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Computed Tomography Angiography and Magnetic Resonance Angiography Imaging of the Mesenteric Vasculature

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Computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are highly accurate cross-sectional vascular imaging modalities that have almost completely replaced diagnostic catheter angiography for the evaluation of the mesenteric vasculature. CTA is the technique of choice when evaluating patients with suspected mesenteric ischemia; it permits to differentiate between occlusive and nonocclusive etiologies, to evaluate indirect signs of bowel ischemia, and in some instances, to provide alternative diagnoses. MRA has the advantage of not using ionizing radiation and iodinated contrast agents and can be appropriate in the nonacute setting. Both CTA and MRA are suitable for the assessment of patients with suspected chronic mesenteric ischemia, allowing to evaluate the degree of atherosclerotic steno-occlusive disease and the existence of collateral circulation, as well as other nonatherosclerotic vascular pathologies such as fibromuscular dysplasia and median arcuate ligament syndrome. CTA provides excellent depiction of visceral aneurysms and has an important role to plan therapy for both occlusive and aneurysmal diseases and in the follow-up of patients after open or endovascular mesenteric revascularization procedures. This article provides an introduction to the CTA and MRA imaging protocol to study the mesenteric vasculature, the imaging findings in patients presenting with acute and chronic mesenteric ischemia and visceral aneurysms, and the value of these imaging techniques for therapy planning and follow-up.
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Introduction

The blood supply to the intestinal tract is derived from the 3 major anterior branches of the abdominal aorta: the celiac artery (CA), the superior mesenteric artery (SMA), and the inferior mesenteric artery (IMA). Examination of patients with suspected mesenteric ischemia or mesenteric aneurysms requires detailed evaluation of these 3 arterial systems and their branches.

Computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are highly accurate cross-sectional vascular imaging modalities that have almost completely replaced diagnostic catheter angiography for the evaluation of the mesenteric vasculature.[1-4] Catheter-based angiography is nowadays reserved for endovascular therapy or when noninvasive studies are equivocal.

The objective of this article is (1) to review the CT and MR imaging (MRI) technique to study the mesenteric vasculature, (2) to review the role of these techniques and the imaging findings in patients presenting with acute and chronic mesenteric ischemia and visceral aneurysms, and (3) to summarize their value for therapy planning and follow-up.

Imaging Technique

Multidetector CTA (MDCTA) allows the acquisition of a 3-dimensional (3D)volume during the peak enhancement phase of the vessels of interest following intravenous injection of iodinated contrast material.[5,6] State-of-the-art CT systems have gantry rotation times under 300 ms and can cover the entire abdomen and pelvis during a breath

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hold with 0.6-mm isotropic collimation.[7,8] Accurate scan timing is achieved by using automated bolus timing techniques. For the initial assessment of patients referred with symptoms of mesenteric ischemia, we perform a biphasic scan consisting of arterial and portal venous phases, the latter with a fixed scan delay of 70 seconds after the start of the contrast agent injection. To minimize the radiation dose, we do not perform an unenhanced CT scan as part of our mesenteric ischemia protocol.[9] For the assessment of mesenteric aneurysms, we perform only an arterial phase scan. In patients who underwent treatment of an aneurysm with a covered stent, we perform a triphasic scan (unenhanced, arterial and portal venous phase) similar to that in patients after aortic aneurysm endografts.[10] The unenhanced acquisition is helpful for detecting endoleaks. We do not use oral contrast or water before the scans.

We review the maximum intensity projection images for delineation of stenoses and use axial source images and multiplanar reformation for evaluation of stent patency or vessels with calcification. Volume-rendering techniques can be helpful for the evaluation of complex visceral aneurysms. Radiation exposure is an ongoing concern with CT. All vendors actively pursue ways to reduce radiation dose while maintaining image quality. We incorporate iterative reconstruction techniques in all our scan protocols with significant dose reduction.[11] Dual-energy CT (DECT) is another evolving CT technique using 2 simultaneous acquisitions at different energy levels, allowing differentiation of material based on quantifiable differences in X-ray attenuation.[12] DECT characterizes iodine, calcium, and other materials within tissues by their different absorptiometric properties. In particular, DECT-based automated bone removal and calcified plaque removal are useful for mesenteric CTA. By creating monochromatic data sets, dual-energy CTA has the potential to minimize blooming and beam hardening artifacts that simulate or conceal vascular stenosis.[13]

Recent concerns about nephrogenic systemic fibrosis have led to increased interest in noncontrast-enhanced MRA, and a number of different techniques have been used to assess the mesenteric vasculature. Time-of-flight MRA, phase-contrast MRA, and MR oximetry have been used in the past but ultimately have been abandoned with the advent of newer, more reliable scan techniques.[14-18] Steady-state free precession MRI is a newer noncontrast MRI technique that is useful for the assessment of the aorta, but less so for the smaller mesenteric arteries.[19] More recently, cardiac-triggered 3D steady-state free precession sequences were developed for renal and mesenteric noncontrast MRA using respiratory gating.[20,21] This allows scanning without breath holding; however, the sequence is not as robust as the contrast-enhanced MRA (ceMRA) techniques and is mainly useful for evaluation of the proximal celiac and mesenteric arteries.

The use of 3D ceMRA forms the backbone of MR examinations of the mesenteric vasculature.[22-24] A high-resolution 3D T1-weighted gradient-echo pulse sequence is used in conjunction with intravenous injection of gadolinium contrast material. With this technique, images of the aorta and its branches can be acquired during a breath hold. We repeat the sequence 3 times to obtain portal venous and systemic venous information in addition to the arterial phase. With the use of modern 1.5- or 3-T MR systems, phased-array coils and parallel imaging techniques, high-image quality, and depiction of small and distal branches can be achieved.[25] Spatial resolution and slab thickness of the 3D imaging volume can be adjusted to tailor the acquisition time to the breath-hold interval. Typically, 60-88 sections of 1-2 mm in thickness constitute a 3D slab. Repetition time and echo time for the 3D gradient-echosequence are chosen as short as possible,[22] with modern MR scanners allowing a repetition time of 3 ms or less, resulting in acquisition times between 10 and 20 seconds. The echo time is typically in the order of 1.0-1.5 ms, short enough to avoid the effects of spin dephasing that can cause signal loss in areas of turbulence and result in overestimation of stenosis. High-quality mesenteric ceMRA achieves sub 1-mm uninterpolated isotropic voxels; however, its resolution is still inferior to CTA. Arterial signal in ceMRA is based solely on the T1 shortening effect of the gadolinium bolus during its first pass through the vascular territory of interest. Therefore, correct timing and dosing of the gadolinium bolus is critical to achieve high arterial contrast and image quality. An extracellular paramagnetic MR contrast agent is infused via a peripheral venous access using an automated injector at a dose of 0.1 mmol/kg, which we find to be sufficient for high-quality abdominal MRA.[24] The center of k-space is primarily responsible for image contrast, and peak arterial enhancement is timed to coincide with its acquisition. It is therefore important to adjust the acquisition timing to the type of k-space mapping, for example, sequential vs centric. The peripheral k-space lines determine image detail, and it is not necessary to maximize arterial contrast during this phase of data acquisition. For this reason, the gadolinium bolus needs only last for part of the scan duration, which allows for reduced contrast dose. The injection rate is adjusted to produce a contrast bolus lasting approximately one-half to two-thirds of the scan duration, and we use an automatic triggering technique. Typical injection rates range from 1-2 mL/s.[24,26] Several groups have investigated the influence of caloric stimulation on image quality with conflicting results and thus we do not use this technique.[27,28] The use of anticholinergic agents has not been proven to affect positively on image quality.[29] Compared with catheter angiography, state-of-the-art ceMRA has favorable interobserver variability in the common and proper hepatic arteries, the splenic artery, the SMA, as well as the portal, superior mesenteric, and splenic veins.[30] However, agreement is poor, and catheter angiography is still necessary for the evaluation of the intrahepatic arteries, the SMA branches as well as the IMA.[31] Despite continually improved technology, mesenteric ceMRA is clearly inferior to MDCTA. One of the advantages of performing ceMRA on 3-T system is the ability to reduce the contrast dose owing to the inherently higher signal of