Simultaneous Deep-local Hyperthermia and 1.5T MR Imaging – an Experimental Systems Interactions Study

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Purpose: The HYPERcollar applicator was initially designed as a standalone array for simulation guided conformal radiofrequency (RF) hyperthermia treatment of head and neck (H&N) tumors [1]. A magnetic resonance (MR)-compatible prototype of the HYPERcollar, called the MRlabcollar, was subsequently designed and shown to be effective in focusing RF energy in phantoms [2]. A comprehensive characterization of interactions between the MRI scanner and MRlabcollar is critical to ensure minimal degradation to image quality, especially with simultaneous operation of both RF sub-systems. In this work, we quantify changes in metrics that impact MR image quality when the MRlabcollar is inserted into a 1.5T magnet bore. We characterize (i) image SNR in a H&N phantom in different arrangements, (ii) the relative B_1^+ uniformity estimated from experimental flip angle maps with and without the HT array, (iii) B_0 distortion due to placement of the array, and (iv) phase-difference MR thermometry (MRT) maps acquired during RF transmit from the array. The most critical impact of the results is that *concurrent* heating and imaging is feasible with no significant adverse effects on image quality.

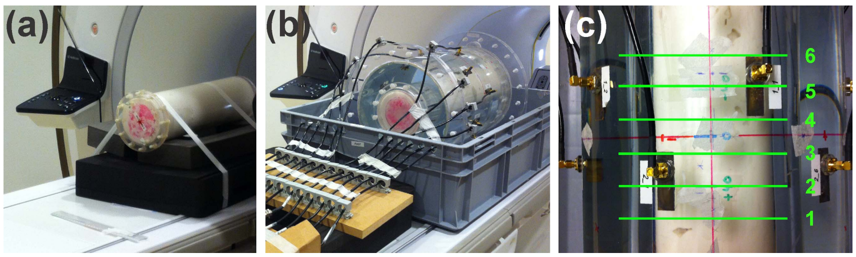

***Fig. 1** (a) H&N phantom in bore alone (setup 1) (b) H&N phantom in MRlabcollar (setup 2). Here the phantom is in the same orientation and position as from setup 1 (c) Top view of phantom in setup 2 showing approximate slice locations for the primary region of interest.*

Methods: A H&N phantom was made with muscle-simulating "superstuff" (TX-151) interior (cylinder dia=100mm) and fat exterior (outer layer, with dia=135mm) [3]. SNR, B_0 field mapping, and flip angle mapping tests were performed with the phantom alone in the bore (setup 1) as depicted in Fig. 1a. The phantom height was measured and its position was marked to ensure the exact same placement when inserted into the MRlabcollar, as shown in setup 2 of Fig. 1b. All tests were repeated for setups 1 and 2. SNR tests were performed with a spoiled gradient-echo (SPGR) sequence (TE = 20ms, TR = 220ms, Flip 30°, FOV 40cm, matrix 256x128, NEX 1, axial slice 10mm, at 5mm spacings, body coil T/R). Slices were acquired to cover the phantom position near the RF patch antennas, as shown in Fig. 1c. Flip angle maps were acquired using an SPGR sequence (TE = 5ms, TR = 6000ms, FA = α, 2α, FOV 40cm, matrix 128x128, NEX 1, axial slice 10mm, at 5mm spacings, 6 slices) and processed by taking the *arc-cos* of the ratio of signal intensities at the α and 2α flip angles. B_0 field mapping was done by taking the phase difference between two gradient echo scans using a GRE sequence (TE = 4ms, TR = 250ms, Flip = 35 , FOV 40cm, matrix 128x128, NEX 1, axial slice 10mm, 2.5mm spacing, 24 slices). An SPGR sequence (same parameters as SNR experiments) was used to generate proton resonance frequency shift (PRFS) MRT maps *while* the MRlabcollar was actively transmitting at 434MHz (2W/channel). B_0 drift was measured and used to correct PRFS MRT maps [4]. All images were acquired on a 1.5T GE MR450w scanner (GEHC, Waukesha, WI), and post-processing was performed with Matlab (Mathworks, Natick, MA).

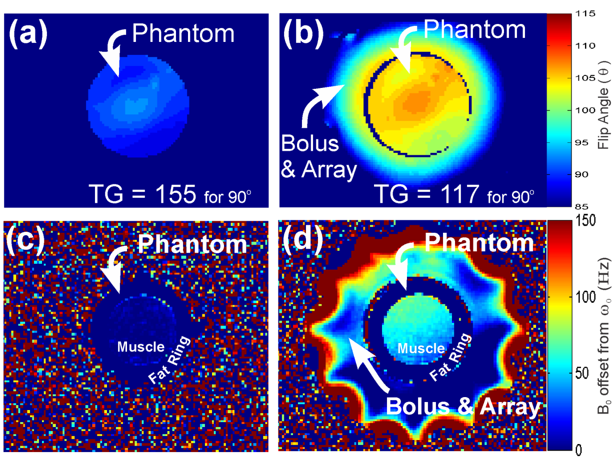

***Fig. 2** (a) Flip angle map for phantom in setup 1 (b) Flip angle map for phantom in setup 2. TG indicates the scanners transmit gain required to get an apparent 90 degree spin flip (c) B_0 field map for setup 1. (d) B_0 field map showing ~75Hz change with the addition of the HT array.*

Results: The figures in Fig. 2a-b show flip angle maps calculated for the same slice in the H&N phantom for setup 1 and setup 2 respectively. The flip angle maps represent an indirect measure of the B_1^+ fields inside the phantom, and were used to check if any antenna or conductive element led to shielding of RF transmitted/received by the body coil. Fig. 2a-b shows results that indicate in both setups there is similar uniformity of the B_1^+ transmit/receive field, yet in the MRlabcollar setup there is less power required to generate a 90 degree flip angle, as shown in Fig. 2b by the over-flipped spins in the phantom at a *lower* transmit gain. Data was similar for all slices (not shown here). The over-flipping is likely due to the increased permittivity of the DI water in the bolus surrounding the phantom in setup 2 (Fig. 1b) acting to direct transmit RF towards the bolus center. B_0 maps in Fig. 2c-d show an increase in field disturbance when the phantom is in the array. This is most likely due to conductive elements at the top of the HT array. A final test of systems interaction was performed to assess the feasibility of acquiring MR images while the MRlabcollar HT array was also transmitting. Results are shown for drift-corrected PRFS MRT images in Fig. 3a-b, and indicate that no image distortions are seen when concurrent heating and imaging is performed. Here no additional hardware filtering or image processing steps were needed to preserve image quality. **Conclusions:** Experiments show that the conductive elements present on the MR-compatible MRlabcollar lead to a ~75Hz distortion in B_0, although shielding of RF transmitted/received by the body coil is not observed. Overall, the DI water bolus acts to help reduce the power needed to flip spins, and in general this leads to ~10-15° over-flipping at the center of the MRlabcollar. This may need to be taken into account when setting the Ernst angle for low-TR SPGR sequences typically used for MRT. Finally, this work shows that *concurrent heating and MR imaging* can be achieved at 1.5T with this setup, allowing for more flexibility when performing MRT during RF HT treatments.

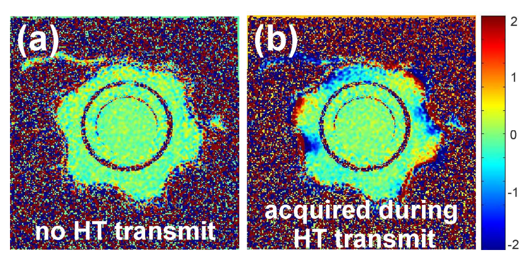

***Fig. 3** (a) Baseline MRT phase-difference map acquired without MRlabcollar transmit (b) MRT phase-difference map acquired during MRlabcollar transmit at 434MHz and 2Watts per channel, acquired before any phantom heating.*

References: [1] Paulides et al. Phys Med Biol 2010;55:2465-80, [2] Bakker et al. ISMRM 2013;3790, [3] Pellicer et al. ESHO 2013, [4] De Poorter et al. MRM 1995;33:74-81