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Dual-Energy CT Imaging Applications in the Liver

- In dual-energy CT (DECT), simultaneous imaging occurs at low and high energies, which allows for improved detection of pathologies and characterization of tissue composition.
- Data post-processing of DECT can yield virtual monochromatic (or mono-energetic) images (VMC), virtual unenhanced images (VUE), and material-specific images that highlight iodine (MD-I) and other elements.
- DECT imaging of the liver can:
    - Aid in the detection of hypo- and hyper-vascular lesions
    - Diminish the impact of metal artifact
    - Improve lesion characterization
    - Allow tumor staging
    - Assess treatment response
    - Improve characterization of diffuse hepatic processes such as fatty liver and fibrosis
- Radiation exposure in DECT is comparable to that in standard single-energy CT.

In standard single-energy CT scanning, the X-ray data is acquired using a single X-ray source, generating an X-ray beam with peak kilovolt energy of, for example, 140 kVp. The X-ray beam is not mono-energetic but is a spectrum of energies (polychromatic). In dual-energy CT, two X-ray beams of different kVp energies are emitted, typically 80 kVp and 140 kVp, either by mounting two sets of X-ray sources and detectors or by rapid switching of a single X-ray source. The data acquired by scanning at two different energies is then processed by complex built-in software to generate different sets of post-processed images.

Virtual mono-chromatic (VMC) or mono-energetic images can be generated to simulate images from a mono-chromatic beam, ranging from 40 keV to 140 keV. Low-energy VMC images generally have higher contrast, especially in contrast-enhanced images. However, they have higher image noise and more artifacts. In contrast, high-energy VMC images are less noisy and have fewer artifacts but lower contrast. In addition, it is possible to generate material-specific images form DECT data. For example, material-specific iodine density (MD-I) images show the distribution and concentration of iodine in tissues. Alternatively, material-specific water images remove the contribution of iodine from the images to produce virtual unenhanced (VUE) images, which resemble true non-contrast CT images.

This variety of images can be very helpful in a number of liver imaging applications including lesion detection, lesion characterization, staging, and assessment of treatment response. Other applications are under investigation including the characterization of diffuse liver diseases such as fibrosis and steatosis.

Lesion Detection

Post-processed images from DECT can improve the ability to detect both hyper- and hypo-vascular lesions due to primary and secondary hepatic malignancies. This capability is especially helpful for patients with fatty liver disease or cirrhosis. Several clinical and phantom studies have demonstrated that low-energy (50–65 keV) VMC images improve the detection rate for hyper-vascular lesions such as those from hepatocellular cancer. MD-I images are specifically useful for this purpose because they can clearly show the enhanced uptake of iodine in a malignant lesion (Figure 1). For hypo-vascular lesions, low-energy VMC and MD-I images improve detection by enhancing the liver-to-lesion contrast.

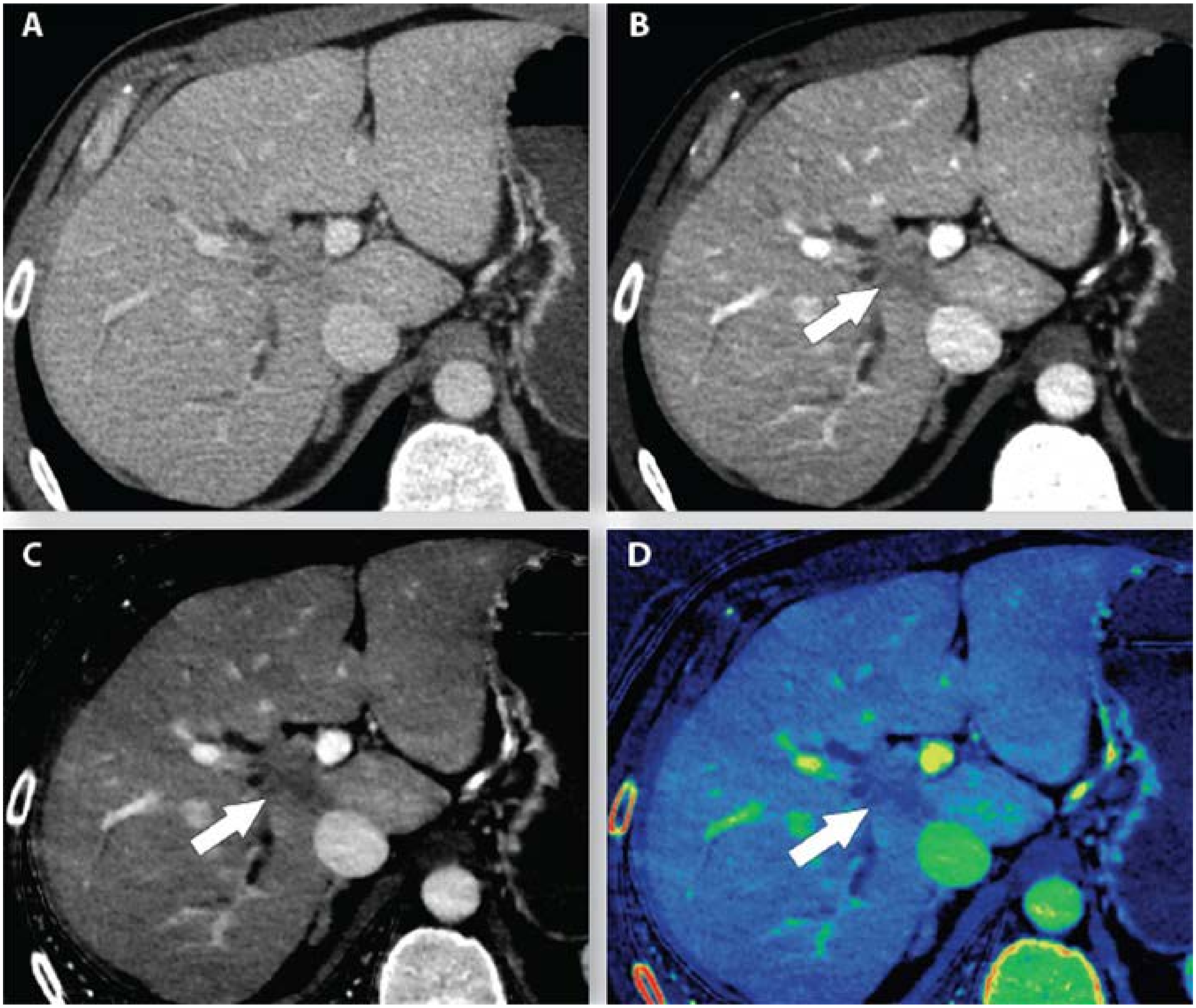

Figure 1. Contrast-enhanced DECT of a 45-year-old man with a history of jaundice and biliary stricture. Axial contrast-enhanced CT image **(A)** shows right intrahepatic biliary ductal dilatation although the cause of the obstruction is not obvious. Axial post-processed 50 keV VMC **(B)**, MD-I images **(C)** and MD-I image with color overlay **(D)** improve delineation of a soft tissue mass (arrow) at the porta hepatis, obstructing the right biliary duct and invading the caudate lobe of the liver. Biopsy and MRI confirmed the diagnosis of cholangiocarcinoma.

DECT can also aid in visualization of lesions that are obscured by streak artifacts caused by metal implants, such as fiducials or surgical clips. Post-processed VMC images and MD-1 images reduce the metal artifacts and improve the ability to detect lesions (Figure 2).

Lesion Characterization

DECT can be helpful in differentiating between cysts and metastases, both of which can appear hypodense on contrast-enhanced CT. Metastases take up iodine contrast material whereas cysts do not. Therefore, MD-I images will show differences in image density, enabling their diagnosis. Likewise, DECT can also help distinguish hyperdense and hyper-vascular lesions in a single contrast-enhanced scan without the need for a separate unenhanced scan. Hyperdense lesions, such as hematomas, do not take up iodine, which can be demonstrated by MD-I images and confirmed by VUE images (Figure 3).

Tumor Staging and Assessment of Response

DECT can help stage primary and secondary hepatic malignancies because MD-I images can improve the conspicuity of hyper-enhancing lesions such as hyper-vascular metastases (*e.g.*, melanoma, neuroendocrine tumors).

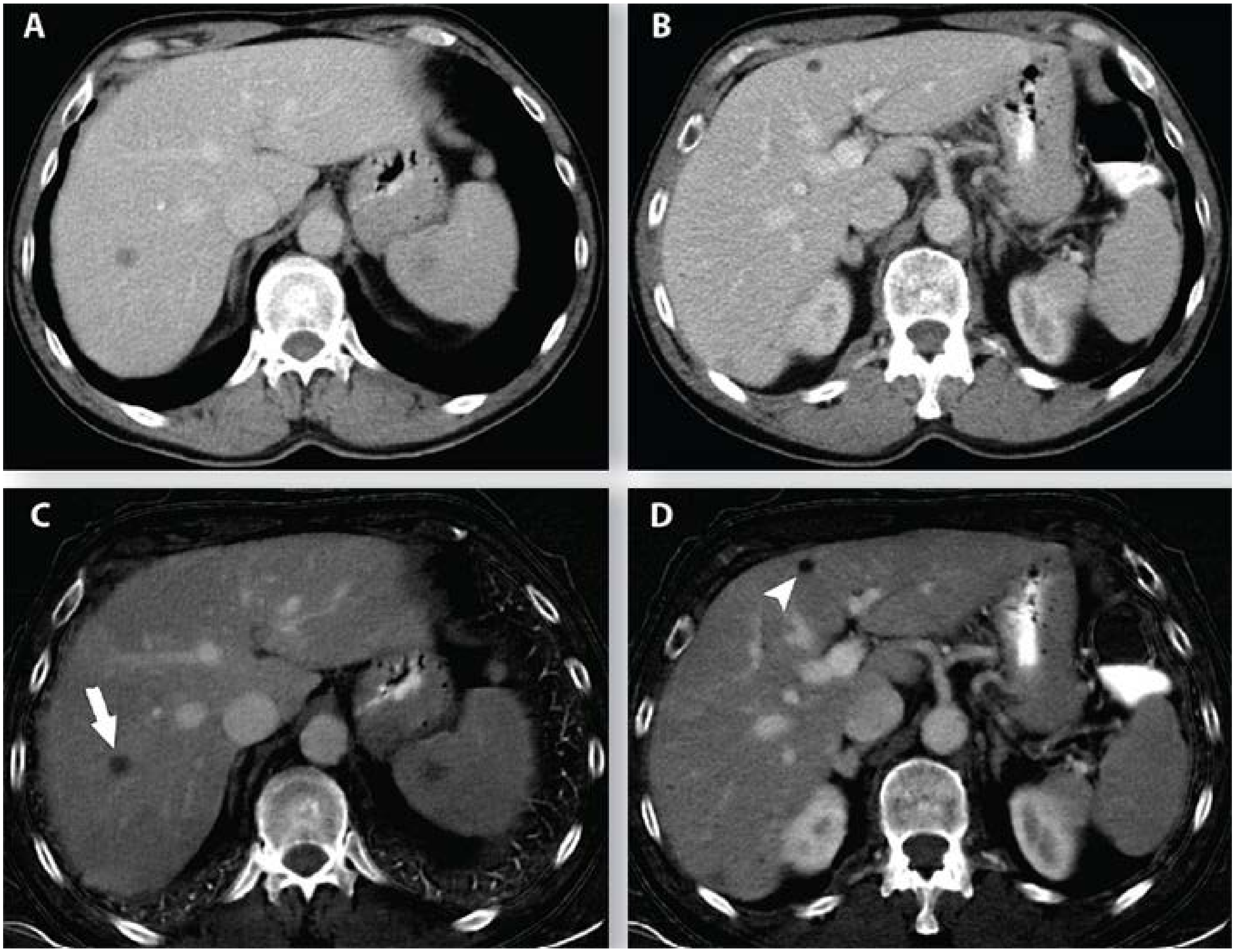

Figure 2. DECT of a 65-year-old man with history of lung cancer. Axial contrast-enhanced CT images **(A, B)** show two tiny heterogeneously hypodense lesions in segments VIII and IV, which are difficult to characterize as cysts or metastases. Axial post processed MD-I images **(C, D)** show distribution of iodine in the two lesions. The lesion with iodine uptake is a metastasis in segment VIII (arrow), while absence of iodine uptake characterizes a cyst (arrowhead).

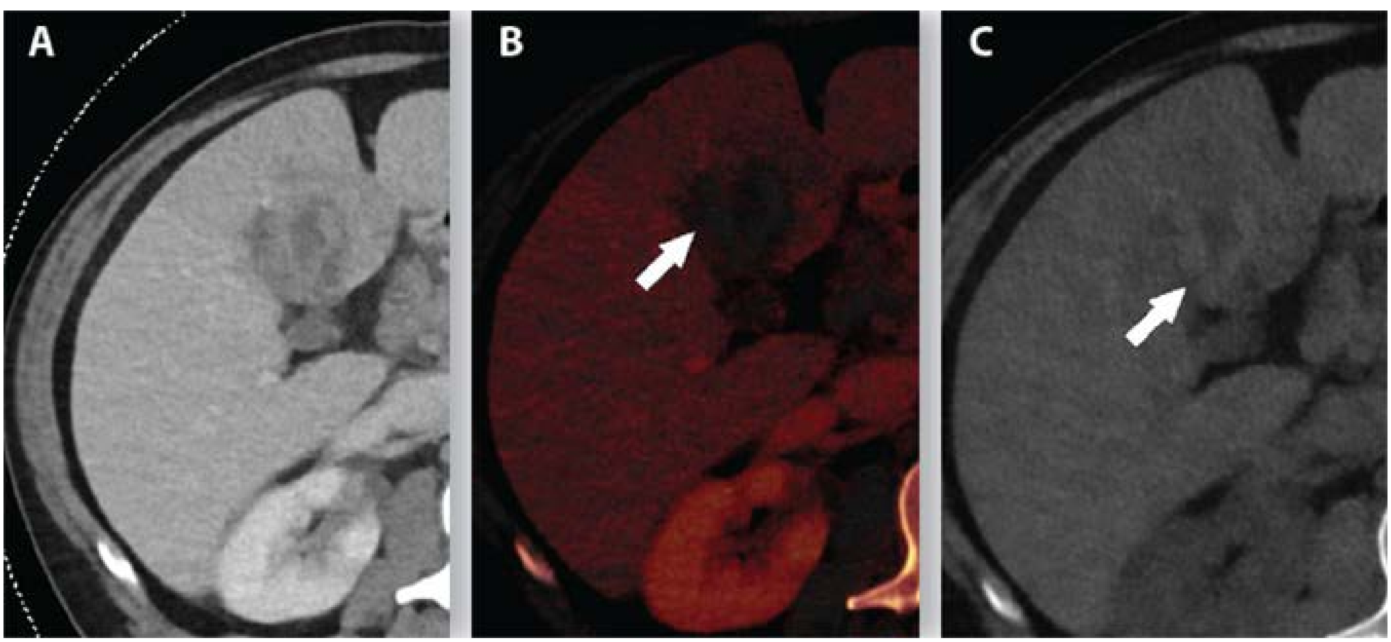

Figure 3. DECT of a 46-year-old man with acute onset of abdominal pain, presented to the ER. **(A)** Axial contrast-enhanced CT shows a heterogeneous hyperdense lesion in the segment IV of the liver, which raises suspicion of a hepatic mass. **(B)** Axial post-processed MD-I images show no uptake of iodine in the lesion, differentiating a hyperdense lesion (arrow), like this hematoma, from a hypervascular one such as HCC or hepatic adenoma. **(C)** Axial post-processed VUE images confirmed the diagnosis of hematoma.

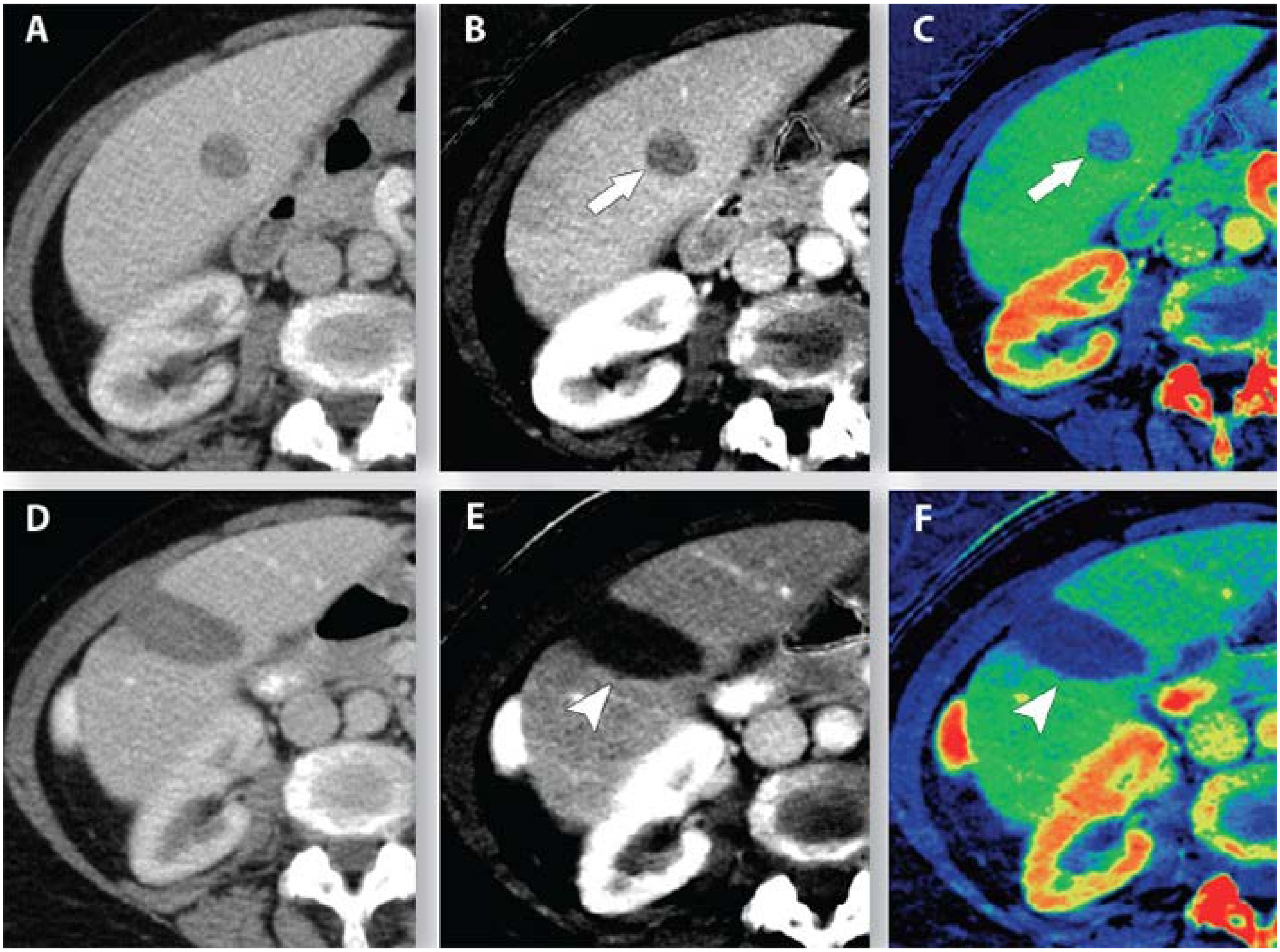

Figure 4. DECT in a 62-year-old woman with history of sarcoma. **(A)** A solitary heterogeneous hyperdense liver lesion in the V segment was noted in SECT images. MD-I images **(B, C)** demonstrate a moderate uptake of iodine, raising the suspicion of metastasis (arrow), subsequently confirmed by liver biopsy. **(D)** After radiofrequency ablation, SECT images show a heterogeneous hyperdense liver lesion, raising the suspect of incomplete ablation or recurrence. However MD-I images **(E, F)** showed no uptake of iodine (arrowhead), excluding the hypothesis of recurrence/incomplete ablation; the heterogeneous appearance of the lesion is due to a post-treatment bleeding.

Post-procedure surveillance to assess response to therapy in liver-cancer patients can be challenging due to the heterogeneous nature of tissues caused by the treatment. For example, the ablation zone following treatment by thermal ablation may include hemorrhage, necrosis, and edema, obscuring the difference between treatment changes and residual tumor. In these cases, DECT can be helpful because post-processed MD-I images can distinguish between hyper-vascular tumor and post-treatment hyperdense areas without the need for a non-contrast acquisition (Figure 4).

New Applications

Research studies are investigating the role of DECT in characterizing diffuse hepatic disease such as fatty liver and hepatic fibrosis. Preliminary studies show that post-processed image data sets from DECT improve assessment of liver fibrosis and hepatic steatosis.

DECT Protocol

The imaging protocol for DECT at Massachusetts General Hospital typically uses X-ray tube voltages of 80 and 140 kVp, 0.625 mm collimation, and slice thickness of 5 mm. Automated tube current modulation varies the radiation dose according to the cross-section of the body during dual-source DECT to minimize exposure. Arterial-phase images are acquired approximately 25–30 seconds after iodinated contrast media (370 mg I/ml) is administered at a rate of 3–4 mL/second. Portal venous-phase images are acquired at approximately 60–70 seconds, and delayed-phase images are acquired >120 seconds after contrast media administration.

Scheduling

Three of 18 CT scanners on the main campus of Mass General are capable of DECT. Two are on Blake 2, and one is in the Emergency Radiology suite. A fourth DECT scanner at Mass General West Imaging provides services to outpatients. Referring physicians may request DECT, or radiologists can choose it depending on the patient's circumstances. Appointments can be made through Epic (inside the Partners network) or Physician Gateway (outside the Partners network) or by calling 617-724-XRAY (9729).

Further Information

For further information on applications of DECT for liver imaging, please contact Avinash Kambadakone, MD, Abdominal Imaging, Department of Radiology, Massachusetts General Hospital, at 617-643-4641.

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