Targeted travelling wave MRI using a coaxial waveguide

S. Alt[1], M. Müller[1], R. Umathum[1], and M. Bock[1]
[1]Medical Physics in Radiology, German Cancer Research Center, Heidelberg, Germany

Introduction

In high field MRI the RF wavelength in tissue is significantly lower than the dimensions of the imaged object. Under these conditions classical volume resonators create unwanted standing wave patterns. Brunner et al. [1] proposed to use travelling waves using the magnet bore as a circular waveguide, to create a more homogenous RF excitation over a large field of view. However, the travelling wave in the bore causes a very high SAR either in the head or the lower extremities [2].
To restrict the RF energy deposition to a well-defined region around the magnet iso-center, we propose a coaxial waveguide insert in the magnet bore. The insert guides the RF pulse energy to the field of view and shields both distal parts of the body, thus reducing the overall SAR load to the patient. The coaxial waveguide is connected directly to the RF transmitter, and both RF transmission (Tx) as well as RF reception (Rx) is possible with this setup.
In this work we assess the feasibility of the proposed method with FDTD simulations and a detailed anatomical model from the virtual family (ITIS Corp, ETH Zuerich, Switzerland) [3]. Furthermore, preliminary results with a downsized hardware prototype setup are shown.

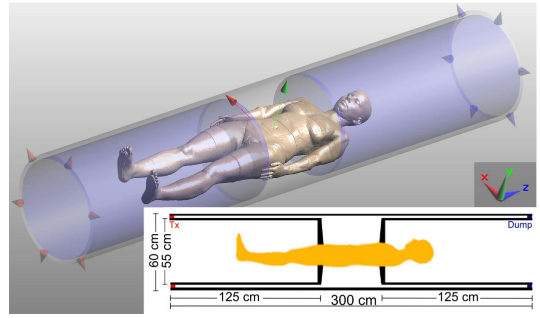

Figure 1: Simulation model of the coaxial waveguide setup. The travelling RF waves are inserted at the sources on the left end (red arrows) and guided between the outer and inner conductors, so only the central part of the body is exposed. Remaining RF energy is dissipated by the resistors on the right (blue arrows).

Materials and Methods

RF field simulations have been performed with the coaxial transmission line (Fig. 1) using a commercial FDTD software (SemcadX v14, Speag, Zurich, Switzerland). The geometry of the setup was chosen to mimic the dimensions of a 7 T high field MRI. At the 50cm-wide opening of the inner conductors, the anatomic model "Ella" (female adult, 26yrs old, 1.60 m, 58kg) from the virtual family set was placed. Conductive layers were introduced to close the gaps between the anatomic model and the central ends of the inner conductors. At each end of the waveguide 6 equidistant ports are used as sources and energy sinks, respectively. Simulation included 10 periods of harmonic transmission at 300 MHz (Larmor frequency at 7 T) with a discretization grid size of 22.7 million cells. The transverse magnetic field (B1) distribution was extracted for the anatomic model. SAR calculations according to IEEE-1529 were performed inside the gap as well as within both inner conductors.
A hardware prototype of half the size shown above was constructed and tested within a 7T whole body MRI (Magnetom 7T, Siemens, Erlangen Germany). The coaxial waveguide was connected via a Tx/Rx-switch and used for both transmission and reception of the signals.

Results and Discussion

Simulations showed that the native coaxial TEM mode is maintained through the gap. While the TEM mode creates a smooth B1 distribution in longitudinal direction, it leads to destructive interference of the magnetic field near the longitudinal axis, thus creating a signal void in the center (Fig. 3). As intended, B1 and SAR are maximal within the gap (Fig. 2). Compared to target region mean SAR is reduced by 97.5% at the transmission side (legs) and by 98.4% at the contralateral side (head, shoulders), and peak SAR values are reduced by 94.4% and 94.6%, respectively. Figure 4 shows gradient echo data of a fish (ex vivo) with the hardware prototype. The RF pulse was successfully guided to the gap and the RF signal was received with the same waveguide. The inherent central signal attenuation can be seen near the spine.

Conclusion

Simulation and preliminary tests with a hardware prototype show that it is feasible to use an interrupted coaxial waveguide to guide travelling waves to the designated imaging region. RF energy is deposited in a central region of the body with low SAR exposure at the distal ends. The unwanted magnetic field attenuation near the central axis is inherent to the coaxial propagation mode (TEM) and could be reduced and/or shifted by adding different electrical loads or by tailoring the excitation pattern at the 6 feed points.

References

[1] Brunner et al, Nature, **457**(7232):971-972**.** (2009)
[2] Andreychenko A et al, Proc. Intl. Soc. Mag. Reson. Med **17**:501 (2009)
[3] http://www.itis.ethz.ch/index/index_humanmodels.html

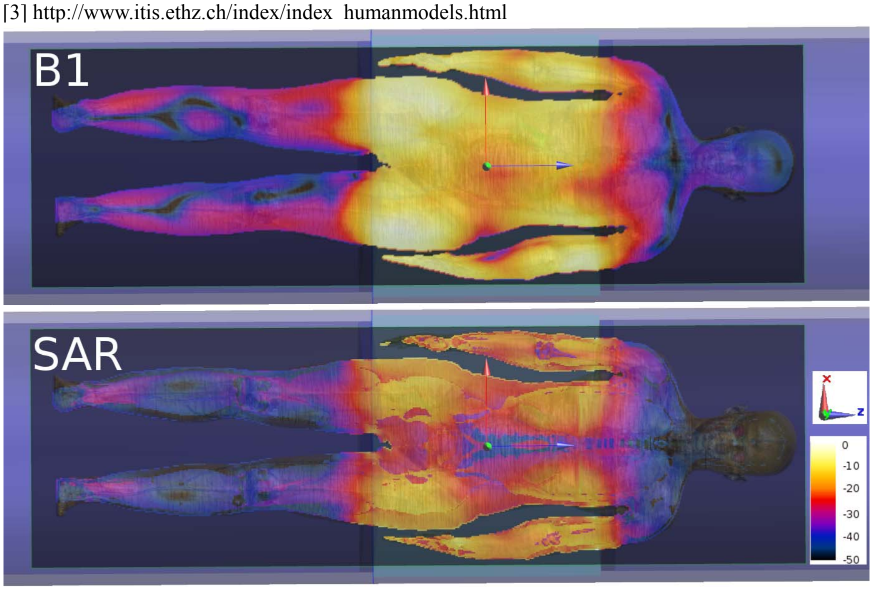

Figure 2: Time-averaged and dB-normalized B1 and SAR distributions at a coronal slice through the body. Before and outside of the gap wave propagation is contained between the inner and outer conductors, so only the central part of the body is exposed.

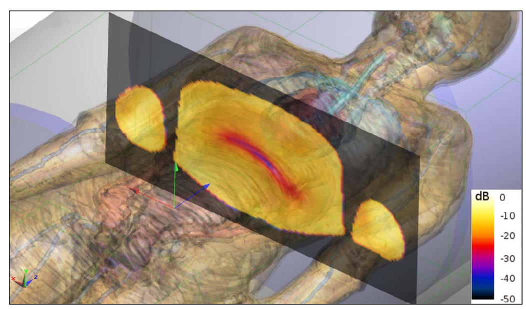

Figure 3: Time-averaged and dB-normalized B1 distribution on a transverse slice. The signal void near the longitudinal axis can be seen.

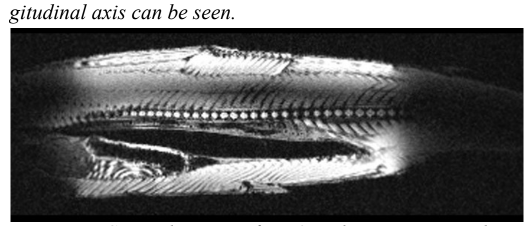

Figure 4: Coronal image of a 48cm long, ex vivo salmon trout acquired with the prototype hardware setup. Only the 20cm-long central portion of the fish in the central gap is illuminated.