Dependence of Temperature Increase on Pulse Sequence with Equivalent Time-Average SAR

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Introduction: In previous calculations of temperature for MRI, only a continuous SAR input mode was implemented (1-4) and the effect pulse sequence on the temperature rise was not explicitly considered. Here, we investigated the temperature variation between continuous wave (CW), multi spin-echo (MSE) and gradient-recalled echo (GRE) pulse sequences with the same time-average SAR for the human head inside a TEM coil operating at 64MHz (1.5T) and 300 MHz (7T). With a time-average SAR of 3W/kg over the human head for 10 minutes, the continuous SAR input mode induced a slightly higher temperature rise than did pulsed SAR sequences. The temperature rise in the MSE and GRE sequences were almost identical.

Method: A home-built implementation of the FDTD method (5) was utilized for simulating the TEM coil. The coil had an inner diameter (distance between rungs on opposite sides of coil) of 28cm, an outer (shield) diameter of 33cm, and a length of 19cm. The RF coil was modeled after a TEM resonator with multiple sources to achieve a current distribution such that all rungs had equal current magnitude and current phase was proportional to angle of location in the azimuthal plane. The head model had a resolution of 3mm in each dimension. Tissue geometry and mass density were obtained from the United States Air Force Research Laboratory. Calculations were performed at 64MHz and 300 MHz corresponding to MRI at 1.5 and 7.0 Tesla static magnetic field strengths. Electrical properties of tissue were derived from the literature using a 4 Cole-Cole fitting technique and parameters published previously (5). Temperature was modeled in the head with a finite difference implementation of the Pennes Bio-heat equation with an established convection-based boundary condition (1, 5, 6).

Temperature was calculated for 10 minutes of imaging at 3.0 W/kg time-average SAR over the head for each of three SAR input time courses: continuous wave (CW), multi spin-echo (MSE) and gradient-recalled echo (GRE). For the pulse sequences, the TR of MSE and GRE was set to 200ms. For MSE (considering five echoes), the TE was 11ms, the duration of the 90^o pulse was 3ms and the duration of each 180^o pulse was 1.5ms (based on our Bruker MR system's default parameters). Therefore, SAR during the 90^o pulse was 18W/kg and SAR during each 180^o pulse was 72W/kg. For GRE, the duration of the pulse was 1ms, resulting in the extreme instantaneous SAR value of 600W/kg during the pulse. This is not practical in experiment, but was simulated as an extreme case of high-power, short-duration RF pulsation.

Result and Discussion: The SAR distribution at 64MHz and 300MHz during exposure to a head-average SAR of 3.0 W/kg is shown in Fig 1. In Fig 2, the ΔT difference between CW, MSE and GRE SAR input modes after 10min are shown at both 64MHz and 300MHz. The CW input generates higher temperature elevation than the pulsed sequences. This is because in pulse modes there is a slight temperature decrease between two consecutive pulses. From Fig. 2, the difference in temperature increase more in peripheral tissues than in the brain. In high perfusion tissue areas (such as the human brain), perfusion removes heat very rapidly. However, in the muscle and fat area (head boundary), the low perfusion rates result in negligible temperature decrease between pulses. No decrease in temperature between pulses is possible in the CW SAR input mode.

While the differences in temperature increase due to pulse sequence for the range of parameters modeled here may be considered negligible, the fact that the CW input results in the highest temperatures indicates that modeling CW can be considered the most conservative approach. While it is possible that modeling of longer TRs than those simulated here may result in larger differences, the differences are still not expected to be significant.

References:
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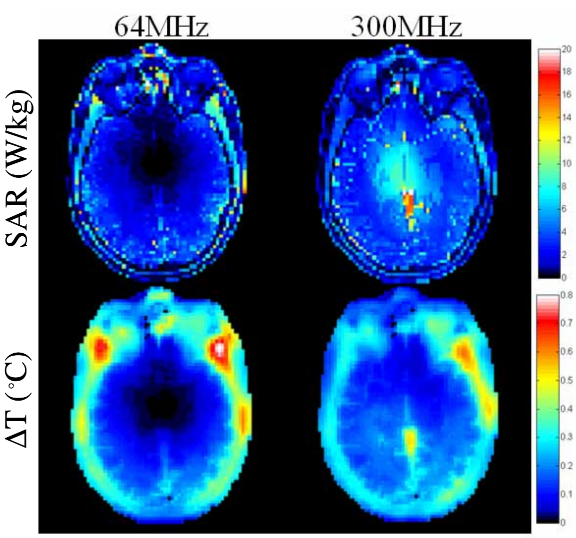

Figure 1. SAR distribution and temperature increase ΔT for CW SAR input. Linear color scale ranges from 0 to 20 W/kg for SAR, and from 0 to 0.8°C for ΔT.

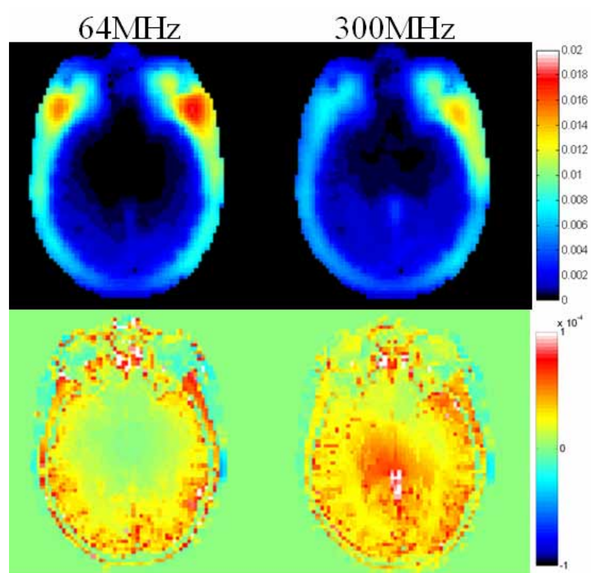

Figure 2. Difference in temperature increase ΔT between CW and MSE sequences (top) and between MSE and GRE sequences (bottom) at 64 (left) and 300 MHz (right). Linear color scale ranges from 0 to 0.02°C for CW-MSE (top), and from -0.0001 to 0.0001°C for MSE-GRE (bottom).