Recent Advances in Brain and Spine Imaging

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KEYWORDS

• Advanced MR imaging • High-field imaging • Susceptibility weighted imaging • Time-resolved MRA • MR perfusion • MR spectroscopy • Diffusion tensor imaging • Functional MR imaging

KEY POINTS

- A variety of advanced MR imaging techniques have been incorporated into clinical imaging protocols for routine use, specific applications to particular disease entities, or as problem-solving tools on an ad hoc basis.
- The advent of high-field MR imaging units, coupled with improvements in gradient performance, coil technology, and pulse sequence design, has facilitated growth of routine use of advanced MR imaging techniques in practice.
- Novel methods of enhancing imaging contrast on structural images include techniques such as balanced steady-state free precession, double inversion recovery, susceptibility weighted imaging, and gadolinium cisternography.
- Techniques such as time-resolved MR angiography, cine phase contrast flow quantification, dynamic susceptibility contrast MR perfusion, arterial spin labeled perfusion, proton MR spectroscopy, and diffusion-weighted imaging allow for imaging of specific physiologic phenomena in the brain.
- Presurgical planning has benefitted from the complementary roles of diffusion tensor imaging and blood oxygenation level dependent functional MR imaging techniques.

INTRODUCTION

Because a broad variety of pathologic processes are found in the practice of neuroradiology, and the structures to be imaged are less affected by cardiac and respiratory motion than in other parts of the body, numerous advanced MR imaging techniques have found clinical use in the imaging of the brain and spine. Some techniques have found such widespread utility that they have been incorporated into nearly all imaging protocols; others have found niche applications to answer specific clinical questions, and yet others have been optimally used in combination with other advanced MR imaging techniques. The later sections highlight the various advanced imaging techniques in use in clinical neuroradiology. Because high-field MR imaging along with advances in scanner hardware and pulse sequence design has facilitated adoption of many of the other techniques, the article begins with a discussion of the contribution of high-field imaging. The next several sections review novel methods of generating image contrast and increasing sensitivity to pathology in structural imaging, such as the use of double inversion recovery (DIR) and susceptibility weighted imaging (SWI). Next, a variety of techniques targeting aspects of brain and spine physiology are reviewed, including cine-phase contrast flow quantification, dynamic susceptibility contrast (DSC) perfusion, and proton MR spectroscopy (MRS). Finally, the techniques of diffusion

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tensor imaging (DTI) and blood oxygenation level dependent (BOLD) functional MR imaging (fMRI) that have found numerous research applications and a few, but critical, clinical applications for presurgical planning are reviewed. Each of the techniques discussed are in use extensively in the routine workflow at the author's institution and have contributed to the care of their patients. Typical indications and specific acquisition parameters are described in **Table 1**.

ADVANCED MR IMAGING TECHNIQUES

High-Field Clinical MR Imaging Imaging

The advent of high-field clinical MR imaging systems (3-4 T) has allowed for better clinical application of several MR imaging techniques that benefit from higher magnetic field strength. These techniques include BOLD fMRI imaging,[1] DTI,[2] and arterial spin labeled (ASL) perfusion.[3] These and other advanced MRI techniques benefit from the increase in signal-to-noise ratio (SNR) as well as spatial resolution that high-field MR imaging can provide, primarily the result of a linear relationship between the magnetic field strength (B_0) and SNR. Applications of parallel imaging, improved pulse sequences, and higher SNR coils have been added to improve image quality. For dynamic techniques, temporal resolution can be increased by sacrificing SNR and spatial resolution. When the additional SNR is instead used to achieve improved spatial and contrast resolution, conventional structural imaging sequences benefit from high field, affording increased sensitivity to disease. For example, studies of multiple sclerosis (MS) have found an increased number and volume of gadolinium-enhancing lesions and increased volume of T2 hyperintense lesions at 3.0 T versus 1.5 T[4] and determined that additional patients fulfilled diagnostic criteria for MS at the higher magnetic field strength.[5] **Fig. 1** demonstrates examples of increased sensitivity to MS lesions at 3.0 T in comparison with 1.5 T.

Steady-State Free Precession for High-Resolution Imaging

Balanced steady-state free precession (bSSFP) based MR imaging techniques have found a variety of clinical applications. Utilization has also been facilitated by the introduction of very fast, strong, and precise gradient systems. A feature of bSSFP sequences is their mixed T1 and T2 contrast and very high SNR.[6] Because the T2/T1-weighted contrast is frequently not optimal for detection of brain signal abnormality in neuroradiology, major applications have focused on high spatial and contrast resolution between cerebrospinal fluid (CSF) and surrounding structures when performed with heavy T2 weighting. For example, an important cause of trigeminal neuralgia is neurovascular compression. In most cases, a crossing arterial vessel causes compression, but venous structures may also result in neurovascular compression. Steady-state free precession sequences such as the 3-dimensional (3D) constructive interference in the steady state (CISS) and fast imaging employing steady-state acquisition (FIESTA) sequence have shown utility in the evaluation of trigeminal neuralgia[7] and hemifacial spasm[8] wherein there is similar neurovascular compression of the facial nerve. **Fig. 2** demonstrates utility of a FIESTA sequence for the identification of neurovascular compression in hemifacial spasm. Similarly, bSSFP sequences have found utility in the evaluation of the fluid-filled inner ear structures in the setting of sensorineural hearing loss[9] as well as high-resolution MR myelography for the detection of CSF leaks and postoperative or posttraumatic pseudomeningoceles.[10]

Double Inversion-Recovery Imaging

DIR sequences suppress signals from both the CSF and the white matter (WM), achieving excellent contrast between gray matter (GM) and WM and improving detection of lesions.[11,12] Compared with the T2-fluid-attenuated inversion recovery (FLAIR) sequence, DIR imaging may exhibit improved sensitivity to identify abnormalities with only slightly prolonged T2 values in relation to the WM or GM. In the setting of MS, by suppressing signals from WM and CSF, DIR MR imaging provides superior delineation of GM and increased lesion contrast in both GM and WM. As a result, cortical lesions are more readily detected by DIR imaging than by conventional imaging sequences that are generally poor at detecting and localizing cortical lesions.[13] In the setting of epilepsy, DIR is considered helpful for increased detectability of hippocampal sclerosis[14] and other abnormal signal changes in epilepsy.[15] **Fig. 3** demonstrates an application of DIR Sampling Perfection with Application optimized Contrast using different flip angle Evolutions (SPACE) in the evaluation of epileptogenic foci. In the author's practice, the DIR sequence is used exclusively on their presurgical workup for medically refractory epilepsy and has proven useful in the detection of cryptogenic epileptogenic foci.

Automated Segmentation and Volumetric Analysis

A variety of approaches to automated segmentation and volumetric analysis of the brain structures