Evaluation of Celiac and Mesenteric Vascular Disease with Duplex Ultrasonography

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A retrospective study of 25 patients was performed to evaluate the applicability of duplex ultrasonography to the celiac and superior mesenteric circulation. Lateral contrast aortograms were compared to the pulsed-Doppler spectral data from duplex examinations in fasting subjects. A significant correlation was identified between the celiac-aortic diastolic ratio and the degree of stenosis measured angiographically, but such a relationship could not be established for the superior mesenteric artery. These data suggest that duplex ultrasonography may not be a reliable screening test for mesenteric vascular disease. KEY WORDS: Duplex sonography; Ultrasonography; Mesenteric circulation; Doppler.

Although it is uncommon, chronic mesenteric ischemia can be associated with devastating morbidity. This diagnosis often is not considered when evaluating patients with weight loss or abdominal pain, and clinicians have been somewhat reluctant to pursue the work-up of this disorder with invasive angiography because of the potential and real risks of this diagnostic approach. No reliable noninvasive test has yet been developed that establishes the presence of chronic mesenteric ischemia.

Duplex ultrasonography combines B-mode imaging and Doppler sonography. This ultrasound application allows precise Doppler interrogation of vessels that can be identified on the two-dimensional echo image. Analysis of the spectrum of shifted Doppler frequencies at a particular location in the vessel, dictated by the examiner's placement of the sample volume, allows detection of arterial stenoses and associated disturbed flow. This method has proved to be accurate in the detection of carotid stenosis,[1] renal artery stenosis,[2] and deep vein thrombosis[3] when compared to angiography and venography. Because of this accuracy, duplex scanning has become an important clinical tool in the physician's diagnostic armamentarium.

After having proved its clinical utility in other applications, investigators have begun to look at a possible diagnostic role from duplex ultrasonography in the visceral circulation. Jäger and coworkers first reported the detection of mesenteric occlusive disease using duplex scanning in 1984.[4] Moneta and colleagues[5] have described the visceral blood flow response to various meals using duplex ultrasonography and have showed that blood flow velocities were quite similar among a group of healthy, normal volunteers without evidence of atherosclerosis. Jäger and associates[6] confirmed these findings and also concluded that volume flow could be calculated with this technique. One report of four patients with symptoms of chronic mesenteric ischemia and angiographic mesenteric vascular disease showed that velocity changes can be detected by duplex ultrasonography.[7]

To examine the applicability of duplex ultrasonography to the mesenteric circulation further, a group of patients with a spectrum of visceral atherosclerosis as defined by arteriography were evaluated.

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METHODS

The clinical histories, contrast angiograms, and spectral waveforms of 25 patients were reviewed retrospectively. The patients had a variety of clinical problems, which included suspected chronic mesenteric ischemia (five cases), chronic abdominal pain (four cases), renovascular hypertension (four cases), aortic aneurysm (three cases), and lower extremity ischemia (nine cases). Appropriate angiography was performed for these clinical indications, but all patients in this study also had lateral aortograms to specifically identify the origin of the celiac trunk and superior mesenteric artery (SMA).

Angiograms were reviewed by one investigator (D.A.H.) without knowledge of the duplex results. The degree of angiographic stenosis was assessed and the percentage reduction of the diameter of the celiac trunk and SMA was calculated. If a stenosis existed at the origin of the vessel, the vessel diameter 1 cm beyond was taken as normal. When stenoses occurred beyond the origin, the diameters of the vessel 1 cm proximal and 1 cm distal to the stenosis were averaged. The residual lumen diameter was then expressed as a percentage of this value, and the degree of diameter reduction was calculated. All measurements were made with calipers to the nearest half-millimeter.

Duplex ultrasonography was performed with Ultramark 8 and 9 duplex scanners (Advanced Technologies Laboratories, Bothell, WA). When the Ultramark 9 unit was used, color Doppler assisted vessel identification and detection of anatomic variants, and occasionally it identified areas of flow disturbance that aided in positioning the sample volume. The data presented here were all based on spectral analysis, and B-mode images were not used to estimate the degree of stenosis. A 3 MHz sector scanner or 2.25 MHz phased array scanhead with a range-gated pulsed Doppler was used to identify the appropriate vessel and position the sample volume. Doppler spectral shifted frequencies were recorded at an angle of 60 degrees or less. Sample volume size was maintained at 1.3 cu mm. Frequency data were converted to velocity data using the software within the instrument. All examinations were performed by the same investigator (M.M.N.), and all patients fasted overnight before the examination.

Doppler velocity data were recorded and subsequently compared to the angiographic results. Peak systolic, peak diastolic, and end-diastolic velocities in the SMA and celiac trunk were the parameters examined. Aortic flow may differ considerably from patient to patient and may affect normal flow velocity in the visceral arteries. As has been described in renal duplex scanning,[2] we derived a second set of Doppler data by dividing the velocities obtained in visceral arteries (peak systolic, peak diastolic, and end-diastolic) by the corresponding velocities in the aorta. These visceral artery–aorta velocity ratios also were compared to the angiographic findings.

The absolute velocities and ratios were compared to the angiographic results in stenotic and nonstenotic vessels by the Wilcoxon Rank Sum Test and statistical significance determined by the Kruskal-Wallis test. This revealed whether nonstenotic and stenotic vessels could be distinguished by duplex ultrasonography. Analysis of the relationship between duplex velocities and the severity of stenosis was performed using the Spearman correlation, which established whether duplex velocities or ratios correlated with the severity of angiographic stenosis.

RESULTS

Angiography

A spectrum of vascular disease was present in the population studied (Table 1). In the SMA, 60% of patients had stenotic lesions. Half of these represented diameter reductions of 50% or more, including five frank occlusions. Fifty-two percent of the celiac arteries were stenotic. Of these, 70% had greater than 50% stenosis, including two cases of occlusion. The pattern of disease distribution also varied. When considering lesions of greater than 50% stenosis as indicating the presence of disease, 12 patients had no disease, nine had single vessel disease, and four had involvement of both the SMA and celiac artery.

Duplex Ultrasonography

The absolute velocities (peak systolic, peak diastolic, and end-diastolic) and their ratios to the corresponding aortic velocities were compared in vessels with and without angiographic stenosis. Of all these parameters, the peak diastolic ratio (ratio of peak visceral artery diastolic velocity to peak aortic diastolic velocity) correlated best with the presence and severity of stenosis.

SMA. Although an increased peak diastolic ratio correlated best with the presence of SMA stenosis, this relationship was not statistically significant ($P = 0.27$; Kruskal-Wallis test). This was true whether the investigators included cases with any degree of stenosis or

Table 1: Results of Angiography (Number of Vessels Affected)

	Superior Mesenteric Artery	Celiac Artery
No stenosis	10	12
<50% stenosis	7	4
>50% stenosis	3	6
Occlusion	5	3
Total	25	25

whether only lesions that were hemodynamically significant (>50%) were considered. Even when occlusions were excluded, none of the parameters examined was related significantly to the angiographic results. Not unexpectedly, the diastolic ratio did not vary with the severity of stenosis (R = 0.28, $P = 0.20$; Spearman correlation).

Celiac Artery. Of the parameters examined, only the peak diastolic ratio increased significantly when celiac stenosis was present ($P = 0.04$; Kruskal-Wallis test) (Fig. 1). This was true when the data included stenosis of any degree, but not when only hemodynamically significant lesions were included. Significant correlation was seen between peak diastolic ratio and the degree of angiographic stenosis (R = 0.45; $P = 0.03$; Spearman correlation) (Fig. 2).

SMA Versus Celiac Artery Velocity. An unexpected finding was a relationship between SMA and celiac artery velocities. A significant correlation exists between the peak diastolic ratios of these vessels in the patient population studied ($R = 0.57$; $P = 0.01$; Spearman correlation) (Fig. 3). This suggests that velocity increases in one vessel are accompanied by a concomitant increase in the other.

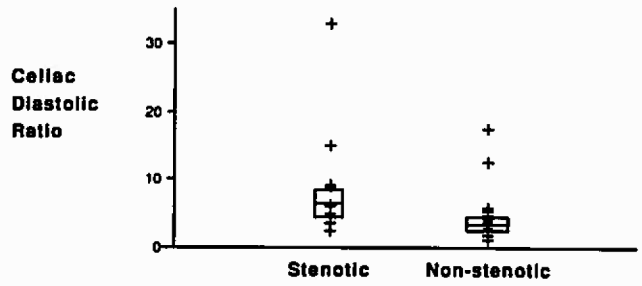

Figure 1 Celiac artery diastolic ratio in stenotic and nonstenotic vessels. Boxes enclose those values contained between the first and third quartiles. A significant increase is seen in the diastolic ratio in stenotic vessels.

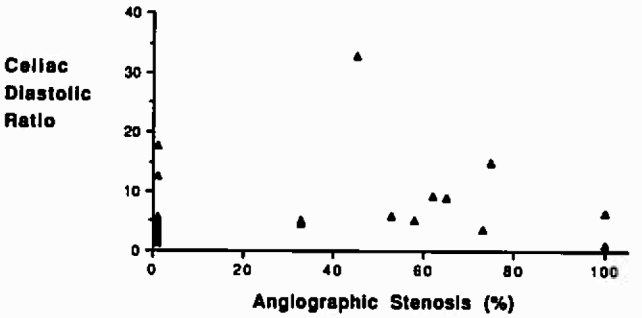

Figure 2 Relationship of celiac artery diastolic ratio to the degree of angiographic stenosis. A significant correlation between these two variables exists.

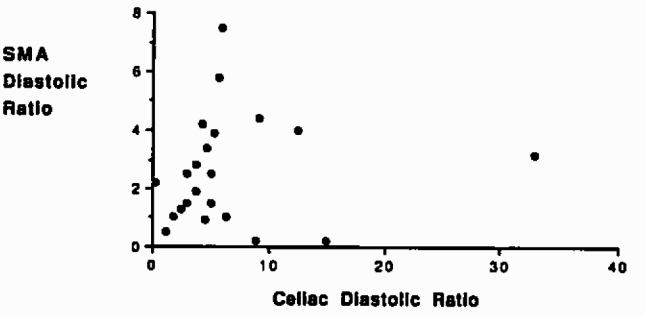

Figure 3 Relationship of SMA diastolic ratio and celiac artery diastolic ratio. A significant correlation exists, suggesting that collateral vessels may increase flow in nondiseased vessels.

DISCUSSION

The diagnosis of acute mesenteric ischemia has been notoriously difficult because of the variability of associated clinical signs and because end organ ischemia may occur without occlusion of the more proximal arteries (so-called nonocclusive mesenteric ischemia). In patients with severe atherosclerosis of celiac and superior mesenteric arteries, a syndrome of chronic mesenteric ischemia has been described consisting of postprandial abdominal pain, weight loss, and malabsorption. These patients may also develop focal or diffuse ischemia associated with intestinal gangrene that may involve all or part of the bowel wall. Because of the chronicity of their symptoms, the diagnosis usually is overlooked, and a reliable and safe test that can identify the presence of severe mesenteric occlusive disease would be a valuable aid to diagnosis. In these patients, angiographic criteria have been developed that are strongly suggestive of compromise of the mesenteric vascular bed; these criteria include severe stenosis (>50%) or occlusion of two of the three mesenteric vessels. A test capable of detecting this pattern of disease would clearly define a group of patients at risk.

The accuracy of duplex scanning depends on several factors. First, the vessel being investigated must be readily identified on B-mode imaging, allowing the examiner to "sweep through" the vessel. Using this technique, focal stenoses can be detected. Random placement of the sample volume, without interrogating the entire area at risk for stenosis, can lead to false-negative examinations owing to normalization of the flow velocities in pre- and poststenotic regions. The use of angle correction when Doppler angles of greater than 60 degrees are used introduces considerable variability in spectral data and increases the chance of error. Calcification may render a vessel totally unsuitable for this technique. Another factor that may influence the accuracy of duplex scanning involves the collateral flow. The vascular distribution must be relatively isolated so that collateral flow does not lead to a failure to detect proximal high-grade stenosis or occlusion.

Although duplex scanning has been proved to have accuracy in other vascular beds,[1–3] this study suggests that it may be difficult to develop specific criteria that reliably predict the presence of significant celiac or SMA stenosis. If this technology is to be reliable diagnostically, sonographers would have to expect significant correlations between velocity data and angiographic findings. We were able to identify only one such correlation when the celiac-aortic diastolic ratio was compared to angiography. This relatively weak (although statistically significant) relationship and the absence of any such findings in the SMA suggest that diagnostic criteria with satisfactory sensitivity and specificity will be difficult to establish.

Because relatively few hemodynamically significant stenoses (>50%) were present angiographically in the patients studied, it could be argued that we have not adequately evaluated duplex ultrasonography in the detection of lesions likely to cause clinical symptoms. Even considering this, we remain concerned over the high velocities found in numerous angiographically normal arteries and our inability to detect occlusions.

Although few symptomatic patients were included in this study, 32% of the superior mesenteric arteries and 36% of celiac arteries were occluded or had significant stenosis. We do not believe that a paucity of symptomatic patients limits this study because, as in carotid occlusive disease, asymptomatic stenosis may still have important clinical ramifications. Duplex ultrasonography should detect stenotic arterial lesions accurately regardless of symptoms, and to our knowledge no data exist that contradict this.

Our results are at odds with those of other investigators. Moneta and coworkers[8] have demonstrated in a retrospective study that peak systolic velocity correlates with the degree of stenosis in both the superior mesenteric and the celiac arteries, and furthermore they have developed diagnostic criteria with very acceptable sensitivities and specificities. Bowersox and colleagues[9] have published similar data indicating that the detection of significant lesions in the SMA is possible with duplex ultrasonography; however, this was not true of the celiac trunk. Similar to our experience, this latter group of investigators identified numerous patients with collateral flow patterns that seemed to confound complex examinations. Clearly, carefully conducted prospective studies will have to be carried out by numerous investigators before the applicability of duplex ultrasonography to splanchnic artery occlusive disease will be established.

Of interest is the finding of a relationship between celiac and SMA velocities. That is, increases in velocity seem to occur in both vessels simultaneously. One explanation for this phenomenon is the presence of focal stenosis in both vessels, but this was relatively uncommon in the patients in this study. An alternative hypothesis suggests that focal stenosis in one vessel leads to a compensatory flow increase in the other. This compensatory flow increase allows perfusion of collaterals (pancreaticoduodenal) that exist between the celiac and SMA and prevention of clinical ischemia (Figs. 4 and 5). This phenomenon could have a significant impact on the accuracy of duplex scanning.

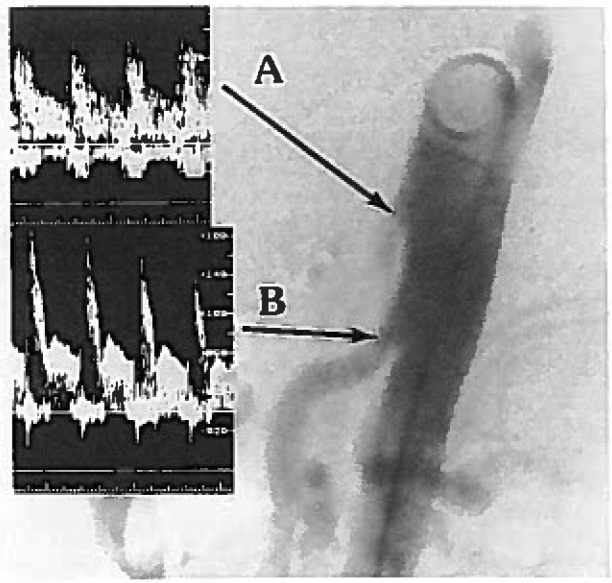

Figure 4 Lateral aortogram in a patient with mesenteric vascular disease. *A* identifies a preocclusive stenosis in the celiac artery. The accompanying duplex spectral waveform shows marked attenuation of peak systolic velocity (35 cm/sec; normal = 125 ± 20 cm/sec). *B* identifies the normal SMA. Despite the normal angiographic appearance, the SMA spectral waveform exhibits an increase in peak systolic velocity (180 cm/sec; normal = 125 ± 20 cm/sec). This is probably related to increased flow in the SMA and not to stenosis.

The physiologic response of the splanchnic circulation to a meal is an increase in blood flow. We have performed postprandial duplex examinations in a number of persons with documented visceral artery occlusive disease. In general, we have not found this to be a helpful adjunct and do not believe it improves diagnostic accuracy. In the presence of significant stenosis (>50%), we have seen a range of responses from normal to marked increases in velocity, and in some cases abolition of detectable flow. Although we have not found postprandial studies helpful, this does not preclude the possibility that such "stress tests" might improve the accuracy of duplex scanning in the future as we learn more about the response of chronically ischemic bowel to a nutritional challenge.

In conclusion, certain velocity parameters derived from duplex scanning change in the presence of stenosis. In this study, however, we were unable to iden-

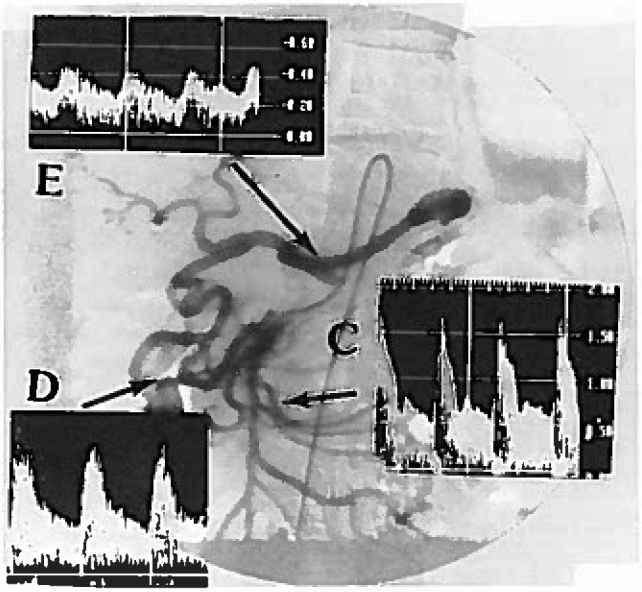

Figure 5 Anteroposterior aortogram from same patient as in Figure 4. *C* demonstrates the SMA and *D* is a collateral between the SMA and celiac artery. *E* shows the celiac artery filling from the collateral. This supports the notion that the SMA can have increased flow velocity in the absence of hemodynamically significant stenosis.

tify specific criteria that might be expected to accurately disclose celiac and superior mesenteric artery stenosis. Other investigators have reported better accuracy in the presence of high-grade lesions, and perhaps the spectrum of disease in the current investigation accounts for our findings. In addition, the detection of complete occlusions may be confounded by the sometimes abundant collaterals that exist in the mesenteric circulation.

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