Travelling-wave MRI: Initial results of in-vivo head imaging at 7T

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Introduction: MRI in humans at ultra-high field strengths of 7T and beyond offers superior sensitivity and intriguing contrast options, especially for neurological applications. However, at such high fields the restricted axial coverage of transmit resonators [1] is a main hindrance to studies of lower brain regions, such as the cerebellum, the brain stem and the upper spinal cord, as well as the entire neck. In resonators the formation of standing-wave field patterns results in highly inhomogeneous RF coverage. To overcome this problem it has recently been proposed to rely on travelling waves for coupling to the nuclear magnetization [2]. The first demonstrations of this concept were limited to phantoms and the lower extremity. The aim of the present work was to establish the safety and feasibility of travelling-wave MRI of the human head in-vivo.

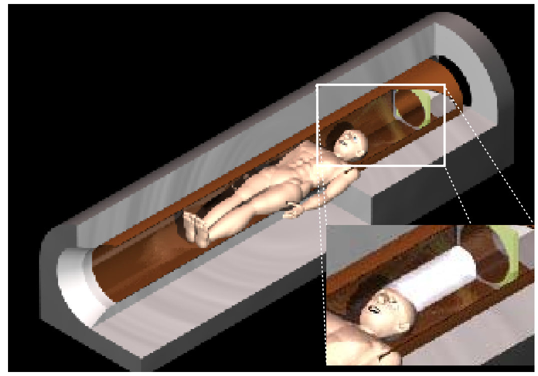

Figure 1: Setup with and without matching cylinder

Setup: For generating travelling waves a patch antenna was used, feeding the cylindrical waveguide (580 mm diameter) formed by the RF screen of a human whole-body MRI scanner (Achieva 7T, Philips Healthcare, Cleveland, Ohio). The antenna was positioned at a distance of 90 cm from the head (Fig.1). The volunteer was positioned with his head towards the antenna and placed such that the linear range of the gradient system encompassed the head and neck. In part of the study a cylinder (Ø=20 cm, length=25 cm) filled with aqueous sugar solution (ε~60) was used to improve the mode conversion from the unloaded bore to the head (Fig.1).

Safety: The potential hazard of RF heating by the travelling-wave setup was assessed by numerical simulation using FDTD software (SEMCAD®, Schmid&Partner Engineering AG, Switzerland) in conjunction with an anatomical whole-body model [3] inside the waveguide. In accordance with standards for safety of RF devices [4], the simulations revealed a worst-case local SAR deposition of 0.02 W/Kg per Watt of input power (averaged over 10 g of tissue). Since the maximum average forward power fed to the antenna was limited to 3 W, the experiment resided well within safety margins.

Imaging: In order to study the feasibility and performance of head imaging with this setup 2D RF-spoiled gradient echo sequences were performed, using the patch antenna for both transmission and reception. The flip angle was kept low (<10°) in order to keep the resulting signal intensity linear as a function of B_1^+ and B_1^-, thus reflecting the product of the two. The field of view of all acquisitions was set to 500 mm, which was the maximum supported by the gradient system.

Results: Figure 2 shows initial sagittal and coronal imaging results, demonstrating extended coverage of the brain, brain stem, and spinal cord, as well as the neck and shoulders. Considering the tissue RF wavelength of about 12 cm the absence of major intensity dips confirms substantial travelling-wave components. Nevertheless, local intensity maxima are observed, one in the parietal region and a second more pronounced one in the brain stem, both resulting from standing-wave portions caused by dielectric interfaces. Simulations (Fig.3) suggested that a dielectric cylinder extending from the head towards the antenna could serve for mitigating the formation of standing waves to a certain degree. This benefit was indeed observed in the parietal region, but was not as conspicuous in the center of the head (Fig.3.3).

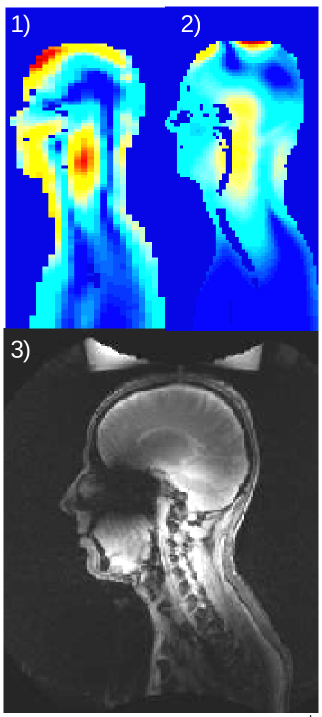

Figure 3: Comparison of B_1^+ field distribution inside a human head in the setup 1) and with a matching cylinder present. The maps are scaled to the maximum field present in each situation. 3) Image acquired with matching cylinder showing reduced brightening at the top of the head compared to Fig.2.1.

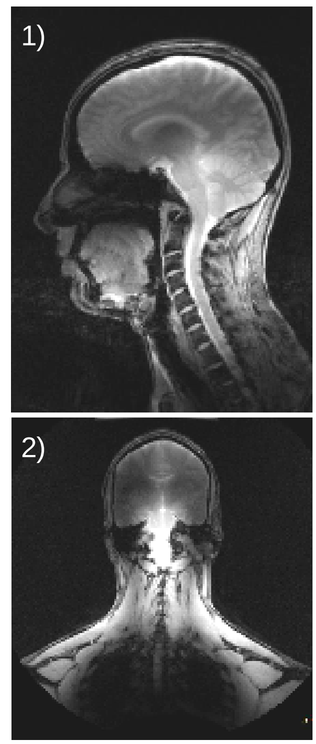

Figure 2: 1) Sagittal and 2) coronal images acquired using travelling waves showing the extent of the RF coverage achieved in the head to shoulder region.

Discussion & Conclusion: According to the safety validation performed in this work travelling-wave MRI is feasible in the human head and should permit the use of at least similar power levels as conventional head-sized resonators. Imaging results show that travelling-wave excitation readily enables RF coverage of the entire head and neck and even the shoulders, indicating a promising advantage over local resonators. Simulations and initial experiments using additional dielectric material show that the residual non-uniformities are related to partial reflections at dielectric interfaces, especially at the top of the head and the shoulders. Dielectric matching holds the potential to mitigate these effects and the initial data have indeed shown some improvement. However, further investigations are required to establish if dielectric matching permits substantial further improvements of the RF uniformity and if the RF coverage can be extended to the chest and abdomen.

[1] Z. Zhai et al. Proc. ISMRM, 2007, p. 3249, [2] Brunner et al. ISMRM 434 (2008) [3] Christ A et al. The Virtual Family – Development of anatomical CAD models of two adults and two children for dosimetric simulations, [4] IEEE C95.3: IEEE recommended practice for measurements and computations of radio frequency electromagnetic fields with respect to human exposure to such fields,100 kHz-300 GHz.