Radiology Rounds

A Newsletter for Referring Physicians
Massachusetts General Hospital
Department of Radiology

Volume 6, Issue 9 September 2008

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Imaging for Pre-Transplant Evaluation of Living Donor Liver Transplantation

- **Imaging plays a vital role in assessing the suitability of a potential donor for transplantation and for planning surgery**
- **CT or MR imaging are used to evaluate for diffuse and focal disease**
- **CT or MR angiography and venography are used to identify variants in vascular anatomy**
- **CT or MR cholangiography are used identify variants in biliary duct anatomy**
- **Image post-processing is used to generate 3-D images that are used to estimate liver volume and to map the vascular and biliary anatomy for surgical planning**

Liver transplantation, first introduced 40 years, is the recognized treatment of choice for patients suffering from end-stage liver disease, including documented fulminant hepatic failure (FHF), decompensated cirrhosis, or hepatocellular carcinoma within defined criteria. Unfortunately, the demand for liver transplantation is greater than the supply of cadaveric livers. There are approximately 17,000 patients listed for liver transplantation in the United States, but only 5,000 transplants are performed each year. Thus, many patients succumb to the complications of end-stage liver disease while awaiting organ transplant. Living donor transplantation, an alternative that was first developed for pediatric recipients and later expanded to adults, can alleviate this shortfall and decrease the number of deaths of patients on waiting lists.

Living donor surgery is not without risk and potential donors must be carefully assessed for their suitability. There are many factors to be considered including donor age, immunological compatibility, medical history, liver and renal function, and the presence of disease that could compromise the health of the donor or the success of the transplantation. CT and or MR imaging plays a significant role in this process and is necessary for parenchymal evaluation for diffuse liver disease, focal lesion detection, liver volume estimation, and evaluation of the vascular and biliary anatomy of the liver.

Liver Volume

Accurate preoperative estimation of the donor's liver volume is essential to ensure that the volume is sufficient for the graft to be successful and for the donor to survive. Provided that there is no diffuse liver disease, a remaining liver volume of 30-40% is sufficient for the donor to survive. The liver rapidly regenerates and the volume is fully restored within a few weeks after surgery. The size of the recipient is also a factor. The minimum size for donation is considered to be 0.8% of the recipient's weight, after correction for any diffuse liver disease. For pediatric patient recipients, the left lobe is sufficiently large for this purpose. For adult recipients, right lobe donation is the norm (Figure 1).

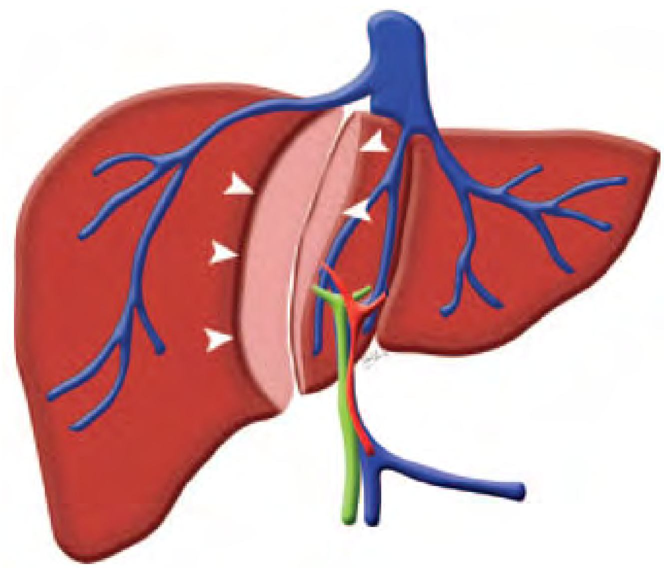

Figure 1. Diagram shows the hemihepatectomy plane (arrowheads). This plane connects the gallbladder fossa and IVC and runs 1 cm to the right of the middle hepatic vein. (Diagram courtesy of Susanne Loomis - REMS)

Commercially available software for both CT and MR imaging can be used to produce 3-dimensional liver models that enable volume measurements with an accuracy of 95-97%.

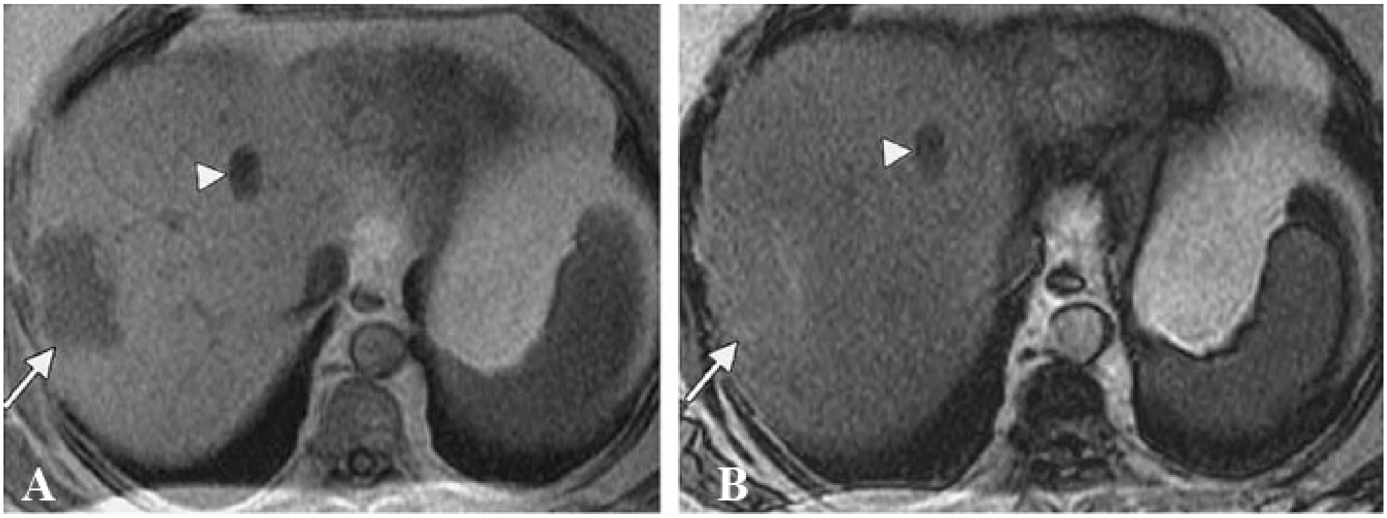

Figure 2. Axial in-phase (A) and opposed-phase (B) GRE images show fatty infiltration of the liver. The decreased signal intensity of the liver on the opposed-phase image (B) indicates that fat is present in the liver. The spleen or paraspinal muscles act as the internal standard. Incidentally noted are two focal lesions in the liver: a hemangioma (arrow) and a cyst (arrowhead).

Parenchymal Disease

Identification and quantification of diffuse liver disease such as fatty liver disease is critical for both the donor and recipient. Fatty liver disease affects 20-40% of the population in Western countries and effectively lowers the functional size of the liver. Moreover, transplants of steatotic livers with > 50% concentration are associated with a greater likelihood of ischemic reperfusion injury. CT can provide an estimate of fatty infiltration by comparing the attenuation in Hounsfield units (HU) to that in the spleen. Similarly, MR imaging can be used to assess fatty infiltration by comparing the signal intensity using and in-phase and opposed-phase protocol (Figure 2).

The presence of focal lesions, such as adenomas, focal nodular hyperplasia, or hemangiomas (Figure 2) may be incidentally detected in a healthy adult using contrast-enhanced imaging with either CT or MR. The presence of such lesions may increase surgical morbidity or contraindicate liver surgery. However, benign lesions, such as hemangiomas, especially if single and small in size, are not contraindications for liver donation.

Vascular Anatomy

In order for transplantation to be successful, it is vital to maintain a balance between the blood supply and the venous drainage of the graft. Venous congestion can seriously damage the graft, causing its failure. Therefore it is essential to know the location of the principle vessels in order to ensure that they will be left intact and that they can be successfully anastamosed to the recipient's vasculature. Even small hepatic venous branches should be left intact or reconstructed. The anatomy of the hepatic arterial and venous systems is quite variable, and the classic anatomy is only found in 55% and 60%, respectively, of the population. The surgical techniques of the transplantation procedure are dictated by the individuals' anatomy (Tables 1 and 2) and, therefore, a radiological evaluation of the vascular and biliary anatomy is a prerequisite for surgical planning. Multidetector CT angiography has demonstrated excellent correlation with conventional angiography but has the advantages of less radiation exposure and lower cost. Thin section CT examinations using a multidetector scanner are 3-7 times as fast as single detector scanners and can be performed during a single breath hold. CT angiography (Figure 3A) is performed during the hepatic arterial phase, 20-25 seconds after the injection of iodinated intravenous contrast agent or, if automated bolus tracking is used, when the attenuation in the aorta at the level of the celiac artery reaches 125 HU. A second scan is performed during the venous phase at 60-65 sec after the injection of contrast.

Alternatively, MR angiography (Figure 3B) enables acquisition of a large volume data set during the first pass of contrast material within a single breath hold. However, consistent visualization of the terminal arterial branches, such as the segment IV artery may be difficult in few patients. Like CT, MR venography, in which images are acquired as the contrast agent passes through the veins, is highly accurate in mapping the venous anatomy and delineating venous anomalies.

Table 1. Hepatic Arterial Variants and their Implications for Transplantation Surgery	
Arterial Variants	**Surgical implication**
Variants relevant to donors:	
MHA from the RHA	The hepatic plane would cut this artery, compromising arterial supply to the left lobe of the liver
CHA trifurcation into the RHA, LHA, and GDA	Clamping or ligation of the CHA can cause gastric or duodenal hyperperfusion
RHA or LHA from the CHA before origin of the GDA	Clamping or ligation of the CHA can cause gastric or duodenal hyperperfusion
Variations relevant to recipients:	
Short RHA	Increases surgical complexity and can lead to difficult anastomosis
Celiac artery stenosis	Increases risk of graft failure and biliary complications
Replaced or accessory LHA (Michel types II and V)	Increases complexity of surgery
Replaced hepatic trunk arising from the SMA (Michel type IX)	Increases complexity of the surgery

LHA, left hepatic artery; LGA, left gastric artery; RHA, right hepatic artery; SMA, superior mesenteric artery; From Catalano et al., 2008

Table 2. Hepatic Arterial Variants and their Implications for Transplantation Surgery	
Hepatic and Portal Venous Variants	
Variants relevant to donors:	
Accessory inferior RHV > 3mm	Increase surgical complexity and the surgical technique must be modified
Trifurcation of the portal vein	Surgical planning must be modified because of lack of a portal segment to clamp during surgery, as well as to prevent bleeding in the recipient; difficult anastomosis in the recipient
Portal venules to segment V	Surgical planning must be modified to avoid bleeding and ischemia
Variations relevant to recipients:	
Accessory inferior RHV draining into the IVC > 3 cm form the main hepatic venous confluence with the IVC	Increase surgical complexity and the surgical technique must be modified
Early branching of the segment VIII vein	Increase surgical complexity and the surgical technique must be modified
Anomalous drainage of segments V and VII into the MHV	Risk of medial sector congestion and atrophy
Early confluence of the hepatic veins	Increase surgical complexity and the surgical technique must be modified
Dorsal branch of segment VII supplying the posterior-superior area of the right lobe	Surgical planning must be modified to prevent ischemia in the recipient
Trifurcation of the portal vein	Surgical planning must be modified because of lack of a portal segment to clamp during surgery, as well as to prevent bleeding in the recipient; difficult anastomosis in the recipient
Acute angle of portal vein branching	During regeneration, the liver may engulf the veins and reduce blood supply, causing ischemia in the graft
Short length of the portal vein	May cause allograft failure

MHV, middle hepatic vein; RHV, right hepatic vein; IVC, inferior vena cava From Catalano et al., 2008

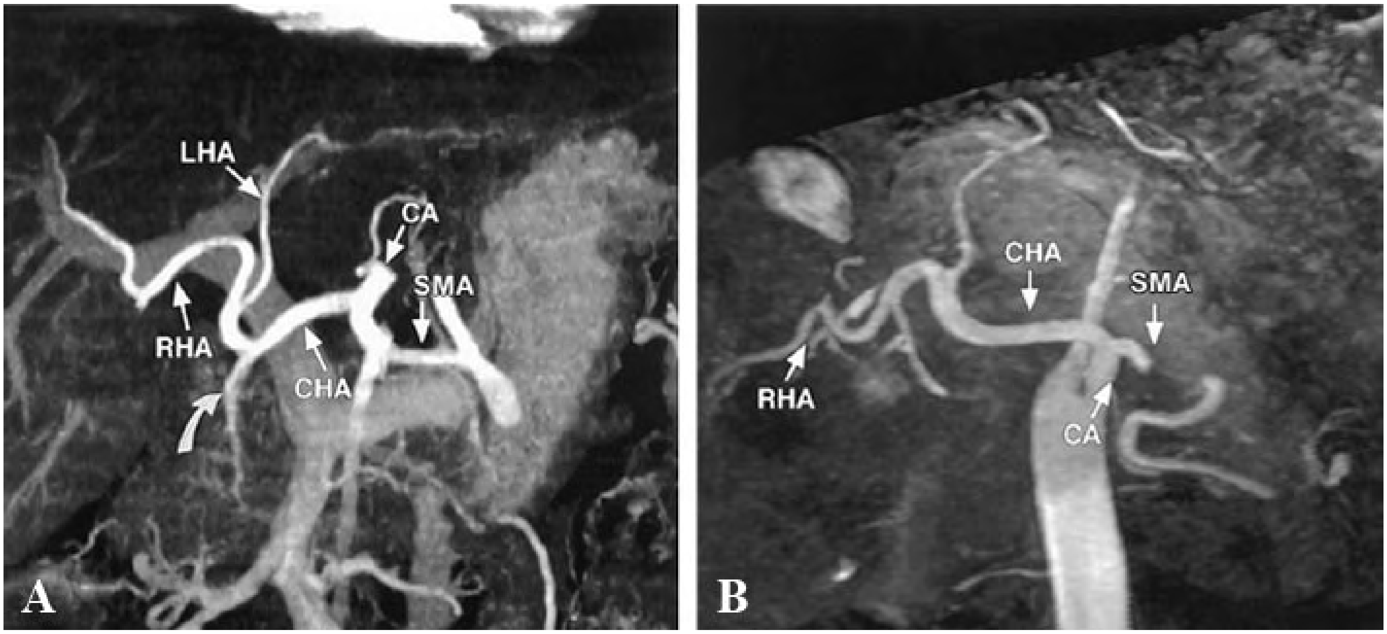

Figure 3. Reformatted images from CT (A) and MR imaging (B) data depict the normal course and branching pattern of the hepatic artery. Note that in a, the gastroduodenal artery (curved arrow) branches off from the common hepatic artery (CHA). The proper hepatic artery divides into the left hepatic artery (LHA) and right hepatic artery (RHA). CA celiac artery, SMA superior mesenteric artery.

Hepatic Ducts

Postoperative biliary complications, occurring in 4-13% of donors and 15-40% in recipients, are the most common cause or morbidity in living donor transplantation. In part this is due to the technical difficulty of performing biliary reconstruction on small caliber ducts and because of leakage from even minor branches that cross the transaction line and are therefore cut during surgery. Forty per cent of the population have anomalous biliary tract anatomy and knowledge of the individual variations are essential to minimize the likelihood of complications.

Although an interoperative cholangiogram is the standard of reference, this approach runs the risk of aborted operations if complex anatomy is discovered that precludes liver donation. CT cholangiography (Figure 4A), performed using an intravenous biliary contrast agent, enables good visualization of the biliary tree to the second order biliary branches.

MR cholangiopancreatography (MRCP) can be used to evaluate bile duct anatomy without the aid of contrast agents. Although this technique has high signal contrast, it may not be adequate for visualizing a non-dilated biliary system because of the lower image resolution of T-2 weighted images. Alternatively, a biliary contrast agent and T-1 weighted imaging (Figure 4B) can be used, which results in good resolution of the normal biliary tree.

Image Post-Processing

A complete set of CT angiography, CT venography, and CT cholangiography, and parenchymal images can be completed in a single session lasting 15 minutes. A similar set of MR images can be completed in 45 minutes.

Once complete, image post-processing is used to generate 3-D images (Figure 5) that can be superimposed to show the vascular and bile duct anatomy. The radiology report is presented in a structured format in order to clearly convey the findings to the surgeon. A radiologist will review the images with the transplant surgeon to help plan the surgery in order to optimize the success of the transplant and to minimize risk to the donor.

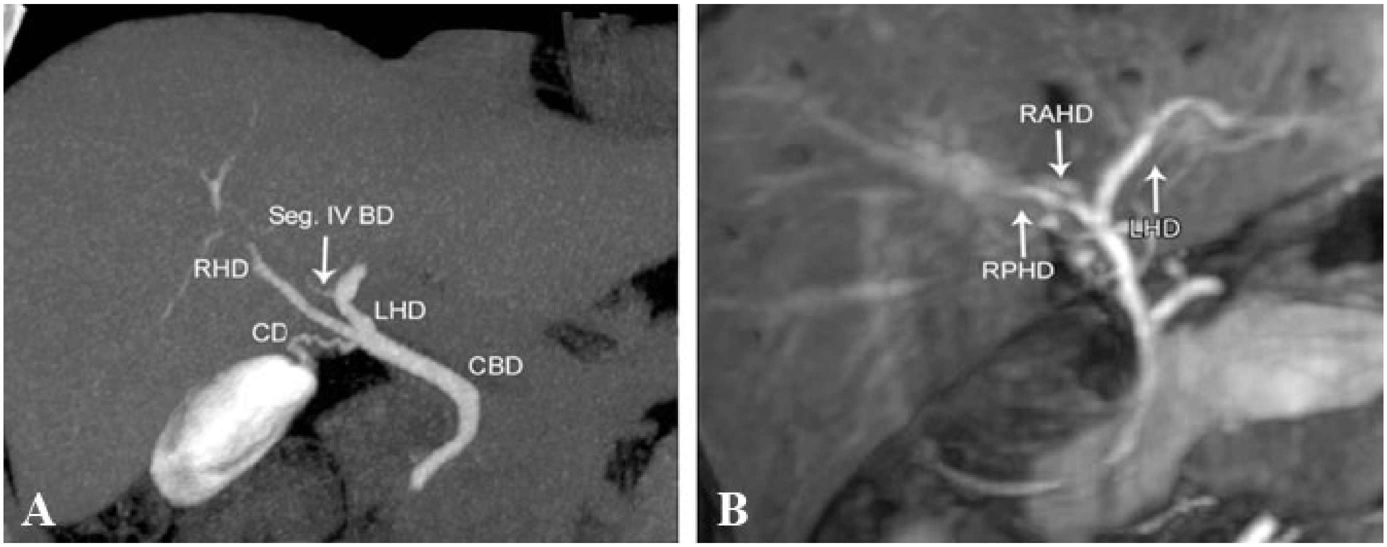

Figure 4. (A) Coronal MIP image from 3D multidetector CT cholangiography, performed after intravenous administration of iodipamide meglumine, shows the segment IV bile duct (Seg IV BD) draining into the left hepatic duct (LHD) in a 64-year-old man with a right lobe liver metastasis from colorectal cancer. (B) Mangafodipir-enhanced MIP image from preoperative MR cholangiography shows biliary trifurcation in a 52-year-old liver donor. CBD, common bile duct; CD, cystic duct; RHD, right hepatic duct; LHD, left hepatic duct; RAHD, right anterior hepatic duct; RPHD, right posterior hepatic duct.

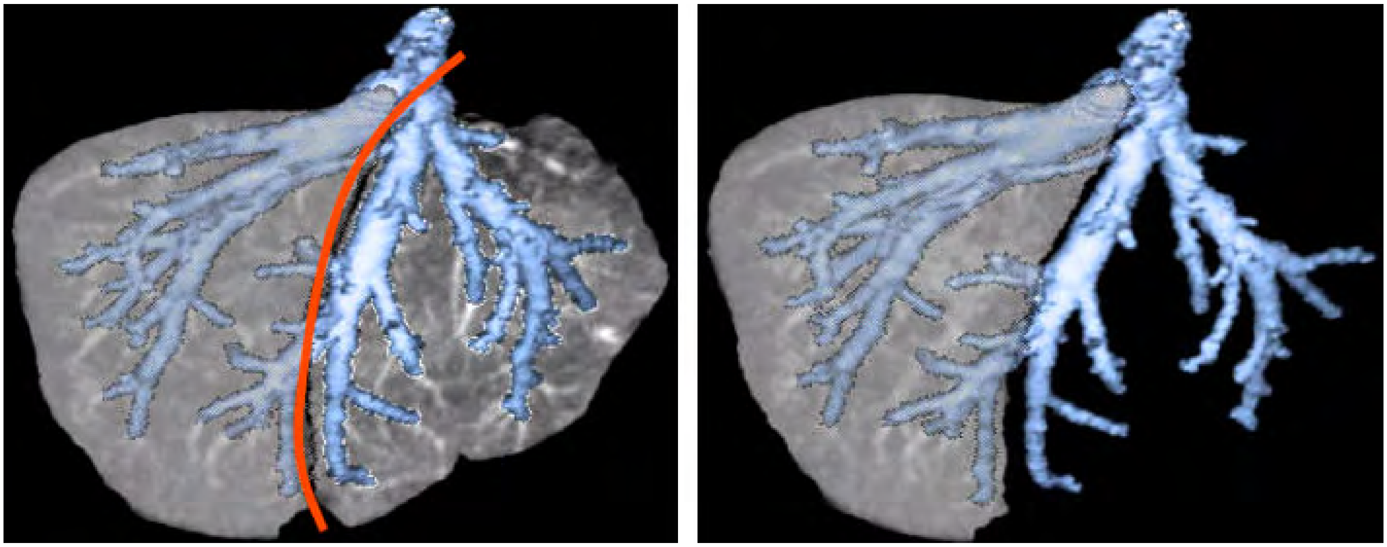

Figure 5. Superimposed 3-D volume reconstruction of the liver and 3-D vascular maps are used to assist in understanding the relative location of key structures and determining the surgical plane of a virtual hepatectomy (red line).

Scheduling

MR angiography, venography, and MRCP as well as CT angiography, venography, and cholangiography are performed on the main MGH campus, Mass General West Imaging in Waltham, and Mass General Imaging, Chelsea. The examinations can be scheduled via online Radiology Order Entry (http://mghroe/) or by calling 617-724-9729 (4-XRAY).

Further Information

For further questions, please contact Dushyant Sahani, M.D., Director of CT Imaging Services, Abdominal Imaging and Intervention, Department of Radiology, Massachusetts General Hospital at 617-726-3937.

We would like to thank Dushyant Sahani, M.D., Director of CT imaging, Department of Radiology, and Martin Hertl, M.D., Transplant Unit, Department of Surgery, Massachusetts General Hospital, for their assistance and advice for this issue.

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