CHAPTER 4

ASPECTS OF CLINICAL IMAGING AT 7 T

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The intrinsic improvements in signal-to-noise ratio, spectral dispersion, and susceptibility contrast with increasing static magnetic field strength, $B_0$, has spurred the development of MR technology from its very first application to clinical imaging. With maturing magnet, RF, and gradient technology, the clinical community has seen the static magnetic field of clinical systems increase from 0.2 to 1.5 to 3.0 T. Today, the "high field" label for human MR research describes initial experiences with 7, 8, and 9.4T systems. While currently primarily research instruments, this technology is bound to cross the boundary into the clinical diagnostic arena as key technical issues are solved and the methodology proves itself for addressing clinical issues. In this chapter we discuss the particular advantages and disadvantages of ultra high field systems for clinical imaging as well as some of the immediate technological challenges that must be solved to derive the full benefit of the extraordinary sensitivity of these systems, which has been glimpsed from their research use.

1. INTRODUCTION

When looking back to the history of clinical MRI we see a strong effort to find the cutting edge of useful MRI with respect to magnetic field strength. The first clinical systems in 1983 started at 0.35 and 0.5 T and were followed immediately by the development of 1.0 and 1.5 T in the mid to late 1980s. The latter field strengths have been the focus of MRI over the last 20 years. Although higher field strengths, such as 4 T [1,2], systems have been tested in the late 1980s and early 90s, it is only in the late 90s and early 2000s that even 3 T made it into the clinical arena.
Over the last 5 years, 3 T has become an important clinical field strength. All major vendors now deliver and focus strongly on 3T whole-body systems. Others also deliver dedicated head systems at 3 T [3]. Currently a strong majority of about 14000 systems operate at 1.5 T. About 400 clinical 3T systems are installed, and the numbers are increasing steadily with maturing 3T technology.

Since the signal-to-noise ratio (SNR) increases approximately with magnet field strength [4], going to higher magnetic fields in MRI has always been a driving force for improving the capabilities of MRI. For example, SNR-starved techniques such as fMRI [5] and diffusion tensor imaging (DTI) [6] strongly benefit from increases in field strength. Newer developments for speeding up imaging time, such as SENSE [7], SMASH [8], and GRAPPA [9], also benefit from the increase in SNR at higher field strength because of their intrinsic tradeoff of SNR versus imaging speed. In addition, MR spectroscopists always looked for higher field strength to enhance sensitivity and because spectral dispersion increases with magnetic field strength.

So overall there was, and still is, a push to go to higher field strength in order to explore its benefits for clinical and research imaging. In the late 80s and early 90s the first visionary push was made to seek funding for whole-body MRI systems up to 10 T [10]. However, it took until 1998 for the first 8T system to finally be built and installed at Ohio State University [11], followed by the first 7T magnet at the Center for Magnetic Research at the University of Minnesota in 1999 [12]. The second 7T system was then installed at MGH in 2001 and has been operating since early 2002. Recent installations at 7 T are now operating at the National Institutes of Health (NIH) in Bethesda, MD, the Institute for Neurobiology (IFN) in Magdeburg, Germany, and New York University (NYU) in New York City. Other sites are currently under construction, includes ones at Niigata University (Japan), Stanford University, the University of California at San Francisco, and the University of Nottingham (England). Ambitious, even higher field strengths are currently being explored that allow human subject access. At the University of Illinois (Chicago) a 9.4T/650-mm system is under test. The Center for Magnetic Resonance Research at the University of Minnesota also has a 9.4T/650-cm bore system operating since the end of 2004 [13]. An 11.7T system for human use is in discussion and planning in France [14]. However, 7 T seems to have become a quasi-standard at the moment, because affordable magnets are available with 900-mm warm bores. This allows the standard clinical gradient coils to be inserted. Demand for 7 T is rising worldwide. We estimate that the number of 7T scanners that will be delivered in the next five years will be approximately the same as the number of 3T systems that were installed in the 90s before the commercializing wave of clinical 3T scanners arrived.

All these UHF systems are used to explore MR imaging and spectroscopy applications for research and clinical use. $T_1$ becomes longer with increasing field [15]. This offers some advantage for MR angiography as the background tissue can be suppressed more easily. It was one of the main clinical wins for going to 3 T. $T_2$ does not change with magnetic field strength. However, $T_2^*$ becomes shorter with increasing field strength due to increased macroscopic and microscopic susceptibil-