Clinical Applications of Ultra High Field 7T MR – Moving to FDA/EU Approval:

NEW RESEARCH TOWARD ADDITIONAL CLINICAL APPLICATIONS

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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 technical solutions for 7T imaging and point out recent research that could expand the applicability of 7T to clinical questions.

An idealized pyramid representing the steps leading to acceptance of a new diagnostic test would begin with Technical Performance at the lowest level, then move up to Diagnostic Performance, Diagnostic Impact, Therapeutic Impact, Patient Outcome and finally Societal Efficacy [1-2]. Much of the work thus far at 7T has been focused on Technical Performance, i.e. showing improved SNR, CNR, or other objective factors not requiring the subjective interpretation of a human observer. This is the level where physicists and engineers are most active. There have now also been several studies looking at Diagnostic Performance, where human interpretation of the images enters and radiologists, cardiologists, etc. get on board. To date, there have not been any 7T studies at the higher levels in the pyramid. This is not necessarily a prerequisite for clinical introduction: at 3T, there is also very little data for these layers; nevertheless, 3T is widely accepted based on subjective appraisal of its performance by the medical community.

When moving up to 7 Tesla, one is confronted with a number of challenges including higher specific absorption rate (SAR), enhanced susceptibility and chemical shift artifacts, and inhomogeneities in the B_1 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 T_2* and BOLD contrasts [3]. To leverage these advantages and maximize the potential of 7T for clinical applications, diverse technical improvements need to be introduced to counterbalance the challenges.

Particularly problematic at 7T at the present time is the uneven illumination of the body anatomy during high-frequency excitation of large anatomical cross-sections. Thus, it is likely that the first clinical devices will have a limited approval to conduct examinations of the head and extremities. Even in the head and extremities, a major emphasis of ultra-high field research lies in providing RF coil technology and novel methods of RF tissue excitation to improve RF homogeneity.

Initial research in thorax and abdominal imaging at 7T has demonstrated basic feasibility [4-5]. This work generally involves multi-channel transmit coils and the use of static RF shimming of the B_1^+ transmit field [6-7] (Fig. 1). Recently, new acquisition strategies have been proposed utilizing a combination of multiple RF shims [8-9]. To achieve the highest fidelity in control over the RF field, dynamic RF shimming (Transmit SENSE) may offer the greatest opportunity for obtaining high quality images while remaining within SAR constraints [10]. In any case, early results in the torso already indicate that with further refinement, 7T will become viable for full body imaging (Fig. 1).

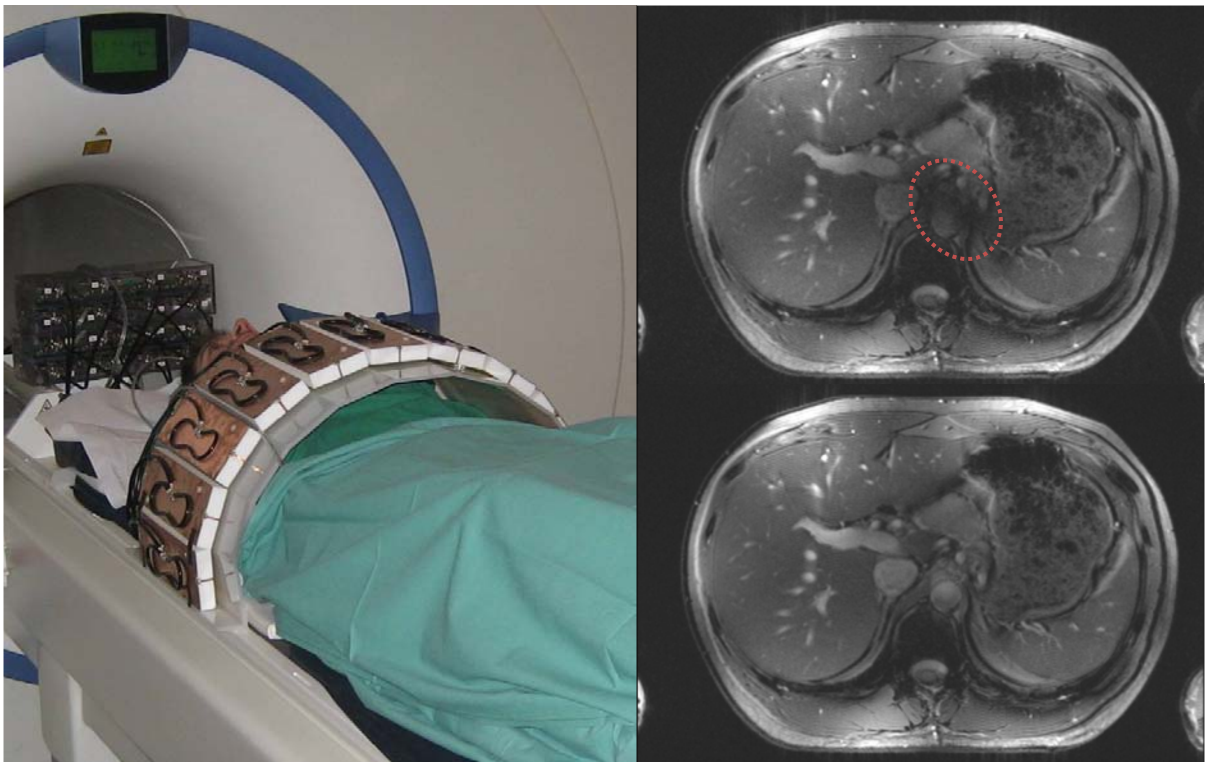

Figure 1: A 16-channel transmit/receive coil based on stripline elements [11] is shown (left). By applying complex weightings to the excitation pulses on each channel (RF shimming), a significant improvement in excitation uniformity and image quality can be achieved in the abdomen (top right), but residual signal drop-outs remain (ellipse). A combination of two shims using TIAMO [8] provides a significant improvement in image quality (bottom right).

A common technique in clinical MRI for examining organ systems which extend beyond the homogenous magnetic field volume of 40-50 cm is to utilize multistation approaches. Such examinations can be used for whole-body screening of atherosclerotic disease [12] or for oncologic staging [13]. At 7T, these approaches are challenging due to the lack of a built-in transmit body coil. Employing a moving table platform, initial whole-body imaging has been demonstrated, demonstrating that it will be feasible to perform these types of examinations after further technical research (Fig. 2).

A further area of technical improvement is in high-resolution imaging. The higher SNR at 7T facilitates the acquisition of smaller voxel volumes in theory; 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 [14] provides a perfect synergy for sub-sampling k-space and reducing measurement times, and new prospective motion compensation solutions are being investigated to reduce artifacts [15].

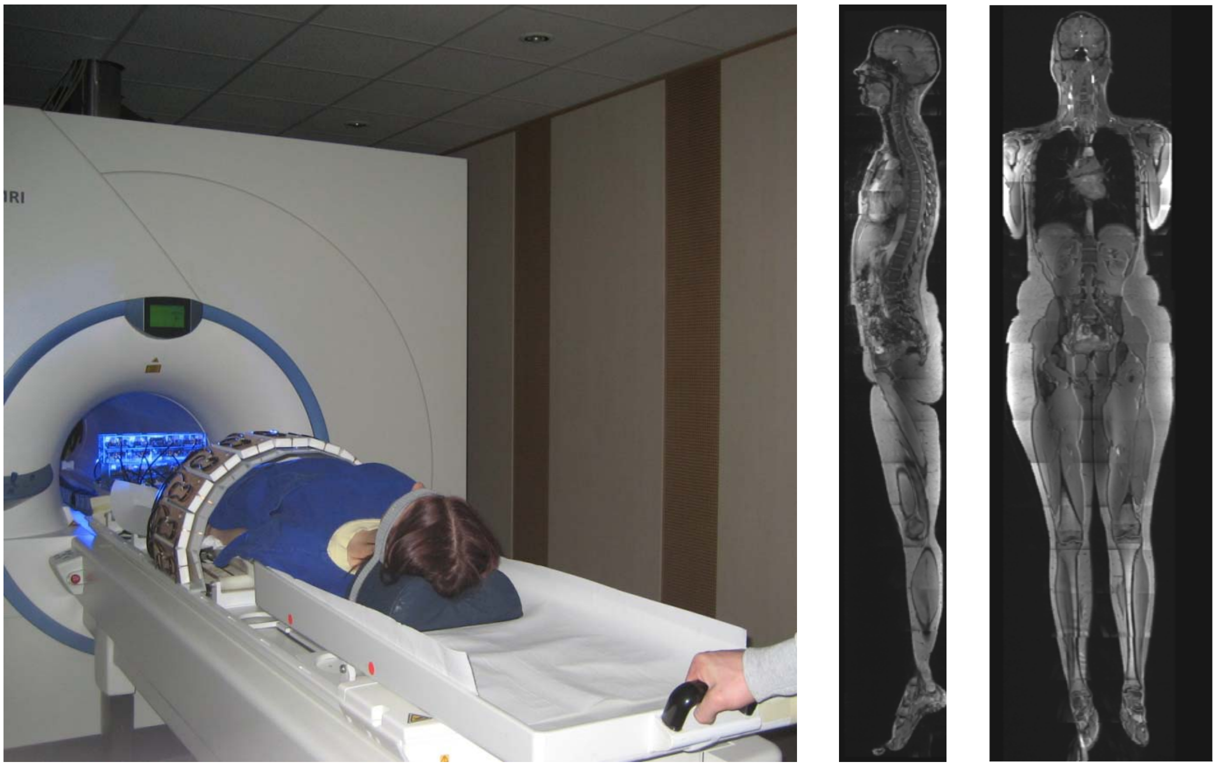

Figure 2: By mounting the coil from Fig. 1 on the patient table of the imager, the subject can be slid through the coil from station to station on a rolling table platform (AngioSURF). This arrangement enables multistation head-to-toe imaging (sagittal and coronal FLASH images, middle and right).

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. However, multiple technical challenges need to be overcome to realize the full potential of 7T. Many technical solutions have already been introduced, and the evaluation of 7T for several clinical applications has commenced. Initial experience confirms that 7T MRI represents an extremely promising technology to optimize existing diagnostic possibilities in many neurological and musculoskeletal diseases, and this potential is likely to be expanded to various pathologies throughout the body as new research enables further technological progress and the pursuit of additional clinical questions.

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