Ultra-High Field Cardiovascular MRI:

RF COIL TECHNOLOGY & MR METHODOLOGY

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When pursuing cardiovascular imaging at 7 Tesla, one is confronted with a number of challenges that require adjustments in coil technology, imaging sequences, and triggering strategies [1]. The purpose of this presentation is to illustrate some of the latest methodological advances that have been achieved in the pursuit of 7T cardiovascular MRI.

One of the most prominent technical hindrances to clinical application of 7T to cardiovascular applications is uneven RF penetration and the consequent inhomogeneous excitation of the body tissue. RF inhomogeneity is particularly problematic in anatomical regions outside the brain and extremities that have large cross-sections. Therefore, a major emphasis of ultra-high field cardiovascular research lies in providing improvements in RF coil technology and in the methods of RF tissue excitation. Initial results indicate that 7T will be viable even in the torso, as is already the case at 1.5T and 3T.

Initial research in heart imaging at 7T has demonstrated basic feasibility [2]. This work generally involves multi-channel transmit coils and the use of static RF shimming of the B_1^+ transmit field [3] (Fig. 1). Recently, new acquisition strategies have been proposed utilizing a combination of multiple RF shims [4-5]. In the middle term, dynamic RF shimming (Transmit SENSE) may offer the greatest opportunity for obtaining high quality images while remaining within SAR constraints [6].

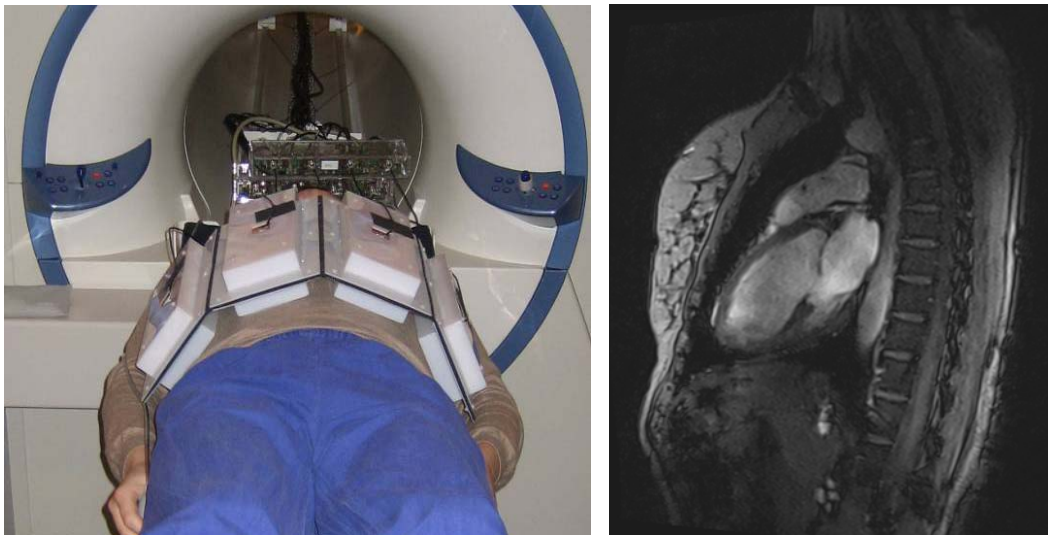

Figure 1 depicts a multi-channel transmit/receive coil that is based on stripline elements [7]. With this coil, the 8 elements (4 anterior, 4 posterior) can be controlled independently of each other during tissue excitation. Thus, a significant improvement in excitation uniformity and coverage can be reached as demonstrated in this frame from a long-axis CINE spoiled gradient-echo (FLASH) acquisition. The blood-to-myocardium contrast at 7T is superior versus lower field strengths for this sequence type.

Early observations have revealed inherently positive blood-pool-to-myocardium contrast at 7T in various gradient-echo sequences regardless of image orientation. The etiology of the high blood-pool signal intensity remains partially unresolved. Due to the utilization of local transmit/receive RF coils at 7T, flowing spins are not pre-saturated by RF pulses before they enter the imaging region. Hence, the contribution of inflowing "fresh" spins to the hyperintense blood signal may be greater than with an extended body transmit coil [8]. The hyperintense blood pool in spoiled gradient-echo sequences is particularly advantageous for wall function studies of the heart [2, 9-10]. Although balanced steady-state free precession (bSSFP) sequences (e.g. TrueFISP, FIESTA, or balanced FFE) represent the state-of-the-art for wall-motion studies at lower field strengths and demonstrate outstanding performance at 1.5T, such bSSFP sequences are severely compromised at 7T by contrast loss (blood-to-myocardium), dark banding artifacts due to off-resonance effects, and generally severe signal inhomogeneities. In addition, SAR restrictions inhibit the utilization of a suitably high excitation flip angle. Cine spoiled gradient-echo sequences (e.g. FLASH, SPGR, or FFE), on the other hand, provide suitable imaging quality with good signal homogeneity over almost the entire cardiac volume and good blood-to-myocardium contrast (Fig. 1).

A clear weakness of cardiac imaging at 1.5T and even at 3T is the unreliable depiction of the coronary arteries. At 7T, it should be theoretically possible to further improve spatial resolution and thus resolve fine details of these very small structures. Even with a fairly conventional RF transmission approach, initial coronary imaging at 7T has been demonstrated, but there are still many technical challenges to be addressed before image quality is fully competitive with either 1.5T or 3T [11-12]. In addition to other challenges, respiratory and cardiac triggering are vital to compensate for physiologic motion during any type of cardiac study. At 7T, ECG triggering functions quite poorly due to the elevated T wave and other interferences [13]. An alternative which has been pursued to overcome this issue is the use of acoustic rather than electrical-based triggering [14].

The cardiovascular system can be considered an organ distributed throughout the entire body. As a consequence, examination of an extended anatomical field-of-view is required to answer many diagnostic questions [15]. A particular example are peripheral run-off examinations, but even whole-body vascular imaging has been proposed for screening purposes [16]. In order to extend the effective field-of-view of the MR imager beyond the homogenous magnetic field volume of 40-50 cm, multistation approaches are utilized. At 7T, these approaches are challenging due to the lack of a built-in transmit body coil. In addition to the logistics of moving the coil relative to the subject, SAR constraints must be critically examined for each station. Employing a moving table platform, initial whole-body imaging has been demonstrated, indicating that it will be feasible to perform these types of examinations after further technical refinement (Fig. 2).

Most cardiovascular work at 7T has thus far been conducted in healthy volunteers, and patient investigations for various pathologies are still outstanding. However, even these early imaging results demonstrate the successful transformation of the increased SNR into a high spatiotemporal resolution, yielding highly defined anatomical depiction and confirming the expected improved performance of parallel imaging. Nevertheless, the impact of enhanced structural and spectroscopic resolution and improved BOLD and T_2*-weighted contrast on diagnostic performance still remains to be determined.

In conclusion, high-field cardiovascular MRI is indeed a challenging endeavor necessitating many technical solutions. However, even very early results have revealed tantalizing new capabilities at 7T. Whether these benefits can be translated to the clinical setting remains to be explored in the coming years.

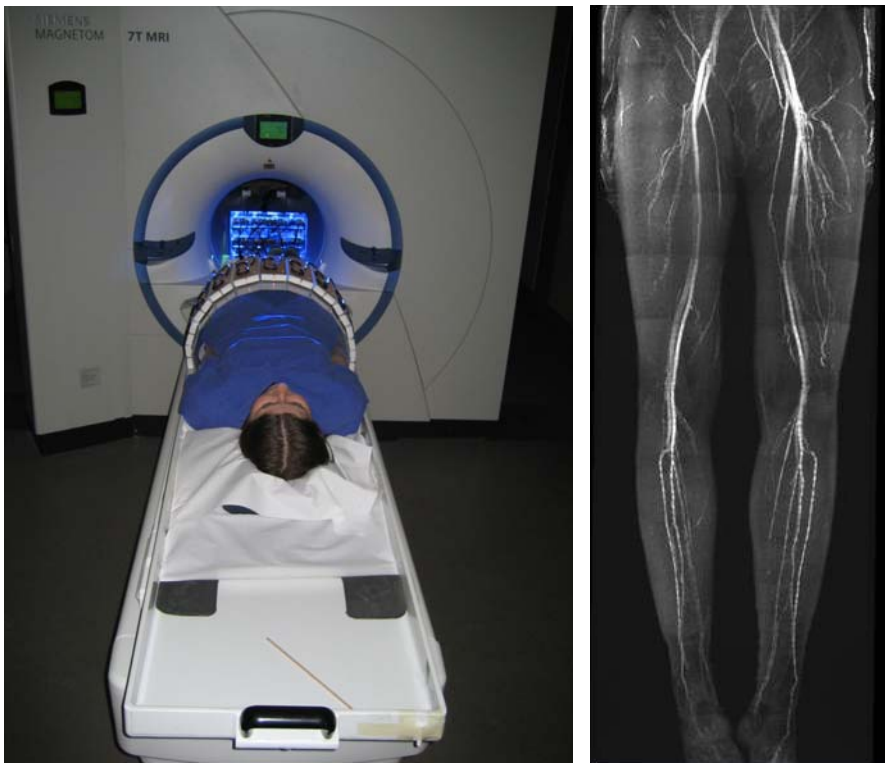

Figure 2 depicts a 16-channel transmit/receive coil based on stripline elements [17]. The coil is mounted on the patient table of the imager, and the subject can be slid through the coil from station to station on a rolling table platform (AngioSURF). This arrangement enables multistation imaging and the examination of the peripheral run-off vessels (right).

References

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