The Effect of Human Model Resolution on Numerical Calculation of SAR and Temperature in MRI

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Introduction: Numerical calculations are used increasingly to predict SAR distributions in MRI. Today a growing number of anatomical models at a variety of spatial resolutions are available, raising practical questions about the relationship between model resolution and calculation results. A previous study showed no obvious discrepancy in maximum 1 cm^3 (≈1g) SAR calculated at different model resolutions (2mm, 3mm and 5mm) for the human head at 64MHz (1.5T) [1]. However, the coil modeled was very simple (a single-channel saddle coil), and higher frequencies [2] were not investigated. Moreover, the relationship between temperature elevation and model resolution is also unclear. In this study, we compare numerically-calculated SAR and temperature elevation for the human head in birdcage coil at 64MHz (1.5T), 128MHz (3.0T) and 300MHz (7.0T).

Method: The birdcage coil and the investigation were implemented with a home-built FDTD code [3]. Anatomical human models with isometric resolution of 1mm, 2mm and 3mm were acquired from the Brooks Air Force Laboratory database. Here, we adapted models with resolution of 2mm, 3mm and 5mm (the 5mm model was resampled from 1mm model) for use with the FDTD method. The central axial, sagittal and coronal planes of the model at all three resolutions are shown in Fig.1. Appropriate dielectric properties of the tissues were used at each frequency. The coil had 16 copper elements, a 30-cm inner diameter, and a 16-cm length. The diameter and length of the shield were 38 cm and 24 cm, respectively. Current sources were placed in each of four break points of each rung of the coil and a 22.5-degree phase shift was set between currents in adjacent rungs. The temperature calculation was accomplished through the bio-heat equation with an established convection-based boundary condition [4]. All field values were normalized for a head-average SAR of 3 W/kg [5] and the time course of temperature changes were computed for during of 15-mins, 30-mins and 120-mins (after temperature rise reached steady state).

Results&Discussion: The SAR distribution at 64MHz is shown in Fig.2. The general SAR distribution is similar at different resolution, but the SAR values at some particular locations have obvious differences. The temperature rise at 300MHz is given in Fig.3. Since the temperature variation depends not only on SAR at a given location, but also on tissue thermal parameters, surrounding tissue properties and heat transfer mechanisms, the model resolution has notable effect on the temperature distribution. Maximum local SAR and temperature increase for each case are given in Table I. At all frequencies, the maximum one-cell SAR (SAR_{1c}) increases monotonically with model resolution, which is in agreement with expectations [1]. The maximum SAR_{1g} and SAR_{10g} also increase with model resolution (by as much as 97%). This result is different from the previous report [1], possibly due to differences in methods for estimating 1g (1 cm^3 box vs. potentially irregular-shaped 1g region) especially at air-tissue boundaries, and because in the previous study the region of highest SAR occurred in the homogeneous vitreous humor. Interestingly, the maximum temperature elevation *decreases* as model resolution increases at all frequencies (by as much as 15.7%). The highest temperature rise is over 2^{o}C (occurring at 64 MHz), although the location is in peripheral tissue. The maximum temperature elevation within brain is less than 1^{o}C.

Conclusion: As model resolution increases, so does the accuracy in representation of small regions of high SAR near tissue boundaries and the accuracy in representation of the effects of thermal conduction. Increasing model resolution from 5mm to 2mm can result in as much as a 97% increase in maximum 10g SAR, and a 15.7% decrease in temperature rise. While SAR calculations are significantly affected by model resolution, mass average (e.g., 1g vs. 10g), and mass-averaging method, temperature calculations are affected much less by these things while producing results more directly relevant to safety. If our results are accurate and these trends continue to higher resolutions, it would seem that estimates of SAR made at any resolution may underestimate actual values, while estimates of temperature rise may actually be more conservative at lower resolutions.

Table I. Maximum one-cell SAR(SAR_{1c}), SAR_{1g}, SAR_{10g} and temperature elevation at different frequencies

		SAR_{1c}	SAR_{1g}	SAR_{10g}	ΔTmax 15-mins	ΔTmax 30-mins	ΔTmax 120-mins
64MHz	2mm	110.83	27.43	14.89	1.61	1.87	1.95
	3mm	62.98	23.31	12.99	1.62	1.88	1.96
	5mm	49.20	17.91	7.84	1.91	2.19	2.28
128MHz	2mm	101.56	23.85	15.45	1.60	1.87	1.96
	3mm	54.20	19.90	11.47	1.65	1.92	2.00
	5mm	42.45	15.28	7.84	1.77	2.06	2.14
300MHz	2mm	68.28	22.26	13.78	1.40	1.62	1.69
	3mm	49.31	18.02	10.34	1.48	1.72	1.79
	5mm	40.07	12.87	8.10	1.65	1.91	1.98

References

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3. Z. Wang, PhD Dissertation, University of Illinois, 2005 4. Z. Wang *et al.* , JMRI,2008;28:1303-1308 5. IEC 60601-2-33, 2006-02

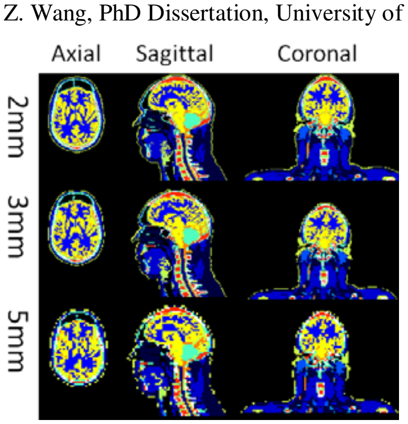

Fig.1. Human head model on central axial, sagittal and coronal planes with different resolutions.

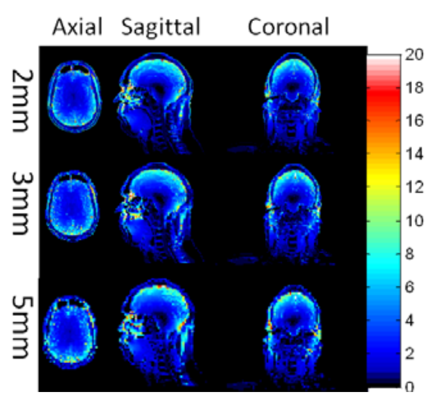

Fig.2. Single-cell SAR on central axial, sagittal and coronal planes at 64MHz at each resolution.

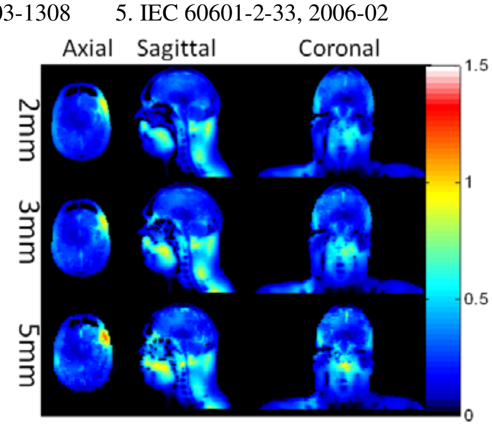

Fig.3. Temperature elevation on central axial, sagittal and coronal planes at 300MHz with different resolutions.