Influence of Deep-Region RF Hyperthermia System on B1+ Field of 1.5T MR Scanner: a Simulation Study

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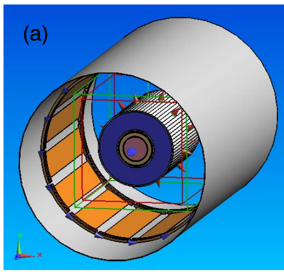
Purpose: Over the last decade, we developed the HYPERcollar applicator and showed focused heating in a number of sites in the head and neck region [1]. The applicator consists of 12 patch antennas placed in two rings operating at 434MHz and allows temperature increase up to 43°C for over 60 minutes. Dose control proved cumbersome since placement of interstitial thermometry catheters in this region is difficult and temperature information is always limited to a few locations. Hence, we are currently working towards integration of the HYPERcollar applicator into the MR scanner, which allows 3D temperature measurements using MR thermometry [2]. The initial applicator setup was earlier redesigned to minimize its metallic parts leading a laboratory prototype ("MRlabcollar") [3]. The main purpose of this study was to use 3D modeling (i) to investigate the influence of the MRlabcollar on the B1+ field of the MR scanner and (ii) to study the level of 434MHz signal from MRlabcollar received by the body coil.



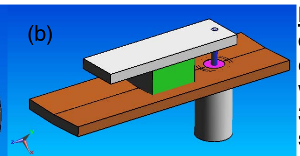


Fig. 1, (a) body coil including MRlabcollar, (b) detail of the patch antenna

Methods: A generic 1.5T 16-rung high-pass birdcage RF body coil model was constructed (radius=355mm, rung length=670mm) using the birdcage tool in the electromagnetic simulation package SEMCAD X (Speag, Zürich, Switzerland). The coil was excited by two edge sources (64MHz, quadrature mode, 60 periods) and tuned by 32 capacitors placed in two end-rings. The electromagnetic field distribution from this simulation was extracted and used as source for all subsequent simulations in this study applying a Huygens source technique (10 periods, dimension 400x400x500mm^3 covering entire MRlabcollar) (Fig. 1a). As phantom, we used cylinder filled with muscle like material TXT-151 (radius r=47mm, relative permittivity ε_r=62.5, electrical conductivity σ=0.79S/m) surrounded by a fat layer (r=65mm, ε_r=8.7, σ=0.024S/m). Both materials were separated by a 3mm thick plastic layer. All metallic parts including the 1.5T body coil, MRlabcollar and patch antennas were simulated as perfect electric conducting (PEC) material. The discretization step was limited in all directions to 1.5mm inside phantom and MRlabcollar. First, we investigated the influence of the MRlabcollar on the B1+ field distributions of the MR scanner using four scenarios: (1) empty coil, (2) phantom alone, (3) phantom and MRlabcollar without the antennas, (4) phantom including MRlabcollar. Second, we simultaneously excited all 12 patch antennas of the MRlabcollar at 434MHz with 240 periods and recorded the level of signal received by the two edge sensors of 1.5T body coil.

Results: The |B1+| of all four scenarios (normalized to 1W incident power) for the Huygens source of the empty coil were compared at two different slice positions, i.e. center of the body coil: z=0mm (Figs. 2a-2d) and through the connector of the patch antenna: z=-53mm (Figs. 2e-2h). Introduction of the MRlabcollar (scenario 4) led to a maximum difference of 43% in |B1+| compared to the setup consisting of body coil and phantom (scenario 2). The peak difference in |B1+| at the center of the body coil with the phantom (scenario 2) compared to the unloaded coil (scenario 1) was 5.8%, and a 1.8% difference was found when antennas were added to the setup (scenario 3 vs. scenario 4). Figure 2h illustrates the localized distortion of |B1+| near the antennas. When all 12 antennas of MRlabcollar were excited (1V, 240 periods), only 7mV peak-peak voltage was induced at the two edge sensors in the body coil.

Conclusion: In this study, we showed the suitability of modeling when merging hyperthermia and MR equipment. We found that the difference of 43% in |B1+| between phantom and MRlabcollar setups is caused by the presence of the deionized water inside the MRlabcollar. No significant changes in B1+ field caused by the metallic parts of the MRlabcollar were observed and only limited filtering in the MR transmit and receive chains is needed since only 0.06% of the 434MHz signal is received by the body coil of the MR scanner.

References: [1] Paulides MM, et al. Phys Med Biol 2010;55:2465-80, [2] Rieke V, et al. JMRI 2008;27:376-90, [3] Bakker JF, et al. ISMRM 2013;3790.

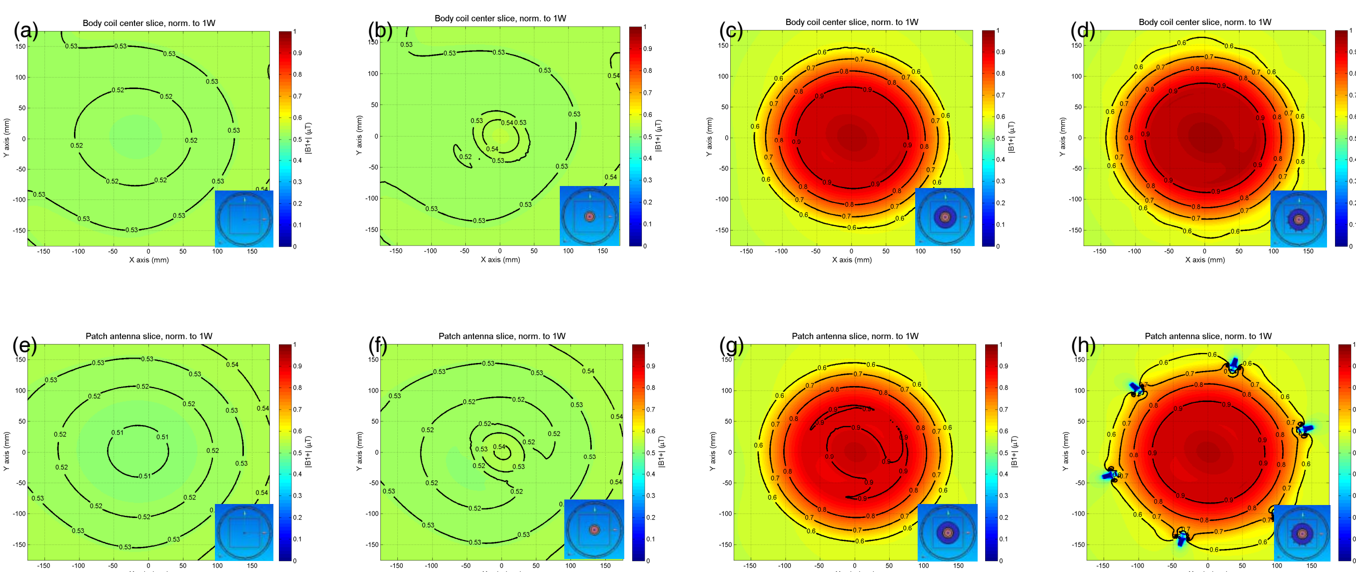


Fig. 2. |B1+|(μT) at the center of the body coil (z=0mm) (a-d) and at the patch antenna connector (z=-53mm) (e-h). Figures (a,e) represent empty coil, (b,f) coil and phantom, (c,g) coil and MRlabcollar without the antennas, (d,h) coil and MRlabcollar.