More on SAR – A practical Guidance for MRI users

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The supervision of the applied rf-power and hence the Specific Absorption Rate (SAR) is one of the most important safety aspects using an MRI scanner for the examination of human subjects. According to the basic relation

\[ \text{SAR} \sim \omega_0^2 B_1^2 \sim B_0^2 \alpha^2 \]

SAR scales both with the square of the main magnetic field \( B_0 \) and with the square of the flip angle \( \alpha \) (assuming constant pulse duration) and thus proper limitation is getting more and more critical for higher field strengths like 3 T or 7 T.

Based on calculations and experimental data SAR limits have been defined in national and international regulations and standards in order to prevent an unacceptable temperature rise within the human body during an MRI exam. The IEC 601-2-33 [1] is the most commonly used guideline and defines whole body SAR limits of 2 W/kg and 4 W/kg for the Normal Mode and First Level Mode respectively and different values for partial body and local SAR (e.g. for extremities up to 10 W/kg).

Using human models and numerical simulations detailed SAR distributions can be calculated for a given MR setup with a specific rf Transmit Coil. Based on these results proper scaling will give the SAR values for any sequence of rf-pulses. Obviously the height, weight, shape and specific composition of the tissue is varying for different patients and therefore in general the scaling of the SAR with the applied rf-pulses will not exactly be the same as for the human model used for the simulations. Consequently the challenge is how the system will effectively control the SAR for the individual subject actually under examination.

Basically there are 2 different approaches for the implementation of a real SAR supervision:

1. The MR system observes a fixed \( B_1 \) (rms-average) limitation for a specific rf-Transmit configuration which will be used for all patients. Since the effectiveness of the resulting \( B_1 \) for a given rf-power is varying for individual humans the limiting \( B_1 \)-values have to be based on a “worst case” estimation of the resulting SAR. This method may or may not take into account the specific position of the patient within the MR scanner.

2. The SAR supervision calculates the individual SAR values for any given rf-power considering the position of the patient within the MR scanner, the actual rf-power deposited in the patient and the specific body properties like height, weight, age, sex, etc.

While observing the given SAR-limits (e.g. 2 W/kg or 4 W/kg for whole body SAR) the individual SAR supervision will typically allow the application of higher \( B_1 \) (rms)-values for most of the subjects, i.e. humans with an “average” size and e.g. a weight of less than 100kg. As a result the patient-individual SAR-supervision will allow protocol settings with the best individual performance for each patient (e.g. optimized # of slices, measurement time, TR, usable flip angle, type of rf-pulses, etc.). Consequently a specific protocol which can be run on a rather small subject may not run for a big patient.
In any case the SAR supervision should include a 2-fold control mechanism which will first check the planned $B_1$ or SAR values in a *look ahead* mode before the sequence is started. The look ahead control will prevent the start of a sequence exceeding the given SAR limits and will give the operator the chance to change SAR relevant protocol parameters. Secondly the rf power which is actually applied should also be measured *online* while running the MR scan to detect any failures or malfunctions of the MR system during the examination of the patient. The online control will directly stop the scan and switch off the rf-power in the event that any of the given limits would be exceeded.

Besides having an effective implementation of the SAR control on the MR system it is important that the MR operator as well complies with all defined safety measures. Especially proper patient positioning is essential in order to prevent burns which could occur if the patient’s arms, legs, or knees form closed conductive loops for the rf-field. Furthermore all of the contraindications as defined in the MR operator manual have to be observed carefully to prevent any uncontrolled heating of the patient e.g. by distorted rf-fields or by eddy currents induced by conductive implants.

**References:**

[1] IEC 601-2-33 Ed. 2.0, 2002; Medical electrical equipment – part 2-33
   Particular requirements for the safety of magnetic resonance equipment for medical diagnosis