Mesenteric and celiac duplex scanning: A validation study

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Purpose: **To validate the accuracy of previously established duplex ultrasound criteria for ≥50% superior mesenteric artery (SMA) and celiac artery (CA) stenosis by comparison with arteriography.**

Methods: **Duplex criteria established retrospectively in our laboratory in 1991 identified an end-diastolic velocity (EDV) ≥45 cm/sec, or no flow signal, as highly sensitive (100%) and specific (92%) indicators for SMA stenosis ≥50% or occlusion. EDV was more accurate (95%) than peak systolic velocity (PSV), which had a maximal accuracy of 86% at a PSV ≥300 cm/sec, with low sensitivity (62%), but high specificity (100%). For CA, accurate velocity thresholds were not identified, but we subsequently noted that retrograde common hepatic artery flow direction from SMA collateral was highly predictive of severe CA stenosis or occlusion. Since publication of those findings, 243 mesenteric duplex scans were performed for clinical evaluation of suspected chronic mesenteric ischemia. Angiographic confirmation was available for a subset of 46. SMA and CA diameters were measured on lateral aortograms by observers blinded to the duplex results, and the original duplex diagnostic criteria were tested for accuracy. In addition, receiver operator characteristic curve analysis was performed on the velocity data to identify the most accurate velocity thresholds in the new data.**

Results: **Duplex was technically adequate in 98% of SMA, 96% of CA, and 89% of hepatic arteries, and arteriograms were adequate in 100% of SMA and 98% of CA. For the SMA, EDV ≥45 cm/sec again provided the best sensitivity (90%), specificity (91%), positive predictive value (90%), negative predictive value (91%), and overall accuracy (91%). As in the retrospective study, PSV ≥300 cm/sec provided low overall accuracy (81%), low sensitivity (60%), but high specificity (100%). Lowering the PSV threshold improved sensitivity but reduced accuracy. For CA, retrograde common hepatic artery flow direction was 100% predictive of severe CA stenosis or occlusion. Velocity data in CA provided accuracy not found in the original study. EDV ≥55 cm/sec or no flow signal had best overall accuracy (95%) with high sensitivity (93%) and specificity (100%). PSV ≥200 cm/sec or no signal also had excellent accuracy (93%), sensitivity (93%), and specificity (94%). In addition, three of four anatomic anomalies were correctly identified by duplex. These included one right hepatic and one common hepatic artery originating from the SMA, and one common celiacomesenteric trunk.**

Conclusion: **This validation analysis confirms that duplex velocity criteria are accurate in the identification of mesenteric occlusive disease. Retrograde common hepatic artery flow direction correctly predicts severe CA stenosis or occlusion. Duplex ultrasound may also identify mesenteric anatomic variants that can influence study interpretation. (J Vasc Surg 1998;27:1078-88.)**

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Jager et al.[1] originally suggested that duplex ultrasound might serve as a screening test for chronic mesenteric ischemia. They identified elevated celiac artery (CA) and superior mesenteric artery (SMA) blood flow velocities in a patient with postprandial abdominal pain, diarrhea, and weight loss. Arteriography subsequently confirmed the presence of severe stenosis in these vessels. In 1991, Moneta et al.[2] published Doppler velocity thresholds for SMA and CA stenosis on the basis of a retrospective

comparison of duplex ultrasound data with mesenteric stenosis measurements from lateral aortograms in 34 patients. That study identified peak systolic velocity (PSV) thresholds, or the absence of flow signals in an identified artery, as accurate parameters in the identification of ≥70% splanchnic arterial stenosis or occlusion. Later the same year, our group published a similar retrospective comparison on the basis of a cohort of 24 symptomatic patients. In contrast to the Moneta article, we found end-diastolic velocity (EDV) more accurate than PSV in the diagnosis of SMA stenosis.[3] Our analysis of CA Doppler velocity data failed to identify accurate threshold values because two patients with severe CA stenosis had low rather than high Doppler velocities. We speculated that the presence of generous collateral circulation from the SMA through the gastroduodenal arcade could provide an alternate source of arterial inflow such that velocities across a severe CA stenosis might not increase as much as expected. Indeed, in a later publication, we pointed out that reversal of blood flow direction within the common hepatic artery because of SMA collateral was highly predictive of severe CA stenosis or occlusion.[4]

In 1993, Moneta et al[5] published the first prospective validation of mesenteric diagnostic criteria.[5] One hundred patients who underwent lateral aortography for a variety of indications were studied with mesenteric duplex scanning. Excellent accuracy for the originally identified PSV thresholds was confirmed in the SMA and the CA. Later that year, Harward et al.[6] published a series confirming the ability of duplex to accurately identify ≥50% SMA and CA stenosis, but this group analyzed their Doppler data expressed as frequency shift rather than velocity. They did not attempt to validate either the Moneta[2] or Bowersox[3] criteria. The first confirmation of mesenteric duplex thresholds identified in one laboratory then validated by another appears to have been published by Perko et al.[7] in 1997. Although this Copenhagen group emphasized the importance and accuracy of diastolic velocities in evaluation of mesenteric occlusive disease, they also found 90% accuracy for the SMA and 94% accuracy for the CA when the Moneta PSV criteria were tested against angiographic stenosis of ≥50%. The current study provides more focus on this issue with a prospective validation analysis of our original diagnostic criteria.[3,4] We retested the EDV and PSV thresholds for the SMA and did a follow-up analysis on the ability of retrograde common hepatic arterial flow to predict severe CA stenosis or occlusion. A fresh receiver operator curve accuracy analysis was also performed on PSV and EDV from these data. In addition, we addressed the ability of duplex ultrasound to identify anatomic variants in mesenteric anatomy because these occur frequently.

METHODS

Patient selection. The Dartmouth-Hitchcock Medical Center vascular laboratory database was reviewed to identify all patients who underwent mesenteric duplex scanning after completion of our initial series. Patients were included if the indication for duplex examination was evaluation of suspected chronic mesenteric ischemia. We excluded those patients who underwent mesenteric scanning to evaluate previous splanchnic revascularization, portal venous disease, or other suspected abdominal pathology. This left a cohort of 243 patients, including including 46 who underwent contrast injection angiography within 2 months of the duplex examination. These patients comprise the study group for this report. In two instances, duplex examinations were requested only for the CA, resulting in a sample size of 46 for the CA and 44 for the SMA.

Mesenteric duplex scanning. Registered vascular technologists in our clinical laboratory performed the duplex scanning. These seven individuals have extensive scanning experience, but none are dedicated research sonographers. The scans were routine clinical examinations, not investigative procedures. Technologists were unaware of the angiographic results, even in the rare case when the angiogram preceded duplex scanning. Patients were studied after an overnight fast because food intake is known to substantially alter mesenteric velocities and waveform characteristics.[8] The majority of patients underwent a cathartic bowel preparation the night before the study. At the discretion of the ordering physician, a small number of patients did not take cathartics.

We performed the majority (80%) of these studies using a Siemens Q2000 colorflow scanner with an 3C40D probe (Siemens Medical Systems, Issaquah, Wash.). This scanhead has imaging and Doppler transmitting frequencies of 3.0 MHz. Five studies (11%) were performed on with an ATL HDI3000 colorflow scanner and a C4-2 probe (Advanced Technology Laboratories, Inc., Bothell, Wash.). This transducer has an imaging frequency of 4.0 to 2.0 MHz and a Doppler frequency of 2.5 MHz. We completed four studies (9%) on a Diasonics DRF-400 gray-scale scanner with using a 3.0 MHz imaging and 2.25 MHz pulsed Doppler probe (Diasonics Inc., Milpitas, Calif.). This differed from our original study, which used the Diasonics DRF-400 to perform all examinations.

The following is the duplex scan protocol. The CA and SMA are identified in sagittal approach with an effort made to identify both vessel origins along the anterior surface of the aorta in a single view. The CA is followed from its origin to the bifurcation into common hepatic and splenic arteries. Velocity measurements are taken in the CA, and flow direction and Doppler velocities are sampled in the common hepatic artery. Likewise, the SMA is evaluated from its origin distally. Close attention is paid to sample volume angle correction during determination of velocities, and velocity determinations are made only at Doppler angles of 60 degrees or less.[9] Inability to obtain a Doppler flow signal with the sample volume placed within a well-imaged vessel is interpreted as representing a total arterial occlusion. When the SMA is found to have a nonturbulent biphasic waveform rather than the normal triphasic waveform, the technologist searches carefully for a replaced hepatic artery. This vessel can be seen as a large branch arising from the right lateral aspect of the SMA and heading directly toward the liver. Likewise, when any other unusual anatomy is encountered, the known anatomic variants are considered in formulation of the study interpretation.

Angiography. Standard Seldinger technique and biplanar imaging was used to perform aortograms. Most studies used a combination of digital subtraction and traditional "cut" film technique, with a trend toward exclusive use of digital subtraction in recent years. Individuals who were not aware of the duplex results reviewed lateral projections and used electronic calipers to measure CA and SMA. Percent stenosis was calculated by comparing the width of the contrast column within the stenosis with the closest normal distal diameter, excluding any regions of poststenotic dilatation.

Data analysis. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated by standard formulae, and receiver operator characteristic (ROC) curves for PSV and EDV were constructed.[10] Hepatic artery flow reversal by duplex was tested for its ability to predict CA stenosis or occlusion as identified on angiograms. Anatomic variants identified by duplex scanning were compared with angiographic findings.

RESULTS

Patients. Forty-six duplex scans were performed within 2 months of angiography in 45 patients. Mean patient age was 69 years with a standard deviation of 9.6 years and a range from 44 to 91 years. Thirty-one of these patients (69%) were female. The group had a high incidence of severe mesenteric occlusive disease, with 53% of the women and 36% of the men undergoing revascularization after the diagnostic studies. Nineteen procedures were surgical (86%), and three patients underwent percutaneous intervention (14%).

Angiography. The SMA had 0% to 49% stenosis on 23 (52%) of the angiograms, and 21 (48%) of the visualized SMA had 50% to 99% stenosis (n = 15) or were occluded (n = 6). Two studies in the 50% to 99% group had severe SMA stenosis that was not quantifiable because occlusive disease extended throughout the length of the visualized segment, rendering measurement of a normal distal diameter impossible. In each case, the original interpreting radiologist who performed the study described the vessel as severely stenotic on the basis of decreased flow of contrast. In addition, surgical exploration confirmed clinically significant stenosis in both cases. Thus, the 50% to 99% angiographic stenosis group included these two cases for duplex comparison despite the absence of a numerical stenosis measurement. For the CA, 18 angiograms (39%) revealed a normal or minimally stenotic vessel, and 27 (59%) had 50% to 99% stenosis (n = 16) or were occluded (n = 11). One CA did not visualize adequately for measurement, and the patient did not undergo mesenteric revascularization. Thus, there was no basis for comparison, and the patient's CA duplex results were excluded from further analysis.

Mesenteric duplex scanning. We obtained interpretable duplex data from 44 of 46 CA (96%), 41 of 46 of common hepatic arteries (89%), and 43 of 44 SMA (98%). Comparison of the SMA duplex velocity data with angiographic stenosis measurements confirmed an EDV of ≥45 cm/sec, or the absence of flow signal, as an accurate duplex ultrasound threshold for identification of a ≥50% SMA stenosis with a sensitivity of 90%, specificity of 91%, PPV of 90%, NPV of 91%, and an overall accuracy of 91% (Table I; Fig. 1). Accuracy values were similar at EDV thresholds of 55 cm/sec and 65 cm/sec, but overall accuracy decreased for EDV thresholds above 65 cm/sec or lower than 45 cm/sec. This SMA accuracy analysis includes two patients for whom findings other than the velocity readings influenced original duplex interpretation. In one patient, we clearly identified a replaced right hepatic artery originating from the right lateral aspect of the SMA and extending to the porta hepatis. Although the EDV in the SMA was 68 cm/sec, the waveform was crisp, biphasic, and had a clear systolic window. The velocity profile was uni-

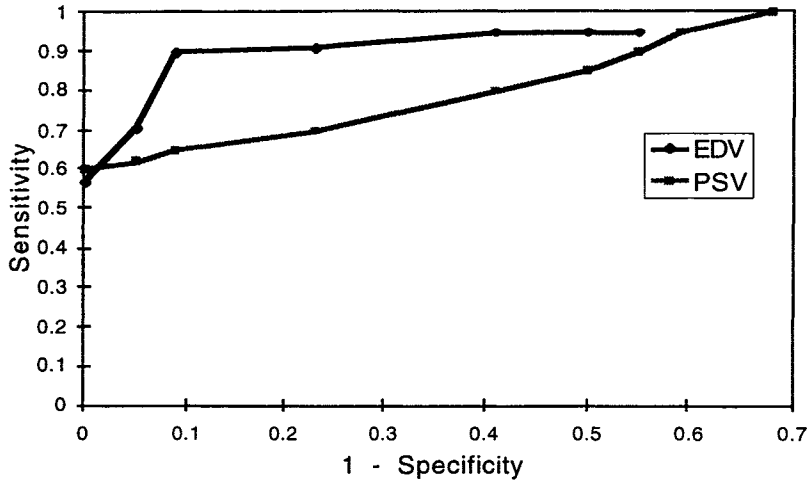

Fig. 1. ROC curves for PSV and EDV accuracy in the SMA. EDV curve reveals higher sensitivity and specificity throughout. Inflection point of maximal accuracy for EDV is at 45 cm/sec.

Table I. Accuracy of end diastolic velocity (EDV) and peak systolic velocity (PSV) for identification of SMA stenosis*

No flow signal or EDV ≥:	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*Accuracy*
25 cm/sec	0.95	0.32	0.57	0.88	0.63
35 cm/sec	0.95	0.59	0.69	0.93	0.77
45 cm/sec	**0.90**	**0.91**	**0.90**	**0.91**	**0.91**
55 cm/sec	0.90	0.91	0.90	0.91	0.91
65 cm/sec	0.90	0.91	0.90	0.91	0.91
75 cm/sec	0.81	0.91	0.89	0.83	0.86
85 cm/sec	0.71	0.95	0.94	0.78	0.84
95 cm/sec	0.67	0.95	0.93	0.75	0.81
105 cm/sec	0.57	1.00	1.00	0.71	0.79
No flow signal or PSV ≥:	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*Accuracy*
150 cm/sec	1.00	0.32	0.57	1.00	0.64
175 cm/sec	0.95	0.41	0.59	0.90	0.67
200 cm/sec	0.85	0.50	0.61	0.79	0.67
225 cm/sec	0.80	0.59	0.64	0.76	0.69
250 cm/sec	0.70	0.77	0.74	0.74	0.74
275 cm/sec	0.65	0.91	0.87	0.74	0.79
300 cm/sec	**0.60**	**1.00**	**1.00**	**0.73**	**0.81**

* Most accurate EDV identified in original study, ≥45 cm/sec (in bold) is confirmed in validation set. Most accurate value identified in original study, ≥300 cm/sec (in bold) is also confirmed.

form along the SMA with no focal elevation. Because of these findings, the interpreting physician noted the elevated SMA EDV was more likely attributable to hepatic blood flow than to presence of a stenosis. The angiogram verified this conclusion, and we considered the study a true negative in the validation analysis. A second study with an SMA EDV of 44 cm/sec was interpreted as positive by the original reader because the velocity was obtained just beyond, rather than in, the apparent region of greatest stenosis. We agreed with the rationale that higher velocities would have been obtained if the technologist had been able to sample the worst spot, and we called this a true positive in the validation analysis despite a velocity just below threshold. If these two special cases are excluded from the accuracy calculations, sensitivity, specificity, and overall accuracy remain essentially unchanged at 90%, 90%, and 90%, respectively.

PSV was less accurate than EDV in the diagnosis of an SMA stenosis. A threshold ≥300 cm/sec resulted in the highest attainable PSV accuracy of 81%, with low sensitivity (60%), but high specificity

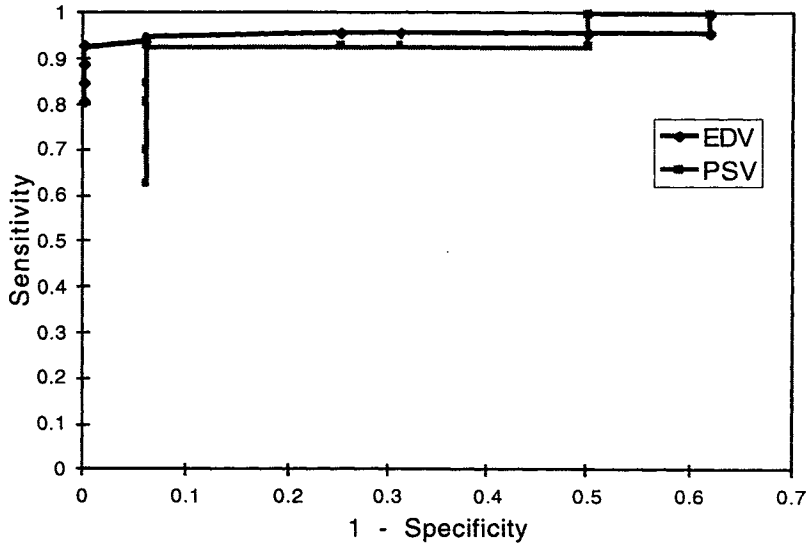

Fig. 2. ROC Curves for PSV and EDV accuracy in the CA. PSV and EDV curves are virtually superimposed, both with high accuracy. Inflection point of maximal accuracy is at 55 cm/sec for EDV and 200 cm/sec for PSV.

Table II. Accuracy of end diastolic velocity (EDV) and peak systolic velocity (PSV) for identification of CA stenosis*

No flow signal or EDV ≥:	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*Accuracy*
25 cm/sec	1.00	0.38	0.73	1.00	0.78
35 cm/sec	0.96	0.38	0.72	0.86	0.74
45 cm/sec	0.96	0.75	0.87	0.92	0.88
55 cm/sec	**0.93**	**1.00**	**1.00**	**0.89**	**0.95**
65 cm/sec	0.89	1.00	1.00	0.84	0.93
75 cm/sec	0.85	1.00	1.00	0.80	0.91
85 cm/sec	0.85	1.00	1.00	0.80	0.91
95 cm/sec	0.81	1.00	1.00	0.60	0.88
No flow signal or PSV ≥:	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*Accuracy*
125 cm/sec	1.00	0.50	0.77	1.00	0.81
150 cm/sec	0.93	0.50	0.76	0.80	0.77
175 cm/sec	0.93	0.69	0.83	0.85	0.84
200 cm/sec	**0.93**	**0.94**	**0.96**	**0.88**	**0.93**
225 cm/sec	0.85	0.94	0.96	0.78	0.88
250 cm/sec	0.81	0.94	0.96	0.75	0.86
275 cm/sec	0.70	0.94	0.95	0.65	0.81
300 cm/sec	0.63	0.94	0.95	0.60	0.74

* Value with highest accuracy in bold.

(100%). Reducing the PSV threshold to lower velocity values increased sensitivity, but overall accuracy decreased because the number of false positives increased faster than the rate at which false negatives decreased (Table I; Fig. 1).

Doppler velocity criteria were accurate in the diagnosis of CA stenosis. For identification of a ≥50% CA stenosis or occlusion, an EDV of ≥55 cm/sec or the absence of flow signal resulted in a sensitivity of 93%, specificity of 100%, and overall accuracy of 95% (Table II; Fig. 2). PSV was also accurate for diagnosis of CA stenosis or occlusion. A PSV of ≥200 cm/sec or absence of flow signal resulted in a sensitivity of 93%, specificity of 94%, and overall accuracy of 93% (Table II; Fig. 2).

Analysis of retrograde blood flow in the common hepatic artery was again uniformly predictive of severe CA stenosis or occlusion. Fig. 3 shows an example of

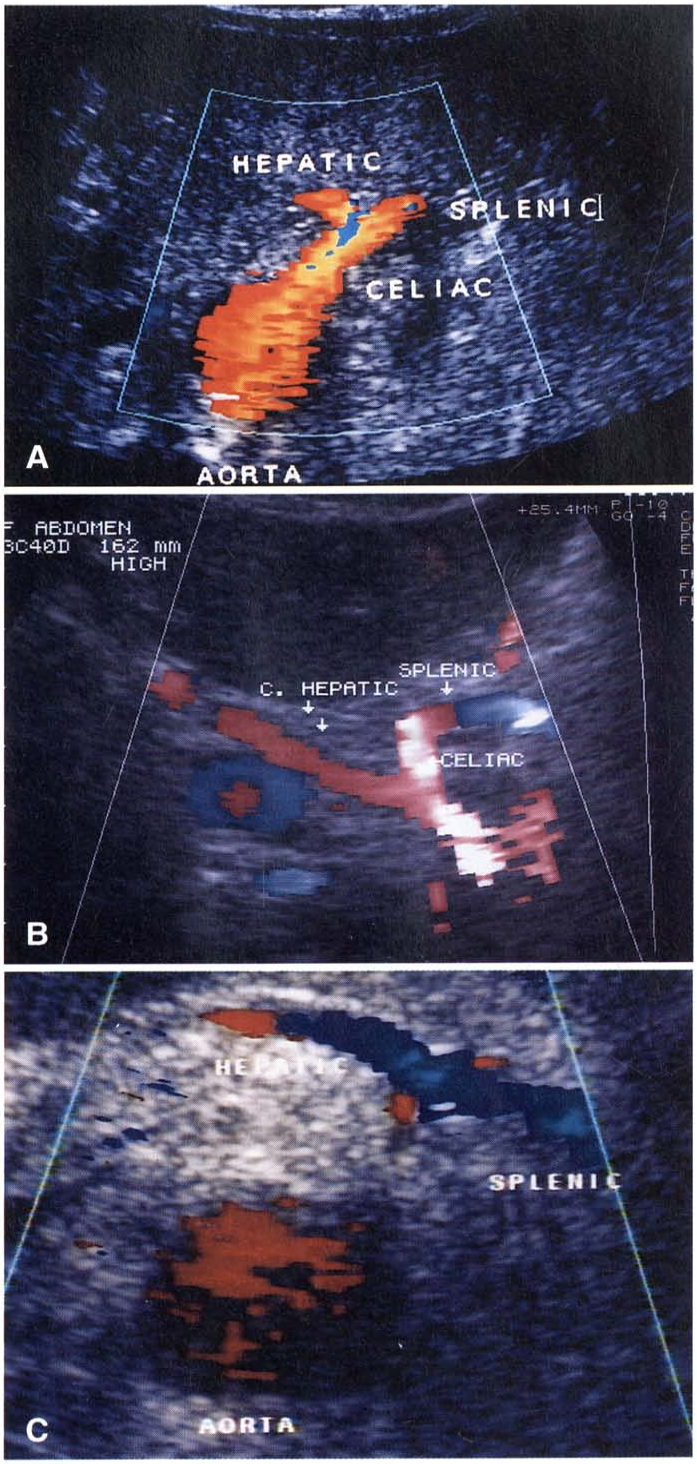

Fig. 3. Colorflow duplex appearance of aorta and celiac axis in transverse image plane. **A,** Antegrade blood flow in celiac artery fills origins of the common hepatic and splenic arteries. **B,** Normal celiac bifurcates into common hepatic and splenic arteries, with antegrade blood flow in each branch identified by red color tag identifying flow towards the transducer. Bifurcation of celiac is the "seagull sign" used by sonographers. **C,** In case of occluded celiac, aorta is visible, but one cannot identify flow in location where celiac should be. Blood flow in common hepatic and splenic is in same direction, away from the duplex probe, as signified by uniform blue color assignment and confirmed by Doppler. This should not be the case if flow were traveling through a patent celiac into the two main branches. Findings predict a severe CA stenosis or complete occlusion.

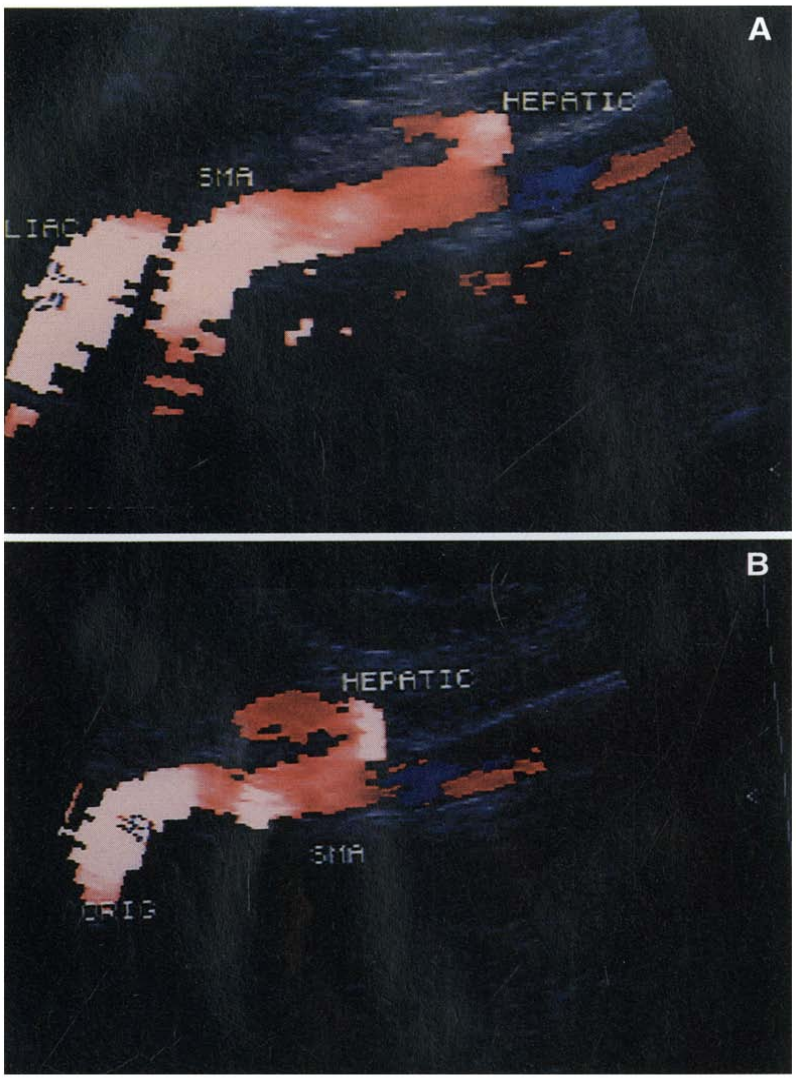

Fig. 4. Sagittal view of aorta with both CA and SMA origins identified on a single screen. **A,** This is a typical starting point for most exams to gain appreciation of proximity and relative location of the vessels. This approach is also useful to avoid misinterpretation of an occasional renal artery that may arise anteriorly from the aorta. In this particular case, an unusually large branch arose from the proximal SMA. PSV in the SMA was normal. The Doppler waveform had no significant spectral broadening, but displayed elevated end-diastolic flow atypical for the SMA in a fasting patient. **B,** Further evaluation of the branch revealed that it traveled directly to the porta hepatis. Since another artery had been identified originating from the celiac and leading to the porta, the anomalous SMA branch was identified as a replaced right hepatic rather than a replaced common hepatic. Angiography confirmed the findings.

a normal colorflow CA duplex image and an example of retrograde common hepatic flow with an occluded CA. Eight duplex studies identified retrograde hepatic flow. Angiography confirmed CA occlusion in six of these, and the other two had stenoses of 80% and 87%, making the PPV of this finding 100% for CA occlusion or severe stenosis. Retrograde hepatic flow failed to identify five of the CA occlusions. In four of these, the hepatic artery simply did not visualize well. In the remaining case, the right hepatic was correctly identified as originating from the SMA, and the left hepatic was not identified.

Duplex scanning correctly identified three of four major anatomic anomalies in this patient study group. The angiograms revealed replaced hepatic arteries in two of the 46 cases (Fig. 4). One was the

Table III. Anatomic variants identified by means of duplex ultrasound, and established incidence per Kadir[15]

Anomaly identified on angiogram	*Anomaly identified by duplex (before angiogram)*	*Incidence*
Replaced right hepatic from SMA	Yes	17%
Replaced common hepatic from SMA	Yes	2.5%
Common hepatic originating from aorta	No	2%
Common Celiacomesenteric origin from aorta	Yes	<1%

more common form, a replaced right hepatic, and the other was a replaced common hepatic. The duplex examination correctly identified both of these, on the basis of the finding of a low resistance biphasic rather than triphasic waveform, in addition to visual identification of a large SMA branch directed toward the liver. Finally, the duplex also correctly identified the relatively rare finding of a common celiacomesenteric trunk. Table III cites the incidence of these anomalies.

DISCUSSION

This validation analysis confirms the ability of duplex ultrasound scanning to identify stenotic SMA. As in our original report, we found a threshold EDV ≥45 cm/sec, or no flow signal, the most accurate mesenteric duplex scanning diagnostic parameter for identification of a ≥50% SMA stenosis or occlusion, providing an overall accuracy of 91%. The EDV accuracy of 91% was better than any identifiable PSV threshold.[3] For the CA, we confirmed the original observation that identification of retrograde flow in the common hepatic artery is highly predictive of severe CA stenosis or occlusion.[4] In this study group, the PPV of retrograde hepatic artery flow was 100% for major CA disease. The common hepatic artery is a relatively easy vessel to identify by duplex in its laterally-directed course from the celiac axis to the liver. Evaluation of this artery may be especially helpful in situations where the celiac origin is tortuous, difficult to sample accurately for velocity measurement, or simply difficult to find. In contrast with our original analysis, we found that both EDV and PSV provided remarkably accurate diagnostic parameters for a ≥50% CA stenosis or occlusion. Specifically, the ROC analysis revealed that an EDV of ≥55 cm/sec provided a 93% sensitivity and 100% specificity for an overall accuracy of 95%. A PSV ≥200 cm/sec provided nearly equivalent values of sensitivity (93%), specificity (94%), and overall accuracy (93%). Our study again confirms the ability of duplex ultrasound to identify patients with significant SMA and CA stenoses without performance of postprandial testing.[2,3,5,8] Finally, our report adds new knowledge with the observation that colorflow duplex ultrasound technology is sufficiently powerful to identify anatomic variants in this area.

Our observation that EDV provides substantially more diagnostic accuracy in the SMA and slightly greater accuracy in the CA is in agreement with a recent analysis by Perko et al.[7] but differs from the Moneta publications where excellent sensitivity, specificity, and accuracy were identified and prospectively confirmed for both vessels using PSV.[2,5] Applying the Moneta SMA threshold of PSV ≥275 cm/sec to our data resulted in a sensitivity of only 65% compared with the Oregon group's 92%. Indeed, to achieve sensitivity more than 90% for PSV, our threshold PSV would have to decrease to 175 cm/sec, a level at which overall accuracy is only 67%. When two studies find excellent, but different, parameters for diagnosis of mesenteric occlusive disease, what accounts for the difference? In this case, we found four potential explanations by examining details of the respective reports. The explanations include differences in gender, instrumentation, angiographic stenosis threshold, and the method of accruing patients.

The validation study published by Moneta et al.,[5] was a comparison of mesenteric duplex to angiography in a group of 100 patients scheduled to undergo lateral aortography for a variety of indications. Eighty-eight percent of the patients were men, a gender distribution similar to the Oregon groups initial retrospective study. Only 13 of these individuals had suspected chronic intestinal ischemia, whereas the remainder underwent the angiographic study to evaluate peripheral vascular disease. Angiography revealed a 24% incidence of mesenteric occlusive disease in the CA and 14% in the SMA. In our study, all patients had suspected intestinal ischemia. Seventy percent were women, an incidence similar to our original report. We documented occlusive disease in 48% of SMA and 59% of CA. Thus, both the means of collecting the patients and the gender distribution differed substantially between the Moneta reports and our own. Because Moneta's patients were almost exclusively men and ours were primarily women, neither data are likely to have adequate statistical power to identify a gender difference in blood flow velocity parameters of normal or stenotic SMA. It is interesting, however, to note that the five cases accounting for the lower accuracy of PSV versus EDV in our study were all women.

Although few authors have addressed the subject of patient selection in duplex ultrasound accuracy analysis, Hunink et al.[11] argued that selection of patients for angiography on the basis of the results of duplex ultrasound introduces a "selection bias" if those same angiograms are then used to determine ultrasound accuracy. Assuming this is true, the Moneta validation study may be a more objective basis for testing mesenteric duplex accuracy even if few of their patients actually had SMA or CA occlusive disease. Unfortunately, neither the observed gender discrepancy nor the possibility of selection bias serves to explain why the observed differences between our results and those of Moneta et al. occurred primarily in the SMA, and findings in the CA were quite similar.

Differences in angiographic stenosis threshold provide an explanation for some of the observed duplex velocity disparities. Both of Moneta's studies used a 70% angiographic cut-off, and studies from our lab and those by Harward et al.,[6] and Perko et al.,[7] used a 50% angiographic threshold to distinguish normal from stenotic arteries.[2,12] This might not be confusing until one considers that Perko et al.[7] applied the Moneta 70% duplex velocity criteria, derived for 70% angiographic stenosis, to their own angiographic data derived at a 50% angiographic stenosis. Yet, they found the Moneta values to be remarkably accurate. In addition, our own ROC analysis for a 50% CA stenosis revealed the best duplex accuracy (93%) at a PSV ≥200 cm/sec, the exact value Moneta found to be most accurate for 70% stenosis. The distribution of angiographic stenosis provides at least one answer to this puzzle. In our study, all patients had abdominal symptoms, and about half of them were determined to have mesenteric occlusive disease. Patients who eventually received the diagnosis of chronic intestinal ischemia typically had severe occlusive disease, and patients who had other final diagnoses tended to have normal mesenteric vasculature. This resulted in a bimodal distribution with relatively few data points between 50% and 70% stenosis. In fact, only 12% of our data points fell within that particular 20% stenosis range. Thus, fine tuning of the diagnostic thresholds may occur as greater numbers of patients accrue within the 50% to 70% stenosis range.

Could equipment differences account for the observation that PSV is most more accurate in the Moneta studies of SMA stenosis and EDV is substantially more accurate in ours? This may be the most likely answer. Our group previously showed that velocity determination variation exists among different brands of equipment when evaluating the carotid bifurcation. We have postulated that this may account for the wide array of recommended duplex threshold values in the literature for identification of 60% and 70% carotid stenoses.[13] In our laboratory, Siemans and Diasonics equipment produce accurate and similar velocity readings in the carotid bifurcation. Our ATL scanner, however, produces equally accurate but slightly higher velocities for the same degree of stenosis. Thus, some equipment specific variation may be inherent in the instrumentation even before considering the complexities of deep abdominal scanning. We used Diasonics equipment (DRF 400) for our original mesenteric study, and we used primarily Siemens instrumentation instrumentation (Q2000) for this study. Because of the similarity of these two instruments identified in our carotid duplex velocity analysis, we were not surprised to find nearly exact similar results in the mesenteric validation. The Moneta mesenteric studies, however, used Acuson scanners, making it possible for a portion of the observed differences to be on the basis of equipment-based velocity variation.

Another equipment issue may account for our lower accuracy with PSV to identify visceral artery stenosis. With the low transmitting frequency transducers required to sample abdominal arteries, the Siemens Q2000 scanner may alias at blood flow velocities above 200 cm/sec. Low velocity aliasing is more likely when the Doppler angle is substantially less than 60 degrees, and 20 degree to 50 degree angles are frequently required to evaluate the visceral artery origins. Aliasing is not a problem in the neck or lower extremity where signal transmission time is short. In the abdomen, however, aliasing at low velocities is typical because capture of the reflected signals requires more time, necessarily making the pulse repetition frequency (PRF) quite low. Design of the Q2000 did not include the so-called "high-PRF" electronic circuitry that allows a system to double or triple the true PRF, thereby increasing the detectable velocity beyond which aliasing occurs.[14] To accomplish this maneuver, high PRF systems interpose a second or third range gate, or sample volume, between the desired sample volume and the probe. This doubles or triples the recorded velocity at which aliasing will occur, but it adds an element of ambiguity regarding the true source of the reflected signals. As long as only one of range gates is sampling blood flow movement, no major interpretive problems occur. Many of the currently marketed duplex ultrasound instruments have high PRF circuitry.

In the absence of high PRF circuitry, we determined PSV in many stenotic mesenteric vessels by

adding the velocity of the aliased, or "wrapped" segment of the Doppler waveform to the portion not aliased. The original manufacturer recommended this technique, but we do not believe that clinical validation has been extensive.[14] Thus, some loss of accuracy may occur when SMA PSV is calculated in this manner. This potential source of error almost never occurs at the lower frequency shifts encountered when measuring EDV. It is less likely to occur in the CA where very high PSV, even in stenotic vessels, is less common than in stenotic SMA. In fact, we derive further support for this explanation from the excellent correlation we found for between PSV and angiographic stenosis in the CA where the PSV threshold was a lower and more readily measurable 200 cm/sec. Almost none of the Doppler spectra aliased during that portion of the examination in the current series. In summary, design limitations of the instrumentation may also account for the difference between our findings, where SMA EDV was more accurate, and those of Moneta et al., where SMA PSV was more accurate.

A final discussion point addresses anatomic variants. On the basis of angiographic studies of the mesenteric vasculature, these reportedly occur with an approximate overall frequency of 20%.[15] In our study, only 4 patients (9%) had anatomic anomalies. None of the previous reports dealing with mesenteric occlusive disease have addressed in any detail the identification of anomalies by duplex. In at least one of our cases, accurate identification of a replaced right hepatic artery prevented an incorrect designation of SMA stenosis. Outflow through the right hepatic to the low resistance bed of the liver explained why the patient had an elevated EDV, but no other duplex findings to suggest arterial pathology. In total, duplex correctly identified three anomalies, but missed the fourth—a common hepatic artery originating from the aorta. The gray-scale Diasonics DRF400 instrument was used to perform that study early in the validation series. Colorflow technology may have helped to identify the true source of the common hepatic when it was not seen arising from either the CA or the SMA. To afford the most accuracy to the duplex study of mesenteric disease, we believe sonographers should be familiar with the anatomic variants and should search for them when the major vessels are not readily identified in their normal locations.

In conclusion, some controversy exists in the literature regarding exact duplex threshold values for identification of SMA and CA stenosis. Nevertheless, the more important message is that mesenteric duplex scanning is an excellent screening test for patients undergoing evaluation for chronic intestinal ischemia. Clinical vascular laboratories can accomplish reliable performance of this study, which will limit the number of patients who must undergo require mesenteric angiography.

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DISCUSSION

Dr. William W. Babson, Jr. (Plymouth, Mass.). Have you had any success with diagnosis of the acute mesenteric occlusion with this technique?

Dr. Robert M. Zwolak. We have not applied this technique often. You know the acute patient needs a terribly expeditious workup, and this is not the best setting for a prospective trial. We did use the technique once and thought we saw an occluded superior mesenteric artery. For the most part, when patients with suspected acute mesenteric ischemia are first seen, the "fire alarm" sounds and the patients either go directly to angiography or to the operating room.