Influence of a Receive Coil on SAR and Temperature Increase at 3T: Simulations & Experimental Measurements

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Introduction: Receive-only surface coils near the subject are widely used to maximize SNR and/or accelerate image acquisition. Although one or more detuning circuits are typically in place to inhibit a resonant condition in the surface coils when the transmit RF coil (usually a body coil) applies significant RF power, currents can still be induced on the conductive elements of the receive coils, and these coils still present significant conductive boundaries to the transmitted fields. Previously, numerical investigations have indicated non-negligible effects of receive-only arrays including detuning circuits on SAR in a human subject [1]. More recently, numerical simulation results were compared directly to MR-based PRF temperature maps for a simple surface coil with a variety of circuits adjacent a simple phantom [2]. Effects at the surface of the phantom, however, are not easily acquired with the MR-based measurements due to known susceptibility issues at the air/phantom interface. In this study, we measure surface temperature using infrared (IR) thermal images and compare results to temperature simulations.

Methods: A single-loop copper strip, to mimic a surface coil, with 2 mm gap (an open circuit to represent a detuning circuit) was placed on the top of a rectangular-shaped agar-gel phantom (w×d×h=88×154×68mm^3), then placed in a head-size birdcage coil (BC) (Figure 1a). It should be noted that a number of commercial receive coils have only a single gap for tuning, matching, and detuning circuits, so this is not an unreasonable representation. The surface coil was mounted on a 2mm-thick Teflon plate. The BC was driven at 125.44 MHz in quadrature with a frequency synthesizer (PTS 200, PTS, USA), RF amplifier (LA200UELP, Kalmus, USA), and quadrature RF splitter. We applied 25 W RF power for 2 minutes. The applied RF power was monitored during the experiments using a directional coupler and RF power sensor (U2001A, Agilent, Inc., USA). Immediately after 2 minutes of driving the BC, we acquired surface IR thermal images (E60bx, FLIR System, Inc., USA) from the top of the phantom. The emissivity of the IR camera was set to 0.95. We repeated the above experiment with 2mm and 10 mm distance between coil and phantom. Temperature simulations with the same configuration of the experiments were performed to compare the temperature distribution (Figure 1b). To do this, SAR was determined with numerical calculations and commercially available software (XFdtd; Remcom, Inc., USA) [2] for the cases with (2 mm distance) and without (10mm distance) the surface coil resting on the phantom. We used the measured conductivity, relative permittivity, and density as 2.97 S/m, 74.15, and 1021 kg/m^3 at 125.44 MHz, determined using RF impedance analyzer and the dielectric probe kit (E4991A, 85070D, Agilent, Inc., USA). With the simulated SAR, we calculated the temperature change with a finite difference implementation of the Pennes bioheat equation [3].

Results and Discussion: Figure 2 shows notably higher SAR and temperature in the phantom when the surface coil is present than when it is not. The pattern of heating follows the shape of the conductive portion of the surface coil. The single-cell SAR, without the coil (Figure 2e), was notably lower than with the coil (Figure 2a). The SAR data were scaled to an input power of 25W. The calculated temperature changes with and without the surface coil are shown in Figure 2b and 2f, respectively. These results show the temperature of the subject would rise significantly when the subject is close to the surface coil. The maximum temperature change in Figure 2b is 3.7 °C. The IR thermal images form the top surface of the phantom clearly show the changed temperature distribution due to the surface coil on the phantom, and support the temperature calculations. In Figure 2c and 2g, we show IR thermal images of 25 W with and without the surface coil, respectively for 10 mm coil-phantom distance. Their maximum temperature changes were 2.3 °C, and 1.1 °C, respectively. We also show an IR image with 2 mm coil-phantom distance (Figure 2d) with a maximum temperature change of 7.1 °C. The IR thermal image for 2 mm distance (Figure 2d) shows higher temperature change than calculation (Figure 2b). This is possibly due to the absence the Teflon plate during the temperature calculation, which could act like a thermal insulator in the experiment, prohibiting heat from escaping the phantom. Figures 2b, c, and d support this inference; when the surface coil was placed 10 mm above the phantom so that an 8mm air space is present (Figure 2c), the IR thermal pattern better matches the calculation (Figure 2b) than the 2 mm case (Figure 2d). When the coil was only 2mm from the phantom (Figure 2d), the greatest temperature increase is observed on the surface of the phantom just below the gap in the coil. This indicates that when a receive-only coil is very close to the subject, conservative electric fields at gaps in the coil may contribute to heating. While this is closer to the subject than external coils are typically placed, internal coils (such as endorectal coils) can be even closer to the tissue.

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References: [1] Wang *et al.*, ISMRM 2009, p. 3102 [2] Oh *et al.*, ISMRM 2010 p 1444 [3] Collins *et al.*, JMRI 2004;19:650-656

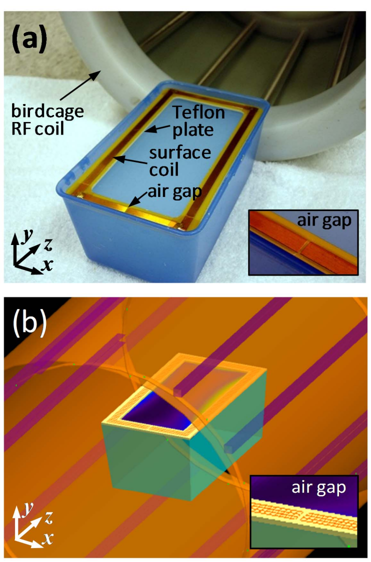

Figure 1. (a) Agar phantom with surface coil, (b) XFdtd model (phantom, surface coil with air gap, and head-size birdcage coil) for SAR simulations

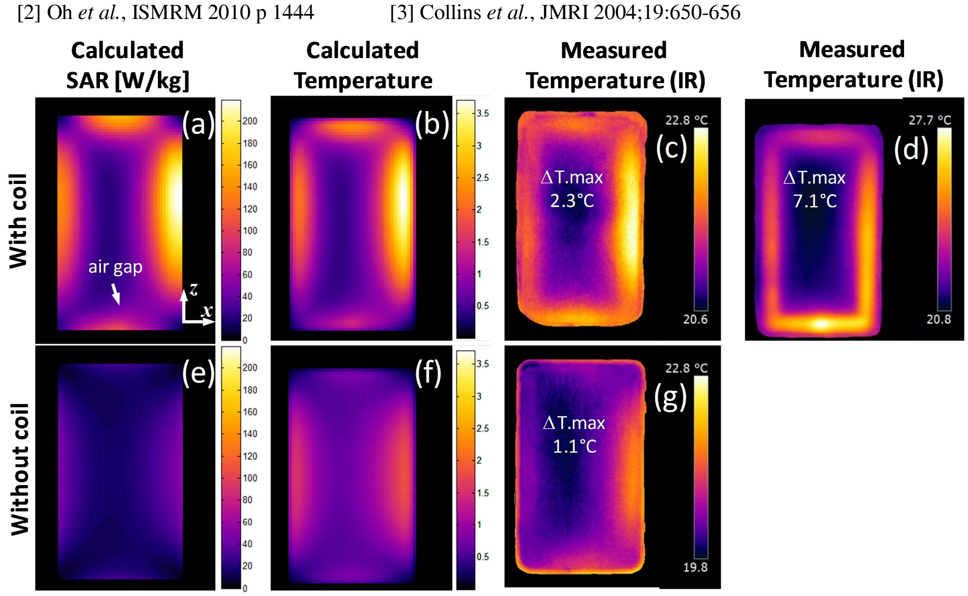

Figure 2. Calculated SAR on the top of the phantom (a) with and (e) without surface coil. Calculated temperature map (b) with and (f) without surface coil. Measured temperature map with IR camera (c) with (10mm distance) and (g) without surface coil, (d) measured IR temperature with coil (2mm).