

Liver MRI

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INTRODUCTION

MR imaging is a useful and increasingly popular method for imaging the liver. Liver MR is most commonly used to evaluate an indeterminate focal hepatic lesion detected on other imaging studies and to image patients with contraindications to iodinated contrast material. Other clinical indications are also developing, especially now that it is clinically recognized that liver MR is more sensitive and accurate for detection and characterization of focal lesions than CT or US.

In order to perform liver MR well, a radiologist must optimize the imaging protocol for the specific MR system used, understand the proper application of several basic MR sequences, and know the MR appearance of several common focal hepatic lesions. A basic liver MR protocol involves 3-4 pulse sequences that can generally be acquired within twenty minutes. This includes T2-weighted, inversion recovery, and T1-weighted sequences as depicted in Figure 1.

Indications for liver MR

- Evaluation of an indeterminate lesion
- Contraindication to liver CT (Renal insufficiency, iodine allergy).
- Evaluation of therapeutic response to chemotherapy or other therapy.
- Normal CT or US but high clinical suspicion.
- Metastatic disease staging.
- Liver transplant evaluation.
- Evaluation of the cirrhotic liver.

Accurate detection and characterization of focal hepatic lesions can be performed with MR imaging. Specific sequences, such as inversion recovery, are highly sensitive for the detection of lesions. Once detected, they can often be accurately characterized as malignant or benign, cyst or solid tumor, etc., based upon their appearance and relative signal intensity on T1- and T2-weighted sequences.

Intravenous contrast material can increase MR's sensitivity and specificity for detection and characterizing of focal hepatic lesions. While useful, intravenous contrast material is not necessary for every liver MR examination. Prior to making an informed decision on the proper use of intravenous contrast, a radiologist must first be able to perform and interpret an unenhanced liver MR study.

The following emphasizes the performance and utility of unenhanced liver MR, although references to the use of contrast agents are made for completeness. Use of liver MR varies widely by institution and depends upon established referral patterns, relative availability of MR and CT time, and physician comfort level for reading and ordering liver MR studies.

MR EQUIPMENT, PULSE SEQUENCES, AND IMAGING PARAMETERS

MR Equipment

The efficacy of liver MR has been proven using magnet strengths from 0.5 to 1.5 Tesla (T). High field strength units generally produce images with the greatest liver-to-lesion contrast and have shorter image acquisition times. Optimal imaging techniques are field strength dependent, so no single imaging protocol can be applied to every system and always used the same way. For example, T2-weighted images are more sensitive than T1-weighted images for lesion detection at 1.5 Tesla while T1-weighted images are more sensitive at 0.5 Tesla.

The use of phased-array surface coils significantly improves liver signal-to-noise, lesion-to-liver contrast, lesion detection, and image definition.

Imaging Parameters

Liver MR imaging protocols usually use a combination of T1-weighted, inversion recovery, and T2-weighted images. Together, these provide complementary information that can be used for image interpretation. There is no single liver protocol that can be used optimally for every clinical situation. Depending upon the complexity of the case and the questions asked, additional sequences may be needed.

The following sample protocol can be used as a general-purpose MR imaging protocol (Table 1).

T2-weighted images

T2-weighted images are used for both detection and characterization of focal liver lesions. A routine liver imaging protocol includes a Fast Spin-Echo (FSE) T2-weighted sequence. FSE sequences use long

repetition times (TRs), greater than 2000 msec. Selection of echo time (TE) is important since image contrast is dependent on this value. The optimal TE used clinically varies from 80-100 msec. Even longer TE's are used for characterization of hemangiomas and cysts.

The addition of fat suppression to a T2-weighted FSE sequence further improves image quality by reducing motion artifact and improving tissue contrast.

T2-weighted Images

- Used for both lesion detection and characterization.
- SE or FSE acceptable.
- Fat saturation reduces motion artifact and improves tissue contrast.
- Respiratory triggering or compensation is useful.
- Optimal TE varies from 80-105 msec.

T2-weighted SE images have been traditionally used for liver MR and they have been shown to have utility for both lesion detection and characterization.

Unfortunately, since only a single echo is obtained during a long TR, data acquisition times for a single T2-weighted SE study commonly exceed 13-18 minutes. Because of the long acquisition times, SE images are sensitive to motion-related artifacts.

Motion compensation methods such as respiratory triggering are helpful but often further increase scan times. T2-weighted FSE imaging generates T2-weighted images more rapidly than SE imaging. Following each 90 degree excitation pulse, FSE imaging uses 180 degree refocusing pulses to generate multiple echoes, instead of acquiring a single echo as is done in SE imaging. This markedly reduces acquisition times from 13-18 min down to 3-6 minutes. However, since multiple echoes cannot be obtained simultaneously, they are clustered together around a desired "effective TE" (TE_{eff}). This causes FSE T2-weighted images to have somewhat different image contrast than SE images.

Fat is usually bright on FSE images while it is intermediate to dark on SE images. Depending on the number of echoes obtained (echo train length), FSE images may have some blurring; limiting the echo train length to 4-8 will minimize this while still significantly reducing scan time.

Inversion Recovery

Table 1. Routine Liver MR Protocol

	1. Scout	2. T2	3. T1
Sequence	Ultrafast T2 (SSFSE, HASTE)	T2 (FSE, TSE etc)	Fast GRE (FMPSPGR, FLASH etc)
Plane	Coronal	Axial	Axial
NEX	1	2-3	1
TR	8	>2000	150-250
TE	99	102	4.4 (and 2.5)
Flip angle	NA	NA	70-90
Thick	8	5-8	5-8
Gap	2	0-2	0-2
Matrix	256 x 160	256 x 256	256 x 160
Options	Breath-hold	Respiratory triggering Fast sat	Breath-holdFast sat

Short inversion-time inversion recovery (STIR) MR is a sensitive technique for detection of hepatic lesions that is performed as part of hepatic MR protocols. Studies have demonstrated that STIR MR images have a higher sensitivity than other non-enhanced MR sequences and sensitivity similar to CT during arterial portography (CTAP) for detection of hepatic lesions. STIR sequences provide fat-suppressed images with additive T1 and T2 contrast. Since both primary and secondary hepatic malignancies typically demonstrate prolongation of both T1 and T2, STIR sequences are especially useful for detection of pathology. However, malignant and benign lesions both tend to be very bright on STIR images, so they are best used to detect lesions but not to characterize them once detected.

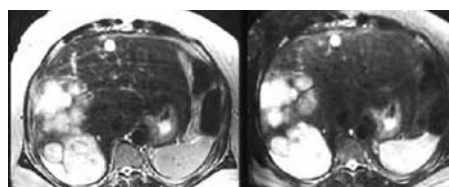
Clinically, STIR images may depict focal hepatic lesions that are either not seen or are more subtle on other pulse sequences.

STIR Images

- Used for both lesion detection only.
- Benign and malignant lesions are hyperintense.
- Has a nonspecific form of fat suppression.
- Sensitivity approaches CTAP for lesion detection.
- Have additive T1 and T2 contrast.

T1-Weighted Imaging

The most commonly used T1-weighted sequences for liver imaging are gradient



echo (GRE) and conventional spin-echo (SE). GRE sequences generate images with

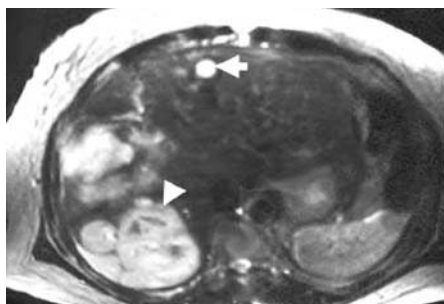


Fig. 2. Both a liver cyst (arrow) and multiple right lobe liver metastases (arrowhead) are depicted on this T2-weighted SE (TR 2500, TE 80) image.

high signal-to-noise and high lesion-to-liver contrast within a short period of time. GRE sequences are used widely because on many MR systems, the entire liver can be covered with T1-weighted GRE images in the time of a breath-hold. (See below for

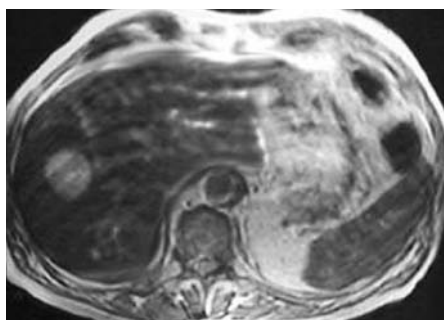


Fig. 3. Moderate respiratory motion artifact degrades this T2-weighted SE image (TR 2500, TE 80) that required 12 minutes to acquire.

Fig. 1. T2-weighted image (FSE TR 4100, TE 102) with and without fat suppression. Fat suppression decreases respiratory artifact from the subcutaneous fat, increases the dynamic range of signal intensities, and increases conspicuity of focal hepatic lesions.

more information on breath-hold techniques).

GRE images generate an echo by using gradient reversal instead of a 180 degree refocusing pulse, as used with SE imaging. They use very short echo times (TE) and variable flip angles (FA) and produce images with either T1 or T2* weighting.

Specific GRE pulse sequences are vendor specific. Commonly used sequences include fast multiplanar spoiled gradient-recalled (FMPSPGR), gradient recalled acquisition in the steady state (GRASS), and fast low-angle shot technique (FLASH).

Several vendors now provide a 3d GRE sequence for dynamic liver imaging. This

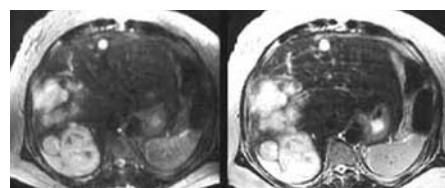


Fig. 4. T2-weighted SE (TR 2500, TE 80) left and FSE (TR 4100, TEef 102) right images have different image contrast. The FSE image has greater fat and spleen signal and is somewhat more T2-weighted, due to a longer TR.

allows for near isotropic voxels and better-reconstructed data sets. Many centers currently use these sequences that can also be used to simultaneously obtain a 3d angiogram or venogram.

T1-weighted GRE images may have pulsation artifacts from the aorta that can be misinterpreted as a focal lesion in the left lobe. This artifact is reduced with the use of parallel saturation bands placed above and below the imaging volume. Changing phase and frequency direction will displace the artifact 90 degrees, if a question persists. GRE images also have an increased susceptibility to magnetic field inhomogeneities.

Conventional SE T1-weighted imaging. SE imaging of the liver is still performed but is a less optimal technique for liver imaging. SE imaging requires relatively long acquisition times that preclude the use of breath-hold technique. In addition, focal liver lesions

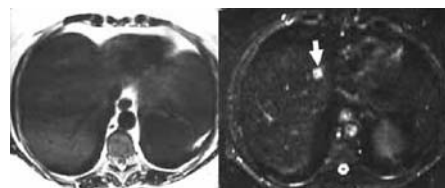


Fig. 5. A hepatic metastases was not depicted on a T2-weighted FSE (TR 4100, TEef 102) image, left, but is well visualized (arrow) on a STIR image (TR 3000, TE 60, TI 160), right.

have poor conspicuity as compared to GRE T1-weighted images. Significant respiratory related motion artifacts that may be present. To minimize this, some MR systems enable the use of respiratory-triggering or phase reordering.

T1 weighted Images

- GRE images are acquired much faster than SE.
- FMPSGR, GRASS, and FLASH are some of the sequences used.
- Entire liver may be imaged during one 15-30 sec breath-hold.

The development of fast MR sequences has reduced acquisition times to the point that some sequences can be acquired in less than 30 seconds, the length of time most people can hold their breath. Acquisition of data during suspended respiration removes the major source of image artifacts, respiratory motion. When using T1-weighted GRE sequences, the entire liver can be imaged during a breath-hold. Depending on the MR system, from 12 to greater than 30 single slices can be acquired in 15-30 seconds.

Some FSE T2-weighted and STIR images can also be performed as a breath-hold, but fewer slices are usually obtained per acquisition than with T1-GRE sequences, and it may take 1-3 breath-holds to cover the entire liver.

To perform a breath-hold acquisition, patients are coached in the technique, prior to entry into the magnet. This improves their compliance and understanding of the technique and gives the MR technologist an estimation of how long they will be able to hold their breath during the study. Prior to performance of the acquisition, patients are told to perform several deep breaths before the order to suspended respiration. End-expiratory breath holding leaves the diaphragm and liver in a more reproducible location and minimizes misregistration, but shortens the overall duration of breath holding for most patients. Supplemental nasal oxygen can increase the duration of the breath-hold if needed and if not clinically

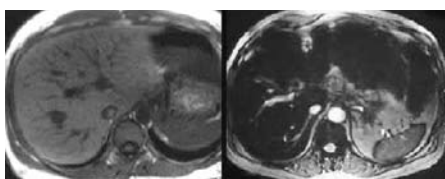


Fig. 6. GRE sequences can produce images with either T1 or T2* weighting. Short TEs and high FAs generate T1-weighted images (FMPSGR TR 160, TE 4.4, FA 80) left, while longer TE's and lower FAs generate T2-weighted images (TR 50, TE 30, FA 20) right.

contraindicated. The large majority of patients will perform adequate breath holding if properly instructed and supported.

Breath hold Technique

- Perform practice breath-holding prior to entry into MR
- Tailor length of breath-hold to individual patient's ability
- Nasal oxygen may improve length of breath-hold if not contraindicated
- Suspending respiration at end expiration is most reproducible

Dynamic T1-weighted Gadolinium-enhanced Imaging

Dynamic gadolinium-enhanced T1-GRE imaging is very useful for the accurate characterization of focal hepatic lesions. A rapid bolus of 0.1 mmol/kg of gadolinium-

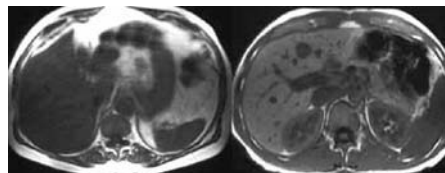


Fig. 7. Respiratory and motion artifact degrades the T1-weighted SE (TR 400, TE 11) image on the left. Breath-hold GRE image (FLASH TR 150, TE 4.4, FA 80), right, clearly depicts intrahepatic blood vessels and lesions, and has sharply defined margins.

chelate is given via long I.V. tubing while the patient is in the center of the magnet. Multiple sets of breath-hold T1-weighted GRE sequences are then acquired, each set covering the entire liver.

The first set is started approximately 20 seconds following the beginning of contrast infusion, to coincide with the arterial phase

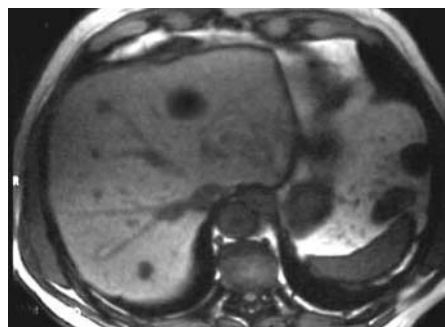


Fig. 8. Depending on the system used, from 12 to more than 30 T1-weighted GRE images, similar to this FLASH (TR 150, TE 2.5), can be obtained in a breath-hold. This is sufficient to image the entire liver using 6-10 mm single slices in 15-30 seconds.

of perfusion. A portal-venous phase study is then obtained approximately 20-30 seconds later, followed by 1-3 delayed phases acquired at various intervals out to about 10 minutes, if needed. This series of images depicts the pattern of enhancement of hepatic neoplasms, which are used for lesion characterization.

Dynamic Gadolinium-enhanced Imaging

- A 20-gauge angiocatheter and extension tubing placed prior to study.
- Perform precontrast T1-GRE breath-hold study.
- Gadolinium and flush injected rapidly while patient is in bore of magnet.
- Arterial-phase study obtained about 20 seconds after start of contrast infusion.

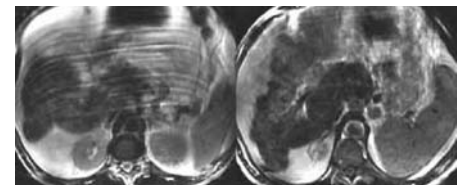


Fig. 9. A non breath-hold FSE T2-weighted image (FSE TR 4100, TE 99), left, of a patient with cirrhosis and ascites, is degraded by respiratory and motion artifact. A breath-hold version of T2-FSE (TR 2000, TE 99), right, has similar T2 contrast but little motion or respiratory

- Portal-phase study obtained 1 minute after start of contrast infusion.
- 1-3 delayed-phase studies obtained at varying intervals out to 10 minutes if needed.

Ferumoxides-enhanced Imaging

Ferumoxides are a new class of organ-specific contrast agents approved for use with MR imaging. The ferumoxides consist of small particles of iron-oxide with a biodegradable coating which are phagocytized by the reticuloendothelial system (RES). Tissues containing RES (and therefore ferumoxides) have shortened T1, T2, and T2* values. This causes loss of signal noted most markedly on T2-weighted images. Hepatic malignancies, which are hyperintense, become more conspicuous and are easier to detect as the adjacent liver becomes darker.

Ferumoxide-enhanced MR has greater detection capability for focal hepatic neoplasms than unenhanced MR or CT. Ferumoxides are also used to characterize areas of RES activity, such as in FNH.

Ferumoxides-enhanced Imaging

- Iron-oxide particles.
- Localizes to the RES system, 80% of which is in the liver.
- Tissue with RES becomes dark on post-contrast T2-weighted images.
- Lesions without RES, such as metastases, are more easily detected.
- Lesions with RES, such as FNH, become dark after contrast.

Opposed-phase Imaging

Opposed-phase imaging is a T1-weighted GRE method used to detect fat and water mixtures. Fat and water protons have different resonance frequencies. Depending upon the echo time used, images may be acquired when fat and water protons are resonating either "in-phase" or 180 degrees "out-of-phase" with each other. When tissue containing fat and water mixtures is imaged in-phase, the signals generated from fat and

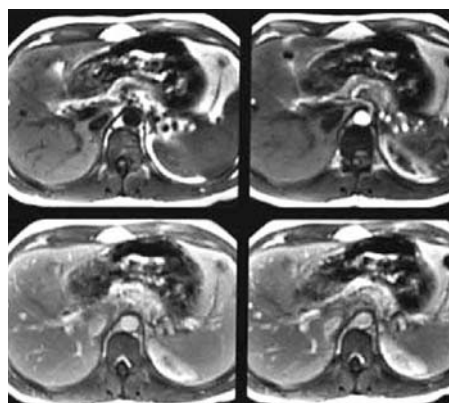


Fig. 10. Multiple breath-hold T1-weighted GRE (FLASH TR 150, TE 4.4, FA 80) sequences acquired following a gadolinium-DTPA bolus. Each set of 24 images was acquired during a different phase of hepatic perfusion. Precontrast, upper left; arterial phase, upper right; portal phase, lower left; delayed phase, lower right.

water protons are additive, when imaged out-of-phase, the signals are destructive. Areas of focal or diffuse hepatic fat will lose signal on out-of-phase images, as compared to in-phase images.

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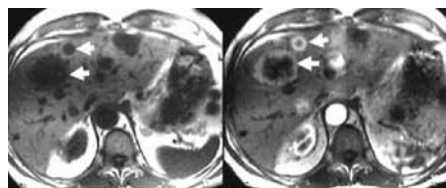


Fig. 11. Precontrast and early post gadolinium-enhanced T1-weighted GRE (FLASH TR 170, TE 4.4, FA 70) images of hepatic metastases (arrows) demonstrate an early complete peripheral ring of enhancement.

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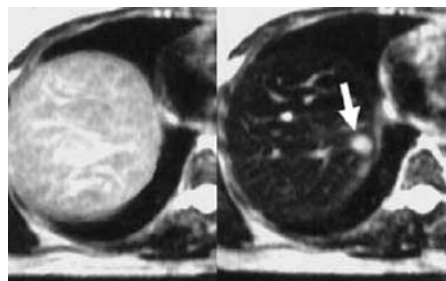
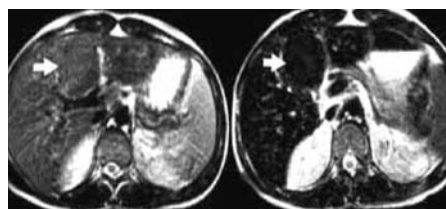


Fig. 12. Precontrast and ferumoxides-enhanced T2-weighted SE (TR 2500, TE 80) images. Focal metastatic lesion, arrow, is depicted only on post-ferumoxides images.

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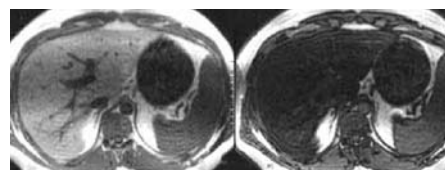


Fig. 14. Diffuse hepatic steatosis is depicted by the homogeneous loss of signal between in-phase T1-weighted GRE (FLASH TR 160, TE 4.4, FA 80) image, left, and out-of-phase T1-weighted GRE (FLASH TR 160, TE 2.4, FA 80) image, right.

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Fig. 13. A 5 cm FNH, arrow, is shown to lose the same amount of signal intensity as the rest of the liver on these precontrast (left) and ferumoxides-enhanced (right) T2-weighted images (FSE 5000, TE 90).

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