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DUPLEX ULTRASONOGRAPHY IN EVALUATION OF SPLANCHNIC ARTERY STENOSIS

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Duplex ultrasonography emerged as a noninvasive diagnostic test for splanchnic artery stenosis in the early 1980s.[4] Prior to this, arteriography had been not only the gold standard but essentially the only objective means to evaluate stenosis in the celiac artery (CA) and superior mesenteric artery (SMA). Investigations have since proceeded from the evaluation of normal mesenteric arteries and the assessments of gastrointestinal physiology to the delineation of splanchnic artery stenosis. Although duplex ultrasonography can identify splanchnic artery stenosis, the determination of chronic mesenteric ischemia remains a clinical diagnosis made by appropriate history, physical examination, and arteriographic confirmation of high-grade stenosis or occlusion of the splanchnic arteries.

TECHNIQUE

Technologic advancements in scanhead design, image resolution, and the development of color flow Doppler imaging have allowed duplex ultrasonography to be used in examination of the deep vessels of the abdomen. However, regardless of the quality of equipment employed, mesenteric duplex examinations are disappointing unless they

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are performed by highly trained, experienced vascular technologists. Most individuals who consistently perform high-quality studies have certification as a registered vascular technologist (RVT), along with a working knowledge of intra-abdominal anatomy and at least 1 year of intensive experience with duplex techniques.

The only verified criteria for quantifying splanchnic artery stenoses are based on interpretation of Doppler-derived blood flow velocity waveforms. Although the B-mode image is crucial in placing the Doppler sample volume within the vessel to be examined (Fig. 1), and color flow may aid in locating the vessel itself and areas of suspected stenosis, neither of these modalities alone has been systematically evaluated in terms of providing useful, clinically relevant information. Of key importance is obtaining high-quality Doppler waveforms at a constant angle of insonation, commonly accepted as 60 degrees. Variations in Doppler angle have profound effects on measured blood flow velocities. Rizzo et al[14] showed that changing the Doppler angle as little as 20 to 30 degrees alters the resultant peak systolic velocity (PSV) as much as 120% in the SMA and 56% in the CA. Likewise, Jager et al[4] determined that divergence of the Doppler angle by 2 degrees results in a 7% change in SMA blood flow velocities.

Respiratory motion, intra-abdominal gas, previous intra-abdominal surgery, obesity, and large body habitus all contribute to the technical difficulty of the mesenteric duplex studies. To obtain an optimal study, patients should be on a clear liquid diet the day before the examination and refrain from all oral intake for at least 8 hours prior to the study. Occasionally, administration of simethicone (40 to 80 mg orally) 2 hours before the examination may be required to further reduce bowel gas.

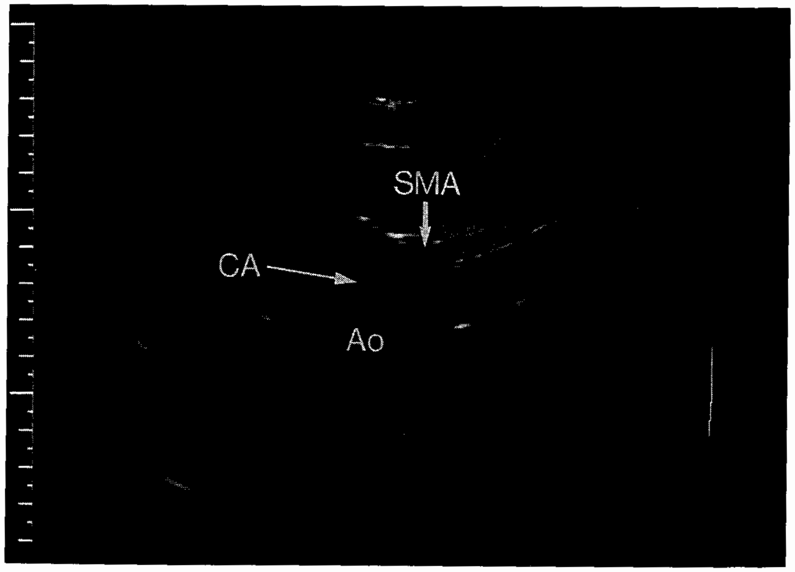

Figure 1. B-mode ultrasonography of splanchnic vessels. SMA = superior mesenteric artery; CA = celiac artery; Ao = aorta.

The patient should be positioned supine with the head of the bed elevated 30 degrees. An anterior midline approach is used. Low-frequency scanheads of 2.5 to 3.5 MHz are required, although extremely asthenic individuals can occasionally be examined with a 5-MHz probe. The SMA and CA are visualized in the upper abdomen with longitudinal orientation of the scanhead. Doppler velocity waveforms are systematically recorded from several sites along the course of each vessel, with particular attention to the vessel origins. The CA is more difficult to visualize and may not be amenable to examination in up to 20% of study patients. Orienting the scanhead transversely may improve visualization of the CA.

The inferior mesenteric artery (IMA) is not reliably insonated by most laboratories. Some studies have reported insonation of the IMA as a means of evaluating the impact of food and lactulose administration on colonic blood flow.[10] Use of IMA duplex scanning in the clinical setting of possible mesenteric ischemia has, however, not been reported.

FASTING AND POSTPRANDIAL VELOCITY WAVEFORMS

Normal fasting SMA and CA blood flow velocity waveforms are distinctly different. Fasting SMA velocity waveforms reflect high resistance in the resting intestinal circulation. The waveform is frequently triphasic, with a peak systolic component, an end-systolic reverse flow component, and a diastolic flow component. Diastolic flow is often near zero, reflecting the high resistance of the mesenteric circulation in the fasting state (Fig. 2). Celiac artery waveforms are generally biphasic, with a peak systolic component, no reversal of diastolic flow, and a relatively higher diastolic flow component than the SMA (Fig. 3). The high diastolic flow component in the CA, like that of the internal carotid artery and the renal artery, reflects a low-resistance circulation. The liver and spleen have high metabolic requirements and therefore a low arterial bed resistance. This is reflected in the high diastolic flow of the normal CA.

In 1984, Jager et al[4] evaluated blood flow velocities in the SMA and CA in both the fasting and postprandial states. The common carotid artery served as a control. Twenty healthy volunteers were evaluated with B-mode imaging and Doppler-derived velocity waveforms to determine peak systolic, late systolic, and end-diastolic velocities. A significant increase in SMA diameter was detected 15 minutes after a 1000-calorie meal, with maximal dilatation of 122% at 45 minutes. In addition, mean systolic flow velocity in the SMA rose from a mean of 22.2 cm/sec to a mean of 57.0 cm/sec at 45 min ($P < 0.0001$). End-systolic reverse flow was lost and diastolic flow increased markedly, reflecting the

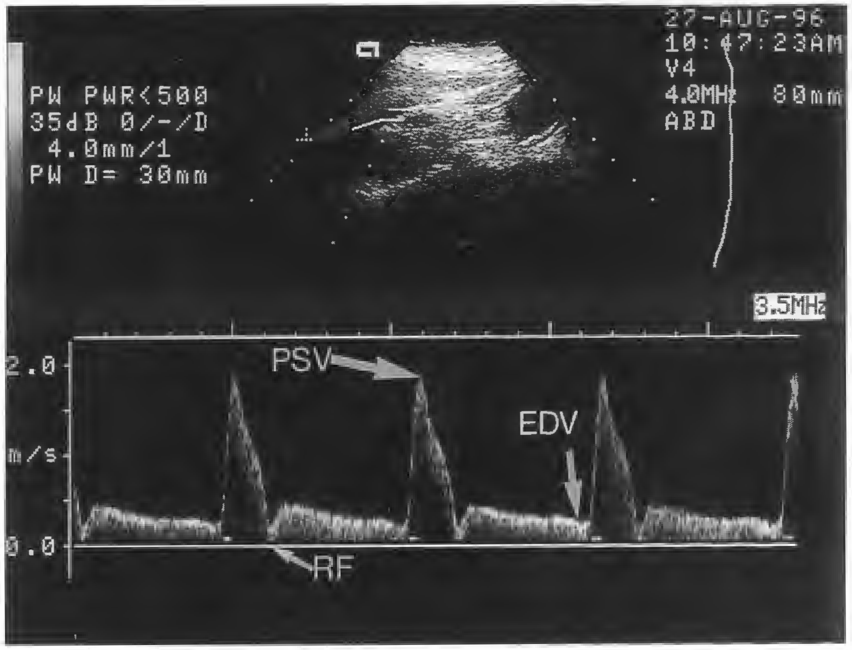

Figure 2. Normal fasting SMA waveform with peak systolic velocity (PSV) of 190 cm/s and end-diastolic velocity (EDV) of 40 cm/s. Note reverse flow (RF); it is difficult to see in this patient's scan.

decreased end-organ arterial resistance of postprandial intestinal hyperemia (Fig. 4). Postprandial increases in CA blood flow, however, are minimal, reflecting relatively high fixed arterial demand of the liver and spleen. It has also been determined that the magnitude of SMA hyperemia depends on the nutrient presented to the intestinal lumen. A mixed caloric meal produces a greater increase in SMA flow velocities than equal caloric loads of fat, glucose, or protein alone.[6] Marked increases in postprandial SMA flow velocities have also been noted by others.[2,5,6,11,12]

Quamar et al[13] also evaluated SMA blood flow in healthy volunteers following ingestion of glucose and lactulose. SMA blood flow was found to increase by 53% after the glucose load, but no significant change occurred following lactulose ingestion, suggesting that intestinal absorption is required to incite a vasomotor response. A food challenge produced a two-fold increase in SMA PSV within 45 minutes, with an end-diastolic velocity (EDV) increase of almost threefold during the same time period.

Lilly et al[5] used duplex scanning to evaluate changes in splanchnic artery blood flow with various pharmacologic stimuli. The effect of intravenous glucagon infusion on CA and SMA velocities was studied, and a significant increase in PSV in both the SMA and CA was found.

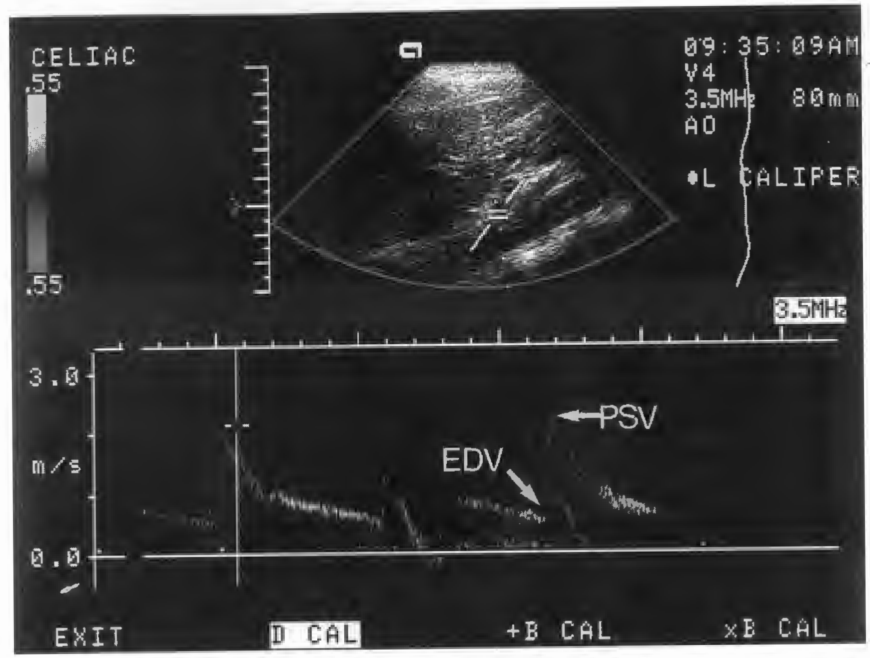

Figure 3. Normal fasting CA waveform with PSV of 150 cm/s and EDV of 50 cm/s.

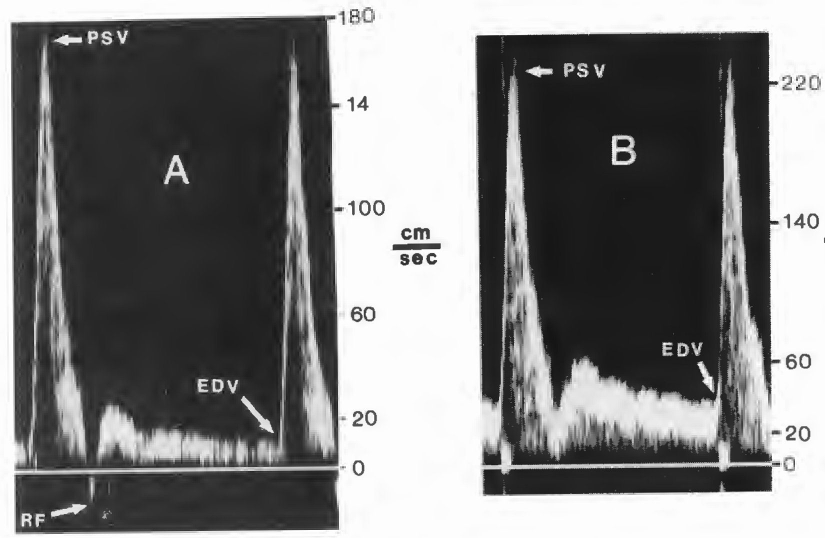

Figure 4. *A*, Preprandial and *B*, postprandial SMA waveforms showing an increase in PSV from 180 to 230 cm/s and an increase in EDV from 15 to 35 cm/s. Note the loss of reverse flow (RF). (*From* Moneta GL, Taylor DC, Helton WS, et al: Duplex ultrasound measurement of postprandial blood flow: Effect of meal composition. Gastroenterology 95:1294–1301, 1988; with permission.)

PSV in the CA increased significantly, but the rise in the SMA diastolic velocity was not significant. SMA resting diastolic flow reversal was eliminated with glucagon infusion. Vasopressin infusion produced significant decreases in both systolic and diastolic velocities in the SMA and CA.[5]

All the above data support the application of duplex imaging to the measurement of blood flow velocity within the SMA and CA. Investigators then questioned whether it was possible to detect hemodynamically significant stenoses in patients with suspected mesenteric ischemia.[12]

DATA IN PATIENTS WITH SPLANCHNIC ARTERIAL STENOSES

In 1986, Nicholls et al[12] retrospectively evaluated four patients with radiographically proven splanchnic artery stenoses with mesenteric artery duplex examinations. Fifteen normal subjects were studied as well. Significant increases in blood flow velocities were found in the stenotic vessels compared with normals, suggesting that duplex scanning might be used to screen patients for splanchnic artery stenoses (Fig. 5).

In 1991, we retrospectively compared mesenteric duplex examinations and arteriograms of 34 patients. Ratios of SMA and CA PSV and EDV to the aortic PSV, as well individual SMA and CA systolic and diastolic velocities, were plotted according to the level of angiographic stenosis in the SMA and CA. The data suggested that a SMA PSV greater than 275 cm/sec was predictive of 70% or greater SMA angiographic stenosis with a sensitivity of 89%, specificity of 92%, positive predictive value of 80%, and negative predictive value of 96% (Fig. 6). For the CA the data suggested a peak systolic velocity greater than 200 cm/sec correlated with 70% or greater CA angiographic stenosis (sensitivity 75%, specificity 89%, positive predictive value 85%, negative predictive value 80%) (Fig. 7). Velocity ratios and EDVs offered no improvement in the detection of 70% or greater stenoses in either the SMA or CA.

We then prospectively evaluated the above criteria. One hundred patients underwent lateral aortograms and splanchnic artery duplex scanning. One hundred percent of the CAs and 99% of the SMAs were visualized angiographically. Ninety-three percent of the SMAs and 83% of the CAs were successfully insonated with duplex scanning. Mean PSVs and EDVs in the SMAs with 70% or greater stenosis were 395 ± 143 cm/sec and 109 ± 75 cm/sec, compared with 167 ± 62 cm/sec and 23 ± 13 cm/sec for SMAs with less than 70% stenosis (P = 0.0001) (Fig. 8). Mean PSVs and EDVs in the CAs with 70% or greater angiographic stenosis were 352 ± 154 cm/sec and 100 ± 58 cm/sec, compared with 175 ± 90 cm/sec and 52 ± 56 cm/sec for CAs with less than 70% angiographic stenoses (P = 0.0001) (Fig. 9). An SMA PSV greater than 275 cm/sec predicted 70% or greater stenosis with a sensitivity of 92%, specificity of 96%, positive predictive value of 80%, and negative pre-

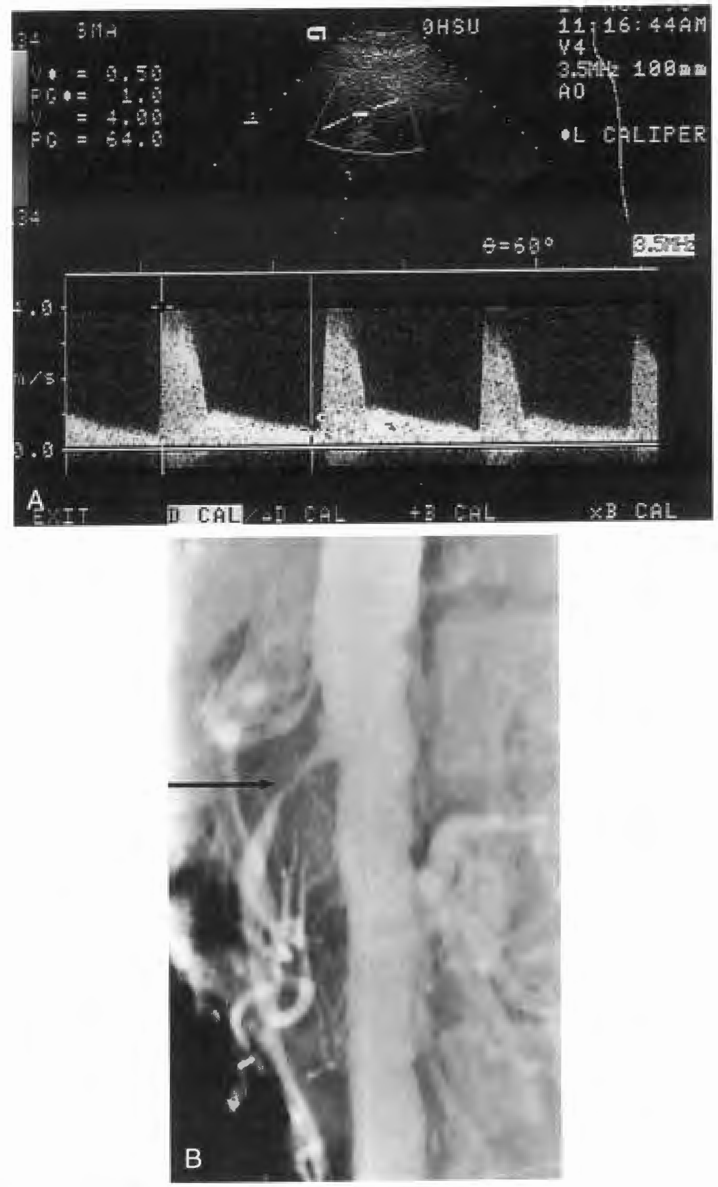

Figure 5. Duplex ultrasound velocity waveform *(A)* of the SMA origin, revealing a peak systolic velocity of 400 cm/s, suggesting the high-grade stenosis noted on a subsequent angiogram *(B, arrow)*.

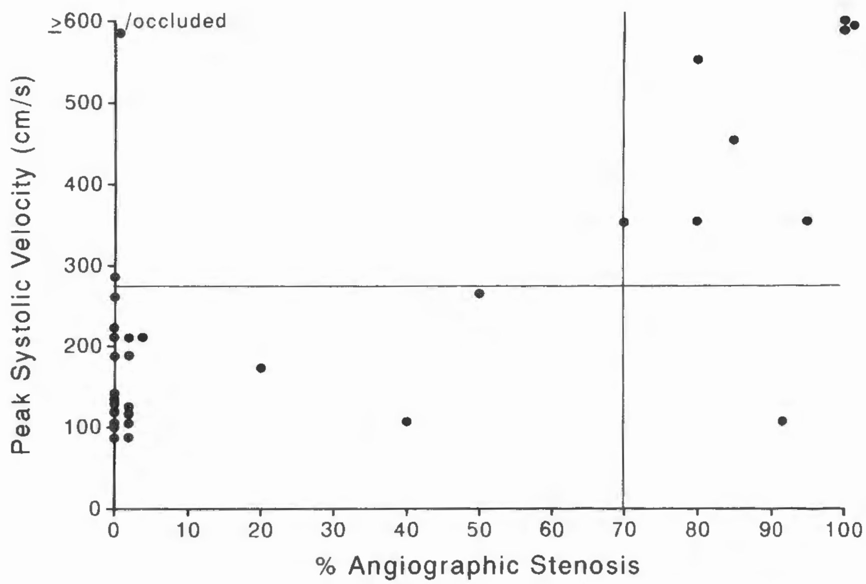

Figure 6. Superior mesenteric artery PSV as a function of angiographic stenosis. Note that the angiographic occlusions successfully identified by duplex scanning are positioned at the extreme upper right of the figure. The horizontal line indicates the proposed PSV (275 cm/sec) for detecting a ≥70% angiographic stenosis *(vertical line)*. (*From* Moneta GL, Yeager RA, Dalman R, et al: Duplex ultrasound criteria for the diagnosis of splanchnic artery stenosis or occlusion. J Vasc Surg 14:511–520, 1991; with permission.)

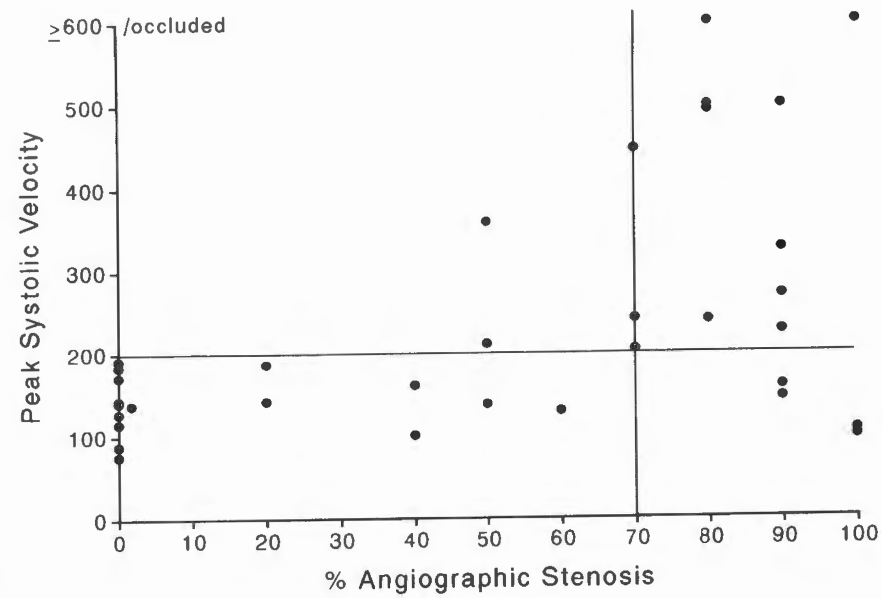

Figure 7. Celiac artery PSV as a function of angiographic stenosis. Note that the angiographic occlusion successfully identified by duplex scanning is positioned at the extreme upper right of the figure. The horizontal line indicates the proposed PSV (200 cm/sec) for detecting ≥70% angiographic stenosis *(vertical line)*. (*From* Moneta GL, Yeager RA, Dalman R, et al: Duplex ultrasound criteria for the diagnosis of splanchnic artery stenosis or occlusion. J Vasc Surg 14:511–520, 1991; with permission.)

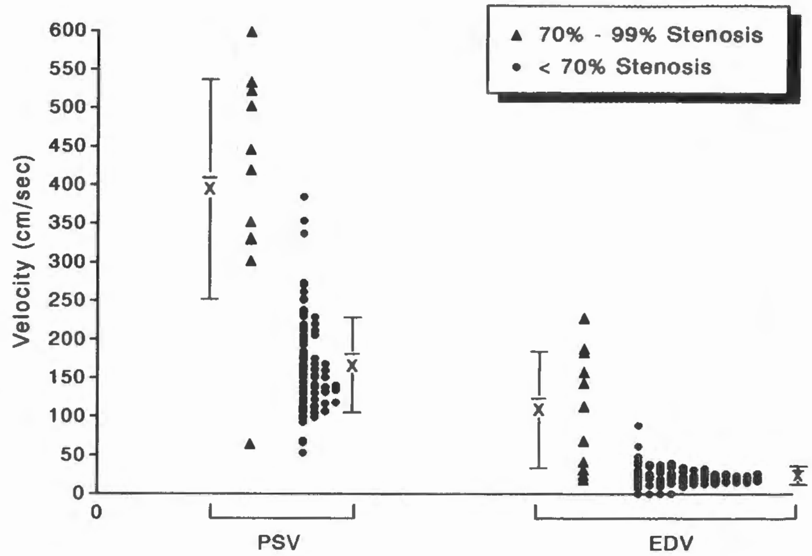

Figure 8. Peak systolic velocity and EDV in the SMA in those patients with ≥70% angiographic stenosis (▲) and <70% angiographic stenosis (●) $P < 0.0001$. (*From* Moneta GL, Lee RW, Yeager RA, et al: Mesenteric duplex scanning: A blinded prospective study. J Vasc Surg 17:79–86, 1993; with permission.)

dictive value of 99%. For the CA, the proposed criteria of a PSV greater than 200 cm/sec to predict a 70% or greater CA angiographic stenosis yielded a sensitivity of 87%, specificity of 80%, positive predictive value of 63%, and negative predictive value of 94%.[8]

Other investigators have found results similar to ours. Bowersox et al[1] performed retrospective review of mesenteric duplex results compared with splanchnic arteriograms. These investigators noted that an SMA EDV greater than 45 cm/sec predicted greater than 50% SMA stenosis with a sensitivity of 100% and specificity of 92%, whereas an SMA PSV greater than 300 cm/sec predicted greater than 50% stenosis with a sensitivity of 63% and a specificity of 100%.

Harward et al[3] also performed a retrospective review of 38 patients with a variety of symptoms who had undergone both mesenteric duplex scanning and lateral splanchnic arteriography. These investigators believed that SMA and CA PSVs demonstrated a linear relationship with angiographic stenosis and that a 50% stenosis could be predicted with an overall sensitivity of 94% and specificity of 84%.

FOOD CHALLENGES IN DIAGNOSIS OF ARTERIAL STENOSIS

Investigators have suggested that postprandial duplex studies of the SMA may aid in noninvasively identifying SMA stenoses, a so-called

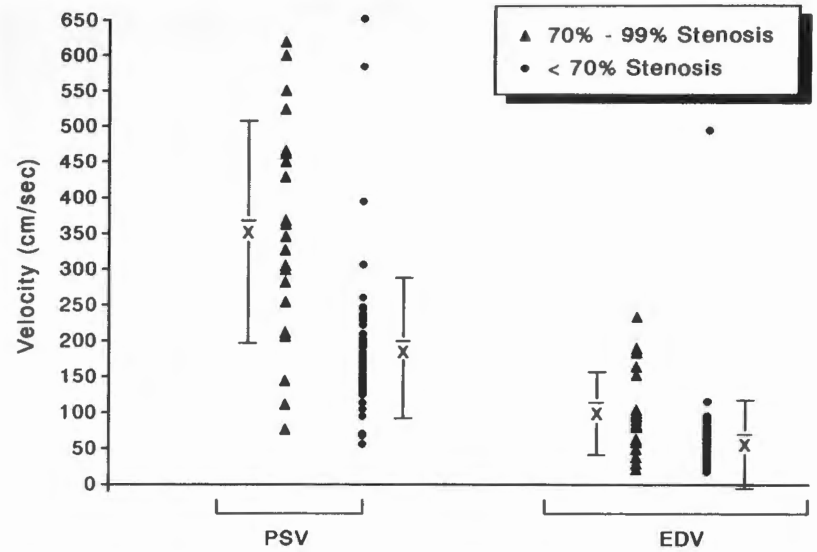

Figure 9. Peak systolic velocity and EDV in the CA in patients with ≥70% angiographic stenosis (▲) and <70% angiographic stenosis (●) $P < 0.0001$. (*From* Moneta GL, Lee RW, Yeager RA, et al: Mesenteric duplex scanning: A blinded prospective study. J Vasc Surg 17:79–86, 1993; with permission.)

gut stress test analogous to a treadmill exercise test performed for coronary artery disease.[2, 5, 11] Muller[11] performed a study comparing controls with 10 patients with postprandial abdominal pain thought likely to be the result of mesenteric ischemia. He noted elevated PSV and EDV in controls after a food challenge and abnormally high SMA PSV and EDV in patients with stenoses. Muller concluded that evaluation of preprandial versus postprandial SMA and CA velocities might somehow aid in detecting SMA stenoses.

To further clarify the potential clinical utility of postprandial SMA duplex studies, we performed fasting and postprandial SMA duplex examinations in 25 healthy controls and in 80 patients with vascular disease. Splanchnic arteriography was performed on the 80 patients with vascular disease. Patients were grouped according to their degree of angiographic SMA stenosis. Fasting duplex studies were considered positive for 70% or greater SMA stenosis based on an SMA PSV of greater than 275 cm/sec. Preprandial and postprandial SMA PSVs did not differ between controls and those patients with less than 70% SMA stenosis, whereas fasting SMA PSVs were significantly higher in those with 70% or greater SMA stenosis. Compared with controls, the absolute increase in postprandial SMA PSV was lower in those with 70% or greater SMA stenoses. By defining a positive postprandial study as a failure of SMA PSV to increase more than 20% over baseline (an increase of greater than 20% is a nearly uniform finding in normal patients), we

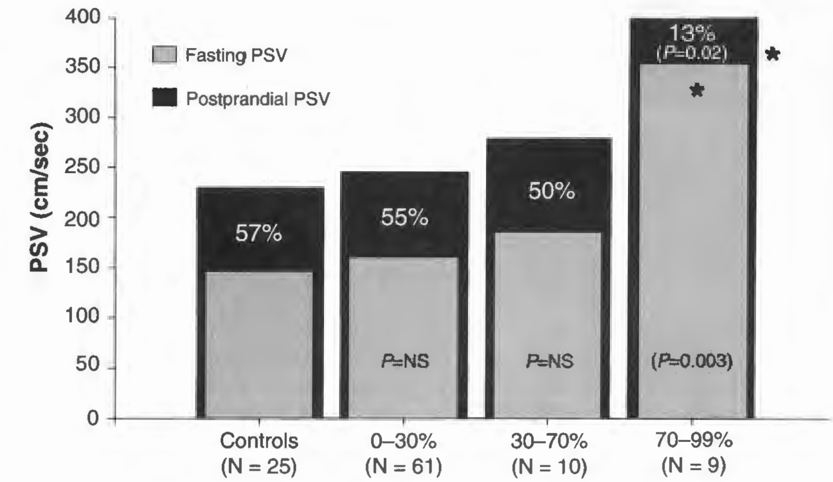

Figure 10. Preprandial and postprandial PSV in groups of patients based on percent angiographic stenosis. P values represent comparisons of velocities from one group to the next lower group. The area above the mean fasting PSV is the mean postprandial percent increase after test feeding. *$P < 0.001$ when comparing mean fasting and postprandial velocities in group three versus values in the control group and group one. (*From* Gentile AT, Moneta GL, Lee RL, et al: Usefulness of fasting and postprandial duplex ultrasound examinations for predicting high-grade superior mesenteric artery stenosis. Am J Surg 169:476–479, 1995; copyright 1995 by Excerpta Medica, used with permission.)

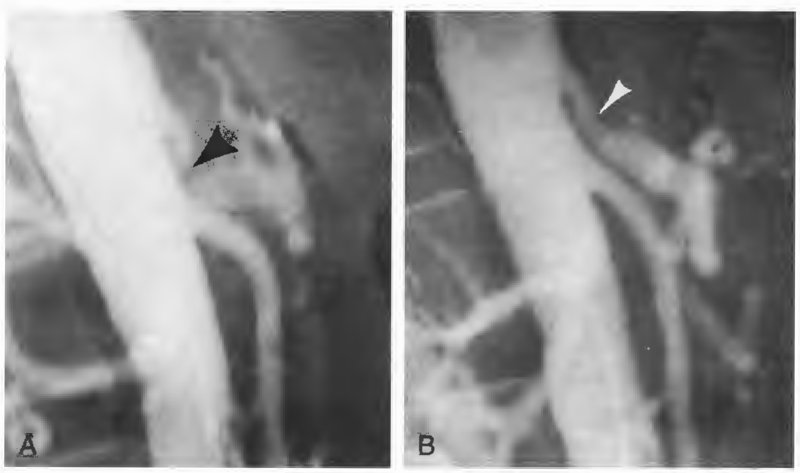

Figure 11. Lateral aortograms showing extrinsic compression of the celiac artery *(arrowhead)* by the median arcuate ligament of the diaphragm in expiration (A) and relief of compression with deep inspiration (B). (*From* Moneta GL, Lee RW: Diagnosis of intestinal ischemia. *In* Rutherford RB (ed): Vascular Surgery, ed 4. Philadelphia, WB Saunders, 1995, pp 1267–1278.)

Figure 12. Color flow imaging demonstrating turbulent blood flow in the celiac artery as a result of arcuate ligament compression on expiration. This turbulence disappeared upon inspiration.

determined that postprandial studies offered no improvement over fasting examinations in identifying high-grade SMA stenoses (Fig. 10).[2] At this time, we do not recommend routine postprandial studies in the evaluation of patients with possible mesenteric artery stenosis.

OTHER USES OF DUPLEX SCANNING IN MESENTERIC OCCLUSIVE DISEASE

Duplex scanning has been described in the evaluation of celiac axis compression syndrome (or median arcuate ligament syndrome). Although the very existence of this syndrome as a cause of clinically significant visceral ischemia is hotly debated, CA PSVs can be shown by duplex scanning to increase with expiration and decrease with inspiration in patients in whom the median arcuate ligament of the diaphragm is reversibly compressing the CA (Fig. 11).[17] In cases in which it is feasible to obtain a clear study of the CA, patients suspected of suffering from this syndrome may be evaluated with duplex scanning using the velocity criteria developed for 70% or greater stenoses (Color Fig. 12).

Duplex scanning may also be used for postoperative surveillance of mesenteric artery revascularizations. Although no strict criteria have been developed for normal velocities within a mesenteric bypass graft, a postoperative baseline duplex examination compared with regular follow-up studies may be used to recognize a threatened graft. Based on follow-up duplex studies, we have proceeded with angiography and subsequent graft revision in three patients with failing mesenteric artery bypass grafts (Fig. 13). A prospective study is needed to delineate further the criteria for graft surveillance.

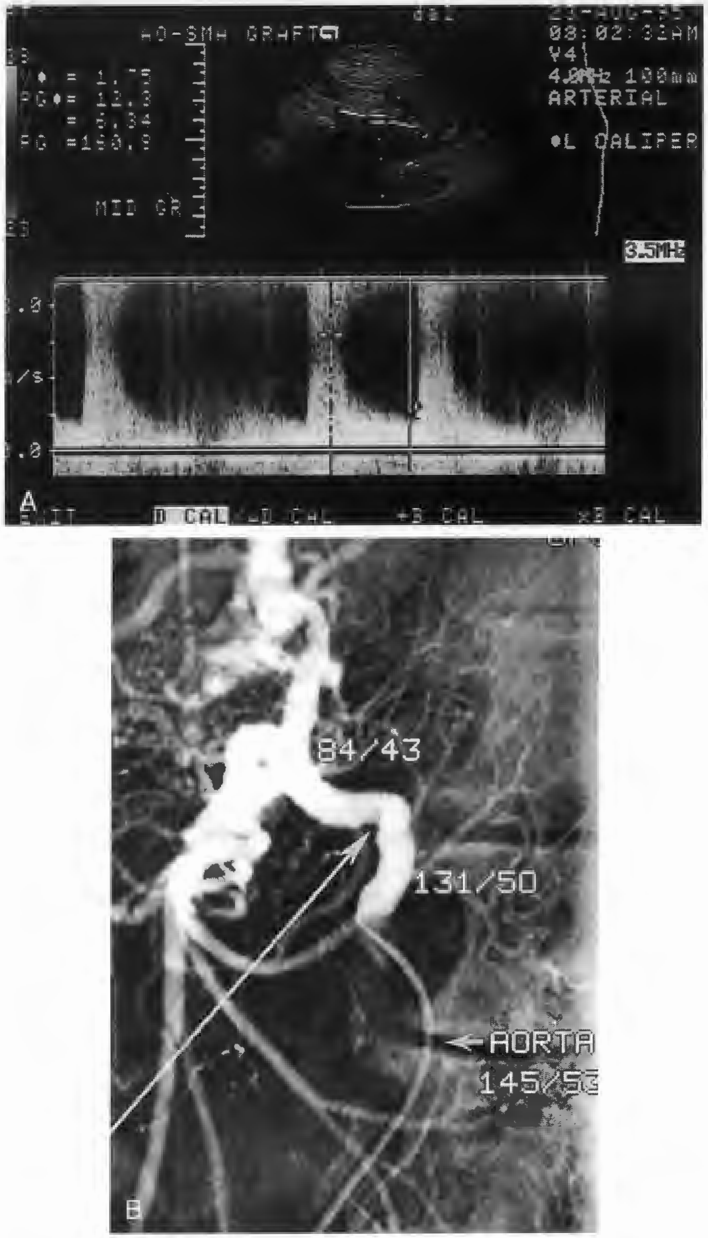

Figure 13. *A,* Duplex ultrasound surveillance examination of an SMA bypass graft revealing an elevated PSV of 300 cm/sec. *B,* The angiogram below the duplex demonstrates a kink in the graft *(arrow)* with a corresponding pressure gradient of 47 mm Hg at the region that was insonated. The patient subsequently underwent prophylactic graft revision.

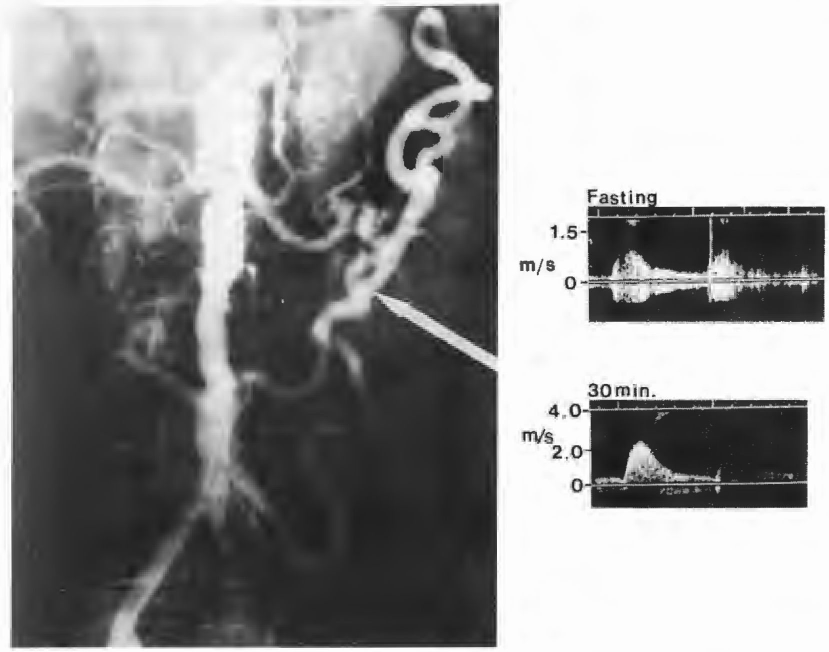

Figure 14. The angiogram demonstrates a large splanchnic artery collateral vessel in a patient with ostial occlusions of both the SMA and the CA. Thirty minutes after a 350-calorie, mixed-nutrient meal, PSV in the collateral vessel increased from 108 to 260 cm/sec (141%). End-diastolic velocity increased from 22 cm/sec to 49 cm/sec (123%). (*From* Moneta GL, Cummins C, Castor J, et al: Duplex ultrasound demonstration of postprandial mesenteric hyperemia in splanchnic circulation collateral vessels. J Vasc Tech 15:37–39, 1991; with permission.)

Although mesenteric duplex examinations are usually limited to the SMA and CA, insonation of the IMA and associated collaterals may be important in cases of asymptomatic high-grade stenosis or occlusion of the SMA and CA. A markedly hypertrophied IMA and its collaterals can serve as the primary blood supply to the abdominal viscera. In such cases, the IMA is often easily insonated and has postprandial blood flow characteristics indicative of flow to the SMA distribution (Fig. 14).[10]

SUMMARY

Duplex ultrasonography accurately identifies high-grade stenoses in the SMA. Analysis of velocity data reveals few false positives and virtually no false negatives in the determination of high-grade SMA stenosis by duplex scanning. We therefore utilize duplex scanning to perform early screening studies of patients with symptoms suggestive of chronic visceral ischemia. If the duplex findings are negative, we recommend evaluating for other sources of abdominal pain. If the findings are positive, prompt angiography is indicated. It is important to remember that although duplex scanning can identify mesenteric artery stenosis, it cannot diagnose intestinal ischemia. By establishing duplex scanning as a useful and accessible noninvasive screening tool, it is hoped that the time between onset of visceral ischemic symptoms and diagnosis of chronic visceral ischemia will be shortened significantly, potentially reducing the morbidity and mortality of the disease.

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