Duplex criteria for native superior mesenteric artery stenosis overestimate stenosis in stented superior mesenteric arteries

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Objectives: **Superior mesenteric artery (SMA) duplex scanning is utilized to screen for high-grade (≥70%) SMA stenosis (peak systolic velocity [PSV] ≥275 cm/second) and for follow-up of SMA bypass grafts and stents. Expected duplex scan findings in SMA bypass grafts have been recently reported. There is, however, little information correlating duplex scans from stented SMAs to procedural angiograms in patients treated for high-grade (≥70%) SMA stenosis. We report validation of duplex scan criteria for high-grade native artery SMA stenosis, and also duplex scan examined results after SMA stent placement correlated with angiograms and angiographic measured pressure gradients pre- and post-SMA stent placement.**

Methods and Results: **Thirty-five patients with symptoms consistent with mesenteric ischemia were treated with SMA stents. Pre-intervention angiography demonstrated >70% SMA stenosis or SMA occlusion in all but 3 patients. Pre-intervention pressure gradients were obtained in 20 stenotic but patent SMAs and averaged 57 ± 38 mm Hg; range, 15 to 187 mm Hg. Eighteen of the patients had SMA duplex scan prior to angiography, and 17 demonstrated an SMA PSV ≥275 cm/second or no flow, (mean 450 ± 152 cm/second in patent arteries; range, 256 to 770 cm/second). Post-stent placement angiography demonstrated <30% SMA stenosis in all 35 patients. Post-stent pressure gradients were obtained in 22 patients and averaged 11 ± 13 mm Hg; range, 0 to 45 mm Hg, (*P* < .001 compared to pre-stent pressure gradients in a paired test) and were elevated in patients with ≥60% celiac artery stenosis compared with those with <60% celiac artery stenosis (*P* < .006). Mean early post-stent duplex PSV scans obtained in 13 patients, were 336 ± 45 cm/second; range, 279 to 416 cm/second (*P* = .011 compared to pre-stent PSVs).**

Conclusion: **SMA stenting provides good anatomic results and significantly reduces measured pressure gradients. Duplex scans measured SMA PSVs are reduced post-stent placement but despite good angiographic results remain above criteria predicting high-grade native artery SMA stenosis. Duplex scan criteria developed to identify high-grade native artery SMA stenosis accurately predict high-grade native artery SMA stenosis but overestimate stenosis in stented SMAs. New duplex scan criteria are required to predict high-grade stenosis in stented SMAs. (J Vasc Surg 2009;50:335-40.)**

Initial diagnosis of significant visceral artery stenosis can be made using a duplex ultrasound scan.[1,2] There are now well established duplex ultrasound scan criteria for identification of high-grade stenosis in the superior mesenteric artery (SMA). Studies performed at our institution comparing mesenteric duplex scans and arteriograms demonstrated that an SMA peak systolic velocity (PSV) of ≥ 275 cm/second or no flow signal is a reliable indicator of a 70% or greater angiographic stenosis of the SMA.[3-5] Similar studies performed at Dartmouth Hitchcock Medical Center have validated the accuracy of duplex ultrasound scans in the assessment of mesenteric artery stenosis.[6-8]

Surgical revascularization of the mesenteric arteries employing either antegrade or retrograde bypasses or transaortic endarterectomy is the gold standard of treatment for chronic mesenteric ischemia. In recent years, however, stenting of the SMA has emerged as an alternative method of revascularization in patients considered high risk for open surgical methods of mesenteric revascularization.

With well established duplex scan criteria for identifying high-grade SMA stenosis in native arteries, investigational efforts have recently shifted to using duplex scanning as a follow-up tool for patients with visceral artery revascularization. Mesenteric bypass grafts have traditionally been followed in the postoperative period with duplex ultrasonography scans, and there are now data comparing duplex scan results in retrograde and antegrade visceral bypass grafts.[9] These data can serve as a reference for postoperative surveillance of mesenteric bypass grafts. There are, however, no systematic evaluations of mesenteric artery stents with the use of duplex scanning.

There is reason to suspect that duplex scan criteria developed for stenosis in native mesenteric arteries may not be applicable to stented SMAs. It appears higher velocity levels are required for identification of stenosis in stented internal carotid arteries and renal arteries then would be expected from criteria developed for identifying stenosis in native internal carotid and renal arteries.[10-15] A similar situation may exist for the mesenteric vessels. The purpose

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of this study was to determine whether traditional duplex scan criteria for high-grade native artery mesenteric artery stenosis can be extrapolated to stented SMAs.

PATIENTS AND METHODS

We reviewed combined interventional radiology and vascular surgery registries for all visceral arterial angiography procedures performed from January 1997 to December 2007, at Oregon Health & Science University. Patients who underwent SMA stenting for atherosclerotic lesions were identified and selected for review. Specific angiographic data extracted included percent angiographic SMA, celiac and inferior mesenteric artery stenosis prior to stent placement, pressure gradients measured across the SMA lesion prior to and after stent placement. Pressure gradients were obtained with a coaxial system with the aortic pressure obtained from the sheath in the aorta and the SMA pressure obtained from the catheter tip placed beyond the stenosis. Stent type, stent diameter and length, number of stents placed, and residual angiographic stenosis after stent placement were also recorded. Vascular laboratory data included fasting duplex determination of the maximal native artery SMA PSV pre-stenting and the maximal PSV in the region of the SMA stent (proximal and distal ends of the stent as well as intrastent) post-stenting of the SMA.

Early clinical failures were evaluated with repeat angiography. Follow-up angiography was not performed in the absence of clinical indications.

Duplex scans, angiographic images, and catheter-derived pressure gradients in the SMA prior to and after stenting of SMA stenoses were compared. Technical success of SMA stent placement was defined as <30% angiographic SMA stenosis after stent placement. Pressure gradients were not used as a measurement of technical success of the SMA stent procedure.

Data were collected into the Excel program (Microsoft, Redmond, Wash), and analyzed using statistical software SPSS 13 (SPSS Inc, Chicago, Ill). Pressure gradients and PSV measurements were expressed as the average +/− standard deviation. Pre- and post-stent gradients and PSV were compared using a paired *t* test or the Mann Whitney *U* test.

RESULTS

During the study period, 35 patients considered high risk for open surgical intervention underwent SMA stent placement for either acute or chronic symptoms of visceral ischemia. Symptoms included acute onset of abdominal pain, postprandial abdominal pain, diarrhea, vomiting, weight loss, and sitophobia (fear of food). Excluding procedures performed for de-branching of the aorta for stent graft repair of thoracoabdominal aneurysm, there were also 86 open mesenteric revascularizations performed during this same time frame.

Angiographic stenosis pre- and post-SMA stent placement. Angiographic degree of SMA stenosis was determined in 10% increments using calibers from lateral aortograms in all patients both pre- and post-stenting. All patients except 3 had ≥70% diameter stenosis of the SMA prior to stenting. Two patients had occlusion of the SMA prior to stent placement. Twenty-four patients (69%) had concomitant ≥70% celiac artery stenosis or occlusion, 2 patients had aberrant hepatic arteries arising off of the stenotic SMA, and all but 2 patients had high-grade inferior mesenteric artery (IMA) stenosis (≥70%) or occlusion. Overall, 31 patients (89%) had high-grade stenosis of two of the three principle mesenteric arteries. The 3 patients with <70% SMA stenosis had approximately 60% diameter reduction of the SMA and pre-stent pressure gradients measuring more than 47 mm Hg. Two had concomitant celiac artery occlusion or 90% stenosis.

Comparison of pre- and post-SMA stent catheter derived pressure gradients. No celiac artery or inferior mesenteric artery stenoses or occlusions were treated. SMA stent placement was technically successful as defined by angiographic criteria in all cases with all 35 patients treated having <30% angiographic residual SMA stenosis following stenting. A total of 44 stents were placed, with 2 4-mm stents, 7 5-mm stents, 18 6-mm stents and 17 7-mm stents used. A single SMA stent was placed in 28 patients, two stents were placed in 6 patients, and 1 patient had four stents placed.

Pre-intervention pressure gradients across the SMA stenosis were obtained in 20 stenotic but patent SMAs (two occluded SMAs were stented) and averaged 57 ± 38 mm Hg; range, 15 to 187 mm Hg. Post-stent pressure gradients were obtained in 22 patients and averaged 11 ± 13 mm Hg; range, 0 to 45 mm Hg. In 15 cases, post-stent pressure gradients were ≤15 mm Hg with 7 patients having post-stent measured pressure gradients >15 mm Hg (17, 18, 20, 20, 25, 40, 45 mm Hg). When pre- and post-stenting pressure gradients were compared using a paired *t* test in the 18 patients with stenotic SMAs that were stented, the pressure gradients fell significantly from a mean of 57 mm Hg to 10 mm Hg, $P < .001$ (Figs 1 and 2).

There were 6 patients with <60% celiac artery stenosis who had pressure gradients measured in the SMA following stent placement. In all but 2 of these patients, the post-SMA stent pressure gradient was 0 and in the remaining patient it was only 7 mm Hg. Sixteen patients with ≥60% to 99% celiac artery stenosis or occlusion had SMA pressure gradients measured post-placement of the SMA stent. The mean post-SMA stent pressure gradient in these patients was 14 mm Hg (range, 0 to 45 mm Hg). Comparing pre- and post-stent pressure gradients in patients with <60% celiac stenosis to those with ≥60% celiac stenosis showed the presence of a celiac stenosis ≥60% was associated with an increased SMA pressure gradient post-SMA stenting, $P = .006$.

Pre- and post-stent fasting duplex ultrasound scan examinations. Fasting pre-stent screening duplex scans were performed in 18 patients. Peak systolic velocities in the native SMA were greater than 275 cm/second in 16. Mean PSV was 450 ± 152 cm/second in patients with patent arteries, range 256 to 770 cm/second. Two patients had occluded SMAs with no demonstrated flow in the

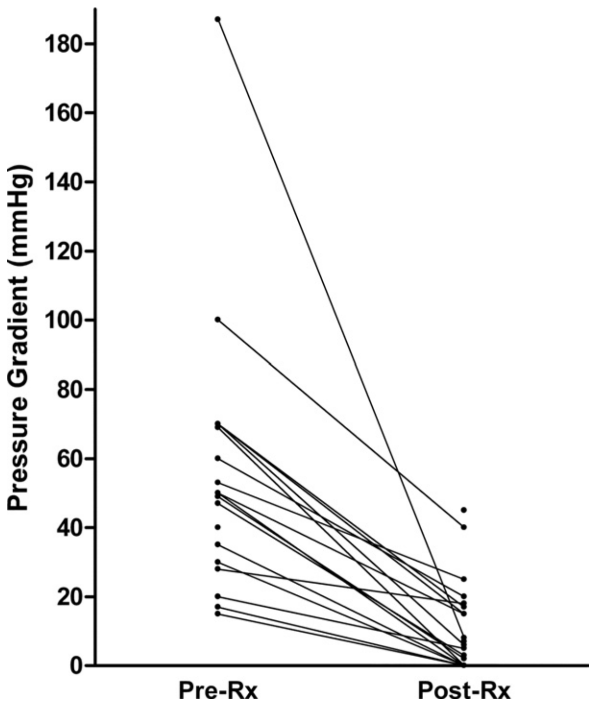


Fig 1. Dot plot of pressure gradients pre- and post-stenting of the SMA.

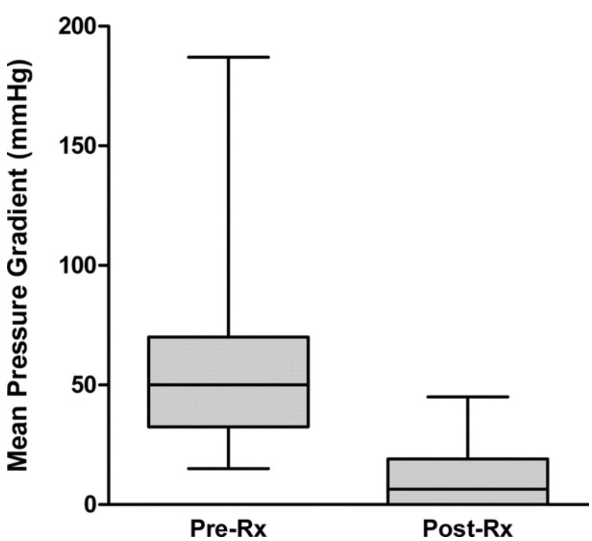


Fig 2. Box plot showing pressure gradient in the SMA pre- and post- stenting. Thick horizontal lines, boxes and error bars denote median, interquartile range and range, respectively, $P < .001$.

vessels by ultrasonography scan prior to stent placement. Thirteen patients underwent post-stent surveillance ultrasonography scans between 1 and 45 days (mean 11.5 days) following placement of the SMA stent. Peak systolic velocities exceeded criteria for ≥70% native SMA stenosis (≥275 cm/second) in every post-stent velocity measurement, mean 336 ± 45 cm/second, range 279 to 416 cm/second

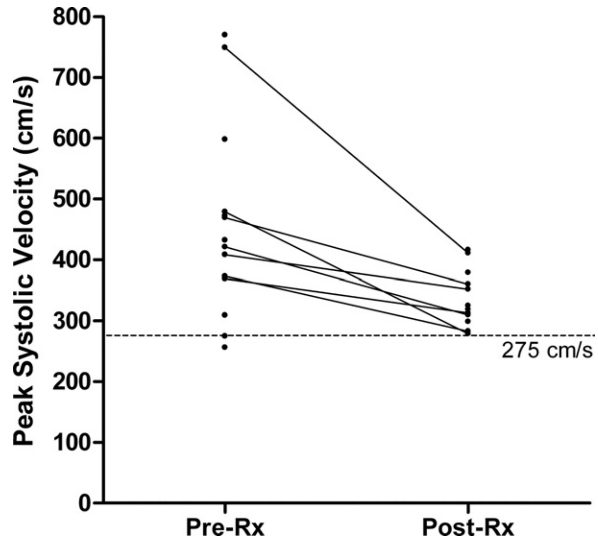


Fig 3. Dot plot of SMA PSVs prior to and after SMA stent placement.

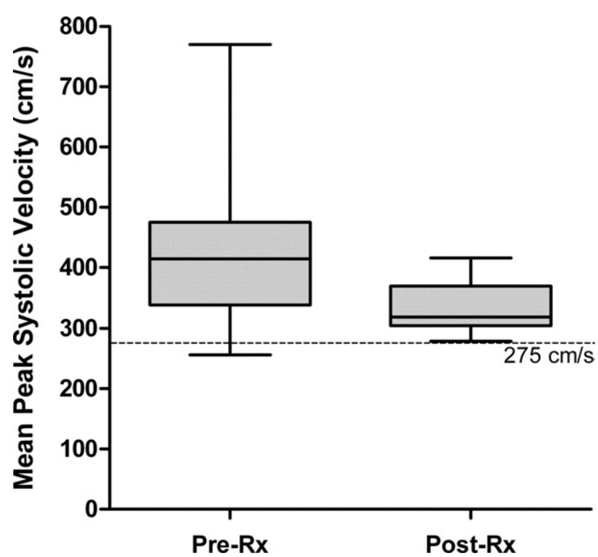
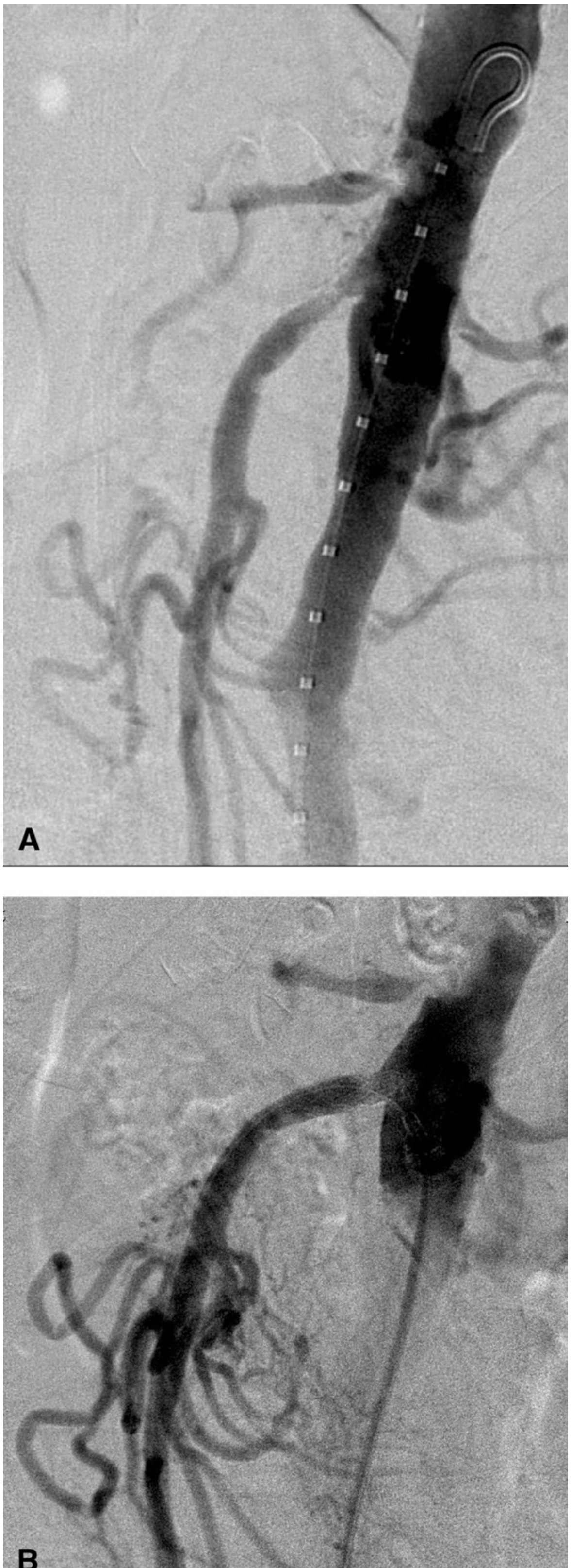


Fig 4. Box plot showing SMA PSVs pre- and post-stenting. Thick horizontal lines, boxes, and error bars denote median, interquartile range, and range, respectively, $P = .011$. Dashed line represents >70% SMA stenosis for PSV >275 cm/second.

(Fig 3). PSV measurements in paired samples were, however, significantly lower post-stent than pre-stent, $P = .011$ (Fig 4).

Early clinical failures. There were two early clinical failures of the SMA stent within 45 days. One patient had a measured SMA pressure gradient that fell from 70 mm Hg pre-stent to 17 mm Hg post-stent and remained symptomatic. That patient had repeat angiography with no change from the immediate post-stent angiogram and underwent mesenteric artery bypass with long-term relief of symptoms. A second patient had a residual 20 mm Hg gradient follow-



ing stent placement with a normal appearing post-stent angiogram and also remained symptomatic. Follow-up angiography 2 days later showed a questionable web-like defect at the proximal end of the stent. An additional stent was placed with apparent improvement of the angiographic image but no change in the measured pressure gradient across the SMA. Symptoms improved but recurred 3 years later and the patient underwent mesenteric bypass with improvement of symptoms and no further procedures for 4 subsequent years.

DISCUSSION

Mesenteric duplex scan criteria for the diagnosis of native artery SMA stenosis are well established.[3-8] Criteria were developed simply by comparing duplex scans to lateral angiograms and did not involve measuring angiographic pressure measurements as were performed in this study. Nevertheless, a SMA PSV of ≥275 cm/second has proven to be a reliable indicator of ≥70% angiographic stenoses in the native SMA and duplex ultrasound scan has become widely employed in the evaluation of patients with a myriad of abdominal symptoms consistent with mesenteric ischemia.

Visceral bypass is standard care for management of visceral ischemia resulting from SMA stenosis. Postoperative duplex scanning has an established role in monitoring mesenteric bypass patency, since clinical examination alone has limited sensitivity (as low as 33%), in the detection of mesenteric graft occlusion in patients with recurrent abdominal symptoms.[15] We have, indeed, recently established criteria for expected PSVs in both antegrade and retrograde mesenteric bypass grafts.[9]

Since its introduction in 1980,[16] percutaneous endovascular treatment of SMA stenosis is an increasingly utilized option for treatment of SMA stenosis. With the recent refinements in technique and improvements in equipment, including low-profile (0.014-inch) stent devices, endovascular revascularization of mesenteric stenoses provides a minimally invasive alternative to open surgery. Several studies have presented the results of angioplasty, and/or stenting in treatment of visceral ischemia. The overall periprocedural mortality rate of the endovascular approach is between 0 and 13% and the complication rate is between 0 and 25%. The technical success rate of the endovascular approach is 90-100%.[17-22] Duplex scan characteristics, however, have not, to our knowledge, been systematically defined for stented SMAs after treatment of SMA stenosis.

Despite promising periprocedural results, SMA stenting may be less durable than surgical intervention with reported lower long-term patency and recurrence ranging from 0% to 60%.[22,23] Brown et al[21] found that compared with open surgery SMA stent patients have lower perioper-

Fig 5. A, Pre-stent lateral aortograms demonstrating high grade SMA stenosis. **B,** Follow-up lateral aortograms immediately post-placement of SMA stent. The measured PSV 1 day post-stent was 360cm/second.

ative major morbidity, shorter hospital and intensive care lengths of stay, but are seven times more likely to develop restenosis, four more times likely to develop recurrent symptoms, and 15 times more likely to require re-intervention. AbuRahma et al[20] reported a 35% restenosis rate at 1 year in their series of 24 patients who underwent stenting for chronic visceral ischemia. This high incidence of late restenosis was based on Doppler criteria. Fenwick et al[24] also found high restenosis rates based on Doppler criteria for their patients treated with SMA stents. In their study, however, restenosis did not correlate with recrudescence of symptoms.

Although follow-up of endovascular treated mesenteric vessels is said to be important because of the high incidence of restenosis or occlusion in stented vessels, there is no evidence that intervention on the basis of duplex scan-defined restenosis improves long-term patency or prevents recurrence of symptoms.[10] This may in part be because the criteria used to define stenosis in native non-stented arteries are not applicable to stented SMAs.

Resch et al[25] found no correlation between the remaining pressure gradient in the SMA following endovascular recanalization and the relief of symptoms. Our data indicates pressure gradients fall following placement of an SMA stent. There is, however, variation in post-stenting pressure gradients measured across the SMA without clear correlation with angiographic stenosis or short-term clinical failure of the SMA stent but apparent correlation with presence or absence of a high-grade celiac artery stenosis. This likely reflects the complex hemodynamics and flow characteristics of the splanchnic circulation where perhaps collateral flow, even in the presence of a residual SMA pressure gradient post-stenting, can compensate for a less than perfect local hemodynamic result in the SMA following SMA stenting. The correlation of residual pressure gradients in the SMA following stenting with high-grade celiac artery stenosis suggests that a stented SMA by itself is insufficient to normalize the splanchnic circulation although in most cases the improvement in overall intestinal blood flow is sufficient to improve symptoms of intestinal ischemia.

While a fall in the pressure gradient across the SMA post-stent placement likely indicates some favorable hemodynamic effect of the stent-there is clearly no consensus as to clinical utility of measuring pressure gradients in the SMA following placement of an SMA stent. Our data suggests there may be a wide range of post-SMA stent pressure gradients that, at least in the short term, are associated with an acceptable clinical result of the SMA stent. While our two early clinical failures had post-stent pressure gradients ≥15 mm Hg (17 and 20 mm Hg, respectively) there were 5 other patients who did well in the short term with post-procedure SMA measured pressure gradients ≥15 mm Hg. It remains unknown if immediate follow-up pressure gradients will correlate with late clinical failure of the SMA stent.

This study was a hypothesis seeking study performed to evaluate duplex scan characteristics of stented SMAs. When pre-stent and post-stent angiographic stenosis, catheter derived pressure gradients, and fasting duplex ultrasound scan PSVs were compared, all post-stent velocity measurements in stented SMAs, despite normalization of angiographic images and greatly reduced pressure gradients, had PSVs exceeding criteria for high-grade native artery ≥70% SMA stenosis (≥275 cm/second) (Fig 5). This study raises the possibility that duplex scan criteria for assessing SMA stent stenosis developed for native arteries are not applicable to stented arteries.

Certainly a weakness of this study was its retrospective nature and the fact that ultrasound scan measurements or pressure gradients were not obtained in all patients. In addition, angiography was not routinely performed to validate early post-stent duplex scan finding. Therefore, it is not possible to say with 100% certainty that restenosis did not contribute to the post-stent duplex scan findings in some cases. However, angiographic images did initially normalize in all patients and the median time to follow-up duplex scan study was only 11.5 days, making the possibility of frequent restenosis, as determined by angiography, unlikely. In addition, all PSVs measured post-SMA stent placements were ≥275 cm/second and pressure gradients were greatly reduced post-stenting. The data, therefore, uniformly suggests duplex scan criteria for stenosis in native SMAs are not applicable to stented SMAs.

Other duplex scan parameters may be more useful than PSVs in the evaluation of the stented SMA. Because of our long standing use of PSVs in the evaluation of mesenteric artery stenosis, other duplex scan parameters such as post-stenotic turbulence or measurements of residual stenosis from B-mode images are not routinely recorded in our laboratory. Also, previous studies from our institution have shown limited utility of postprandial duplex scanning in the evaluation of native artery mesenteric stenosis and, therefore, postprandial studies are also not routine in our laboratory.[26] However, additional duplex scan parameters may prove useful in the evaluation of stented arteries and should be the subject of future investigations.

Our findings with regard to PSV are, in fact, similar to those for stented carotid and renal arteries where it also appears duplex scan criteria developed for native artery stenosis over estimate angiographic stenosis in stented internal carotid and renal arteries.[10-14] It appears that higher PSVs are likely needed to stratify stenosis in these vessels. There is no consensus as to why stented internal carotid, renal, and now SMAs have higher than expected duplex scan-determined PSVs when compared to angiographic images. It has been suggested that placement of a stent into a native artery alters its biomechanical properties, which may cause an increase in ultrasound scan velocity measurements in the absence of technical error or residual stenotic disease.[13,14]

Compliance mismatch may be part or all of the explanation in the SMA. However, the magnitude of discrepancy between angiographic images and PSVs in stented SMAs seems larger than for the carotid and renal arteries. In stented carotid and renal arteries the problem is primarily with the lower levels of stenosis. A very high PSV still generally corresponds to significant angiographic stenoses in stented carotid and renal arteries. Our patients had significant visceral artery lesions in virtually all their primary mesenteric arteries but only the SMA was treated. It may be that high flow levels through the stented SMA under such circumstances account, in part, for the large discrepancy between ultrasound scan and angiographic findings in stented SMAs. Further research into this question is indicated and we are currently developing an ex vivo flow model of the SMA pre- and post-stent to address this question.

CONCLUSIONS

There are no standardized ultrasound scan criteria for the detection of high-grade stenosis in stented SMAs. This hypothesis seeking study showed that angiographic pressure gradients in stented SMAs are affected by the presence or absence of high-grade celiac artery stenoses. In addition, although fasting duplex scan-measured SMA PSVs are reduced after stenting, they remain above criteria predicting high grade native artery SMA stenosis. It appears duplex ultrasound scan PSV criteria for non-stented SMAs cannot be applied to stented SMAs and new duplex ultrasound scan criteria are required to predict high-grade stenosis in stented SMAs. Prospective studies and post-stent surveillance protocols are needed to more systematically address this question and likely develop new ultrasound scan criteria for evaluation of stented SMAs. In the interim, studies utilizing only ultrasound scan follow-up of stented SMA may be over estimating rates of recurrent stenosis in the stented SMA.

AUTHOR CONTRIBUTIONS

Conception and design: EM, GM
Analysis and interpretation: EM, GM, GL, TL
Data collection: FK, EM, EC
Writing the article: EM, GM
Critical revision of the article: EM, GM
Final approval of the article: EM, GM
Statistical analysis: GL, EC
Obtained funding: Not applicable
Overall responsibility: EM

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