive index, and volume flow vary according to the degree of collateralization.

In this study, the IMA was successfully identified in 86% of all Doppler examinations and 84% of cases with angiographic correlation. The IMA was not seen in 3 cases on either sonography or angiography, consistent with occlusion. Thus, the accuracy for visualization of the IMA was 90% with Doppler sonography compared with angiography. This was very similar to previously reported results from Denys et al[21] (92%), Mirk at al[22] (88.8%) and Erden et al[23] (91%).

It is important to note that the IMA was 1 of 2 stenotic mesenteric arteries in 12 patients in our review of 205 studies. The IMA was also the second stenotic vessel in 4 cases in our group with angiographic correlation. The diagnosis of CMI could not have been made in these patients without routine evaluation of the IMA.

Figure 5. Receiver operating characteristic curves for sonography to determine IMA stenosis using the PSV, EDV, and MAR. Test of null hypothesis: equal areas under curves, $P = .0246$.



Three Doppler parameters were selected for our analysis of severe IMA stenosis; the PSV, EDV, and MAR were chosen because they were validated in previous studies and are currently used in the Doppler examination of the celiac artery and SMA. In our comparison of different Doppler velocity parameters to identify severe (>50% diameter reduction) stenosis in the IMA, we found that the PSV was the most reliable criterion. A threshold velocity of 200 cm/s was found to be consistent with IMA stenosis, with sensitivity of 90%, specificity of 97%, and accuracy of 95%. The EDV and MAR showed lower sensitivity and specificity for high-grade stenosis. Nine of the 10 severe stenoses were identified with this threshold velocity. There was 1 false-positive finding of stenosis that was detected at the threshold velocity of greater than 200 cm/s. This was likely related to cardiac arrhythmia with spurious elevation of the PSV.

Several pitfalls may be encountered during Doppler sonographic evaluation of the mesenteric arteries. Peak systolic velocities may be abnormally low or elevated for reasons other than arterial stenosis. Factors that affect the PSV in the mesenteric arteries include cardiac arrhythmia, high- or low-flow states, and compensatory flow in the IMA in patients with celiac artery or SMA stenosis or occlusion.[23]

One false-positive finding was identified in a patient with cardiac arrhythmia. In patients with cardiac arrhythmia, fluctuation of the PSV is directly dependent on the cardiac stroke volume and the type of arrhythmia. In general, elevated velocities will be observed with severe stenosis of the IMA, although the PSV measurement will vary with the severity of cardiac arrhythmia.[24] In patients with low systemic blood pressure due to cardiac disease, shock, or sepsis, the velocities in the main mesenteric vessels may be abnormally low and may not reach the critical value characteristic of stenosis. Conversely, elevated velocities may be detected in pregnant patients and patients with high cardiac output in the absence of arterial stenosis. In these situations, we generally compare the PSV in the mesenteric artery with the PSV in the aorta. Similar to carotid Doppler studies, the PSV ratio is useful for characterizing stenosis in patients with high- and low-velocity states. The ratio of the PSV in the normal mesenteric artery to the PSV in the aorta is approximately 1. A MAR of grater than 2.5:1 is suspicious for severe stenosis.

Less commonly, increased PSVs in the IMA may be detected in the setting of celiac and SMA stenosis or occlusion. This increased or compensatory flow may drive the PSV above the threshold velocity for severe stenosis. In this setting, the IMA is typically enlarged with increased systolic and diastolic velocities. This phenomenon of compensatory flow depends on the degree of collateralization and vasodilatation of the mesenteric bed. Therefore, careful assessment of the size and flow pattern of the IMA (or other mesenteric artery) as well as identification of adjacent mesenteric arterial disease should alert the examiner to this pitfall. Detection of poststenosis turbulence, bruit artifacts, and tardus parvus waveforms will confirm the presence of severe stenosis of the IMA.

It is essential to recognize that several factors play a role in the visualization of the IMA with Doppler sonography. A large body habitus may preclude adequate visualization of the IMA in some patients. Perhaps more importantly, marked bowel gas may obscure the distal abdominal aorta and branch vessels. We advise our patients to fast before abdominal Doppler studies to improve visualization of these arteries. A very small-caliber IMA or anatomic variation may also challenge the examiner in pursuit of the IMA.

Sonography offers several advantages over CT and magnetic resonance imaging (MRI) in the evaluation of the IMA and mesenteric arteries. The normal IMA is usually a small-caliber vessel and may be difficult to identify with CT or MRI. The ostium of the IMA may be difficult to evaluate with arteriography, CTA, or MRA because of vessel tortuosity. Doppler sonography may show improved visualization of a tortuous vessel by changing the angle of insonation. Compared with arteriography, CTA, and MRA, Doppler sonography is relatively inexpensive and noninvasive and does not require contrast material or ionizing radiation. This is particularly relevant to patients with known allergies to contrast material, renal insufficiency, or renal failure. Computed tomographic and MRI contrast agents may be contraindicated in patients with renal dysfunction. Thus, in many ways, a Doppler examination plays a complementary role to CTA and MRA.

Limitations of this particular study included the small patient sample volume size. This can be explained by the inclusion for analysis of only those Doppler studies with angiographic correlation. Correlative studies were not obtained in all patients with positive Doppler findings. The decision to perform correlative angiography was made by the referring physician on the basis of clinical considerations. Patients with single-vessel disease on Doppler sonography were not routinely sent for angiographic correlation.

Another potential limitation was that CTA and MRA were used as the reference standards along with DSA. Few studies have documented the accuracy of CTA or MRA in the evaluation of mesenteric arterial occlusive disease.[25–29] Nevertheless, in many centers, MRA and CTA are used as first-line diagnostic examinations for the diagnosis of visceral artery disease rather than subjecting patients to the potential risks and complications of invasive angiography.

In conclusion, we think that the detection of IMA stenosis is essential for proper evaluation of patients with suspected CMI and should be included in the Doppler sonographic examination of all patients with suspected CMI. Doppler sonography identifies the IMA in most patients evaluated for abdominal pain. A threshold PSV of greater than 200 cm/s in the IMA is diagnostic for severe stenosis. Doppler sonography is inexpensive and noninvasive and does not require exposure to ionizing radiation or contrast material, thus offering considerable advantages over DSA, CT, and MRI in the evaluation of visceral artery disease.

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