MR guided RF hyperthermia for head and neck tumors: simulation guided design of an MR compatible RF heating array

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Introduction: Clinical phase III trials have established a strong benefit from adjuvant mild hyperthermia (40°C-43°C for 60-90mins) to radio- and chemotherapy for a number of tumor sites, including the head and neck[1]. The development of the HYPER*collar* applicator[2], combined with treatment planning guidance, potentially features target conformal application of hyperthermia. Especially for the head and neck, precise control of the temperature (T) pattern is required due to strong and inhomogeneous cooling in this region and thermo-sensitive tissues nearby. Unfortunately, the currently applied invasive T-probes provide only limited information and their placement is associated with serious discomfort. Therefore, we are developing MR thermometry (MRT) guided hyperthermia, which requires an MR compatible HYPER*collar*. Building upon the correlation between MRT and simulations[3], we applied simulation-guided design of an MR compatible radiofrequency (RF) array that allows experimental investigation of MRT.

Methods: *__Simulations:__* SEMCAD-X (Schmidt and Partner AG, Switzerland) EM and T simulators were used to re-design the patch antenna of the HYPER*collar*, such that the cylindrical 2x6 array is transparent for the MR T/R signals. Hereto, the fully encompassing groundplane was replaced by a 15x50mm groundplane per antenna and we applied a smaller connector (SMA). A particle swarm optimization routine (400 iterations) was used to optimize the patch dimensions for minimizing the reflection coefficient (|S11|) at 434MHz. The array design was studied by simulating the specific absorption rate (SAR_{raw}) and T distributions for both centrally and axially-shifted phase settings. *__Experimental setup:__* The optimized antenna was mounted in a deionized water cylinder (d=300mm, l=450mm) in a 2x6 array. The cylindrical phantom contained muscle-simulating TX-151 superstuff[4] (with d=100mm, ε_r=60, σ=0.84Sm^{-1}, c=3276$Jkg^{-1}K^{-1}$, k=0.55$Wm^{-1}K^{-1}$) and fat[5] cylinders (outer layer with outer d =135mm, ε_r=7, σ=0.04Sm^{-1}, c=2307$Jkg^{-1}K^{-1}$, k=0.20$Wm^{-1}K^{-1}$). *__Measurements:__* The antenna performance was verified by |S11| measurements using a network analyzer. The array performance and MR compatibility were tested by heating experiments and applying MR thermometry, verified by fiber-optic thermometry. Two high power RF amplifiers (Restek, Italy), and splitters were used to provide a total power of 300W equally divided over the 12 antennas. Imaging was performed on a 1.5T GE MR450w scanner (GEHC, Waukesha, WI). A spoiled gradient echo (SPGR) imaging sequence (TE = 20ms, TR = 110ms, flip angle = 29°, matrix 256×128, axial slice 10mm, bandwidth 31.25kHz) was used to generate phase-based proton resonance frequency shift (PRFS) MRT maps. Time-varying B_0 field drift was measured in the concentric fat region, and MRT measurements were corrected for the measured field drift[6].

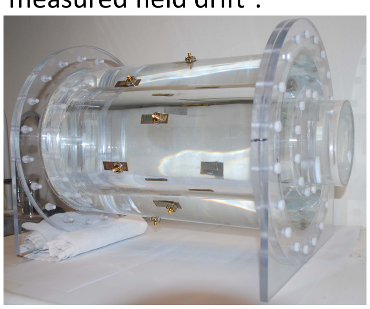

***Fig. 1** Overview of the MR compatible RF heating array*

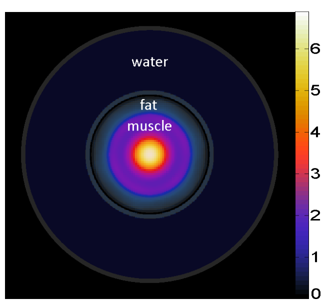

***Fig. 2** Axial predicted T map (°C) after heating.*

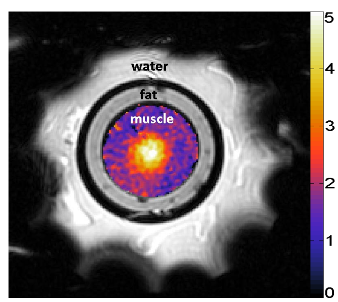

***Fig. 3** Axial MRT map (°C) after heating.*

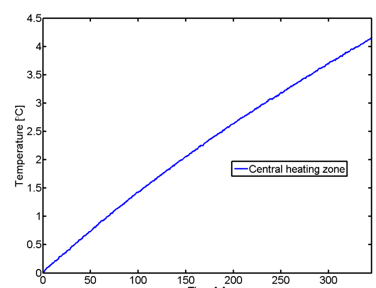

***Fig. 4** Fiber-optic T readings at the central heating zone.*

Results and Discussion: |S11| of all patch antennas was better than -10dB. For 300W input power, a $SAR_{raw,max}$ of 100Wkg^{-1} and T increase of 4.5°C in 6 minutes proved feasible at the center of the fat/muscle phantom. The MRT maps validate MR compatibility of the RF heating setup and, good qualitative agreement is obtained between measurements and predictions, using literature phantom properties. These phantom properties are being measured for a quantitative validation.

Conclusions: The newly developed RF array enables combining focused heat and MR thermometry in concentric fat/muscle phantoms. This work is an important step towards hybrid MR-RF hyperthermia for the head and neck region.

References: 1. Hua et al. IJH 2011, 2. Paulides et al. IJH 2007 68(2), 3. Numan et al. ESMRMB 2012, 4. Ito et al. Electron Comm Jpn 84(4) 2001, 5. Yuan et al. PMB 57(7) 2012, 6. De Poorter et al. MRM 1995;33