Gadolinium-Enhanced MR Angiography of Visceral Arteries in Patients with Suspected Chronic Mesenteric Ischemia

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The purpose of this study was to evaluate accuracy of dynamic gadolinium-enhanced MR angiography (MRA) of the celiac, superior, and inferior mesenteric arteries in patients with suspected mesenteric ischemia compared with catheter angiography or surgery. Sixty-five patients with suspected mesenteric ischemia underwent three-dimensional spoiled gradient-recalled acquisition in the steady state (GRASS) gadolinium-enhanced MRA. Correlative studies were performed on 14 patients, catheter angiography alone was performed on 12 patients, and surgery alone was performed on two patients. Six patients had mesenteric ischemia. In all patients, the celiac artery (CA) and superior mesenteric artery (SMA) were seen well enough to evaluate; however, the inferior mesenteric artery (IMA) could be evaluated in only 9 of the 14 patients. MRA showed severe stenosis (>75%) or occlusion of the celiac axis in seven patients, of the SMA in six patients, and of the IMA in four patients. The overall sensitivity and specificity were 100% and 95%, respectively, compared with catheter angiography and surgery. The two errors were caused by overgrading the severity of IMA disease. Three-dimensional gadolinium-enhanced MRA can accurately demonstrate the origins of the CA and SMA and is useful in evaluation of patients with suspected mesenteric ischemia.

Index terms: Mesenteric ischemia • Gadolinium • MR angiography • MR imaging • Celiac • Atherosclerosis

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Abbreviations: CA = celiac artery, IMA = inferior mesenteric artery, PCA = posterior cerebral artery, SMA = superior mesenteric artery, SMV = superior mesenteric vein, MRA = MR angiography.

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CHRONIC MESENTERIC ISCHEMIA is caused by deficiency of the blood supply to the intestine due to stenosis or occlusion of the splanchnic arteries (1–8). Nonetheless, celiac artery (CA), superior mesenteric artery (SMA), and inferior mesenteric artery (IMA) stenosis commonly is present in patients with severe atherosclerotic disease without clinical sequelae. Most patients do not develop symptomatic mesenteric ischemia unless blood flow in at least two of the three visceral arteries is compromised (3,4). Traditionally, the diagnosis has been confirmed by arteriographic demonstration of severe atherosclerotic narrowing of at least two mesenteric vessels. Catheter angiography is invasive and has increased risk in patients with severe atherosclerotic disease (4–7). Recently, contrast arteriography without the risks of arterial catheterization or nephrotoxicity has become available by using MRI during the arterial phase of a gadolinium contrast bolus (9–11). We report our preliminary experience investigating the mesenteric circulation in patients with suspected mesenteric ischemia using a fast three-dimensional gadolinium-enhanced technique that has been shown to be accurate in evaluating the abdominal aorta and renal arteries (9–11).

• MATERIALS AND METHODS

Sixty-five consecutive patients (43 female, 22 male; 22–83 years of age; mean age, 64 years) referred for investigation of suspected mesenteric ischemia over a 2-year period underwent three-dimensional spoiled gradient echo imaging of the mesenteric vasculature (Fig. 1). Fourteen patients were identified in whom validation of MR imaging findings was available (11 female, 3 male; 28–79 years of age; mean age, 60 years). Twelve of these patients had undergone catheter angiography, and two patients underwent surgery alone. The 51 patients without correlation were excluded from further analysis. All patients had undergone extensive investigation for abdominal pain, weight loss, or food intolerance; no cause was identified for their symptoms.

All imaging was performed on a 1.5-T system (Signa, GE Medical Systems, Milwaukee, WI). The body coil was used for signal transmission and reception. A sagittal or coronal T1-weighted sequence was used for localizing purposes (TR/TE 300 msec/12 msec, 2 NEX, 40–48 cm

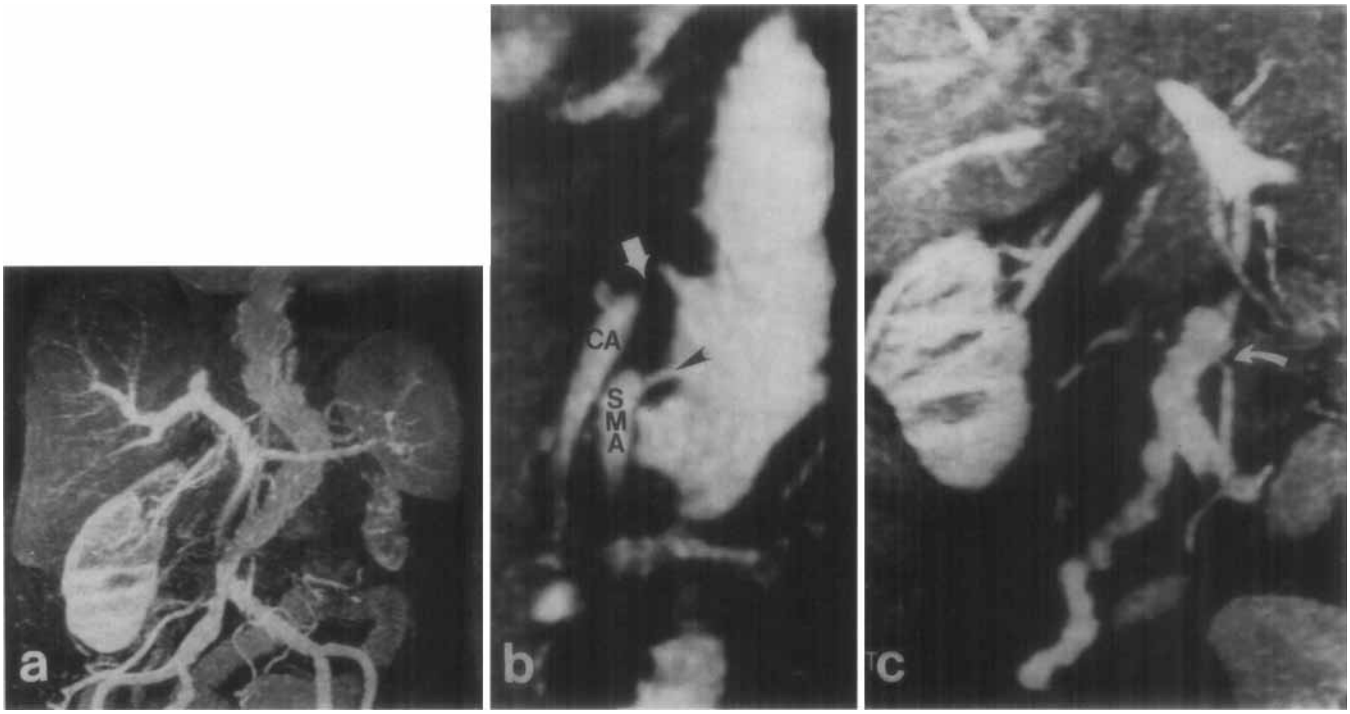

Figure 1. Images of a 80-year-old female with suspected mesenteric ischemia; 28-second, three-dimensional MRA was performed during infusion of 42 ml pf gadolinium. Despite severe symptoms, the patient was unfit for surgery, so angiography was not performed. **(a)** Frontal 5-cm-thick maximum intensity projection shows diffuse severe atherosclerosis of the abdominal aorta. The portal vein is normal. **(b)** Sagittal subvolume maximum intensity projection shows tight stenosis or occlusion (white arrow) of the CA and >50% stenosis of the SMA origin extending more than approximately 8 mm. Note severe aortic atheroma. **(c)** Axial oblique subvolume along the origin of the IMA shows 50% narrowing of the vessel at its origin (curved arrow).

field of view, 256 × 192 matrix). A fast spoiled gradient echo sequence was prescribed from the midline slice of patients from whom the gadolinium-enhanced MRA was acquired in the coronal plane and from a posterior slice at the level of the midlumbar vertebrae of patients in whom the sagittal plane was used. During the course of the study, the gadolinium-enhanced technique evolved from a 4-minute acquisition during free breathing with a constant infusion of gadolinium via a spring-loaded pump to a single breath-hold technique in 28 seconds. Slice thickness varied between 2 and 3.5 mm; 32 slices were obtained within the imaging volume. No saturation pulses were used. In all cases with data acquired in the coronal plane, the arms were crossed over the chest or extended above the head for the dynamic gadolinium-enhanced sequence. The gadolinium, 42 ml (21 mmol) in all cases, was injected through a 20- or 22-gauge iv catheter connected to a 2-m length of connector tubing. In cases in which the images were acquired in a single breath-hold, the patient was instructed to take several deep breaths followed by suspension of breathing in full inspiration for the duration of the scan. The scan was started manually by the radiologist performing the examination using the chassis-mounted controls. Parameters for the breath-hold three-dimensional spoiled gradient echo scan were TR/TE/flip 6.5 msec/2.1 msec/45°, 256 × 128 matrix, 32 kHz bandwidth, 32–36 field of view, 1 NEX (imaging time, 27–32 seconds).

Conventional arteriography using standard cut-film or digital subtraction technique was performed on 12 patients. Angioplasty was attempted on one of these patients. Two patients underwent surgical revascularization.

All MR images were reviewed by a radiologist experienced in interpretation of angiography and MRA together with the MR fellow who supervised acquisition of the images. This interpretation was rendered before acquiring angiography or surgical correlation for 14 patients. For the other two patients, angiography was performed before MRA, but the MR images were interpreted without knowledge of the angiography results. In this way, all studies were interpreted while the investigators were blinded to information about angiography results or surgical outcome. Images were reviewed on the workstation monitor (Advantage Windows, GE Medical Systems, Milwaukee, WI) using multiple operator-defined reconstructions. Grading of stenoses was as follows for the CA, SMA, and IMA: normal (grade 0), mild stenosis <50% (grade 1), moderate stenosis 50–75% (grade 2), severe stenosis >75% (grade 3), or occluded (grade 4). The entire image analysis required approximately 30 minutes per patient in addition to the radiologist's time required for supervising acquisition of the image data.

• RESULTS

Arteriography and Surgery

Both CA and SMA were normal or had insignificant stenosis in seven patients. Severe, grade 3 stenosis (>75%) or occlusion of both the CA and SMA was present in six patients. In one patient, the CA was occluded but the SMA was normal and the IMA had an insignificant stenosis. The IMA was evaluated by angiography in 6 of the 12 patients in whom angiography was performed. It was severely stenotic in one patient, in whom the CA and SMA also had been found stenotic by angiography. Thus, six patients had mesenteric ischemia.

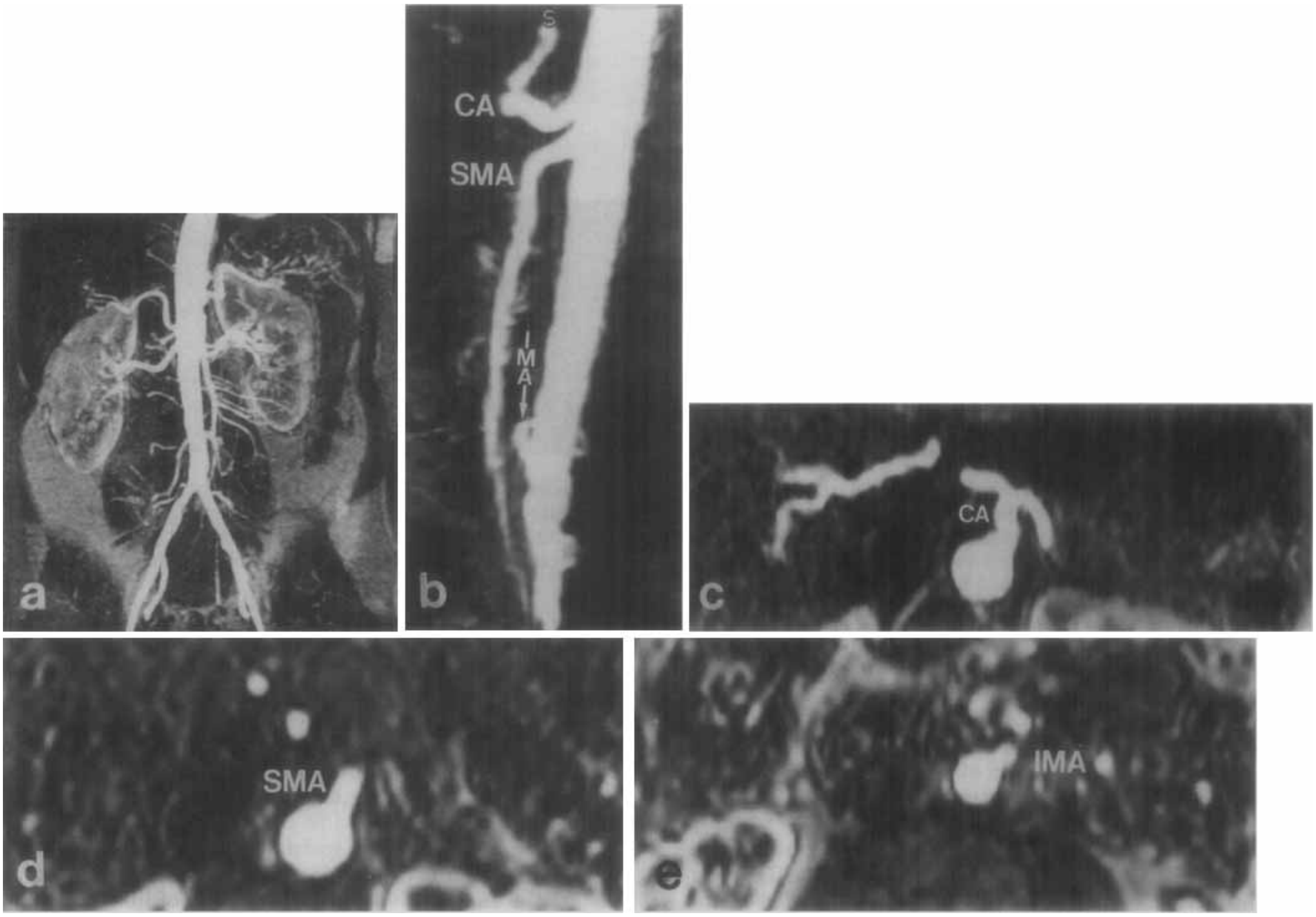

Figure 2. MRA images (28 second, three-dimensional gadolinium-enhanced) of a 54-year-old female with chronic abdominal pain and no angiographic or surgical correlation. **(a)** Frontal, 5-cm-thick maximum intensity projection shows normal arterial anatomy, but SMA and CA origins are obscured. **(b)** Lateral subvolume maximum intensity projection shows normal celiac axis (CA), SMA, and IMA origins. Axial subvolume maximum intensity projections show normal origins and caliber of **(c)** celiac axis (CA), **(d)** SMA, and **(e)** IMA.

Magnetic Resonance Angiography

The CA and SMA origins were seen sufficiently well to evaluate for stenosis in all patients. The IMA origin could be evaluated in only 9 of the 14 patients (Figs. 2–4). Angiography correlation for the IMA was performed on six of these nine patients. Therefore, the accuracy of MR grading could be evaluated in 30 vessels (Fig. 5). There was agreement between the MR grade and catheter angiography grade in 22 of these 30 arteries. MR undergraded two arteries by a single grade and overgraded six arteries (four by a single grade, one by two grades, and one by three grades). The two grading errors of more than a single grade both involved the IMA origin. Considering grade 3 stenosis to be positive and grade 2 or less to be negative, the MRA had an overall sensitivity of 100% and a specificity of 95%. Separating the data by vessel yields a 100% sensitivity and specificity for the CA or SMA alone, and a sensitivity of 100% but a specificity of only 82% for the IMA.

Using the criteria that patients with two or more severely stenotic or occluded mesenteric arteries are positive for mesenteric ischemia, there were six true-positive, one false-positive, seven true-negative, and no false-negative results. Therefore, the overall sensitivity was 100% and the specificity was 87%. The one error was a patient with severe abdominal pain and 40-pound weight loss who had an occluded CA, normal SMA, and mildly stenotic IMA that was overgraded as severely stenotic by MR. MR, however, correctly identified a retroaortic mass that had been missed on a previous CT scans, which was identified as a poorly differentiated sarcoma on biopsy. After chemotherapy, the patient's symptoms abated.

• DISCUSSION

The clinical diagnosis of mesenteric ischemia traditionally has been one of exclusion and typically is made late in the course of the disease by conventional arteriography. The demonstration of significant stenoses in two or more of the three main mesenteric vessels in the appropriate clinical setting establishes the diagnosis (1–8). Typically, these patients have severe atherosclerosis and symptoms suggestive of mesenteric ischemia, such as postprandial abdominal pain, "food phobia," and significant weight loss. For most patients, by the time the diagnosis is made, multiple diagnostic tests that have failed to disclose another cause for the patients' symptoms have been performed. A recent paper reported an average time delay from presentation to diagnosis of 18 months for new cases and 1 month for recurrent cases. The late diagnosis is related to many factors, including the rarity of the syndrome despite the known high incidence of celiac and mesenteric artery stenosis in patients with advanced atherosclerotic disease, the lack of a reliable noninvasive imaging method to confirm or exclude the diagnosis, and the propensity for symptoms of mesenteric

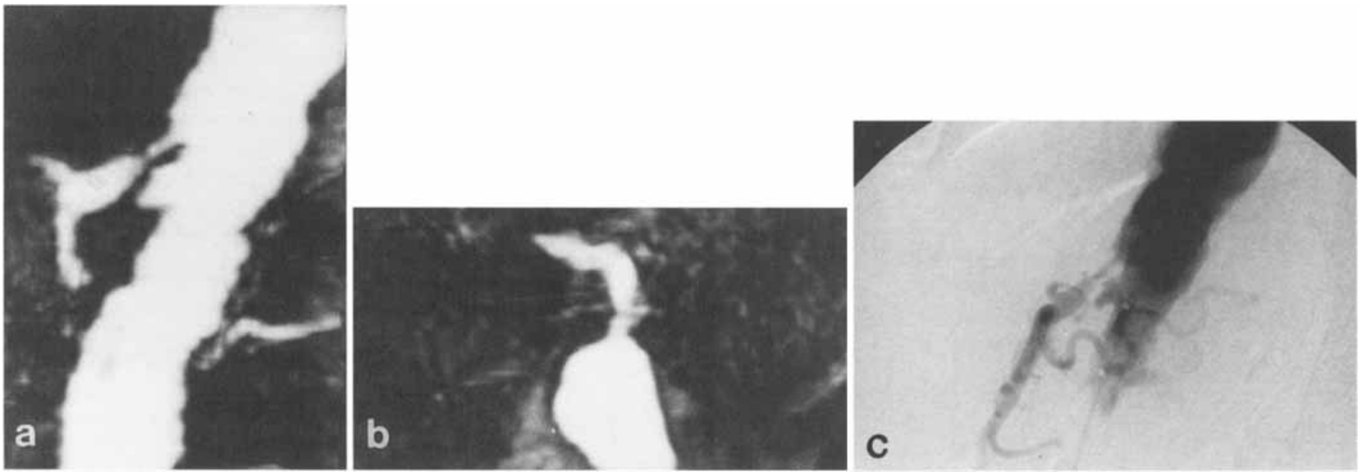

Figure 3. MRA images of a 76-year-old female with suspected mesenteric ischemia; three-dimensional, 28-second MRA was obtained during infusion of 42 ml gadolinium. **(a)** Lateral subvolume maximum intensity projection shows severe stenosis of proximal CA with poststenotic dilatation and occlusion of the SMA beyond its origin. **(b)** Axial oblique subvolume maximum intensity projection along the CA confirms stenosis with atherosclerotic plaque along the left lateral aspect of the vessel wall. **(c)** Lateral aortogram confirms MRA findings of severe CA stenosis and SMA occlusion.

ischemia to overlap with and mimic those of more common intestinal disorders such as peptic ulcer disease, chronic cholecystitis, and pancreatic carcinoma. Establishing the diagnosis is of critical importance, as surgical endarterectomy, reimplantation, or transluminal angioplasty of the diseased vessels offer success rates varying between 80 and 100% for primary success and 50 and 75% for long-term clinical improvement (12–20).

To date, conventional arteriography has been the gold standard for diagnosis of mesenteric ischemia. Doppler sonography and color-flow imaging have been used for noninvasive diagnosis (21–25). However, sonography has significant limitations, including a 25% rate of nonvisualization for both vessels, failure to obtain an adequate signal because of bowel gas or vessel wall calcification, and the possibility of overestimating the prevalence of double-vessel disease because a significant stenosis in one vessel will cause compensatory increased flow in the remaining vessel, thereby inducing a falsely elevated peak systolic velocity within the second vessel (25).

In the current study, we compared MRA with conventional arteriography and surgical findings in a consecutive series of patients referred with a clinical suspicion of chronic mesenteric ischemia. Although 65 patients were studied, correlation was available for only 14 patients. Therefore, the accuracy of gadolinium-enhanced MRA must be evaluated in a larger series of patients. An additional limitation is the bias introduced by including only patients who were selected for additional workup beyond their initial MR examination. This subset of patients is likely to have had a higher prevalence of disease compared to the entire group. One final limitation relates to the use of consensus reading, which can lead to overestimation of the accuracy that could be expected if studies were analyzed by a single reader working alone. Nonetheless, the correct grading of 73% of vessels by gadolinium-enhanced MRA and the overall sensitivity of 100% and specificity of 87% for diagnosis of mesenteric ischemia attests to the promise of this approach.

The fact that atherosclerotic narrowing of the mesenteric vessels almost always occurs at or within 1 cm of the vessel orifice, where the vessel caliber is greatest, places atherosclerotic stenoses of the CA and SMA well within the resolution capabilities of MRA. The smaller size of the IMA may limit appropriate grading of this vessel. Indeed, most of the grading errors in this study involved the IMA. The IMA also can be more challenging to evaluate correctly by arteriography and was identified in only six patients in the current study. With future improvements in spatial resolution of MRI, the limitation of small vessel size in relation to slice thickness and voxel size may soon be overcome, thus allowing accurate IMA evaluation as well.

Because most imaging techniques, including gadolinium-enhanced MRA, provide only anatomic information, a potential problem with interpretation of images is the high incidence of visceral artery stenosis in the asymptomatic population (as high as 18% in one series) (25). For patients with mesenteric artery stenosis and an

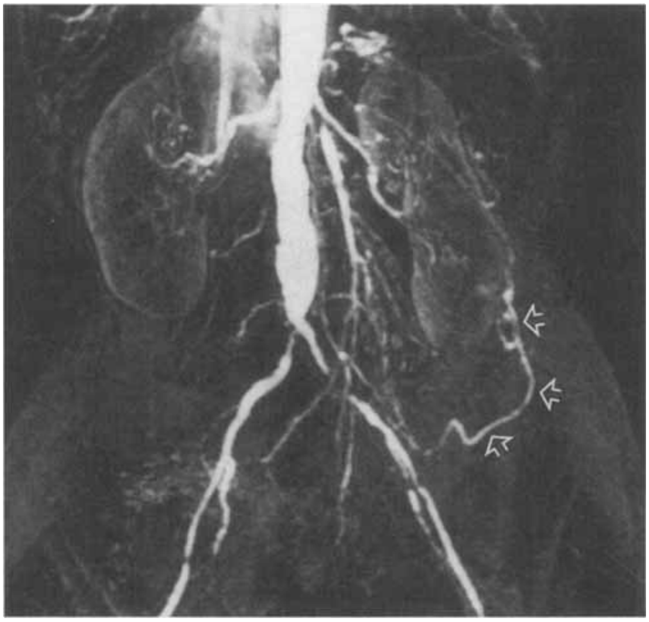

Figure 4. MRA images of a 71-year-old patient with weight loss and severe abdominal pain; three-dimensional, 28-second MRA was acquired uring infusion of 21 ml gadolinium in a small patient. Frontal 5-cm-thick maximum intensity projection shows tight stenosis of SMA extending over approximately 1 cm. IMA occluded at origin; note enlargement of the left colic artery due to increased collateral flow.

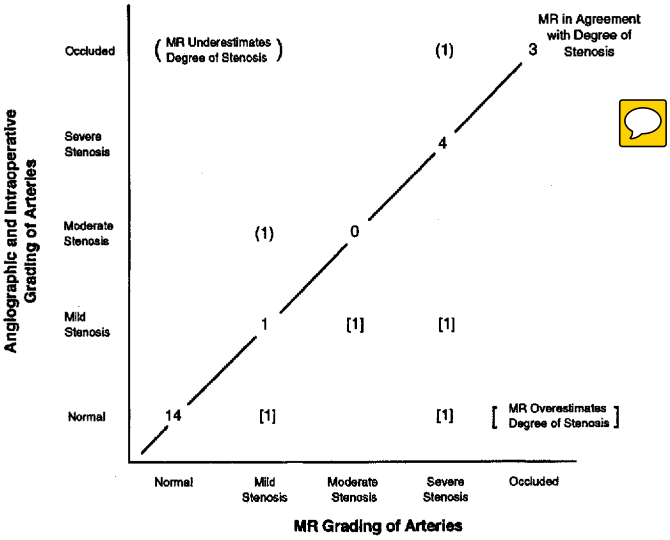

Figure 5. MR grading accuracy for CA, SMA, and IMA in 12 patients with conventional angiography correlation.

equivocal history of mesenteric ischemia (or coexistence of another condition, such as peptic ulcer disease or cholelithiasis, which might account for abdominal symptoms), it may be difficult to predict whether treating the mesenteric stenosis will alleviate symptoms. Functional MRI, in conjunction with other MRI techniques that define anatomy only, might be useful for these patients. Li et al used a cine phase-contrast examination to assess augmented blood flow in the superior mesenteric vein (SMV) after a meal (26). They reported that increased postprandial blood flow within the SMV out of proportion to SMA blood flow is a marker for mesenteric ischemia due to recruitment of collateral flow. By exploiting the known paramagnetic effect of deoxyhemoglobin, this same group also showed close correlation between T2 measurement of blood in the SMV and oxygen saturation in an animal model in vivo (27,28). Identifying low oxygen saturation in the SMV suggests ischemia. Therefore, with MRI, a comprehensive evaluation of a patient with suspected mesenteric ischemia might include gadolinium-enhanced MRA to define anatomy augmented with cine phase-contrast imaging or MR measurement of percentage SMV oxygenation to assess functional significance in patients with stenoses. This was not attempted in the current study.

Recently, authors have attempted to compensate for the highly complex triphasic flow pattern in the SMA, where early diastolic reversal of blood flow leads to considerably lower signal by using systolically gated phase contrast MRA for imaging the mesenteric vessels (29). Although systolically gated phase contrast MRA showed superiority over ungated studies in 10 patients with suspected mesenteric ischemia, the results were disappointing, as only 66% of stenoses seen on conventional arteriography were visualized by MRA; in addition, there were false-positive examinations on phase contrast MRA. This overall poor performance highlights the limitations of phase contrast MRA as a screening or definitive diagnostic test for mesenteric artery stenosis. The limitations of three-dimensional phase-contrast MRA probably relate to a combination of factors, including phase ghosting, motion artifact related to long scan times, and uncertainty regarding choice of appropriate velocity encoding gradient value.

• CONCLUSION

In conclusion, dynamic gadolinium-enhanced images of the mesenteric circulation were accurate for diagnosis of mesenteric ischemia compared with surgery or angiography in this small series. Although the use of a contrast agent adds cost to the procedure, the increased cost may be justified by the high accuracy and the reduced magnet time required. Further studies in a larger series of patients using functional MRI to assess the significance of stenoses identified on gadolinium-enhanced MRA are ongoing.

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