In-vivo Human Forearm Temperature Mapping for Correspondence with Numerical SAR and Temperature Calculations

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Introduction: Recently, experimental MR-based thermographic techniques were used to confirm numerical SAR calculations for a phantom of gel with electrical properties similar to those of tissue [1]. Because temperature change (ΔT) *in-vivo* is greatly moderated by perfusion, a similar validation in a living subject would be very valuable, but is wrought with a variety of technical challenges. In this study, we report recent progress towards such a validation.

Methods: For a source of heat, a frequency synthesizer (PTS 200, PTS, MA, USA), RF power amplifier (LA200UELP, Kalmus, WA, USA), and circular surface coil (8cm diameter, tuned to 164MHz, matched to 50Ω) were used, with the surface coil positioned against the ventral side of the forearm of a volunteer (Figure 1a). For imaging, the heating coil and forearm were positioned inside a single-channel Tx/Rx extremity coil within a Siemens Trio 3T MRI system. Four cylindrical oil phantoms were also placed in the coil for tracking and correction of field drift effects. Before heating, a baseline gradient echo image (TR/TE=100/10 msec, matrix size=128×128, FOV=160×160 mm^2, slice thickness=10 mm, NEX=4) was acquired. The RF heating coil was then driven with 47.5 W of RF power (95% of 50 W after considering loaded and unloaded Q-factor) at 164MHz for 2 minutes, and then another gradient echo image was acquired (as above, but NEX=1). In prior experiments with fiber-optic thermal probes in a gelatin phantom and with human volunteers offline this amount of heating was found to be notable, but tolerable and having only transient effects. The subject was alert and had the ability to remove his arm from the heating coil at any time. Anatomical images covering the entire forearm were also acquired. The ΔT map was acquired based on the proton resonance frequency shift (PRFS) method using the gradient echo images [1]. Using the anatomical images, each tissue was manually segmented to build a 3D numerical model of the forearm for electromagnetic field simulations. Specific absorption rate (SAR) maps were then simulated for the forearm heated with a model of the heating coil using the commercial finite-difference time-domain (FDTD) software (XFDTD, Remcom, PA, USA). Figure 1(b) shows the model of the forearm with the heating coil (coil in red). The simulated SAR maps were finally used to calculate ΔT using our home-built temperature calculation software, for comparison with the experimentally acquired ΔT. In the ΔT calculation, we considered the perfusion rate as a function of temperature [2], temperature decrease during acquisition of the second gradient-echo image (acquired after the amplifier was disconnected to avoid interference effects), and the tuning condition of the RF heating coil.

Results and Discussion: Figure 1(c) shows the experimental ΔT map on the axial slice through the center of the heating coil overlaid with the corresponding anatomical image. The maximum ΔT in the forearm is observed near the heating coil then decreases rapidly with increasing distance from the heating coil. The maximum calculated SAR was found in the blood vessel on the lower-right (Figure 1(d)), since the conductivity of blood is relatively high (1.27 S/m) and it is very close to the heating coil. However, ΔT of nearby muscle tissue is seen to be greater than that in the blood, mainly due to a high effective rate of perfusion within the blood vessel. Qualitatively, the simulated ΔT distribution (Figure 1(e)) appears similar to the experimental one, but the calculated one currently reaches maximum values significantly above the experimental. These differences may be due partly to imperfect matching of the coil in experiment and underestimation of the effects of perfusion in the simulation. To gain better understanding of these factors and acquire data in a wider range of conditions, further studies are planned with continual RF heating (even during imaging), with lower RF power (to reduce the effects of temperature-dependent in experiment), and with nearly continuous imaging (to acquire data at multiple timepoints during the heating period). We will also directly measure the forwarded and reflected RF power from the RF amplifier to better match the experimentally acquired and numerically calculated ΔT map.

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References:

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[2] Wang *et al.*, J Magn Reson Imaging 2008;28:1303-1308

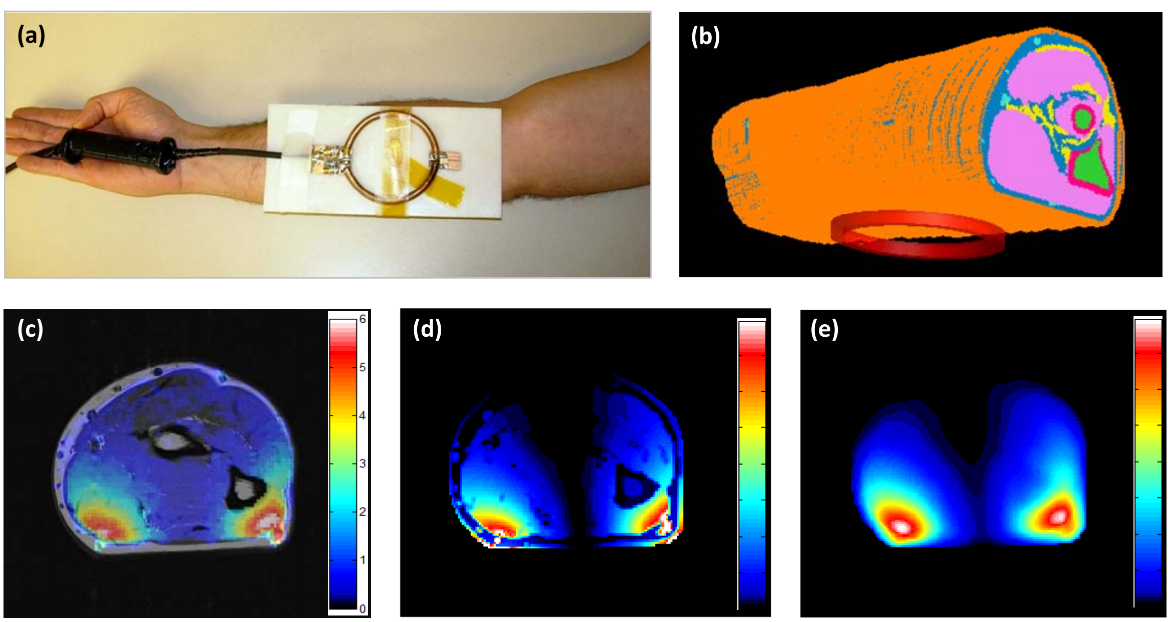

Figure 1. (a) The heating coil placed on the ventral forearm. (b) The forearm model in the XFDTD simulations with the RF heating coil. (c) The MR temperature map superimposed on the corresponding anatomical image. (d) Simulated SAR (unaveraged) image at same position and (e) numerically calculated temperature map using the SAR data set from the FDTD forearm model.