Designing a practical dielectric lining for a whole body traveling wave setup at 7T: tradeoff between RF performance and ease of handling

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Introduction: Recently, a multi-mode coaxial waveguide[1] was introduced as an alternative to volume body coil at high fields. Contrary to conventional volume coil designs, where the performance is strongly degraded by the waveguide action of the RF shield[2], in this new design the waveguide action is exploited to achieve a well distributed RF excitation. The design employs a water tube array as a high permittivity dielectric lining of the RF shield to obtain improved RF shimming and B1 efficiency. For example, it was demonstrated that with the tube array 3 times higher B1 efficiency in head can be achieved[3]. Here, the water tube inset of the multi-mode coaxial waveguide is adapted for more patient comfort and ease of handling. The modified setup was evaluated with the first in-vivo MR experiments which included RF shimming and B1+ efficiency.

Methods: The initially proposed setup of multi-mode coaxial waveguide consisted of the coaxial waveguide, a circular, dielectric lining (32 PVC tubes filled with distilled water[1,3]) and eight radial stub antennas[1]. However, with such a design use of a patient table was impossible. Here, the setup was adapted and modified to accommodate the patient table and the bore of a clinical 7T MR scanner. The dielectric lining was reduced to an arc consisting of only 21 water tubes so the water tube array can be easily placed above the patient table (Fig. 1). Because of the reduced number of water tubes (i.e. circumference of the dielectric lining) the number of antenna ports was reduced from 8 to 5 (Fig.1). B1 and RF shimming efficiency of two setups were compared with the FDTD simulations ("Duke" model, Fig. 2). For an in-vivo MR experiment a healthy female volunteer was placed into the novel design of the multi-mode coaxial waveguide (Fig 1.). To achieve good receive performance a home built 16 channel receive array (each element represented by a rectangular 5x15 cm loop coil) was placed around the body torso. Low flip angle gradient echo MR images (FA=4°, TE/TR=3/30 ms, acq. voxel: 3x3x5 mm3) were acquired of each channel separately for transverse and coronal planes. Relative transmit (Tx) sensitivity maps of each antenna were calculated as a ratio of the individual antenna GRE image and a sum-of-squares combination of all the antennas. For a transverse plane through the pelvic area of the volunteer, the phase settings of the five channels were optimized for a central region using a home built MATLAB tool. With these phase settings an MR image (FA=16°, TE/TR=3.8/76 ms, acq. voxel: 1.3x1.3x5 mm^3) was acquired ("on-line" RF shimming). To validate "off-line" RF shimming (a combined image is obtained by post processing and not acquired on the scanner) the transverse Tx sensitivities of individual antennas were combined "off-line" with the same phases as were played out on the scanner ("on-line" RF shimming). Additionally, an in-vivo B1+ map was acquired (AFI, TR_1 = 25 ms, TR_2 = 125 ms, acq. voxel 6x6x6 mm^3, 3.6 kW total forward peak power) in the same transverse plane with the optimized phases of the Tx channels. For comparison FDTD simulated B1+ maps were combined with the same settings as used in the B1+ mapping experiment in-vivo.

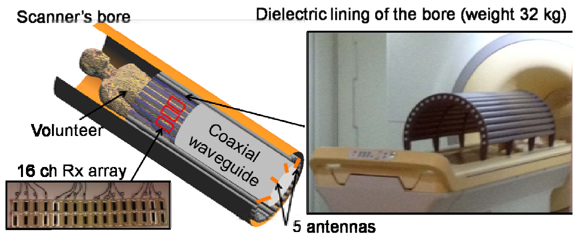

Figure 1. The setup.

Results and discussion: FDTD simulations showed that the reduced number of water tubes did not change the B1+ amplitude and patterns of individual channels significantly. For the upper torso the modified design has even higher B1+ efficiency. However, the modified design has a lower RF performance (20% drop of B1+ efficiency and 45% decrease of B1+ homogeneity in the prostate region comparing to the initial design ([1], Fig. 2). This drop of B1+ efficiency/homogeneity is an inevitable drawback of reduced number of channels. Nevertheless, the improved patient comfort and practicality of the modified setup is a great advantage: the total weight is reduced from 50 to 32 kg and the setup is easily placed on the patient table. Acquired in vivo transverse GRE echo images and calculated Tx sensitivities of individual antennas are plotted in Fig.3. The Tx sensitivities are only slightly affected by residual Rx sensitivity of the local array and body anatomy. Every antenna's transmit field fully covers the pelvis in transverse plane except for several regions with low Tx sensitivity due to destructive RF interferences. The distribution of regions with low Tx sensitivity is distinct for each antenna and can therefore be compensated by RF shimming with all antennas (Fig 3, bottom row). The outcome of "off-line" RF shimming corresponds well to the actual "on-line" RF shimming (Fig.3, bottom row). The RF shimming performance in the coronal plane (Fig. 4) was also evaluated "off-line". All the Tx channels had a large coverage in head-feet direction; however, image quality is lower outside the receivers sensitivity fields. Similar to the transverse plane a good coverage of the coronal plane is achieved with RF shimming. Fig. 5 shows a good correspondence between the in-vivo measured and FDTD simulated B1+ maps. Some deviations can be attributed to the difference between the simulated "Duke" human model and the volunteer. The in-vivo measured B1+ map was superimposed on the corresponding GRE image (Fig. 5). The regions of very low B1+ field were masked. Around 3.5 uT was obtained in a central region of pelvis. This is approximately 2 times lower than a commercial body coil performance for the same peak power at 3T (20uT per 35kW). The low efficiency is most probably due to increased RF losses at 7T than at 3T.

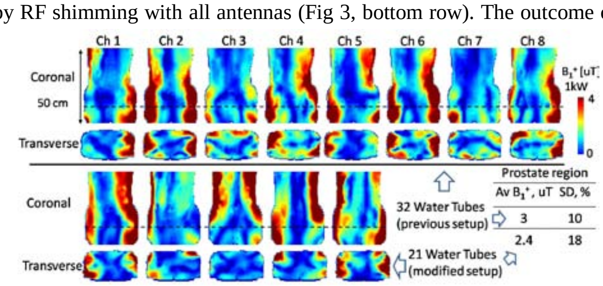

Figure 2. Comparison of the initial and modified designs.

Conclusion: Despite the reduced number of channels and water tubes the modified setup has a large field of view and sufficient RF shimming performance. The "off-line" RF shimming is a reliable prediction of the actual setup performance. The B1+ efficiency of the setup indicates that provided 7T RF amplifiers become available with comparable peak powers as current 3T RF amplifiers, this setup can achieve practical B1+ levels at 7T in the body. To sum up, the modified multi-mode coaxial waveguide is significantly easier to handle and, thus, can be effectively applied in clinical practice as a high field "body coil" at 7T.

References: [1] Andreychenko A et al. Proc. 20th ISMRM'12 # 3376; [2] Vaughan JT et al. MRM 2009 61:244-8; [3] Andreychenko A et al. MRM 2012 doi: 10.1002/mrm.24512.

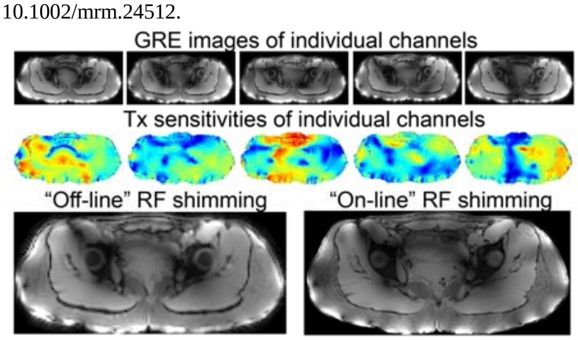

Figure 3. In vivo RF shimming in transverse plane.

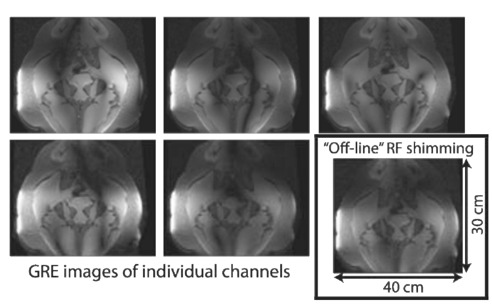

Figure 4. RF shimming in coronal plane effectively removes signal voids of individual channels.

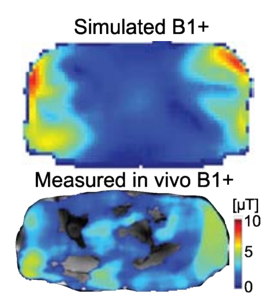

Figure 5. Transverse B1 map in pelvis: FDTD simulations and acquired in vivo.