Optimizing traveling wave RF excitation for in vivo use

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Introduction: Recently, it was demonstrated by Brunner et al. and Van den Berg et al. that the traveling wave concept might offer a promising means of RF excitation in MRI actually benefiting from the higher RF frequency at high fields [1, 2]. In this concept the cavity formed by the circular RF shield inside the bore of the MR scanner can act as an open ended waveguide capable of guiding traveling waves along its longitudinal axis. In this study we took up the challenge to apply and optimize this RF excitation concept for in vivo use. One of the great challenges for such a body excitation concept is to achieve sufficient wave propagation throughout the bore even when it is heavily loaded by a human subject. Standard waveguide theory indicates that around the cut-off frequency (298 MHz for 7 T bore of ∅ 59 cm) wall and load losses will be high. In this study we reduced these losses by lowering the cut-off frequency using dielectric insets in order to create a more efficient wave propagation through the bore.

Methods. An array consisting of 30 tubes (length 120 cm) filled with distilled water was constructed. See fig. 1. This tighly fitting tube array was placed in the centre of the bore of a 7 T MR scanner (Achieva, Philips Medical Systems). A circular patch antenna with two orthogonal ports (situated at 0^o and 90^o from the vertical axis) both matched to 50 Ohm was placed at the beginning of the tube array for excitation and reception. Excitation power was limited to 1 kW peak power to each port. The set up was first loaded with a large elliptical phantom (24x36x88 cm^3) filled with 3 gr/l saline solution. FDTD simulations were performed to analyse the wave propagation for a loaded standard bore and one with the tube array in place. As a dielectric patient model, the male model from the visual family project was used [3]. Spoiled GRE images (TR/TE 76/12 ms, NSA=3, 2x2x20 mm^3) were acquired on a 7 T MR scanner for two cases: with and without the tube array present. Images were recorded for each port separately. For an in-vivo test, a human volunteer was placed in supine position with its shoulders in the iso-centre of the scanner. The FDTD simulations were used to verify the RF safety a priori. In the images ROIs were drawn to determine the signal-to-noise ratio.


Fig. 1: The array (57x47cm^2) consisting of 30 PVC tubes (∅ 40 mm) with the patch antenna.

Results and Discussion Spectral analysis of simulation results for an unloaded bore showed that for the 90^o port the cut-off frequency is lowered from 305 to 270 MHz due to the tube array, while the cut off frequency of the 0^o port is almost unaffected. This is probably due to the asymmetric design of the tube array. In Figure 2 transverse and coronal images are shown for the 90^o excitation port of the elliptical phantom for a standard 7 T bore (a, c) and with the water tubes in place (b,d). While the field patterns are similar, indicating that both operate in the same mode, the signal-to-noise is a factor 6 to 9 higher for the tubes in place corresponding to a 2.5 to 3 higher B_1^+ and B_1^- efficiency (assuming negligible T1 effects). See table 1. The 0^o excitation port did not show this gain. In Figure 3 the FDTD simulated B_1^+ field distributions for a human subject are shown for the 90^o excitation port for a standard 7T bore and with water tubes in place. Also, in vivo an approximately 3 times higher B_1^+ efficiency can be expected in the cerebellum for the water tubes in place. For quadrature drive this gain is slightly lower (factor 1.5). In more distant locations, e.g. in the heart region, the gain is still a factor of 1.8. The experiments confirm these findings (fig. 2 e, f). A SNR gain of a factor 3 in the cerebellum was found for quadrature drive. Simulations and experiments indicated that in vivo an additional effect becomes important. The neck and shoulders form a strong dielectric discontinuity (fig. 4). This leads to a reflection of the incoming dominant TE_{11} mode and conversion to higher order hybrid (TE+TM) modes to fulfill changing boundary conditions. As a result, a local increase in B_1^+ (and electric) field takes place around the neck and shoulders, while the transmission of the wave to the abdomen is reduced significantly. This phenomenon takes place regardless the presence of dielectric insets. For the water tubes, the SAR also peaked at shoulders, while for the standard bore the SAR peak was found in the nasal cavity. See table 1.

Conclusions Dielectric insets result in higher B_1^+ field per unit power and thus, higher transmit fields at distant locations for traveling wave excitation. This was confirmed by simulations and experiments for a large phantom as well as in-vivo experiments. In vivo, an additional important observation was the large reflection at air-tissue interfaces in the neck and shoulder region which leads to strong field focusing in the neck. This effect disrupts the expected excellent B_1^+ homogeneity along the wave propagation direction based upon the traveling wave principle to some extent.

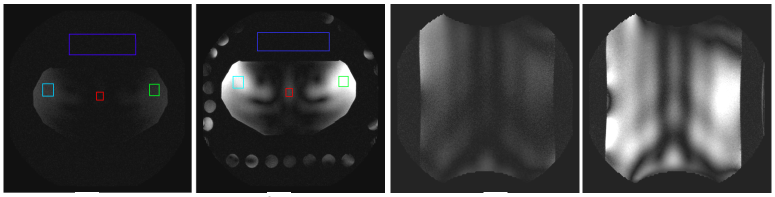
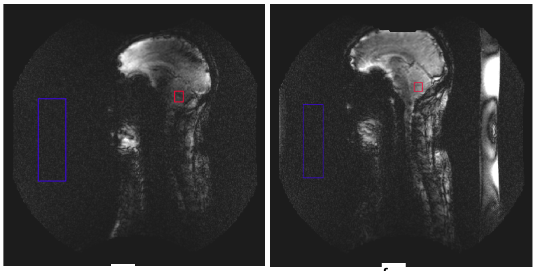


Fig 2: Transverse and coronal GRE images for standard bore (a,c) and water tube array (b,d). Rectangular ROIs are drawn for which in the table the SNR values are depicted. The in-vivo GRE images (e,f) showed a 3-fold higher SNR at the location of the red ROI for the water tubes.



	SNR phantom without	SNR phantom with tubes
	16	92
	11	106
	3	20
	SNR head without	SNR head with tubes
	5	15
	SAR 1 cm^3 without W/kg	SAR 1 cm^3 tubes W/kg
	2.7	5.5

Table 1: SAR was normalized to 50 W delivered continuous power.

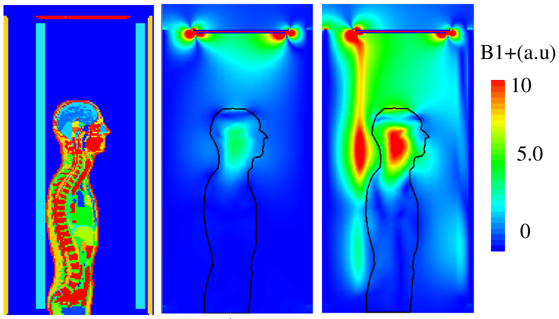


Fig 3: Sagittal simulated B_1^+ field patterns for standard 7T bore (middle) and with water tubes in place (right) for equal RF power. Note the higher B_1^+ field in the abdomen for the water tubes.

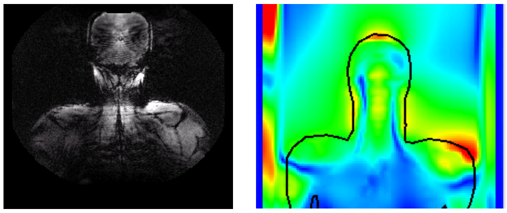


Fig. 4: Coronal GRE image and a simulated B_1^+ field demonstrate the attenuation of the wave due to the shoulders.

References

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