Optimization of SAR calculation for 3-D EM time and frequency domain data

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Purpose: Reliable and fast SAR calculation remains an important goal for RF coil designers. Commercially-available 3-D EM frequency-domain tools do not include IEC-recommended SAR evaluation, and in the available 3-D EM time-domain solvers the SAR evaluation procedures have limited flexibility. For instance, in CST the maximum number of mesh cells for SAR post-processing is now only about 15 million (more are promised in a future release) and the average SAR cannot be evaluated for separate body parts within the coil. Furthermore, all available commercial SAR calculation procedures are very slow (up to 10 hours for 50 million mesh cells). This can easily become a limiting factor in the investigation of the effect of coil tuning on SAR. This excessive slowness is mainly due to a non-optimized determination of the relevant volumes, and implementation of the SAR algorithm only on a single processor core. Our goal was to design a fast and reliable SAR calculation procedure, versatile with regard to both 3-D EM solver strategies, and adapted to multi-core processing.

Method: Implementation of an SAR calculation comprises three stages: data loading and pre-processing, data rescaling to a temporary equidistant mesh, and the SAR calculation itself. When the vendor-specific data file format is known, the solver simulation data can be loaded directly to the Matlab workspace using an in-house data-export subroutine which is much faster than any available export/import commercial software approaches. If the data file format is unknown, the required 3-D EM data may be exported by the solver itself to a temporary file with known format, and then transferred to the Matlab workspace. After loading, the data are automatically trimmed to a rectangular volume as close as possible to the human body model that minimizes SAR calculation domain. For the SAR calculation, the power loss and mass density must be evaluated. Not all simulation tools provide these data. In such cases permittivity data, which are always available, can be used with a look-up table, enable mass density data to be computed during the pre-processing stage.

The 10 gram mass defined by IEC guidelines for SAR calculation must be accurate to 5% or better. Numerical analysis shows that if power loss and mass density data are provided on a temporary equidistant mesh, with well defined mesh refinement steps, then a simple but robust iterative algorithm, involving prediction over cubic volumes of a specified mass, can significantly accelerate SAR calculation, and meet the requirements of IEC guidelines. Our in-house SAR calculation algorithm is based on the Matlab parallel computing toolkit, which supports multi-processor parallelization. In addition to the 10-gram average SAR data relevant to IEC guidelines, values of the average SAR for any head or body parts within a coil can be provided. Knowledge of this value is important for some multi-channel coils because the SAR limit of 3.2 W/kg for SAR average calculated for part of head that is inside the coil can be reached sooner than the normally controlled SAR limit of 10W/kg for a 10 gram average tissue volume.

Results and Discussion: The SAR algorithm described is reasonably fast (less than 40 minutes instead of 10 hours) for post-processing of data derived from a FDTD project with about 50 million mesh cells using an 8-processor core workstation. Fig.1 illustrates the dependence of calculation times on the number of processor cores for HUGO model and various temporary mesh resolutions. Increasing the number of cores gave a nearly linear reduction of computation time, showing the good performance of the Matlab parallel computing toolkit. For the different models used in the SAR calculation, the calculation time was proportionate to the model volume. For Thelonious (a model of a 6 year old child) the SAR calculation time was about half of that for HUGO. For most human body models there is approximately the same relationship between the temporary mesh cell size and the average cube mass tolerance (Fig. 2). If power loss and mass density data are calculated on a temporary equidistant mesh with 0.97 mm cell size or smaller, the 10-gram average SAR peak and head average SAR values become practically independent of cell size (Fig. 3).

Conclusion: A reliable and fast SAR calculation procedure is an important component of array coil performance optimization and investigation of SAR worst case scenarios, based on the RF circuit and 3-D EM co-simulation approach. Vendor-independent SAR calculation offers a reliable tool for comparison of SAR data obtained using different 3-D EM simulation tools.

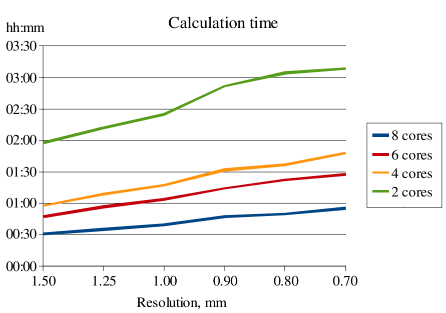

Fig. 1

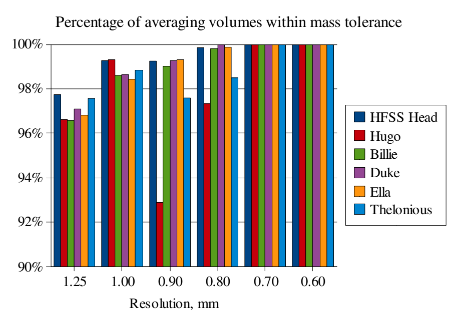

Fig. 2

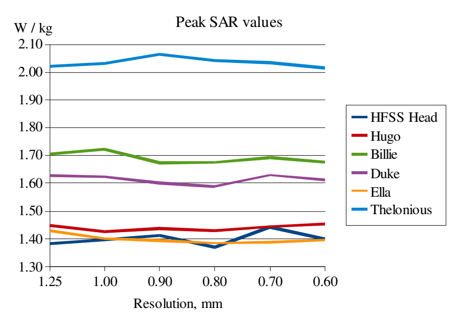

Fig. 3