Effect of Temperature Increase from RF Energy on Metabolic Rate Observed During MR/PET

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Target audience: anyone interested in specifically how temperature increase by SAR absorption may affect measurements of a hybrid systems such MR/PET.

Introduction: MR/PET is a new modality able to combine the high resolution and soft tissue contrast of MRI with the ability of PET (Positron Emission Tomography) to provide information about metabolic rate and molecular events, depending on the radiopharmaceutical agent used. The use of radiofrequency energy in MRI to induce coherent signal also causes heating and temperature increase in body tissues. Because temperature influences the metabolic rate, MR imaging may, in principle, affect the PET data when a metabolism-sensitive agent such as FDG is used. In this work we use computational methods to investigate how significant a change in metabolic rate may be due to temperature increase induced during MR/PET.

Methods: A human body was modeled in a body-sized birdcage coil within a conductive magnet bore at 3T (128MHz). In separate simulations, the head and the heart (Figure 1) were placed at the center of the coil. The electromagnetic fields throughout the body were then computed with a commercially available 3D numeric simulator (XFDTD, Remcom). After the EM field simulation all electromagnetic fields were normalized so that the average Specific energy Absorption Rate (SAR) absorbed in the whole head was equal to 3.2 W/kg when the head was in the center, and so that the average SAR through the whole body was 2W/kg when the heart was in the center: the maximum values recommended in the IEC guidelines for normal mode operation [1].

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

\[ \rho C_p \frac{dT}{dt} = -W_{pO}c_0(T - T_b) + Q/p + p SAR(t) \]  

(1)

where \( c \) is heat capacity, \( W \) is blood perfusion rate, \( k \) is thermal conductivity, \( \rho \) is material density, the subscript \( b \) indicates values for blood, and \( Q \) is the metabolic rate. The temperature \( T \) was computed with a home-built Finite Difference implementation of Eq. 1 for an exposure of 40 minutes at the above-mentioned SAR levels. The values of metabolic rate \( Q \) were continually updated according to the relation [2]

\[ Q = Q_0(1.1)^{T - T_0} \]  

(2)

where \( Q_0 \) and \( T_0 \) represent respectively the value of metabolic rate and the temperature at equilibrium before beginning the MR exam. The core body temperature (seen as blood temperature, \( T_{bo} \) as in Eq. 1) was allowed to increase according to the total energy absorbed by the body [3].

Results: Figure 2 shows the distributions of initial temperature, single-cell (5mm) SAR, final temperature, and temperature increase on a coronal section of the body of the body. Figure 3 shows the distributions of initial metabolic rate, final metabolic rate, increase in metabolic rate, and percent increase in metabolic rate. The relative increase in metabolic rate is most significant (about 45%) in tissues close to the neck, but the highest absolute increases occur in tissues where the heat generation rate is high at equilibrium.

Discussion: These initial results indicate that the acquisition of MR images may affect the metabolic rates observed in FDG-based studies during MR/PET examinations. While gross appearance of PET exams may not be significantly different to the eye in many clinically-relevant studies, for dynamic and quantitative PET studies the potential effect of MR imaging on the observed metabolic rate should be considered. These results are conservative in at least two ways: 1) SAR at the maximum values is applied continuously for 40 minutes, which is rare in actual MR exams, and 2) no thermoregulatory mechanisms are included in the modeling of temperature. This results in larger temperature increases and changes in metabolic rate than might be expected during a typical MR/PET exam, and further study is warranted. Nonetheless, these initial results suggest that investigators should be aware of the potential effects of SAR-related heating on PET images during MR/PET.

References:

Figure 1: Geometry of the problem: birdcage centered around the head (left) and the heart (right).

Figure 2. For imaging the head (top) and the heart (bottom), spatial distribution of (left to right) baseline temperature, SAR (applied for 40 minutes at normal mode head average (top) and body average (bottom) limits), final temperature, and temperature increase.

Figure 3. For imaging the head (top) and the heart (bottom), spatial distribution of (left to right) baseline metabolic rate, final metabolic rate, increase in metabolic rate, and percent increase in metabolic rate.