Non-invasive imaging of the Mesenteric and Splanchnic Vessels

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CTA and MRA IMAGING PROTOCOLS

• Comprehensive CTA and MRA protocols should include post-contrast portal and delayed venous phase imaging in addition to the arterial phase.
• Delayed phase images are required for the evaluation of portomesenteric and systemic veins, as well as the dissections and aneurysms. Slow flow within a pseudoaneurysm or the false lumen of the dissection may only be appreciated on delayed phases.
• Post-contrast equilibrium phase imaging is helpful for demonstrating the organ perfusion patterns, vascular and non-vascular masses, AVM, AVF and perivascular inflammation associated with vasculitic syndromes.

CTA Technique

• Pre-contrast CT:
  – acute portal/mesenteric venous thrombosis
  – high density materials within the bowel lumen – required for identifying active contrast extravasation into the bowel lumen in patients with suspected gastrointestinal bleeding
• Arterial phase imaging with 120cc non-ionic iodinated contrast agent (370) @ injection rate of 4-5 cc/sec
• Arterial phase imaging can be established by using timing bolus (10 cc contrast with an injection rate of 4-5 cc/sec, chased with 40 cc of saline) or bolus triggering @ 120 HU and ROI within the suprarenal abdominal aorta
• Portal phase imaging @ 60 sec
• Venous phase imaging @ 90 sec
• KVP/mAs 120/240

MRA Technique

• Pre-contrast axial and coronal T2-w images
• Mask and post-contrast multi-phase 3D Gd-MRA on sagittal or coronal plane.
• Bolus: 20-30 cc of Gadolinium contrast @ 2 cc/sec, followed by 20 cc of Saline @ 2 cc/sec.
• Arterial phase can be optimized by using timing bolus (axial slice placed at the level of renal arteries, 2 cc contrast injected at a rate of 2 cc/sec, followed by 20 cc of saline with the same injection rate) or automated or semi-automated triggering of the actual acquisition with real time imaging slice placed within the juxtarenal abdominal aorta
• Breath-hold equilibrium phase imaging @ 3 min using SPGR
• Optional Pulse Sequences:
  – 2D PC of the SMA and SMV
  – 2D PC of Portal vein
  – Non-contrast 3D PC imaging

CLINICAL APPLICATIONS of CTA and MRA:

1. Variant Anatomy of the Splanchnic & Mesenteric Arteries & Veins
2. Postoperative surveillance of liver transplant
3. Chronic Mesenteric Ischemia (CMI)
4. Acute Mesenteric Ischemia (AMI)
5. Surveillance of the grafts and stents
6. Aortic Dissection
7. Isolated Dissections of the Visceral Arteries
8. Visceral Artery Aneurysms
9. Active Gastrointestinal Bleeding
10. Intra/Extrahepatic Arterioporal Fistula (APF)
11. Venous Pathologies

Outlook:

• CTA and MRA imaging protocols
• Clinical Applications
• Conclusion
1. Variant Anatomy of the Splanchnic & Mesenteric Arteries & Veins:

- Textbook description of a celiac trunk having three branches (hepatic, left gastric, and splenic) occurs only in only 55% of the population.
- Anatomic variations may alter the approach in hepatobiliary and pancreaticoduodenal surgeries, liver transplantations, laparoscopic procedures, retroperitoneal mass resection, surgical shunting, and hepatic arterial infusion chemotherapy of advanced liver malignancies.
- CTA is an excellent imaging technique in the assessment of the hepatic arteries up to their second-order branches, and the portal and hepatic venous anatomy.
- 3D Gd-MRA is also a highly accurate in depicting the anatomical variations of the celiac trunk and hepatic arteries, as well as the variant venous anatomy.

2. Postoperative surveillance of liver transplant

- Vascular complications are seen approximately 9% of the liver transplant recipients.
- The most common vascular complication is hepatic artery thrombosis (60% of all cases). Hepatic artery is the sole vessel that supplies the biliary system. Acute hepatic artery thrombosis can lead to ischemic biliary complications, such as liver failure, hepatic necrosis, cholangitis and septic shock.
- US, particularly with contrast administration, is the first-line screening method for vascular complications after liver transplantation.
- False-positive diagnosis of hepatic artery thrombosis with US may occur with markedly diminished hepatic artery flow secondary to severe hepatic edema, systemic hypertension, or high grade hepatic artery stenosis or with suboptimal US examinations.
- When US findings are inconclusive, CTA and 3D Gd-MRA are helpful non-invasive imaging tools.

3. Chronic Mesenteric Ischemia (CMI):

- CMI is most commonly associated with atherosclerosis involving the proximal segments of the visceral arteries, but it can also be a manifestation of non-atherosclerotic disorders, including median arcuate ligament syndrome, aortic dissection, isolated dissection of the visceral arteries, vasculitic syndromes and connective tissue disorders.
- Most patients with symptoms have compromised blood flow in at least two of three mesenteric arteries.
- Both CTA and 3D Gd-MRA can accurately grade a stenosis within the mesenteric arteries up to their second-order branches and successfully demonstrate prominent arterial connections.

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| Evaluation of the donor liver | • Hepatic arterial supply to the liver | (
| | • In the course of the artery to segment IV | Aorta and portal vein |
| | • Variants of hepatic arteries and veins, including portal vein | 
| | • Portal vein | 
| | • Liver | 
| Evaluation of the liver recipient | • Celiac trunk stenosis | 
| | • Hepatic artery stenosis | 
| | • Splenic artery aneurysm | 
| | • Complete replacement of hepatic arterial vascular supply to the SMA | 
| | • Portal venous anomalies | 
| | • Flow dynamics of the portal veins, i.e. portal collaterals, mesenteric portal venous collaterals | 
| | • VC, IVC, and SMV stenosis | 
| Postoperative surveillance of liver transplant | • Hepatic artery stenosis | 
| | • Lack of contrast enhancement of the hepatic artery on the arterial phase | 
| | • Delayed phase imaging to detect delayed enhancement secondary to slow flow conditions | 
| | • Hepatic artery stenosis | 
| | • Pseudoaneurysms | 
| | • Portal vein stenosis or thrombosis | 
| | • IVC stenosis | 
| | • Arterial, portal, and delayed phase liver perfusion patterns | 

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3. Chronic Mesenteric Ischemia (CMI):

- The relationship between the vascular obstruction and the decline in intestinal perfusion may not be appreciated just based on the angiographic stenoses.
- Qualitative and quantitative flow measurements using cine phase-contrast (PC) MR from SMA and SMV may provide a more confident diagnosis of the CMI.
- A reciprocal correlation between the degree of stenoses in the SMA and the flow augmentation after a caloric stimulation has been reported.
- Additional PC imaging of the SMV can provide a more accurate assessment of global mesenteric blood flow. Because, mesenteric venous drainage occurs predominantly through the SMV unless there is a concomitant venous occlusion, and thus the blood flow within the SMV reflects blood supply via stenotic SMA and arterial collaterals.
4. Acute Mesenteric Ischemia (AMI):

- Clinical Presentation: abrupt onset of severe abdominal pain. Irreversible bowel damage within 6-8 hours following vascular insult.
- Major causes of AMI:
  - SMA emboli (30-50%): emboli usually originate from the left atrial or ventricular mural thrombus.
  - Acute SMA thrombosis (15-30%): typically associated with a preexisting atherosclerotic lesion, and demonstrates a more silent clinical scenario compared to an embolic event owing to the development of collateral circulation.
  - Acute thromboembolic occlusion of the celiac trunk or the IMA usually do not cause bowel ischemia.
  - Acute mesenteric vein thrombosis (5-10%)
  - Non-occlusive mesenteric vasconstriction (20-30%): usually develops as a result of vasoconstriction of the mesenteric arteries during an episode of cardiogenic shock or a state of hypoperfusion.

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5. Surveillance of the grafts and stents:

- Both surgical and endovascular treatments subject to early or late failure, and thus require close clinical and imaging follow-up.
- Early graft thrombosis and intestinal infarction occur in 5%.
- Routine mesenteric angiography before oral intake is recommended to confirm patency of the graft and provide early intervention if needed.
- Stenosis usually develops within the first 3-6 months after surgery. Advanced stages of intimal hyperplasia can ultimately lead to graft thrombosis. Approximately in 20% of the patients treated with PTA and stent placement or open surgery, a secondary intervention is required.
- CTA and 3D CE MRA are the most suitable noninvasive techniques for long term follow up of the graft and stent patency.

6. Aortic Dissection:

- Both CMI and AMI can be a manifestation of aortic dissection.
- If the visceral artery originates from the false lumen, slow flow or thrombosis of the false lumen may lead visceral organ ischemia.
- Both CTA and 3D CE-MRA are excellent non-invasive imaging tools for complete and dynamic display of aortic dissection and branch vessel involvement.
- Sensitivity and specificity of MDCT in detection of aortic dissection are 95% and 100%, respectively.
- Sensitivity and specificity of 3D Gd-MRA in detection of aortic dissection > 85%.  

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| Surveillance of grafts and stents | - Kinking or twisting of the graft
- Intimal hyperplasia within the graft
- Occluous thrombi or occlusion
- Thrombosis, arterial, dissection or rupture of the parent vessel after angioplasty
- Early malperfusion caused by intimal hyperplasia (hypodense soft tissue over the inner surface of the stent on CT) or thrombosis
- Stent migration or fracture
- Surgical clips and stents cause magnetic susceptibility artifact on MR. Signal drop within the vessel can lead to misinterpretations such as stenosis or occlusion |

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| Pre-operative evaluation in AMI and CMI | - Soft plaque may lead to embolization during manipulation
- Atherosclerotic calcification in the aortic wall may produce safe clamping
- CTA shows both calcified and soft plaques
- Calcified plaques cannot be demonstrated on MRI
- Evaluation of concomitant vascular diseases that may lead to hypoperfusion during aortic clamping |

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| AMI | - Embolic occlusion: abrupt termination of the vessel (cut-off sign). Most emboli lodge at the origin or in the tapered segment of the SMA or just beyond the origin of the middle colic artery. No or only a few collateral vessels are present
- Acute mesenteric artery thrombosis: typically within the proximal 2 cm segment
- Non-occlusive mesenteric ischemia: CA demonstrates narrowing of the origin, multiple thrombi within the mesenteric arteries, altered distal perfusion and narrowing of the mesenteric branches, absence of the mesenteric arcade, and impaired filling of the intramural vessels. These findings are difficult to appreciate with CTA or MRA
- Indirect CT findings of AMI: bowel wall thickening, pneumatosis intestinalis, intramural vessels. These findings are difficult to appreciate with CTA or MRA |

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7. Isolated Dissections of the Visceral Arteries:

- SMA is the most frequent site of isolated dissection
- Pathogenesis of SMA dissection is unknown in most cases. There may be a relationship with:
  - Atherosclerosis
  - Hypertension
  - Compensatory flow increase in SMA due to the severe stenosis of the celiac trunk
  - Cystic medial necrosis
  - Fibromuscular dysplasia
  - Systemic sclerosis
  - Segmental mediolytic arteriopathy
- CTA and MRA have been proven to be as accurate as DSA in evaluating the location and extent of dissection. In fact, DSA may fail to show a dissection if the false lumen is completely thrombosed.
- On the other hand, DSA is superior to both CTA and MRA in evaluating the collateral flow and the relationship of the dissection to distal branches owing to its better spatial resolution.

8. Visceral Artery Aneurysms:

- Splenic artery (60%-80%)
  - Splenic artery aneurysms are more common in females, and associated with medial dysplasia, multiple pregnancies, portal hypertension and liver transplantation.
- Hepatic artery (20%)
  - Usually extrahepatic, more frequent in male.
- Pancreatic and gastroduodenal artery (10%): usually complication of pancreatitis.
- Celiac artery (4%)
- Jejunal and ileocolic arteries (3%)
- IMA (<1%)
- Fibromuscular dysplasia can cause multiple small aneurysms in the mesenteric arteries.
- Both CTA and 3D Gd-MRA are powerful tools for diagnosis, treatment planning and post-procedural follow up.

9. Active Gastrointestinal Bleeding:

- CTA can depict an active gastrointestinal bleeding with a rate of 0.3 mL/min.
- Accuracy of CTA in determining the location of the hemorrhage is approximately 98%. Yoon W et al. Radiology 2006;239:160–167.
- Sensitivity of dual phase CT in the identification of bleeding sources is 83% in patients with severe and moderate GI hemorrhage, and dual phase CT has detected the underlying pathology in 78% of the patients. Scheffel H et al. Eur Radiol 2007;17:553–563.
10. Intra/Extrahepatic Arterioportal Fistula (APF):

- Usually associated with decreased arterial blood flow to the tissue and increased venous pressure distal to the fistula.
- 60% of patients splanchic APF develop portal hypertension.
- 30% of patients with peripheral APFs involving the splenic and mesenteric arteries portal hypertension.
- APFs rarely cause arterial steal phenomenon between the celiac axis and the SMA, particularly when there is portal hypertension, and induces mesenteric ischemia.
- Time resolved 3D Gd-MRA can demonstrate contrast passage from the artery to the portal venous system.

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| Intra- and extrahepatic APF | - Early enhancement at 20–30 second following the contrast administration owing to the arterial blood flow through the vascular connection  
- Wedge-shaped enhancement of the liver segments supplied by an intraportal APF; these areas become isodense/isointense with the liver parenchyma during portal phase (if the portal venous flow is in hepatopetal)  
- Time resolved 3D Gd-MRA can demonstrate contrast passage from the artery to the portal venous system  
- Portal hypertension (splenomegaly, varicous veins)  
- Indirect findings associated with mesenteric ischemia |

11. Venous Pathologies:

- DSA cannot provide sufficient contrast of the portal system and thus cannot display the portal system and collateral vessels simultaneously via arterial catheterization.
- Multiphase CTA and 3D Gd-MRA have been supplanted catheter angiography in the diagnosis and surgical planning of many venous pathology.
- Acute mesenteric venous thrombosis can lead to AMI. CTA and 3D Gd-MRA accurately determines the extension of thrombosis, portosystemic shunts and cavernous transformation of the portal vein.

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| Acute venous thrombosis | - Non-contrast CT images can identify an acute thrombus as hyperdense area within the vein lumen  
- Filling defect within a normal or dilated vein on venous phase images  
- Edge enhancement of the thrombosed vein due to the blood flowing around the thrombus, or inflammation in the wall of the vein  
- Indirect findings associated with AMI  
- Splenomegaly, ascites, portosystemic shunts |

| Cavernous transformation of the portal vein | - Hypo or absent enhancement of the portal vein  
- Homogeneous perfusion of the liver during portal phase  
- Small collateral veins are seen as blurry or nodular enhancement along the course of the portal vein  
- Larger collaterals are seen as multiple curving worm-like enhancing vessels  
- Cavernoma around the porta hepatis indicates portal vein obstruction  
- Cavernoma through dilated perirectal/scolicodental veins indicates SMV obstruction  
- Cavernoma through short gastric, gastroepiploic, and coronary veins indicates splenic vein obstruction |

CONCLUSION:

CTA and 3D Gd-MRA are reproducible, highly sensitive and specific non-invasive imaging tools in the evaluation of large and medium size splanchic/mesenteric arteries, and portal/mesenteric veins.