Calculated Local and Average SAR in Comparison with Regulatory Limits

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Introduction: While the use of numerical calculations is increasingly accepted as a method for ensuring SAR levels remain reasonable in MRI (1), comparison to existing guidelines requires calculation of the maximum SAR averaged over one-gram (SAR_{1g}) for comparison to FDA limits (2) and/or ten-gram (SAR_{10g}) regions for comparison to IEC limits (1), as well as SAR averaged over the entire head or body (SAR_W) (1, 2). SAR in one-gram or ten-gram regions is calculated, reported, or compared to regulatory limits in relatively few published works (3-10). Here we discuss some of our more recent experiences in attempting to compare SAR calculated in the human head and body to regulatory limits. Importantly, even in volume coils at commonly-used frequencies, calculated maximum SAR in any one gram of tissue will exceed FDA limits long before whole-head or whole-body SAR averages. This raises questions about either the interpretation of local SAR calculations in light of the limits, or about interpretation of the limits in light of common practice and new local SAR calculations. Finally, use of numerical calculations for comparison to regulatory limits on local temperature show fairly poor spatial correlation between SAR and temperature, depending largely on the wide variance in perfusion rates of different tissues and the effects of thermal conduction (6).

Methods: Several different coils were modeled encompassing the human head or body at several different frequencies using the FDTD method (6, 8). All calculations were performed with commercially-available software (Remcom, inc.; State College, PA). Local SAR averages were calculated with methods from very simple (3) to very sophisticated (8, 11), and normalized to the magnitude of the pertinent circularly-polarized component of the transmit B_1 field in some important location or averaged over one plane so that it is possible to predict what types of experiments can be performed for a given coil and frequency without exceeding the limits. In addition, for this work the ratio of the local SAR to the whole-head or whole-body average SAR was calculated to determine a scaling factor to estimate local SAR values from measurable whole-head or whole-body average SAR.

Results: The ratio of SAR_{1g} to SAR_W and of SAR_{10g} to SAR_W for two different body models in body-size volume coils at 64 and 128 MHz derived from reference 8 is given in Table 1. The same ratios for calculations of a head in different volume coils at 64 and 300 MHz derived from reference 6 is given in Table 2. In each case, the ratio of the pertinent FDA or IEC limits is shown for comparison.

Discussion: Importantly, these results indicate that SAR_{1g} will always exceed existing FDA limits before SAR_W does – even for volume coils. This is because the ratio of SAR_{1g} to SAR_W is always higher in the calculations than in the published guidelines. This observation is in agreement with previous calculations for a head in a volume coil (3-6), a surface coil on the human chest (7), and other coil/tissue geometries (9, 10). Similarly, calculations of the maximum SAR in any ten-gram region (SAR_{10g}) throughout the head compared to the IEC limits indicate that IEC SAR_{10g} limits will be exceeded before the whole-body average limits when using a body coil (Table 1), but not necessarily when using a head coil (Table 2). Overall, the IEC SAR_{10g} limits appear much less restrictive than FDA SAR_{1g} limits. Because use of numerical calculations for comparison to IEC regulatory limits on local temperature show fairly poor spatial correlation between SAR and temperature, depending largely on the wide variance in perfusion rates of different tissues (6), perhaps organ-based SAR limits or other methods to consider temperature would be valuable.

One implication of modern numerical calculations of SAR (which consider anatomically accurate geometries rather than homogeneous simple shapes) is that in practice, existing limits on local SAR are likely exceeded regularly without consequence. While it is likely that these modern numerical calculation methods are more accurate than standard methods for determining local SAR, it will take some work to reconcile existing SAR limits with results calculated using such methods.

Table 1. Ratio of maximum local to whole-body average SAR for two different subjects in a whole-body volume coil compared to the ratios in the regulatory limits.

	Sub.	$\frac{SAR_{1g}}{SAR_W}$	$\frac{SAR_{10g}}{SAR_W}$
64 MHz	1	18	10
	2	16	11
128 MHz	1	18	10
	2	16	13
FDA limits		2	-
IEC limits		-	5

Table 2. Ratio of maximum local to whole-head average SAR for a human head model in volume coils compared to corresponding ratios in the regulatory limits.

	$\frac{SAR_{1g}}{SAR_W}$	$\frac{SAR_{10g}}{SAR_W}$
64 MHz birdcage	5.4	3.3
300 MHz TEM	5.4	2.7
FDA limits	2.67	-
IEC limits	-	3.12

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