Advanced Neuroimaging 1: Ultra-High Field MRI 7T & Above

WHAT IS POSSIBLE?

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Because of the very positive experience with imaging at 7T thus far, it seems plausible that this field strength will be introduced in the foreseeable future as the next clinical alternative beyond 3T, although the role of ultra-high field strength in the clinic remains to be determined. It is likely that such systems will be utilized for dedicated problem solving in cases where lower field strengths fail to deliver a conclusive answer rather than for general clinical routine. Currently, new 7T magnets with active, superconducting shielding are being introduced by the manufacturers; this significantly reduces the need for passive steel shielding and makes it much easier to set up a system in hospitals and clinics with manageable construction and siting effort. The purpose of this presentation is to illustrate the state-of-the-art of 7T imaging and point out recent progress that could expand the applicability of 7T in particular to clinical neuroimaging.

When moving up to 7T, one is confronted with a number of challenges including higher specific absorption rate (SAR), enhanced susceptibility and chemical shift artifacts, and inhomogeneities in the B1 RF field. On the other hand, 7T provides enhanced SNR and spectral resolution, and also enhanced sensitivity to minute differences in magnetic susceptibility, providing dramatic improvements in T2* (Fig. 1) and BOLD contrasts [1]. To leverage these advantages and maximize the potential of 7T for clinical applications, diverse technical improvements need to be introduced to counterbalance the challenges. In the past few several years, significant progress has been made in introducing optimized head coils with high channel counts and sequence modifications to address these challenges (Fig. 2).

![Figure 1: T2*-weighted images at a) 1.5T and b) 7T in a patient with a large cavernoma in the left angular gyrus (arrow). The 7T image shows much richer contrast within both the grey and white matter, the venous microvasculature is readily visualized, and the susceptibility blooming around the cavernoma itself is larger. On the other hand, there are more severe susceptibility artifacts near the skull sinuses and the chemical shift of the subcutaneous fat around the skull is much greater at 7T (arrowheads).](image)

Beyond hydrogen, enhanced sensitivity also opens the feasibility to perform MRI and spectroscopy (MRS) with other nuclei within a reasonable measurement time. Nuclei such as 13C, 15N, 19F, 23Na, and 31P can potentially be used to obtain new insights into pathophysiological processes. For example, early work has demonstrated isotropic 4 mm 23Na images of the brain in moderate examination times on the order of 10 minutes. Given the large sodium concentration gradient between the intracellular and the extracellular environment, any disease process such as stroke [2] or brain tumors [3] which leads to impairment of this balance would be a good candidate for 23Na MRI.
A further area of technical improvement is in high-resolution imaging. In theory the higher SNR at 7T facilitates the acquisition of smaller voxel volumes; in practice such acquisitions are hindered by the extremely long examination times required to sample k-space and also by subject motion. Voxel volumes of approximately 100 µm isotropic have been demonstrated in research studies. The superior performance of parallel imaging at 7T [4] provides a perfect synergy for sub-sampling k-space and reducing measurement times, and new motion compensation solutions are being investigated to reduce artifacts [5].

Figure 2: Comparison of TOF acquisitions at a) 3T and b) 7T in the same individual, both using a 32-channel head coil. Although SAR becomes an increasing issue at higher static magnetic fields, pulse sequence and imaging protocol adaptations enable leveraging of the higher SNR and better background saturation at 7T, and smaller peripheral vessels become visible. To enable a fair comparison, the acquisition time was kept identical at 5m50s. The spatial resolution was 0.3x0.3x0.5 mm³ at 3T and 0.2x0.2x0.4 mm³ at 7T. The higher resolution could be achieved through increased parallel imaging acceleration factors with no sacrifice in spatial coverage.

The key to the clinical justification of 7T lies in the identification of applications where the higher magnetic field and related properties such as increased SNR lead to a better diagnosis and ultimately to a better outcome for patients. Owing to the many technical solutions which have already been achieved, the evaluation of 7T for several clinical applications has already commenced. Initial experience confirms that 7T MRI represents an extremely promising technology to optimize existing diagnostic possibilities in many neurological diseases. Beyond 7T, 9.4T and 11.7T scanners are already operational for research targeted primarily in the brain, and even higher magnetic fields are on the drawing boards. The drive to higher magnetic fields and the exploitation of this frontier in the effort to address additional clinical questions is likely to continue in the years to come.

References