# RF safety assessment of a 7T head coil using thermal modeling with discrete vessels

**A. L. van Lier[1], C. A. van den Berg[1], D. W. Klomp[1], B. W. Raaymakers[1], and J. J. Lagendijk[1]**
[1]Radiology, Radiotherapy, Nuclear Medicine, University Medical Center Utrecht, Utrecht, Netherlands

**Introduction:**
At 7T there is a need for dedicated coils to ensure optimal RF transmission. Before these coils can be used *in vivo* their RF safety must be checked. Normally, SAR integrated over a certain volume is used as a surrogate measure for induced temperature rise. However, this may lead to over-conservative use of RF power and thus suboptimal diagnostic imaging [1]. In this abstract we apply thermal modeling with discrete vasculature (DIVA) as a method to calculate the thermal effects of RF energy deposition in the head of a patient. We compare results of the DIVA method [2,3], the Pennes' continuum bio heat thermal equation [1] and volume integrated SAR for a commercially available head coil.

**Methods:**
The SAR distribution of a 16 rods 7T high-pass birdcage coil (f = 298 MHz, Nova Medical detunable head transmit coil) was calculated with FDTD simulations using a head model [4] with 13 tissue types and a 2.5 mm voxel size (see figure 1),. Thermal simulations were performed solving Pennes' equation using a finite difference approach. In Pennes' equation the temperature in a certain area is calculated using the tissues specific heat, thermal conductivity and the volumetric perfusion rate. In this thermal model the convectional cooling of the blood is described by an energy drainage term, the so-called heat sink. In Pennes' model it is assumed that the inflowing blood is at a constant temperature (usually body core temperature) throughout the whole volume. However, as the blood in feeding arteries and draining veins traverses through the heated volume, the blood temperature will actually change due to heat exchange. In DIVA, discrete vessels are added to take this effect into account.

**Results:**
The validity of the SAR modelling was verified with $B_1$+ mapping. In figure 2-a and b it is shown that the simulated and measured $B_1$+ maps are comparable. It was found that the $SAR_{max,1cm^3}$ was $1.87.10^{-12}(B_1+)^2 DC$ (DC: duty cycle). The SAR maximum was located medial in the cerebrospinal fluid (CSF) between the precentral gyrus and the parietal bone (see figure 3). $B_1$+ was set such that a $SAR_{max,1cm^3}$ was 8.08 W/kg (approximately the FDA regulations) was achieved. The corresponding average SAR was 1.21 W/kg. The temperature was calculated for a sequence lasting for 10 minutes for the previously described SAR settings. The head was surrounded by air at body temperature, so the head was in thermal equilibrium at the start of the simulation. Figures 4-6 shows a lateral cut through the temperature map generated with DIVA together with the bloodvessels. Figures 5 and 6 illustrate that a more heterogeneous temperature distribution is found for the DIVA simulations compared to the Pennes' result. The maximum temperature rise found by DIVA and Pennes' simulations was both 0.50 K, also located in the non-perfused area near the precentral gyrus.

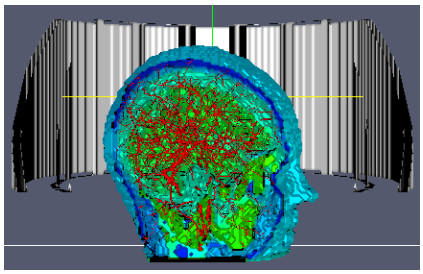

Figure 1: The head model (blue) with the blood vessels (red). and a part of the coil (grey).

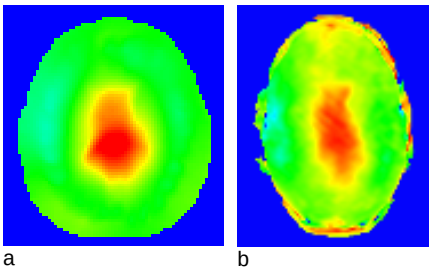


Figure 2: $B_1$+ maps (scale 0.1-1.1 of requested $B_1$+ amplitude) for the a) the simulation and b) the measurement

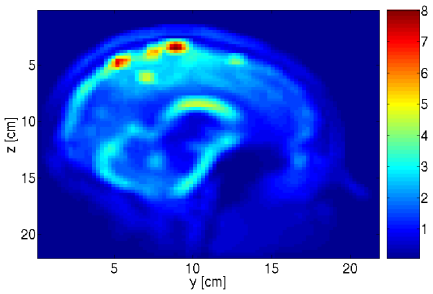


Figure 3: $SAR_{,1cm^3}$, transverse view through the plane with the maximum SAR.

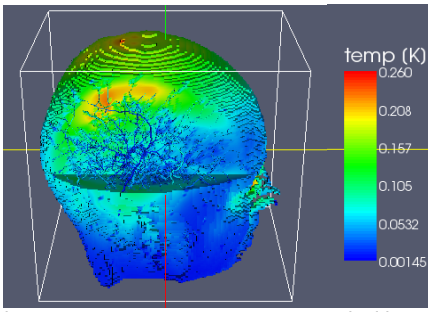


Figure 4: Temperature map generated with DIVA. Cut through the lateral part of the head, with the vessels (blue).

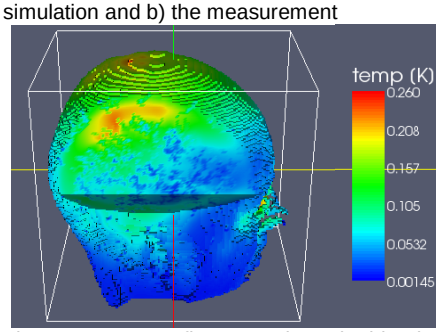


Figure 5: Same as figure 4-a, here the blood vessels are not shown for clarity.

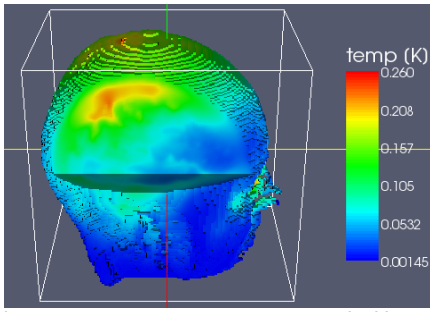


Figure 6: Temperature map generated with Pennes' bio heat transfer equation.

**Discussion:**
Incorporating discrete vessels in thermal simulations brings us one step closer to a full safety assessment of RF energy deposition. Where SAR calculations give a worst-case scenario, because no heat transfer is assumed; thermal simulations give a more realistic image because all means of heat transport are covered. However, the thermal simulations introduced here do still not give a complete description of the temperature increase of the tissue due to RF energy deposition. For example, thermoregulatory responses, such as sweating and vasodilation, are not taken into account for the simulations, which can lead to a lower temperature rise.

**Conclusion:**
It was shown that a high peak SAR occurs in the head for the simulated geometry ($SAR_{max,1cm^3}$ /$SAR_{average}$ = 6.6), located in the highly conducting CSF. Thermal simulations showed that restricting the RF power on the $SAR_{max,1cm^3}$ is over-conservative with a factor of 2, because the associated temperature rise was under 1 K (IEC regulation). For the DIVA method and Pennes' equation a similar $dT_{max}$ was found, where the DIVA model gives a better physiological description of the local temperature distribution.

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[3] Kotte, et al., A description of discrete vessel segment in thermal modelling of tissues, *Phys. Med. Biol.* (1996) **41** 865-884
[4] Van Leeuwen et al., Calculation of change in brain temperatures due to exposure to a mobile phone *Phys. Med. Biol.* (1999) **44** 2367-2379.