Fast Whole-Body Temperature Estimation for Real-Time MRI Safety Assurance

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Target audience: anyone interested in RF safety and specifically in fast temperature calculation.

Introduction: Currently 10g average SAR is the quantity most used to assess RF safety with respect to localized heating, even though temperature through time (i.e., thermal dose) has a much more direct relationship to risk. However, temperature is usually not computed at all due to the complexity of the methods and to the computation time requirements. For this reason, recently some fast calculation methods have been proposed [1-5]. One method [3] allows rapid calculation of the temperature throughout the body during time-varying SAR absorption, by convolving the precomputed temperature increase of the body for a unit power SAR segment with the sequence of power levels used in the MRI scan. Here this method is combined with a method for considering effect of SAR on core body temperature to demonstrate real-time prediction for an actual MRI exam requiring several different imaging sequences with high-SAR levels and numerous different SAR distributions due to re-positioning of the body in the scanner.

Methods: The temperature during a MRI exam of the spine requiring high-SAR sequences while imaging regions from the cervical, thoracic, and lumbar spine was calculated. The temperature (T) over time was estimated using the Pennes Bioheat Equation:

\[
\rho c \frac{dT}{dt} = \nabla \cdot (k \nabla T) - W \rho_b c_b (T - T_b) + Q + \rho \text{SAR}(t)
\]  

(1)

where \(c\) is heat capacity, \(W\) blood perfusion rate, \(k\) thermal conductivity, \(\rho\) material density, the subscript \(bl\) indicates values for blood, and \(Q\) the heat generated by metabolism. The parameters \(\rho, c, W, \rho_b, c_b,\) and \(Q\) in equation (1) were time invariant (ensuring conservative temperature prediction), while the core body temperature \(T_b\) was allowed to increase [6].

The patient was placed in 6 different positions during the exam. Before the exam: For each of these positions the electromagnetic fields and the corresponding SAR distribution, as generated with a birdcage coil operating at 128 MHz (Figure 1), were calculated with a 3D numerical electromagnetic simulator (XFDTD, Remcom). Each SAR distribution has different power levels and spatial distribution of the single short segment (Figure 2). The SAR distributions due to re-positioning of the body in the scanner.

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After the exam: The proposed method provides an accurate calculation of the temperature in a short time, capable of calculating the temperature rise from a 1 hour exam in less than 2 minutes, while the computation time for the full finite difference method is more than one hour. The method was implemented with an in-house C++ code on a personal computer having 8 GB of RAM and 3 GHz CPU processor. The method can be further accelerated with parallel computing implementation, but it already provides results in a time short enough to allow real-time temperature prediction during an MRI exam. The results obtained with the fast computation method predict a maximum temperature increase less than 1% from that of the full finite difference method (Figure 3).

Results and Discussion: The proposed method provides an accurate calculation of the temperature in a short time, capable of calculating the temperature rise from a 1 hour exam in less than 2 minutes, while the computation time for the full finite difference method is more than one hour. The method was implemented with an in-house C++ code on a personal computer having 8 GB of RAM and 3 GHz CPU processor. The method can be further accelerated with parallel computing implementation, but it already provides results in a time short enough to allow real-time temperature prediction during an MRI exam. The results obtained with the fast computation method predict a maximum temperature increase less than 1% from that of the full finite difference method (Figure 3).

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