Abdominal MRI: Protocol Optimization and Choice of Sequences

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Introduction
Over the past decade, body MR imaging has undergone tremendous development. These developments concern 1) the introduction of the higher field MRI magnets such as 3.0T; 2) faster and novel sequences such as Dixon-based and diffusion-weighted imaging (DWI); 3) further optimization and incorporation of DWI into the daily clinical protocols; 4) introduction of newer contrast media with dual hepatobiliary and renal excretion such as Gadobenate (Multihance) and Gadoxetate (Eovist); and 5) development of MR imaging-based biomarkers of disease activity that include apparent diffusion coefficients (ADC), quantification of fat and iron in the liver, MR elastography, and perfusion parameters for tumor treatment response. These developments have significantly improved body MRI and have provided opportunities for newer research. At the same time, for many radiologists and technologists, it has become even more challenging to construct optimal body MRI protocols that can be used for daily clinical practice.

The description below will focus on the liver MRI protocol. During the presentation, other organs as well as newer and relevant sequences will be described and discussed.

The purpose of this presentation is
1. To facilitate radiologists and technologists in protocol optimization and choice of sequences;
2. To provide an overview of the currently available and commonly used MRI sequences at 1.5T and 3.0T;
3. To describe the newer sequences such as DIXON-based and DWI;
4. To present a short description of the MRI contrast media and their role in body MRI;
5. To illustrate the future role of the newer MRI based biomarkers.

Typical liver MRI protocol
SS-FSE coronal
SSFSE axial
Diffusion-weighted imaging (b=20 and b=500)
Dual-phase Gradient echo (in- and opposed-phase) or Dixon
(Timing bolus or other contrast detection method to capture the arterial phase)
Dynamic multi-phasic post-gadolinium axial 3D GRE sequence with fat suppression
Delayed post-gadolinium coronal 3D GRE with fat suppression
T2-weighted FSE with fat suppression (respiratory triggered)
MR imaging technique with the sequence parameters and their specific function

Typical liver MRI protocol:

1) Coronal single-shot turbo or fast spin-echo (SSTSE or SSFSE) or HAlf-fourier Single-shot Turbo spin-Echo (HASTE): repetition time (TR), ∞; echo time (TE), 120 msec; flip angle, 90°; acquisition time, 20 seconds (a single breath hold sequence) → serves as a localizer and provides an overview of the anatomy.

2) Axial SSTSE with relatively short (80 msec) and longer (120-180 msec) TE; acquisition time 20-25 seconds (two breath holds) → detection and characterization of fluid-containing liver lesions such as cysts, hemangiomas, and biliary hamartomas.

3) Axial black-blood echo planar imaging (BBEPI) and diffusion-weighted imaging (DWI): TR, 3400 ms (minimum); TE, 60 ms; frequency and phase matrix 144x256; field-of-view, 310-350 cm with a rectangular FOV 80%; EPI factor, 109; sensitivity encoding (SENSE) factor, 2; half scan factor 60%; b-value 20; acquisition time 25 sec; Bandwidth per pixel in the phase encoding direction was 9.2 Hz and in the EPI readout direction 1387.1 Hz; and the polarity of the phase encoding gradient was set to posterior → provides T2-weighted images in breath hold with better liver-to-lesion contrast than the standard T2-weighted turbo spin-echo with fat suppression. DWI can be used to characterize lesions.

4) Axial two-dimensional (2D) dual gradient echo (both in- and opposed-phase as one sequence in a single breath hold): TR, 150-170 msec; TE, 4.2/2.1 msec; flip angle 80-90°; acquisition time, 20 sec → provides T1-information and detects focal or diffuse fatty infiltration in tumors and tissues.

5) Axial dynamic three-dimensional fat-suppressed gradient echo sequence (VIBE; THRIVE; LAVA): TR, minimum; TE, minimum; flip angle, 10-15°; slice thickness 4-8 mm, interpolated to about 60 overlapping reconstructed sections of 4-2 mm; bandwidth, 62 kHz; acquisition time, 20-25 sec in a single breath-hold → arterial phase is the single most important sequence and serves for the detection of liver lesions; all phases are utilized for the characterization based on the enhancement patterns of lesions.

6) Coronal delayed three-dimensional fat-suppressed gradient echo sequence: TR/TE, minimum; flip angle, 10-15°; slice thickness 4-6 mm, interpolated to about 40 overlapping reconstructed sections of 2-3 mm; bandwidth, 62 kHz; acquisition time, 20-25 sec in a single breath-hold → provides information about the persistent enhancement of lesions such as hemangiomas, capsular enhancement of hepatocellular carcinomas, and peritoneal spread of disease, and biliary tree abnormalities.

7) Axial T2-weighted turbo or fast spin-echo (TSE or FSE) with fat-saturation: TR, 2000 msec; TE, 100 msec; flip angle, 90°; acquisition time, 2-5 minutes (respiratory-triggered) → traditionally this sequence has been used for the detection of solid liver lesions. Most likely, this sequence will be replaced by newer T2-weighted sequences such as BBEPI.

8) Magnetic resonance cholangiopancreatography (MRCP) consists of a 2D heavily T2-weighted sequence with a thick slab of 30-60 mm to provide an overview of the biliary and pancreatic anatomy: TR, ∞; TE, 800 msec; flip angle, 90°; acquisition time, 2 sec per slab which are typically acquired as a radial scan of 5-10 slabs around the common bile duct. This thick slab MRCP is often combined with thin slice coronal SSTSE with a TE of about 180 msec and thin sections (<5 mm).
Table shows the sequences used in a typical liver MRI protocol; please note that BBEPI sequence is similar to diffusion-weighted imaging with a b-value of 20; this sequence can be modified into DWI by increasing the b-value to 500 or higher.

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<thead>
<tr>
<th>Sequence</th>
<th>Parameter</th>
<th>Function</th>
<th>Remarks</th>
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<tr>
<td></td>
<td>TR (msec)</td>
<td>TE (msec)</td>
<td>Flip angle (°)</td>
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<td>Coronal SSTSE</td>
<td>∞</td>
<td>120</td>
<td>90</td>
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<tr>
<td>Axial SSTSE</td>
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<td>90</td>
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<td>2D dual GRE</td>
<td>150–170</td>
<td>2.1/4.2</td>
<td>80–90</td>
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<td>3D GRE*</td>
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<tr>
<td>T2-weighted FSE</td>
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<td>80–100</td>
<td>90</td>
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<td>or TSE</td>
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<tr>
<td>BBEPI</td>
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Note.—BBEPI = black-blood echoplanar imaging, FFE = fast-field-echo (Philips Medical Systems, Best, the Netherlands), FIESTA = fast imaging employing steady-state acquisition (GE Medical Systems, Milwaukee, Wis), FISP = fast imaging in steady-state precession (Siemens Medical Systems, Erlangen, Germany), FSE = fast spin-echo, SSTSE = single-shot turbo spin-echo (or half-Fourier acquisition single-shot turbo spin-echo [HASTE, Siemens]), STIR = short inversion time inversion-recovery, TE = echo time, TR = repetition time, 2D = two-dimensional.

* Performed with fat suppression before and after the injection of gadolinium-based contrast material during the arterial phase and several other phases.

† Non-breath-hold, respiratory-triggered sequence performed with fat suppression.
This figure shows the sequences used in a typical liver MRI and MRCP protocol; please note that Black-blood EPI sequence is similar to diffusion-weighted imaging with a b-value of 20; this sequence can be modified into a DWI by increasing the b-value to 500 or higher.

**Literature**