Body MR Pulse Sequences – General Approach

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MRI techniques continue to evolve rapidly, but most of the principal components of a body MRI examination, and the clinical role of each component, have persisted. The three most important considerations for choosing techniques for imaging the abdomen and pelvis continue to be contrast between normal and pathological tissues, coverage, and ameliorating motion and other artifact [1]. In clinical practice, an MRI of the abdomen and/or pelvis is expected to include comprehensive imaging of the various tissues and organs included in the volume of interest. A routine examination still includes T1-weighted images, T2-weighted images, chemical shift techniques to definitively identify lipid-containing tissues and, in most cases, contrast-enhanced images. An important addition during the past decade has been diffusion-weighted imaging, which requires particular attention to assure adequate image quality. The approach to motion has evolved from averaging to motion compensation to suspended respiration and/or subsecond imaging, although averaging may still have a role for some implementations of diffusion-weighted images.

Whenever possible, it is best to image the principal region of interest during a single breath hold sequence. The advantages of single breath hold coverage include simplicity and avoidance of misregistration. Single breath hold imaging is essential for dynamic multiphasic imaging; the crucial arterial phase can only be acquired during a brief interval of about 20 seconds or less. A combination of image acceleration techniques can be utilized to allow repeated whole-volume acquisitions 2 or more times during a single suspended respiration

Localizer Images

The first set of images obtained is usually a rapid sequence with moderately large field of view. These are usually coronal, or a 3-plane localizer. Although T1-weighted images are commonly used for localizer images, we recommend using pulse sequences that depict T2-contrast. Either single-shot fast spin echo or balanced steady state free precession techniques are recommended. The latter can be implemented as a rapid motion-insensitive 3-plane comprehensive initial survey. We recommend contiguous slices of 6mm thickness or less. The torso phased array coil should be used for all sequences, including the localizer images. They can then be used to confirm positioning of the torso coil by making certain that all parts of the volume of interest are included within the sensitive volume of the coil. If technical issues or patient compliance preclude completion of an exam, a diagnosis may be possible from review of a good quality survey [2].

Single Shot Fast Spin Echo (SSFSE)

SSFSE images are nearly always of high quality and high information content, as long as SNR is adequate. When used as a coronal localizer sequence, the images should be acquired using a 32 - 40 cm square FOV and 5 mm image sections, in two or more breathholds if necessary. Using parallel imaging allows the echo train to be reduced, which decreases blurring on SSFSE images

Next, in the abdomen, axial SSFSE images should be obtained using heavy T2-weighting, with TE_{ef} of about 180-200 msec. These images are invaluable for identifying fluid within ducts and collections, and for characterizing solid versus nonsolid masses [3]. In the pelvis, where soft tissue detail is critical and motion artifact is somewhat less problematic, we obtain higher resolution moderately T2-weighted multishot FSE with TE_{ef} of about 100 msec., as described later.

SSFSE is also used for MR CholangioPancreatography (MRCP). In our routine abdominal exam, we obtain a set of radially oriented, thick slab MRCP images near the end of every abdominal examination; previously administered gadolinium contrast agents will slightly lower the signal intensity of blood on these heavily T2-weighted images, reducing background signal. These should have effective TEs of about 1000 msec, often chosen as the final echo in the echo train. The field of view can be as small as 26 cm; wrap-around artifact will not be a problem because solid tissue has minimal signal intensity because of the long effective TE and fat suppression. The epicenter of rotation should be the common bile duct or pancreatic duct, depending on the application.

Balanced Steady State Free Precession (balanced SSFP, true FISP, balanced fast field echo, FIESTA)

These rapid motion-insensitive images depict moving and stationary fluid as bright, and therefore provide an effective survey of vascular and ductal structures, bowel, and fluid collections[4]. While balanced SSFP images are less effective than heavily T2-weighted SS-FSE images for distinguishing solid tissue from fluid, and for depicting ducts, they are obtained more rapidly, have higher SNR, depict blood vessels better and may have other desirable attributes. The shortest possible TR should be used to reduce artifacts from heterogeneous susceptibility. These images do not replace T2-weighted FSE, but are useful supplements due to their consistent depiction of blood vessels and other fluid-containing structures.

Dual Gradient Echo Axial In-Phase And Out-Of-Phase

These should be obtained as a dual-echo sequence. At 1.5 T, the TEs should be approximately 2.25 and 4.5 msec at 1.5 T, although on some systems the software may be configured to yield slightly different TEs, with acceptable results. At different field strengths, inversely proportionally changes to the TEs must be implemented to generate in-phase and opposed-phase images. For example, at 3T, the TEs are about 1.15

and 2.3 msec. The opposed phase image should always be the first echo, so that signal decay due to T2* vs. chemical shift differences have opposite effects. On some 3T systems, the default implementation yields opposed phase images as the 2nd rather than 1st TE; every effort should be made to change this so the in-phase image is at the 2nd TE. Either 2D multi-slice or 3D technique may be used. Because 3D techniques utilize a lower flip angle, specific absorption rate (SAR) concerns at 3T favor use of the 3D rather than 2D technique. Increasingly, 3D Dixon techniques are utilized to obtain in-phase, opposed-phase, water and fat images all within one acquisition, as described below.

Dynamic Multi-Phasic 3D Fat-Suppressed Spoiled Gradient Echo (VIBE, THRIVE, LAVA)

Optimal dynamic scanning technique for detection and characterization of liver lesions is best accomplished if the entire liver can be imaged one or more times during a single suspended respiration. Dynamic scanning is also beneficial for other applications. A few decades ago, dynamic multiphasic MR imaging was initially implemented using 2D multislice gradient echo technique, often without fat suppression due to time constraints. 3D segmented acquisitions with intermittent fat saturation largely supplanted 2D acquisitions for dynamic scanning and post contrast fat suppressed images, due to their improved efficiency and thinner slices. More recently, 3D 2-point Dixon techniques are more commonly used to generate in-phase, opposed-phase, fat and water images within a single breathhold acquisition[5]. Advantages include increased signal-to-noise due to averaging the signals from first and second echoes, avoidance of artifacts that result from intermittent fat saturation, more robust fat suppression, and greater exam efficiency.

We recommend at least four separate sets of images, corresponding to four separate physiologic phases relative to the dynamic bolus administration of contrast material. TR and TE should be as short as possible, and flip angle should be 10º – 15º. Contrast enhancement is most conspicuous if images are fat suppressed. If a scanner is not capable of obtaining whole-volume 3D fat suppressed images within an acceptable breathhold time, we recommend against using this scanner to perform routine abdominal imaging.

1. Baseline pre contrast images are essential to determine if technical quality and anatomic coverage are adequate. Also, these images provide a basis of comparison to determine the presence or absence of perfusion, which in turn allows confident differentiation between fluid and tissue. The fat suppressed T1-weighted contrast also facilitates identification of hemorrhage.

2. Arterial (capillary; pre-sinusoidal) phase images are especially important for detection of hypervascular malignancies, and for depicting arteries. For some applications, multiple arterial phases may be obtained during the first breathhold, at the expense of reduced spatial resolution or SNR. This may be useful if improved characterization of lesion hemodynamics improves diagnostic specificity. Another benefit of obtaining multiple arterial phases is increased assurance that the optimal arterial phase is included.

3. Blood pool (portal venous) phase images show maximal contrast between liver and hypovascular lesions, and are best for depicting the abdominal and pelvic veins. Since most administered contrast material is present throughout the vascular system at this time, these images are analogous (although not identical) to blood-pool phase images.

4A. Extracellular (delayed; late dynamic; equilibrium) phase images are acquired three or more minutes after injection of extracellular space contrast material, by which time contrast material has diffused into the interstitium of non-CNS tissues. Delayed contrast enhancement is particularly prominent in edematous tissues such as in neoplasms and areas of inflammation, and within fibrosis. If lipid signal is suppressed via frequency-selective saturation, interstitial enhancement is particularly conspicuous.

4B. Hepatobiliary phase images are acquired about 10-20 minutes after injection of hepatobiliary contrast material such as gadoxetic acid. Late dynamic (*transitional*) phase images three or more minutes after injection, as in 4A, may be useful, but these are not effective for enhancing the interstitial space.

Moderately T2-Weighted FSE With Fat Suppression, or STIR

When we obtain moderately T2-weighted FSE images in the abdomen for liver imaging, we prefer to obtain them after, rather than before, gadolinium administration. Other than causing lower signal intensity of kidneys and renal collecting structures, the previously administered gadolinium will have little effect on the image, although there may be slightly improved conspicuity of solid liver lesions. Other advantages of performing this sequence after contrast agent administration include obtaining the important contrast-enhanced images earlier, and allowing a longer interval before obtaining the delayed post-contrast images[6].

For pelvic images, the most important images are generally high resolution T2-weighted images with TE of about 100 msec. We insist on slice thickness of 4mm or less, and gaps of 0.5mm or less. Image resolution should be equivalent to field of view (FOV) of 20 cm, with in plane spatial resolution of 256X256 matrix or higher. If larger FOV is obtained, which is often necessary if parallel imaging is used, suitable increases in matrix should be made so that high spatial resolution is maintained. The most critical plane for high quality high resolution pelvic imaging is axial, but sagittal, coronal or oblique images are also useful. Ultimately, 3D techniques will probably become the preferred method for T2-weighted imaging in the pelvis, but tissue contrast is often still superior with 2D techniques at present. For most pelvic applications, T2-weighted images are more useful without fat suppression, but we generally use fat suppression for one of the 3 imaging planes.

Short TI (tau) inversion recovery (STIR) images include a desirable combination of T2-weighting and inverse T1-weighting. Since liver lesions usually have lower T1 and higher T2 than does liver, STIR images often depict these liver lesions with greater contrast than do fat suppressed T2-weighted images. For liver

imaging, STIR images should be moderately T2-weighted, with a TE between 50 and 70 msec. The disadvantage of STIR images compared with comparable fat suppressed T2-weighted is that the inversion time involves increased acquisition time, and decreased signal. Therefore, the superior tissue contrast of STIR comes at a cost of increased time, lower SNR, and/or lower resolution. If STIR images are used, they must be obtained before administering extracellular space gadolinium chelates, since tissues that enhance have shorter T1, and therefore less signal on STIR images.

If hepatobiliary contrast material is used, post-contrast STIR is highly effective for depicting liver lesions because hepatic parenchymal signal is suppressed due to its shortened T1.

Diffusion-weighted Images

On modern equipment, these should be a routine component of hepatic MRI exams [7], complementary to the more traditional pulse sequences described above. A non-diffusion-weighted set of images is obtained, including an image with b=0, one with low b value such as 20, or both. An image with b=20 resembles an image with b=0, but signal from bulk fluid motion in blood vessels is suppressed, facilitating identification of liver and other lesions compared with vessels. For most body applications, we prefer a moderately high b value of 800; we find that lower b values, such as 500, include too much "T2 shine-through" of bowel and other structures.

For most body applications other than prostate imaging, we examine diffusion-weighted images with b=800 for detecting tumor and other pathology. To distinguish restricted diffusion from T2 shine-through, we visually compare the DWI and low b images. If there is still uncertainty, we examing the ADC maps; because these images are the subtraction of two different images with limited SNR, we find that they are often of insufficient quality to use as a primary pulse sequence. While there are many studies showing correlation with disease of measured Apparent Diffusion Coefficient (ADC), it has not been determined that measuring ADC can be useful for routine image-based clinical decision making in individual cases.

For prostate imaging, a separate approach to diffusion-weighted images is needed. Prostate imaging has been challenging due to the range of benign tissues with long T2 within the prostate, so that tumor is often subtle on T2-weighted images. Diffusion-weighted imaging has become the single most important pulse sequence for detecting and delineating prostate cancer in the peripheral zone, where most tumors occur, but b values of about 1500 are most effective. Thus, even more averages should be obtained than with other abdominal applications. We routinely use NSA = 10 for prostate diffusion weighted imaging. Because of the high T2 of background prostate tissues, careful examination of the ADC maps is critical.

REFERENCES

1. Graves, M.J. and D.G. Mitchell, *Body MRI artifacts in clinical practice: A physicist's and radiologist's perspective.* journal of magnetic resonance imaging. **38**(2): p. 269-87.
2. Dutka, M.V., et al., *Rapid multiplanar abdominal survey using MRI with the steady-state free-precession technique.* journal of magnetic resonance imaging, 2008. **27**(1): p. 198-203.
3. Ito, K., et al., *Hepatic lesions: discrimination of nonsolid, benign lesions from solid, malignant lesions with heavily T2-weighted fast spin-echo MR imaging.* Radiology, 1997. **204**(3): p. 729-37.
4. GB, C., et al., *Steady-State MR Imaging Sequences: Physics, Classification, and Clinical Applications.* RadioGraphics, 2008. **28**(4): p. 1147-1160.
5. Ma, J., *Breath-Hold Water and Fat Imaging Using a Dual-Echo Two-Point Dixon Technique With an Efficient and Robust Phase-Correction Algorithm.* Magnetic Resonance in Medicine, 2004. **52**: p. 415-419.
6. Jeong, Y.Y., D.G. Mitchell, and G.A. Holland, *Liver lesion conspicuity: T2-weighted breath-hold fast spin-echo MR imaging before and after gadolinium enhancement--initial experience.* Radiology, 2001. **219**(2): p. 455-60.
7. Koh, D.-M. and D.J. Collins, *Diffusion-Weighted MRI in the Body: Applications and Challenges in Oncology.* American Journal of Roentgenology, 2007. **188**(6): p. 1622-1635.