Ultra-Fast Calculation of SAR-induced Temperature Increase

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Introduction: Currently, 10g SAR is the quantity used most often to assess safety of MRI sequences and coils with respect to local heating, although it is cumbersome and time-consuming to calculate and by itself is a quantity with limited direct relation to risk. While temperature increase has a much more intuitive and direct relationship to risk it is typically not calculated at all due to the associated complexity and time requirements. For transmit arrays, where the field distributions can be changed while the patient is in the magnet, there is need for methods of meaningful, real-time safety assessment. Here we present a method for estimating SAR-induced temperature increase that is many times faster than existing methods for calculating either temperature increase or 10g average SAR. We compare to a more rigorous existing method for temperature estimation.

Background: For a given unaveraged SAR distribution, increase of temperature (T) over time can be estimated using the Pennes Bioheat Equation:

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) - W \rho_{bl} c_{bl} (T - T_{bl}) + Q + \rho SAR \qquad (2)$$

where is heat capacity, W blood perfusion rate, k thermal conductivity, ρ material density, the subscript *bl* indicates values for blood, and Q the heat generated by metabolism. Although existing numerical methods of implementing this equation can provide reasonably accurate predictions of the temperature increase, they are very time consuming. The first term on the right-hand side, related to thermal conduction, is responsible for the majority of complexity and time requirements of temperature calculations. A method for accelerated estimation of the contribution of thermal conduction could dramatically accelerate temperature estimation.

Methods: we propose to calculate the temperature increase based on the solution of the Pennes' bioheat equation using a Fourier-based low-pass spatial filter for estimating the effect of thermal conduction. The process then involves solution of a first-order differential equation considering the effects of perfusion, metabolic heat generation, and SAR

$$\rho c \frac{\partial T}{\partial t} = - W \rho_{bl} c_{bl} (T - T_{bl}) + Q + \rho SAR \qquad (3)$$

during a certain time interval followed by application of a spatial filter to estimate the effect of thermal conduction. The process is repeated to simulate progression through time. Some consideration of the time interval and the design of the spatial filter is necessary. Experience so far indicates that fairly simple strategies in selection of time interval and filter design can give reasonable results for a wide range of anatomical sample geometries and coil configurations. The method was applied to numerically-determined SAR distributions and compared to numerical temperature calculations for a variety of phantom and anatomical geometries. In Figure 1 and 2 results for a quadrature surface about the occipital lobe are shown.

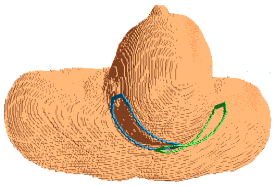

Figure 1: Model used for temperature calculations shown in Fig. 2.

Results and Discussion: The method provides a reasonably accurate calculation of the temperature increase in a very short time: about 60 times faster than a finite-difference implementation of the bioheat equation and about 10 times faster than 10g SAR averaging algorithms, depending on the mesh resolution. Compared to the 10g average SAR, it also considers the contribution of the spatially-dependent blood perfusion rate, and provides an intuitively meaningful result. Predicted maximum temperature increases with the method are within 15% of those calculated with more exact finite difference implementation of the bioheat equation for a wide variety of coil/sample configurations.

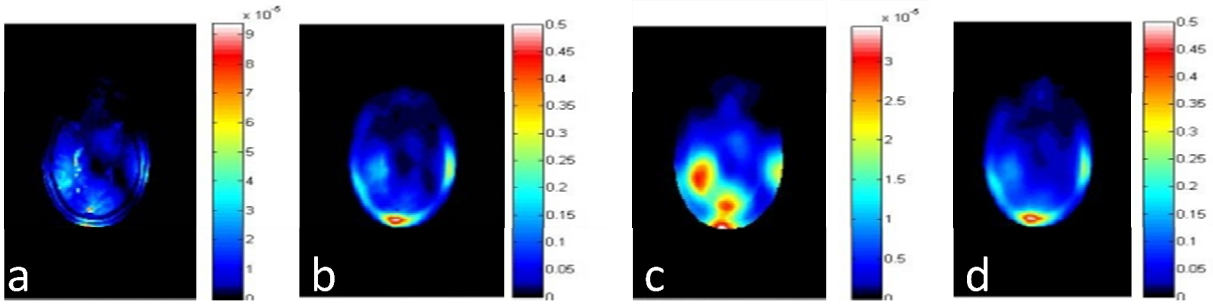

Figure 2: For the model given in Figure 1, plots of (a) the unaveraged SAR distribution, (b) temperature increase calculated with a rigorous finite difference algorithm, (c) 10 g average SAR distribution, (d) temperature increase calculated with the proposed rapid digital filter algorithm.

References

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2. Hirata A., Shiozawa T., "Correlation of Maximum Temperature Increase and Peak SAR in the Human Head Due to Handset Antennas", *IEEE transactions on microwave theory and techniques*, vol. 51, no. 7, 2003