Effective delivery of the traveling wave to distant locations in the body at 7T

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Introduction

The possibility of application of the traveling wave concept for MRI experiments on a whole body at ultra high fields was recently confirmed by the experiments in Zürich and Utrecht [1, 2]. In these experiments excitation and reception is carried out by a single antenna situated at the beginning of the cavity of a 7 Tesla MR scanner which guides traveling waves along its longitudinal axis. The radiated traveling wave first travels through air and then starts to propagate in a (human) body. A strong damping of the wave occurs during the passage through the body and prohibits excitation of the parts which are located far from the antenna, e. g. the pelvic area. Here, we propose a new concept to deliver a maximum B_1^+ power to the intended region for RF excitation using the waveguide with a coaxial inner conductor. Such waveguide is created by the RF shield of the MR scanner and the inserted cylindrical conductive layer that shields part of the body, e.g. the legs. Due to this conductive shield the radiated wave initially does not penetrate into the body and, thus, the undesirable premature wave attenuation is prevented.

Figure 1. The coaxial inner conductive shield.

Methods

In our study the prostate has been chosen for MR imaging at 7T using the concept of the waveguide with a coaxial inner conductor. The conductive shield around the legs of a human subject consists of a thin plastic framework covered with thin aluminum foil. The framework has an elliptic cross-section (length 63 cm, semi-major axis 19 cm and semi-minor axis 15 cm) with one open end. FDTD simulations were performed to compare the strength of B_1^+ excitation in the prostate with and without the conductive shield around the legs (Figure 1). For the simulations a male adult from the Virtual Family was used [3]. The RF safety was also checked with the FDTD simulations. For an in-vivo experiment a human volunteer was placed in the bore of a 7T MR scanner (Achieve, Philips Medical Systems) with his legs towards the circular patch antenna. The Tx/Rx patch antenna has two orthogonal excitation ports which were driven in quadrature both for transmit as well as receive. Each port was supplied with 1 kW peak power. Fast field echo images (FFE, TR/TE = 100/2.2 ms, ACQ voxel 3/3/10 mm^3) were obtained for two situations: with and without the conductive shield.

Results and Discussion

Figure 2 illustrates the FDTD simulated B_1^+ field of the patch antenna for a quadrature excitation for a standard 7T bore with (left) and without (right) the coaxial inner conductive shield around the legs. The simulations demonstrate more efficient B_1^+ power delivery to the area of interest when the shield is present. Figure 3 shows coronal, sagittal and transverse GRE images in the presence of the conductive shield (left) and for a standard 7T bore (right). The measured field patterns are in good correspondence with the simulations. A strong B_1^+ field amplification takes place between the legs (Figure 2, 3, top right). The use of the conductive shield results in a 2 to 6 times higher signal-to-noise ratio in the pelvis compared to the images acquired without the coaxial inner conductive shield (Table 1). The images obtained with the conductive shield reveal much more structures than the ones without the shield. For instance, the structure of the spinal cord appears more clearly using the waveguide with the coaxial inner conductor approach (Figure 3). Additionally, this approach decreases significantly the peak SAR averaged over 1 cm^3 in the body (Figure 4 & Table 1).

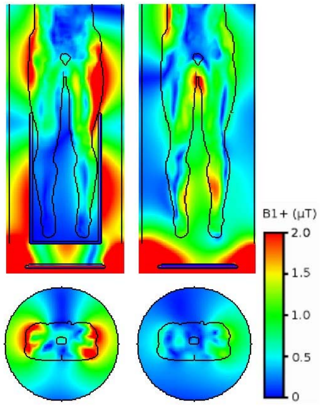

Figure 2. Coronal and transverse simulated B1+ field patterns with (left) and without (right) the conductive shield. The VOI outlined inside the male model corresponds to the prostate. The average B1+ field within the prostate is 2 times stronger in case of the conductive shield.

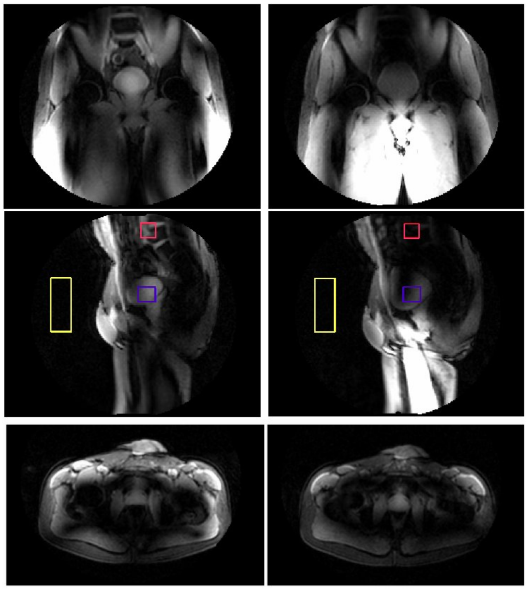

Figure 3. Coronal, sagittal and transverse GRE images of the pelvis, acquired with (left) and without (right) the conductive shield. Rectangular ROIs are drawn for which SNR ratios are present in Table 1.

Conclusions

The first experiments with the traveling wave propagating in a coaxial waveguide formed by the RF shield and the conductive shield have demonstrated the efficient suppression of the wave attenuation on the way to the distant locations. It allows a relative homogeneous excitation of large volumes inside the pelvis or abdomen at 7 T. Moreover, SAR levels in the body are much lower when the conductive shield is present. The waveguide with a coaxial inner conductor approach will be further investigated in terms of the conductive shield geometry and the antenna design.

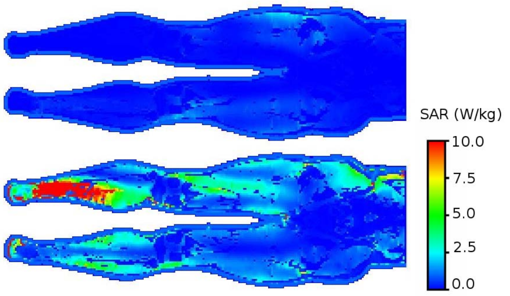

Figure 4. SAR distributions in the body with (top) and without (bottom) the conductive shield.

Table 1.

<table>
<tr><th></th><th>SNR with the conductive shield</th><th>SNR without the conductive shield</th></tr>
<tr><td>🟥</td><td>29</td><td>5</td></tr>
<tr><td>🟦</td><td>36</td><td>16</td></tr>
<tr><td colspan="3">Peak SAR (flip angle 20°, pulse length 1 ms, duty cycle 0.05) in the prostate averaged over 1 cm^3</td></tr>
<tr><td colspan="2">with the conductive shield, W/kg</td><td>without the conductive shield, W/kg</td></tr>
<tr><td colspan="2">4</td><td>54</td></tr>
</table>

References

[1] C.A.T. van den Berg et al., "Whole body RF excitations at 7T by a radiative waveguide concept: the effect of dielectric tuning", ISMRM workshop on Advances in high field MR, Rome 2008

[2] D.O. Brunner et al., "Traveling wave MR on a Whole Body system", 16th ISMRM, Toronto 2008

[3]A. Christ et al., "The Virtual Family – Development of anatomical CAD models of two adults and two children for dosimetric simulations", in preparation