Ultrahigh-Field Magnetic Resonance Imaging: The Clinical Potential for Anatomy, Pathogenesis, Diagnosis, and Treatment Planning in Brain Disease

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KEYWORDS

• MR imaging • Ultrahigh-field • Neuroradiology
• Brain anatomy

Key Points

- Main advantages of ultrahigh-field magnetic resonance (MR) imaging of the brain:
  - Higher signal-to-noise ratio (SNR)
  - Higher contrast-to-noise ratio (CNR)

These features provide higher lesion conspicuousness, spatial resolution, or faster imaging.

- Insight into normal anatomy, pathogenesis, diagnosis, and treatment can be gained for various disease categories.
- Considerations for choosing sequences for clinical application:
  - Pursue highest spatial resolution possible
  - Make use of new contrast
    - T_2*-weighted imaging
    - Phase imaging
- In a patient with suspected brain disease not seen on conventional MR imaging, and no contraindications, an ultrahigh-field MR imaging can be considered.
- Metallic implants are the most important limitation, hampering full application of ultrahigh-field MR imaging in the (acute) clinical setting.
- (Neuro)radiologists should be trained for assessment of ultrahigh-field MR images.

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Diagnostic Checklist

- Clinical volumetric magnetic resonance (MR) imaging sequences at 7 T show more details of cerebral disease compared with lower field strengths.
- Visualizing more details of cerebral disease can, in selected patients, help in diagnosis and treatment.
- 7 T high-resolution MR imaging protocols consisting of a dedicated series of MR imaging sequences have been developed in healthy volunteers, and first clinical patient series show their value.
- The broader range of contraindications is still a limiting factor at a field strength of 7 T, and further testing (eg, stents, clips, implants) has to be performed.

CLINICAL RECOMMENDATIONS

For clinical use, ultrahigh-field 7 T magnetic resonance (MR) imaging has (as a result of increased availability and a vast and increasing amount of clinical studies) the potential to be applied in various disease categories. Data have been obtained at 8 and even 9.4 T as well, but these systems have primarily been focused on technological developments and ex vivo measurements (eg, advanced functional MR imaging studies, ^{23}Na brain imaging).

Apart from unraveling pathogeneses of several disease entities that are not fully understood, like multiple sclerosis (MS), advantages of ultrahigh-field MR imaging regarding diagnosis and treatment are gained in many cerebral diseases, like degenerative brain diseases, tumors, and epilepsy. Choosing ultrahigh-field MR imaging for clinical diagnostics is dependent on several factors, like approximation of the added value of high-field MR imaging, the availability of ultrahigh-field sequences, and patient cooperation. Most sequences used at ultrahigh-field for clinical diagnosis are sequences with a high spatial resolution, and contrast that is substantially more pronounced at ultrahigh-field strength, namely T_2*-weighted and phase imaging. Apart from specific contraindications, ultrahigh-field MR imaging can be considered in any patient in whom a brain disease is suspected but not found on conventional MR imaging. To facilitate the dissemination of ultrahigh-field MR imaging in the high-end neuroradiology workflow, (neuro)radiologists should be trained to assess the sometimes distinctly different contrasts obtained with otherwise conventional sequences.

INTRODUCTION

Since the emergence of nuclear magnetic resonance in medicine in the 1980s, the technique has seen an evolution not surpassed by many other medical developments. From a field strength of less than 0.5 T in the beginning, MR imaging has evolved technically to a widespread use of 3 T MR imaging scanners in current clinical practice. There is abundant scientific literature on new applications and sequences of MR imaging for better diagnosis and treatment of patients. Although the larger randomized trials are mostly based on MR imaging data from more conventional field strengths like 1.5 and 3 T, there is a clear trend toward human MR imaging applications at higher and higher field strengths and the first studies at 11.7 T can be expected shortly, something few in the past would have believed possible.[1]

With all these fascinating new developments within MR imaging, it is sometimes difficult to decipher what is still clinical MR imaging and what has gone beyond clinical medicine: what is, or will be clinically relevant,[2,3] and what is not? This question is important in modern (cost-contained) health care, if a decision has to be made whether to buy a new 1.5 T or 3 T MR imaging scanner or even to contemplate acquiring a human 7 T platform. For optimal triaging of patients the question whether a 1.5 T, 3 T, or, if available, ultrahigh-field MR imaging scan would provide the best diagnostic information may become challenging. In an effort to give some suggestions and directions as to how to address ultrahigh-field MR imaging in the clinical setting, we review the current status and its clinical applicability of ultrahigh-field MR imaging of the brain, after a brief technical description of ultrahigh-field MR imaging itself. In addition, we discuss what diagnostic areas are still relatively unexplored, although several clinical caveats exist. Because the brain is the primary target for ultrahigh-field MR imaging research, as well as the anatomic area most imaged with MR imaging in the clinical setting, we focus on imaging of the brain alone, and do not go into detail about ultrahigh-field imaging of other areas of the body. To keep this review compact and synoptic, our focus is on anatomic imaging of the brain rather than including the increased functional and physiologic imaging capabilities that come with increased field strength.