Duplex Ultrasonography of the Mesenteric Circulation

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Abstract

Arterial occlusive disease of the celiac and superior mesenteric arteries is rare, and patients with symptomatic mesenteric ischemia are encountered infrequently. However, the clinical manifestations of mesenteric arterial occlusive lesions remain enigmatic and range from asymptomatic to catastrophic. Acute occlusions of the celiac artery (CA) and the superior mesenteric artery (SMA) due to thrombosis or embolism can produce extensive, irreversible gut ischemia requiring emergency treatment, and the mortality from these events remains among the highest of all vascular emergencies.

This chapter will review duplex scanning technique and findings in both normal and disease states. Clinical applications including visceral artery aneurysms, celiac artery compression syndrome, and visceral ischemic syndromes will be discussed. The chapter will also incorporate more recent data related to post-procedure surveillance of both open surgical reconstruction and endovascular intervention.

Mesenteric duplex scanning can become a routine noninvasive diagnostic testing modality for the evaluation of patients with suspected visceral ischemia since earlier diagnosis and treatment will significantly reduce the risk of catastrophic gut infarction in these patients. Like all deep abdominal duplex scanning, mesenteric scanning is more technologically demanding than scanning vessels of the neck or extremities. However, continued refinement of the duplex instrumentation makes these examinations exciting areas of clinical advancement.

Keywords

Duplex ultrasound • Celiac artery • SMA • Superior mesenteric artery • Mesenteric ischemia • Mesenteric bypass • Mesenteric artery stenting

Arterial occlusive disease of the celiac and superior mesenteric arteries is rare, and patients with symptomatic mesenteric ischemia are encountered infrequently. However, the clinical manifestations of mesenteric arterial occlusive lesions remain enigmatic and range from asymptomatic to catastrophic. Acute occlusions of the celiac artery (CA) and the superior mesenteric artery (SMA) due to thrombosis or embolism can produce extensive, irreversible gut ischemia requiring emergency treatment, and the mortality from these events remains among the highest of all vascular emergencies. The true incidence of chronic atherosclerotic occlusive disease of the main mesenteric vessels is not well established, the precise relationship to symptoms is poorly understood, and the rate of disease progression is undocumented. It is well accepted that severe, multi-vessel disease may initially produce nonspecific symptoms such as pain after

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eating ("abdominal angina") and weight loss—symptoms that are often mistaken for more common gastrointestinal disorders such as peptic ulcer, gallstone disease, or an occult malignancy. Early diagnosis and treatment of chronic mesenteric ischemia may be of critical importance since progression to thrombosis with gut infarction is fatal in over half the cases when it occurs. However, the nonspecific clinical manifestations of chronic mesenteric ischemia have led to a delay in diagnosis in most patients since arteriography was required in the past for detection of occlusions of the mesenteric vessels. As duplex ultrasound scanning was applied to an increasing number of peripheral and visceral arterial disorders, it was evident that this technique could be adapted to examine the main mesenteric vessels. In this way, mesenteric duplex scanning might serve as an "entry level" noninvasive diagnostic test for the very small number of patients actually suspected of having mesenteric ischemia. In others it might be used to investigate more thoroughly the significance of mesenteric occlusive lesions found by arteriography performed for unrelated reasons. Finally, it could be useful for follow-up of those patients who have undergone visceral revascularization procedures.

Some deep abdominal duplex scanning, including renal and mesenteric arteries [1, 2], the vena cava [3], and the portal venous system [4–6], is now performed in most vascular laboratories or ultrasound departments. However, the low prevalence of mesenteric arterial occlusive disease has resulted in fewer patients to examine routinely compared with other disorders such as carotid artery disease or even renovascular disease. Deep abdominal ultrasonography remains one of the most challenging applications of noninvasive testing due to variations in body habitus and fat distribution, the presence of respiratory motion, and the depth and the variable anatomy of the major abdominal vessels. Even normal mesenteric anatomy is complex with the major vessels and their branches running in a spatially unpredictable fashion. The mesenteric arterial anatomy may become even more variable when large collateral vessels have developed in the presence of occlusive lesions. Duplex scan evaluation of visceral vessels may also be obscured by bowel gas found in normal patients or those with gastrointestinal disorders.

Atherosclerotic lesions of the visceral vessels usually occur at or near the origins of the CA and SMA ("ostial lesions") from the abdominal aorta (Fig. 51.1), which is the most predictable part of the mesenteric anatomy even when more distal branchings are complex. Most clinically important lesions will be identified by examination of the origins of the CA and SMA and scanning of the proximal 2–4 cm of these vessels. It is generally felt that significant clinical symptoms, and/or the risk of gut infarction, exist only when there is severe stenosis or occlusion of at least two main mesenteric vessels. Arteriography is still required to determine the need for treatment and the best therapeutic options, but
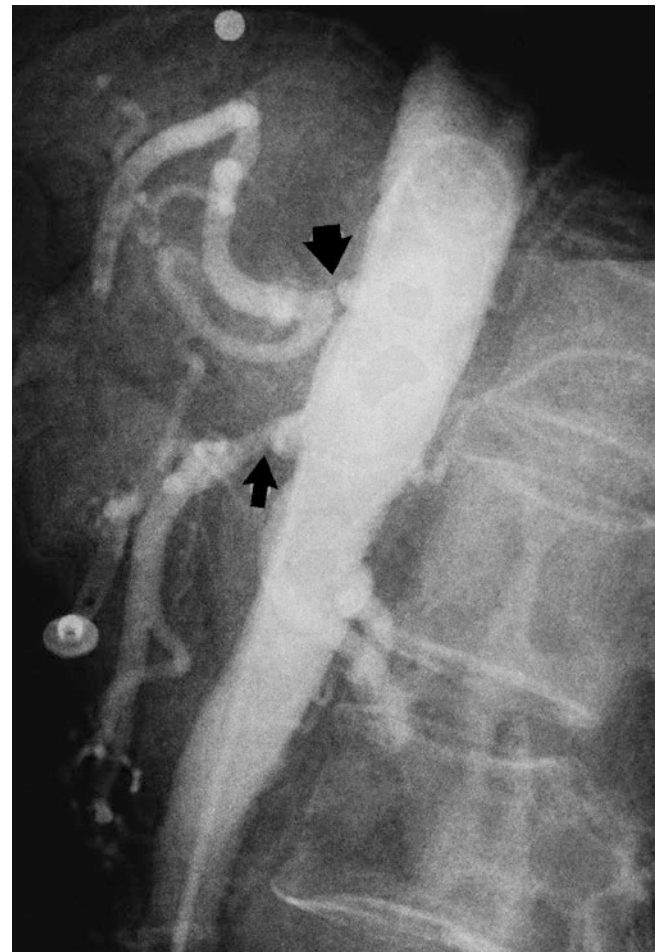

Fig. 51.1 Lateral view demonstrating the typical ostial location of most atherosclerotic lesions in the main mesenteric vessels. There is a severe stenosis of both the celiac (*larger arrow*) and superior mesenteric arteries (*smaller arrow*) near their origins from the aorta

mesenteric duplex scanning may be useful to select those patients who would benefit most from arteriographic study. Thus, one clinical use of mesenteric duplex scanning would be the identification of normal vessels or those with mild to moderate atherosclerosis where arteriography could be avoided and another would be to identify accurately severe occlusive disease of the CA and SMA where mesenteric arteriography would determine the subsequent clinical management of the patient.

Mesenteric Duplex Scanning: Technique

As with all deep abdominal duplex scans, intestinal gas will compromise the technical success of mesenteric examination. An overnight fast is adequate preparation for most elective cases, but simethicone-containing compounds may be useful in cases where bowel gas remains a problem. In patients with a more acute problem, the ileus produced by

any intra-abdominal inflammatory processes (e.g., acute mesenteric ischemia, cholecystitis, pancreatitis, and diverticulitis) greatly limits the usefulness of mesenteric scanning. When a technically adequate examination can be performed, it may be useful in directing further diagnostic evaluation, but in emergent cases where mesenteric ischemia is suspected, arteriography should be performed without delay.

Mesenteric duplex scanning is performed with the patient supine and the head slightly elevated. Low frequency, dedicated abdominal probes are used for mesenteric, renal, hepatoportal, and vena caval scanning. An anterior-posterior midline approach is used to obtain a sagittal scan of the aorta. The origins of the CA and SMA are usually visualized as they course ventrally from the aorta (Fig. 51.2) above the level where the left renal vein crosses the aorta. Most atherosclerotic occlusive lesions in the CA and SMA are at or near the origins of the vessels from the aorta, so insonation of the first few centimeters of each vessel is usually adequate for diagnosis. The inferior mesenteric artery (IMA) originates from the left side of the infrarenal aorta a few centimeters above the aortic bifurcation.

Pulsed Doppler examination is performed using a 1.5–2.0 mm sample volume. Peak systolic velocity (PSV), end diastolic velocity (EDV), waveform configuration, and direction of flow are recorded. Doppler angles of insonation =60° must be employed when sweeping through the vessels. Rizzo et al. [7] observed that pulsed Doppler arterial flow velocities from the mesenteric vessels should be measured at angles of insonation less than 60° or falsely elevated peak systolic velocities will be recorded even in normal vessels. The anat-

omy of the vessels often produces sudden changes in vessel direction, and it is incumbent upon the technologists to be as certain as possible about the location and angle of the sample.

Accurate examination of the celiac trunk may be challenging. The celiac trunk is rarely longer than 1–2 cm, and the anatomy of its branches (common hepatic, splenic, and left gastric) may be extremely variable. The left gastric artery is rarely identified by duplex scan, and routine examination includes the celiac, hepatic, and splenic arteries. While flow in the origin of the CA roughly parallels that in the SMA ventral from the aorta, the branching of the celiac trunk results in rapid changes in the direction of arterial flow at almost 90° to the right (hepatic) and left (splenic) of the main celiac trunk. These anatomic relationships can be appreciated with a transverse B-mode scan of the CA, which has been termed the "rabbit-ear" or "seagull" appearance (Fig. 51.3).

Identification and pulsed Doppler spectral analysis is easier in the SMA than in the celiac trunk. There are generally no major branches of the SMA visualized on routine examination. However a "replaced right hepatic artery" may originate from the SMA in up to 20% of normal cases. Some patients may even have a common trunk origin of both the CA and SMA. The variable collateral patterns that are present in cases of occlusion of a single main mesenteric artery may be even more confusing. Large gastroduodenal or pancreaticoduodenal branches may serve as collateral communication between the CA and SMA, and these may be difficult to interpret by an inexperienced examiner.

The IMA has not been routinely studied but may be identified by scanning down the infrarenal aorta toward the bifur-

Fig. 51.2 Sagittal scan of the aorta in a normal patient is similar to the lateral aortogram and demonstrates the origins and proximal portions of the celiac trunk and the superior mesenteric artery. Pulsed Doppler sampling is performed in the proximal portions of these vessels where most occlusive disease occurs. *SMA* superior mesenteric artery

Fig. 51.3 Doppler spectral analysis in the celiac trunk (CEL) may be challenging due to changes in the angle of insonation produced by its branching into the splenic artery (SA) and the common hepatic artery (HA). These sudden changes in the direction of flow in the celiac branches can produce falsely elevated flow velocities unless the angle of insonation is carefully controlled at =60°. *Ao* aorta
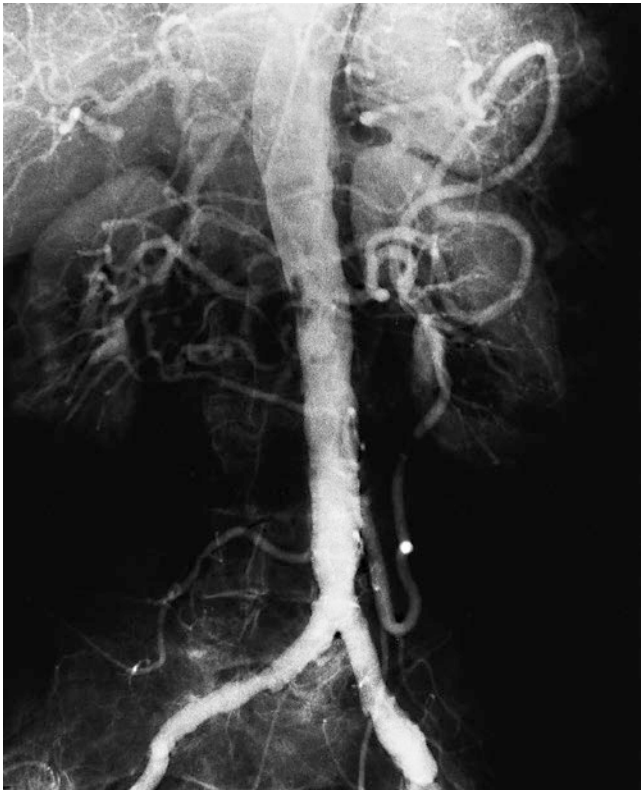
Fig. 51.4 Aortogram demonstrating a dramatically enlarged inferior mesenteric artery (IMA) originating from the left side of the infrarenal aorta several centimeters above the aortic bifurcation. Retrograde flow through the "meandering mesenteric" collateral is demonstrated in this patient with an SMA occlusion

cation where it is generally the only vessel originating from the left side of the aorta. Isolated stenosis or occlusion of the IMA is rare, but it may play a major role in the visceral collateral circulation. The presence of a markedly enlarged and, thereby, easily identifiable IMA may suggest significant occlusive disease of the SMA with the IMA serving as the collateral (Fig. 51.4). However, many patients with mesenteric arterial disease have associated aortoiliac occlusions. Here the IMA may be occluded, but large lumbar collaterals may be mistaken for the IMA on duplex scanning. Another potential source of error in attempt to scan the IMA is the presence of an accessory lower pole left renal artery which would also originate from the left side of the infrarenal aorta. Overall, in most cases it is sufficient to focus the examination on occlusive lesions at the origins of the CA and SMA, since this is the area of involvement in most clinically relevant diseases.

Color Doppler scanning allows more rapid identification of the origins of the CA and SMA from the abdominal aorta and will reduce the time required for an examination. Color-flow scanning may help visually identify focal areas of flow disturbance that require further interrogation or help one detect the absence of flow in one or both of the major

mesenteric vessels suggesting occlusion. It is important to remember, however, that color assignment is based almost entirely upon direction of flow. The anatomic variations discussed above make it evident that beyond the origins of these vessels, sudden changes in flow direction can produce confusing color-flow patterns even in normal subjects.

Reliable, broadly accepted diagnostic Doppler frequency or flow velocity parameters have not been developed for the mesenteric circulation as they have been in most other systems (carotid, renal, bypass grafts, etc.). Most reports of visceral arterial duplex scanning emphasize the determination of PSV, EDV, and the presence or absence of early diastolic reversal of flow. Similar to carotid scanning, significant stenoses are most often identified by a focal increase in systolic and diastolic velocities, and occlusions are identified by the absence of flow, or flow reversal. Unlike renal artery duplex scanning, no improvement in diagnostic accuracy has been observed by normalizing visceral arterial velocity measurements to those in the aorta through the calculation of flow velocity ratios [8, 9]. Some investigators have reported quantitative blood flow (mL/min) measurements using Doppler-derived velocity information in either the portal venous system [10, 11] or in the mesenteric arterial circulation [12–15]. Although there is considerable research interest in volumetric flow data, this estimation is subject to significant error [16–18], and most diagnostic laboratories do not perform such measurements. The presence of elevated PSV and localized turbulence appears to correlate better with angiographically demonstrated arterial lesions in both the peripheral and the central circulation.

Normal Findings

Mesenteric arterial velocity waveforms have certain specific characteristics. At rest, blood flow in a normal SMA has a higher resistance Doppler velocity pattern with early diastolic flow reversal in most cases and late diastolic forward flow (triphasic waveform; Fig. 51.5). Blood flow in the CA as in the renal arteries has a low resistance Doppler velocity pattern with continuous forward flow during the entire cardiac cycle (Fig. 51.6). Spectral waveforms recorded from normal IMA are similar to those from the SMA with a higher resistance pattern with early diastolic flow reversal.

Clinical Applications

Physiologic Measurements

Duplex scanning of the mesenteric vessels in normal individuals has been used successfully to characterize the physiological changes that occur in the visceral circulation after

Fig. 51.5 The normal fasting SMA waveform (*right spectra*) is recognizably different than the celiac artery (CEL, *left*). The triphasic pattern of the normal SMA is reminiscent of that found in higher resistance peripheral arteries
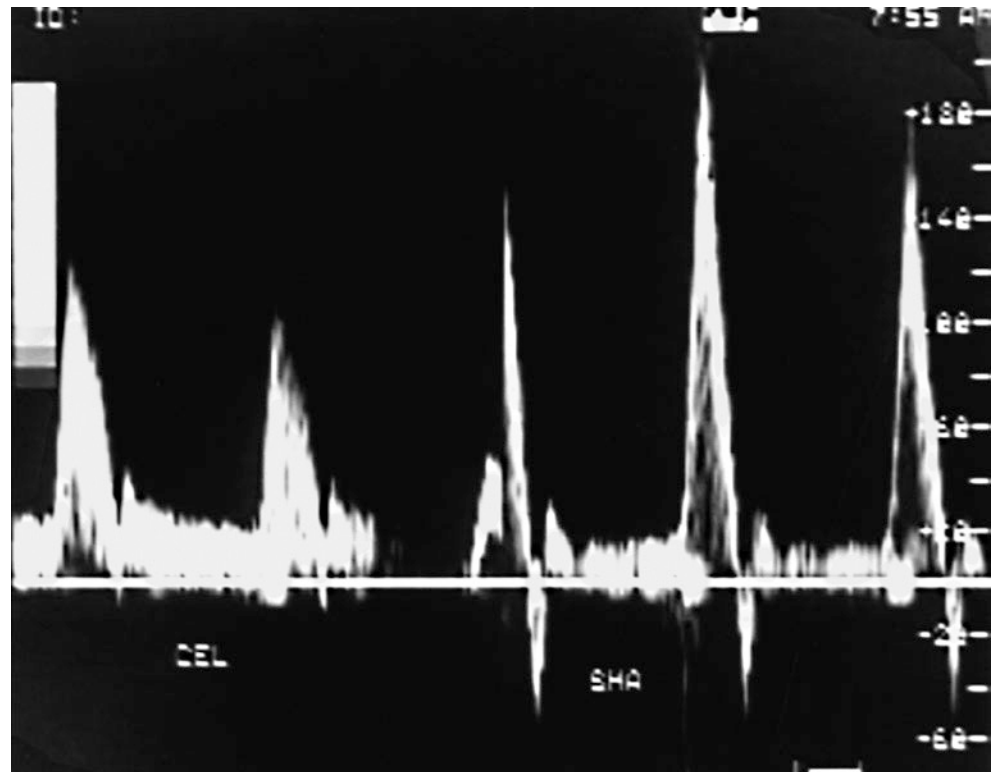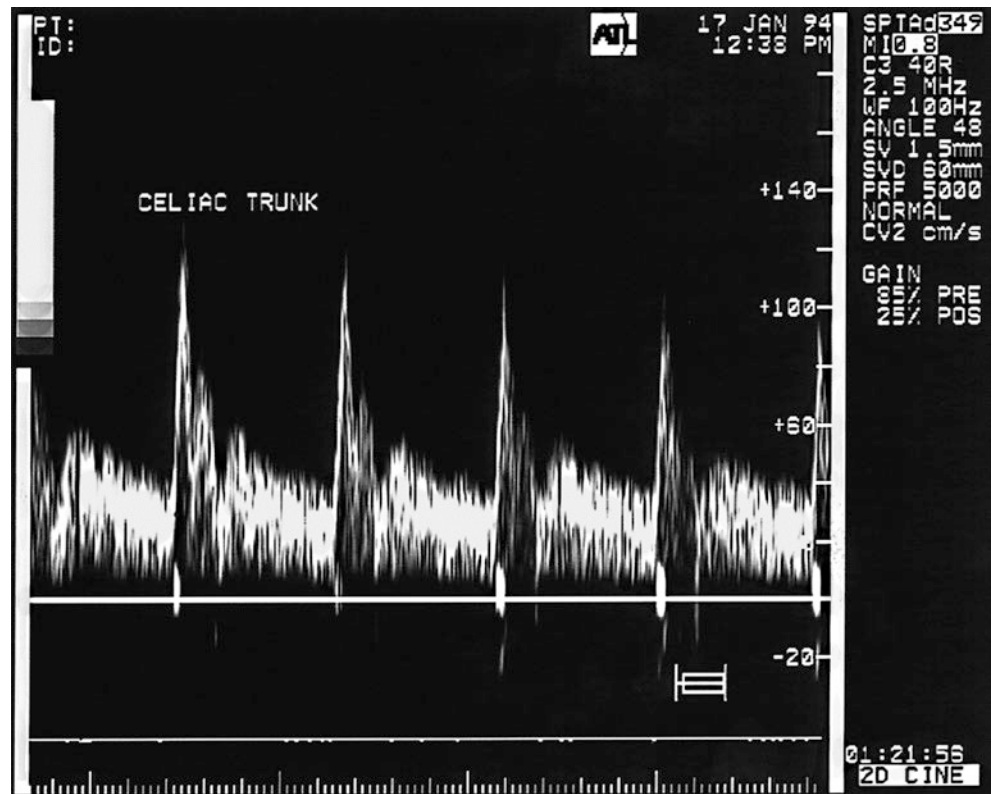

Fig. 51.6 Velocity spectrum from a normal celiac artery demonstrating continuous forward flow throughout systole and diastole

eating. The most reproducible changes occur in the SMA where significant increases in PSV are seen up to an hour after eating [19]. Also, the SMA flow waveform shifts to a low resistance pattern characterized by forward flow throughout the cardiac cycle with loss of the early diastolic flow reversal. The composition of the meal, including volume,

energy content, and the nutritional composition, may influence the observed changes in mesenteric flow velocities after a meal [1, 4, 15, 20]. Fat and carbohydrates appear to be the nutritional components of the meal that produce the most significant postprandial increases in measured PSV [15].

Duplex scanning has also been used to demonstrate the effects of drugs on intestinal blood flow. Several investigators have demonstrated changes in mesenteric arterial flow following the infusion of splanchnic vasodilators such as glucagon and secretin and vasoconstrictors such as vasopressin [19, 21]. Lilly et al. [19] observed that the changes in superior mesenteric arterial flow following glucagon infusion closely paralleled those observed after a meal.

Visceral Aneurysms

Aneurysms of the mesenteric vessels are extremely rare, and the clinical usefulness of duplex scanning for the detection of mesenteric aneurysms remains anecdotal. Ultrasonographic diagnosis of aneurysms of the superior mesenteric [22–24], hepatic [25, 26], splenic [27, 28], gastroduodenal [29], middle colic [30], and pancreaticoduodenal [31] arteries has been reported, but in these cases scanning was often performed due to uncertain gastrointestinal or abdominal complaints. However, duplex scanning may be useful in such cases to select patients for more thorough, focused vascular exam with CT, MRI, or arteriography. Color-flow duplex ultrasonography may be useful for differentiating saccular false aneurysms of the superior mesenteric and splenic artery from other more benign, nonvascular fluid collections in the setting of pancreatitis or other retroperitoneal inflammatory conditions. However, as noted above, an associated ileus with excessive bowel gas may preclude a diagnostic study.

Celiac Artery Compression Syndrome (Median Arcuate Ligament Syndrome)

A focal increase in flow velocities identified at the origin of the celiac artery may be due to extrinsic compression of the CA by the median arcuate ligament of the diaphragm, particularly when this finding is detected in a younger individual. Celiac artery compression syndrome has been reported to produce gastrointestinal symptoms in some patients, but most clinicians regard this as a benign condition with little or no risk of intestinal infarction. In fact, duplex scanning of these lesions is more likely to be performed to evaluate the finding of the celiac stenosis on an arteriogram performed for other reasons (Fig. 51.7). This "lesion" is usually associated with a normal arterial wall and normal aorta with no evidence of atherosclerotic plaque. Scanning during deep inspiration with breath holding produces a relaxation of the
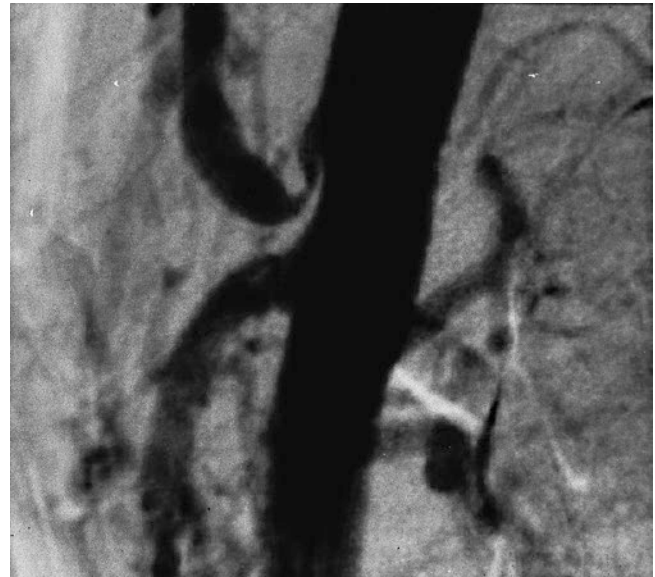

Fig. 51.7 Characteristic arteriographic appearance of proximal celiac artery stenosis due to compression by the median arcuate ligament of the diaphragm. Note there is no evidence of atherosclerosis in the aorta or the SMA. Deep inspiration in this case produced a normalization of both duplex scan findings and the arteriogram

diaphragmatic crus and often results in a return of normal celiac velocities which confirms the diagnosis.

Visceral Ischemic Syndromes

The use of duplex ultrasonography as a screening test to detect major mesenteric arterial occlusive disease in patients suspected of having chronic intestinal ischemia has attracted interest among clinicians, since the diagnosis of mesenteric occlusive disease in the past required arteriography. Jäger et al. [32] first reported abnormal pulsed Doppler waveforms with increased PSVs and marked spectral broadening and in both the CA and SMA of a patient with severe atherosclerotic stenosis in both vessels and symptoms of chronic visceral ischemia. Other authors [33, 34] have used similar criteria of distorted Doppler flow patterns or absence of detectable flow to document high-grade stenosis or occlusion of the intestinal arteries. Moneta et al. [35] reported ultrasound visualization of an enlarged IMA in several patients with high-grade stenosis or occlusion of the celiac and superior mesenteric vessels where that vessel had become the major collateral supply to the bowel.

Standardized velocity criteria for duplex scan diagnosis of hemodynamically significant lesions of the mesenteric arteries (similar to those used in the diagnosis of extracranial carotid artery disease) have not been thoroughly refined. Considering the low prevalence of mesenteric disease compared to carotid disease and the small number of

arteriograms available for comparison, it would appear unlikely that such discrete diagnostic criteria would be forthcoming soon. Nevertheless, several studies can provide general ranges for diagnosis which will be clinically useful for the practitioner. Moneta et al. [9] compared the results of mesenteric duplex scanning to arteriography in 34 patients with known atherosclerosis. This group included patients with suspected visceral ischemia as well as others requiring routine arteriography for lower extremity ischemic symptoms. An analysis of their accumulated data revealed that PSVs above 275 cm/s in the SMA (normal = 125–163 cm/s) could predict a severe SMA stenosis (>70%) with a sensitivity and specificity of 89% and 92%, respectively. A similar diagnostic accuracy was observed by these investigators when PSVs exceeded 200 cm/s in the CA. Total occlusions of the CA and SMA were also accurately diagnosed by duplex scan in this report. This initial retrospective study failed to demonstrate the usefulness of a "mesenteric/aortic" systolic velocity ratio to predict the presence of a severe stenosis in the celiac artery or SMA as has been observed in duplex scanning of the renal arteries. In a subsequent report [36], these investigators prospectively evaluated these diagnostic criteria in 100 patients having arteriograms and demonstrated that mesenteric duplex scanning was indeed sufficiently accurate to be clinically useful as a screening examination in cases with suspected CA or SMA occlusive disease (Fig. 51.8).

The usefulness of mesenteric duplex scanning for the diagnosis of significant CA and SMA lesions was confirmed in the report of Bowersox et al. [37] that compared mesenteric duplex scanning with arteriograms in 25 patients, most of whom were suspected of having visceral ischemia. These investigators observed that a >50% stenosis of the SMA could be best predicted by duplex scan measurement of a fasting PSV >300 cm/s or an EDV of >45 cm/s. These authors were unable to establish reliable duplex scan velocity criteria for CA stenosis. They observed that the anatomy of the CA compromised precise insonation as noted previously in this chapter. Considering the small sample size and the fact that most patients were symptomatic, it is possible that anatomic and collateral variants would account for the observed compromise. Further emphasizing the difficulties encountered in an attempt to define precise duplex ultrasound diagnostic criteria for mesenteric occlusive lesions, Healy et al. [38] were unable to identify any definitive velocity criteria for detection of CA or SMA stenoses.

These observations generally serve to reinforce the continued need for prospective studies with arteriographic correlation. However, as noted above, cases available for study are seen infrequently. Nevertheless the general principles of duplex scan detection of a "critical" stenosis or occlusion in any arterial system apply in the mesenteric vessels: (1) a focal marked elevation in PSV, particularly associated with elevated EDV, (2) post-stenotic turbulence with reduced flow velocities beyond the stenosis, and (3) absent flow in an anatomically well-defined arterial segment, particularly with flow reversal beyond the lesion (suggestive of occlusion). The key to success in the mesenteric circulation relies not so much upon precise velocity criteria but in accurate anatomic identification of the vessels and control of the technologic variables for Doppler examination.
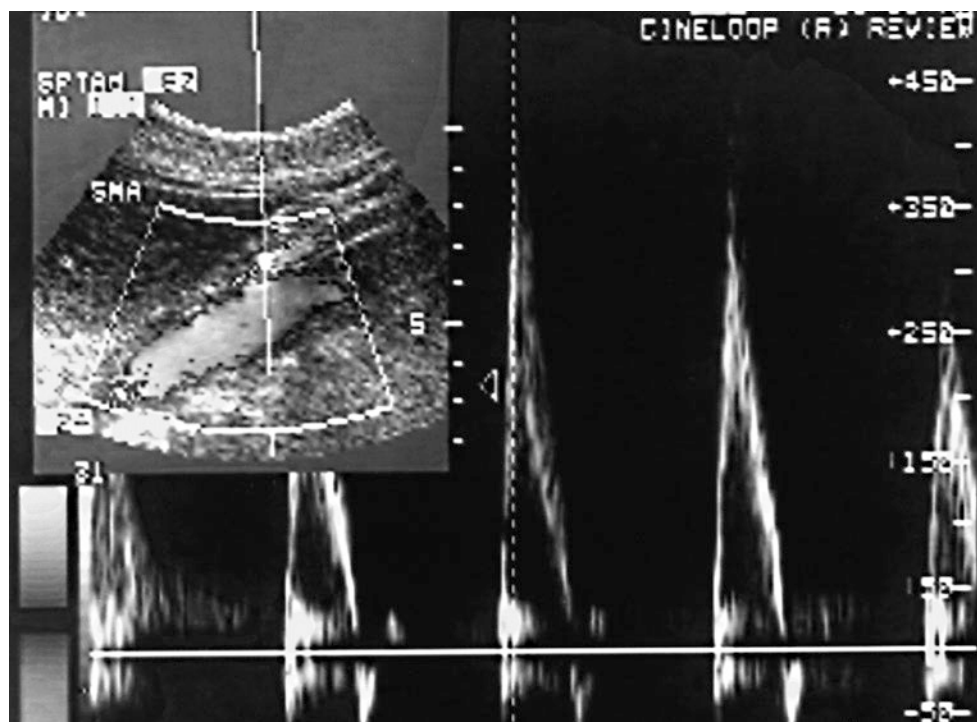

Fig. 51.8 Duplex scan of the proximal SMA reveals a markedly elevated peak systolic velocity >350 cm/s. This suggests the presence of a >70% SMA stenosis

Perioperative Applications

Intraoperative Applications

As with all vascular reconstructions, early technical success is essential in the outcome of mesenteric revascularization. Due to the intra-abdominal location of the bypass, early graft failure may not be readily apparent. Abdominal pain is an unreliable symptom following laparotomy, and if the patient goes on to gut infarction, the outcome is almost uniformly fatal. It is clear then that intraoperative assessment of the technical conduct of mesenteric revascularization procedures is an important clinical component of these procedures. The portability of modern ultrasound equipment and increasing surgeon familiarity with these techniques has led to an increase use of duplex ultrasound scanning to assess technical success following renal and mesenteric revascularization procedures. Oderich and colleagues evaluated the use of intraoperative duplex scanning in 68 patients undergoing operative visceral revascularization [39]. Patients who were identified to have an abnormal intraoperative mesenteric duplex examination had a higher incidence of early graft thrombosis, reintervention, and higher perioperative mortality. The authors concluded that the duplex scan evaluation helped optimize early technical success of mesenteric revascularization procedures.

Postoperative Applications

Revascularization of symptomatic mesenteric arterial occlusions is optimal management, but in the past, the patency of these reconstructions, like initial diagnosis, could only be determined by arteriography. Sandager et al. [40] first reported the use of duplex ultrasonography to evaluate the patency of visceral arterial reconstructions. Duplex scanning successfully documented graft function in six of seven visceral bypass grafts, and findings were correlated with standard arteriography. McMillan et al. [41] reported successful duplex scan follow-up of mesenteric bypass procedures in 30 cases. This study also demonstrated that reliance on recurrence of abdominal symptoms alone has a sensitivity as low as 33% in the detection of mesenteric graft occlusion. Duplex scanning can provide accurate noninvasive documentation of the patency of visceral revascularization procedures without requiring contrast-based imaging (Fig. 51.9).

Liem and colleagues evaluated the duplex characteristics of 43 mesenteric bypass grafts in 38 patients [42]. Midgraft velocities were not significantly impacted by graft material, inflow artery, target artery, or graft configuration (antegrade vs retrograde). Although there were also no characteristics that predicted future graft thrombosis, velocities in patent grafts remained stable from study to study with midgraft PSVs generally between 100 and 200 cm/s. The authors recommended secondary imaging (computed tomography angiography or conventional angiography) if the PSV $\geq$300 or <50 cm/s. There is also a suggestion that a significant change in velocity from one study to the next may be indicative of a stenosis. Limitations of this study include a small sample number and the absence of angiographic correlation. The role of prospective surveillance of these grafts is unknown at present. However, increased experience with postoperative duplex scanning of mesenteric bypass grafts will allow a more accurate documentation of late patency for these procedures, an aspect that has been incompletely studied in the past due to the requirement for repeated invasive contrast studies. Overall, it has become evident that duplex ultrasonography can be used successfully to document the postoperative patency of surgical procedures performed for revascularization of the mesenteric vessels, eliminating the need in most cases for the use of more invasive contrast studies. However, it should be remembered
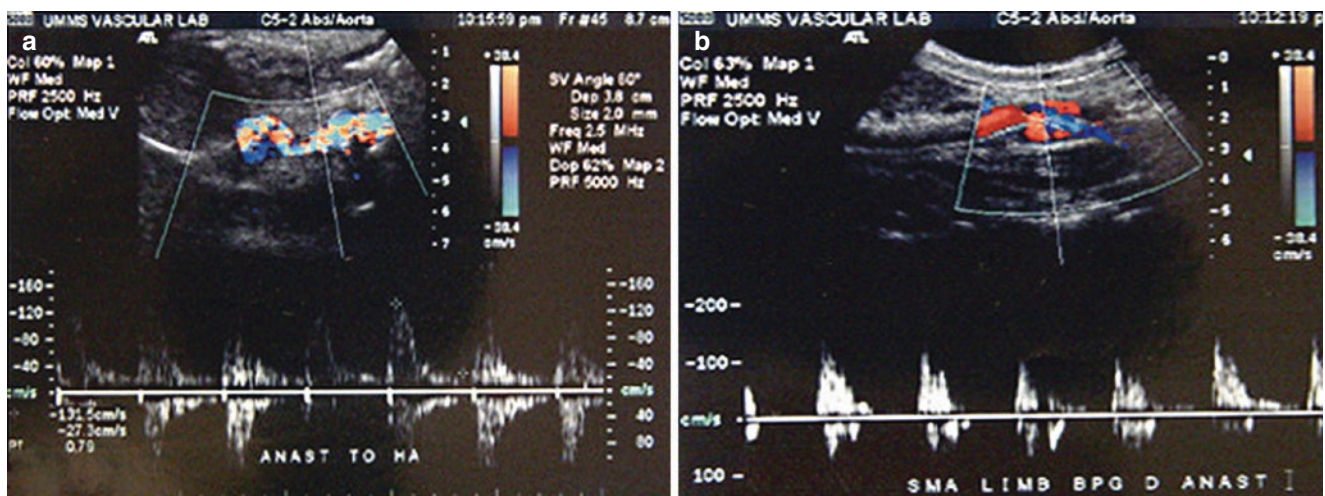
Fig. 51.9 Duplex scan demonstrating patency of a bifurcated arterial bypass graft with one limb to the hepatic artery (**a**) and one limb to the SMA (**b**)

Fig. 51.10 Aortoceliac and mesenteric bypass with a Dacron bifurcation graft using a retrograde technique from the infrarenal aorta. Surgeons wishing to perform postoperative mesenteric duplex scanning must inform the ultrasonographer about the precise surgical details of these reconstructions that are often anatomically complex

that the anatomic construct of these revascularization procedures may be quite complex and often not anatomically intuitive, to even an experienced ultrasonographer. Antegrade bypass from the supraceliac aorta, retrograde bypass from the infrarenal aorta (Fig. 51.10), or iliac arteries with prosthetic or vein grafts may be performed. Thus optimal performance of postprocedural scanning in these cases will be greatly facilitated by provision of the details of the surgical procedure to the ultrasonographer performing the exam.

Endovascular Intervention

Endovascular interventions including balloon angioplasty and stenting have been performed routinely in the renal arteries, and these techniques have also proven to be effective for treatment of mesenteric arterial occlusive lesions

(Fig. 51.11). Steinmetz and colleagues reported their experience in 19 patients with chronic mesenteric ischemia treated by balloon angioplasty or stenting [43]. The authors reported a 100% technical success rate although in 7 of the 19 cases only one of the two vessels intended for treatment was successfully treated. In seven cases stenting was required due to recoil or residual stenosis. Patients having angioplasty and/or stenting in this series were followed up with duplex ultrasound for a mean of 31 months. The primary patency was 75% and long-term pain relief noted in 85% of patients for whom follow-up was available. Three patients developed symptomatic restenosis and were treated with redo angioplasty with resolution of pain. Two other patients were found to have asymptomatic restenosis and were followed conservatively [43]. AbuRahma and colleagues report on 22 patients with 24 symptomatic mesenteric arterial lesions treated with balloon angioplasty/stenting over a 4.5 year period [44]. In this series the initial technical success as defined, per vessel, as residual stenosis <30% and pressure gradient <10 mmHg was 96%. Over a mean follow-up period of 26 months, the primary late clinical success rate was 61% with a freedom from restenosis (=70%), as documented by objective duplex examination, of 30%. Freedom from recurrent symptoms was 67%. Four-year survival rate in these patients was 53% [44].

Duplex ultrasound has been used to evaluate patency following endovascular revascularization of mesenteric arteries (Fig. 51.11). Excellent correlation has been found between a significant decrease in PSV following angioplasty/stenting and a favorable clinical response [45]. PSV following these endovascular treatments may occasionally remain in the abnormal range (>275 cm/s) [45]. Although the PSV will be significantly lower than pre-procedure levels. Sharafuddin and colleagues suggest scanning the SMA beyond the stent and performing the study in a strictly fasting state to reduce artifactual increases in PSV observed in the SMA [45].

In one more recent study, PSV in successfully stented SMAs remained above 275 cm/s in *all* cases [46]. Mitchell et al. report on 13 patients with early post-stent duplex information [46]. While mean PSV pre- and post-stent dropped from 450 cm/s to 336 cm/s, respectively, no stented patient had SMA PSV under the cutoff for >70% native artery stenosis. Similarly, albeit in a smaller series, Fenwick et al. note velocities consistent with >70% stenosis in three out of four successful SMA stent procedures without recurrence of symptoms or weight loss [47].

Based on the experience to date, it does not appear that criteria for native SMA stenosis can be reliably applied to post-stent Duplex evaluation. Until new, stent specific, criteria are established and validated, we would recommend an early post-stent duplex be obtained and serve as a baseline, reserving intervention for either return of symptoms or for significant elevation of PSV over the new baseline measurement.
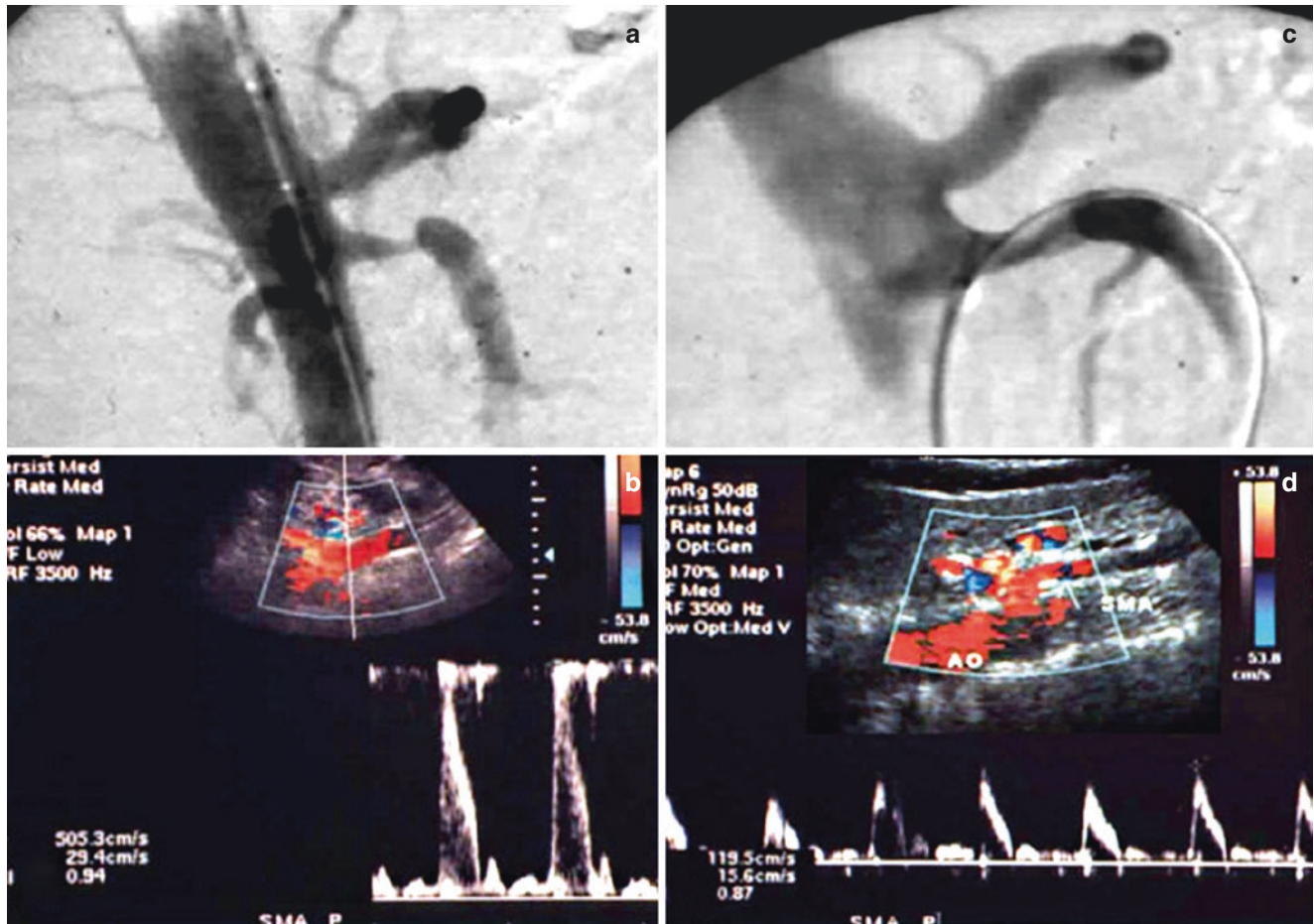
Fig. 51.11 (**a**) Aortogram depicting high-grade stenosis in the proximal SMA, (**b**) corresponding duplex image demonstrating significantly elevated peak systolic velocities of 505 cm/s at the level of the stenosis, (**c**) angiogram post-percutaneous angioplasty and stenting demonstrating resolution of the SMA stenosis, and (**d**) corresponding duplex image demonstrating a patent stent (*arrow*) and reduction of peak systolic velocities to normal (120 cm/s)

Acute Mesenteric Ischemia

Acute mesenteric ischemia is usually produced by mesenteric embolism or mesenteric thrombosis. It would be ideal to provide direct duplex scan identification of discrete mesenteric arterial occlusions in these cases particularly since the approach to treatment may be different. If patients with acute major mesenteric arterial occlusions were examined very early in the clinical course of these problems, duplex scanning might provide an accurate assessment. However, diagnosis is often delayed in these patients, and the associated ileus that rapidly develops renders the scan virtually useless. Takahashi et al. [48] reported dramatically reduced portal venous flow by duplex ultrasonography in one patient with acute mesenteric infarction. Reduced portal vein flow is an indirect reflection of severely reduced mesenteric arterial blood flow, and its lack of specificity would be of limited clinical usefulness in the majority of cases. Prompt arteriography and CT angiography are the diagnostic examinations of choice in such cases since excessive delay in the diagnosis can lead to irreversible intestinal infarction.

Image Enhancement

Unlike vessels in the neck or extremities, the ability to image the mesenteric vessels can often be difficult due to patient body habitus or bowel gas. The low-frequency transducer needed to image at the appropriate depth is hampered by poorer B-mode image resolution. This leads to less accurate placement of the Doppler sample volume. Investigational substances are being developed and studied to assist in enhancing ultrasound imaging of blood vessels. The ideal ultrasound contrast agent would have the appropriate density and acoustic properties to strongly reflect transmitted ultrasound waves. Additionally the contrast agent would be physiologically inert, small enough to easily pass through capillaries, and persist in the vasculature long enough to

complete the study. Perflutren (Definity, Dupont Pharmaceuticals Co.) is one such agent. It can be agitated, injected into a bag of sterile saline solution, and infused intravenously. Blebea et al. studied perflutren in 17 patients to examine its potential usefulness in evaluating the mesenteric arteries [49]. The authors concluded that the contrast material appeared to be safe, but that it is not routinely required and did not significantly improve the accuracy of standard duplex imaging. However, the use of contrast material may be helpful when visualization is difficult with standard techniques due to patient obesity or excessive abdominal gas.

Population Screening

Although duplex ultrasonography has gained acceptance as a first-line screening test for patients with suspected chronic intestinal ischemia [50], the incidence of mesenteric arterial stenosis in the general population has not been well studied. Hansen and colleagues studied over 550 elderly volunteers in an effort to estimate the population-based prevalence of mesenteric artery stenosis in elderly Americans [51]. Using criteria of celiac PSV >200 cm/s and SMA PSV >270 cm/s, or occlusion of either vessel, the authors determined 17.5% of the individuals studied had either a significant celiac or SMA stenosis or occlusion. The majority (10.5%) has isolated celiac stenosis. 1.3% had combined SMA and celiac stenosis. 0.9% had isolated SMA stenosis. 0.4% had celiac occlusion. When all patients with mesenteric arterial stenosis were considered, there was no association with symptoms of weight loss. The authors did note, however, that the combination of celiac occlusion and SMA stenosis was significantly associated with weight loss and concurrent renal artery disease.

Conclusion

Mesenteric duplex scanning can become a routine noninvasive diagnostic testing modality for the evaluation of patients with suspected visceral ischemia since earlier diagnosis and treatment will significantly reduce the risk of catastrophic gut infarction in these patients. Like all deep abdominal duplex scanning, mesenteric scanning is more technologically demanding than scanning vessels of the neck or extremities. However, continued refinement of the duplex instrumentation makes these examinations exciting areas of clinical advancement since there have previously been no other reliable noninvasive techniques for assessment of major intra-abdominal vessels. Like other duplex scan applications, mesenteric duplex scanning can be used to ensure the technical efficacy of mesenteric revascularization procedures, whether surgical or endovascular. Mesenteric duplex scanning can then provide a means of late follow-up assessment of these procedures to document their durability or prevent late procedural failure.

Review Questions

1. Blood flow in a normal superior mesenteric artery has the following characteristics:
   a. High resistance Doppler velocity with early diastolic flow reversal
   b. High resistance Doppler velocity with late diastolic forward flow
   c. Has triphasic wave form
   d. All of the above
2. Blood flow in a normal celiac artery has the following characteristics:
   a. High resistance Doppler velocity with early diastolic flow reversal
   b. High resistance Doppler velocity with late diastolic forward flow
   c. Has triphasic wave form
   d. Has low resistance with continuous flow during the entire cardiac cycle
3. Celiac artery compression syndrome is generally considered likely if:
   a. There is no evidence of aortic atherosclerosis
   b. Deep inspiration produces normalization of duplex velocities
   c. Expiration produces increase in baseline velocities
   d. All of the above
4. The following duplex velocities are compatible with ≥70% superior mesenteric artery stenosis:
   a. PSV of ≥200 cm/s
   b. PSV of ≥250 cm/s
   c. PSV of ≥275 cm/s
   d. PSV of ≥150 cm/s
5. The following duplex velocities are compatible with ≥70% celiac artery stenosis:
   a. PSV of ≥150 cm/s
   b. PSV of ≥200 cm/s
   c. PSV of ≥250 cm/s
   d. PSV of ≥275 cm/s

Answer Key

1. d
2. d
3. d
4. c
5. b

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