Local SAR in Adults and Children at 7T MR: Estimation by the Using of Realisic Simulations

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*Abstract*— The evaluation of the local Specific Absorption Rate (SAR) is a major concern in ultra high field (UHF) Magnetic Resonance (MR) systems. In fact, at UHF, the energy deposition due to the radio-frequency (RF) field increases and its distribution inside the subject becomes extremely inhomogeneous and subject dependent1. Local SAR measurements are not available in present MR systems; thus, electromagnetic simulations must be performed for RF fields and SAR analysis. In this study we resort to 3D full wave numerical electromagnetic simulations for investigating the dependence of the local SAR at 7T with respect to the subject size, i.e. load size. It has been found that the maximum local SAR decreases with decreasing load size: this holds true if the RF magnetic fields (B1+) for the different load sizes are scaled so to achieve the same B1+ slice average value.

# Introduction

Currently, Magnetic Resonance (MR) scanners give an estimation of the average SAR in the sample under test during the exam. The latter value is obtained by the means of an empirical formulation which takes into account the patient parameters, such as the body size, sex, the mass, the conductivity, the body position relative to the transmit RF antennas, etc. The average SAR does not take into account for the presence of possible hot spots (spatial inhomogeneities) and the variability of the subjects. It follows that it is impossible to push the performance (within regulatory limits) because local SAR is unknown.

The aim of our work is to calculate the local SAR in realistic 7T MR exposure through the EM simulation, taking into account a very detailed model of a radio-frequency (RF) surface coil together with the human portion under exam. Specifically, we derive a distribution of the local SAR when the sample under test is excited by a RF pulse in use for realistic MR acquisition. Furthermore, we investigate the dependence of the maximum local SAR at 7T with respect to the subject size, i.e. adults and children.

# Materials and Methods

## The RF pulse

The RF pulse is used in MR as input signal for exciting the spin of the nuclei. More in detail, the RF pulse generates in the sample a magnetic field usually denoted as:

 (1)

 being *τ* the duration of the pulse. The amplitude of the right-hand component of the magnetic field B1, denoted as B1+, is related to the gyro-magnetic ratio γ of the interested atom and the flip-angle (FA) θ as follows [1]:

  (2)

 (3)

In eq. (3), B1+ has been expressed as the product of its peak value and the pulse *a(t)* (having unitary maximum amplitude and, obviously, duration *τ*). In conventional Spin Echo (SE) sequences, commonly used in MR, the maximum signal received by MR system is obtained when the FA of the atoms is equal to *θ*=90° [1]. If γ, τ and *a(t)* are given, we can determine the value of  which leads to the condition *θ*=90°. In our experiment we assume that the scanner transmits a (truncated) sinc-shaped pulse *a(t)* having a duration τ=3.2 ms. We are interested on the Larmor's frequency of the hydrogen at 7T which corresponds a gyro-magnetic ratio γ equal to 42.5MHz/T. By replacing all the variables in eq. (3), we find  to have FA *θ* =90°.

## Local SAR estimation in realistic scenario

Concerning the 3D full wave numerical electromagnetic simulations, we resorted to the Finite Integration Technique (FIT) in Time-Domain employed in CST MW Suite. Specifically, we simulated a single loop having radius 5 cm and positioned near the human calf extracted from the anatomic adult human model HUGO (CST MW Suite), as shown in Fig 1. The coil has been tuned to the frequency of 298 MHz and matched, achieving s11= -10dB (details of the tuning and matching capacitor can be found in [2]). RF fields and SAR inside the calf are calculated when applying 1W of input power. The average B1+ magnitude calculated in the axial slice crossing the coil center is computed, together with maximum of the local SAR (10g, per unit RF cycle) calculated in the same slice.

Next, we repeated the simulations using other human calves extracted from 2 anatomic adult human models (Virtual population, ITIS foundation) and 4 anatomic child models (Virtual population, ITIS foundation). In all the simulations we took particular care in keeping fixed the distance between the calves and the center of the coil (15 mm). Note that the dependence of the tissue dielectric properties on age is not considered [3].

|  |  |
| --- | --- |
|  **( ( (a)**  |  **(b)** |



 **(c)**

Fig. 1. a) Single loop near the HUGO human calf; B1+ (b) and SAR (c) maps in the z-plane, i.e. axial slice, crossing the loop center (loop not shown in maps). B1+ is in μT, SAR in W/Kg.

# Results and Discussion

Fig 1 shows the maps of B1+ magnitude [μT] and SAR [W/Kg] in the axial slice crossing the coil center obtained by using CST MW Suite with the human model HUGO. Both the maps are given only in the region occupied by the load. B1+ shows the typical quadpolar effect generated by a single loop; moreover, it is possible to see that the magnitude of B1+ decreased with depth into the calf. We noted that modification of the matching capacitor leads to a modification of the scale of both B1+ magnitude and SAR maps, but the shape of these maps will be not affected.

Table I summarizes the results obtained by using CST MW Suite for all the anatomic human models here used. Specifically, in the first column the details (gender, age) of the anatomic human models used to extract the calf are given; the second and the third columns show the average B1+ magnitude calculated in the axial slice crossing the coil center and the maximum of the local SAR calculated in the same slice. From the third column, one could conclude that the maximum SAR is higher in small size-load, i.e. in children; this is in agreement with [4] where the SAR due to a plane wave has been investigated. However, from the second column, it is possible to note a large variability in the average B1+. This variability depends on the different shape and size of the human calf models (i.e. different boundary conditions) and on the different loading (i.e. matching) conditions. The fourth and the fifth columns show the average B1+ magnitude and the maximum of the local SAR after scaling the simulations so to achieve the same B1+ slice average value of 7.2μT; note that such value leads to an (average) FA *θ* =90° (thus, this scaling is quite similar to what conventional *autoprescan* routines do). After such scaling, it is possible to note that the maximum local SAR decreases if decreasing the load size, i.e. in children.

The SAR values given in the fifth columns refer to a *unit RF cycle*. The correspondent SAR per *unit* FA *θ* =90° *RF pulse* is given in the sixth column, which appropriately accounts for the duty cycle of the pulse *a(t)*.

However, in order to give an estimation of the SAR during the complete MR exam and to demonstrate the compliance of the actual MR sequence with the requirements (i.e. maximum local SAR in the extremities <20 W/Kg), the averaging time equal to 6 min has to be applied, as specified in [5]. Since the SAR depends on the characteristics of the sequence adopted during the MR exposure, all the parameters related to the sequence itself have to be taken into account in the calculation (thus including the number of RF pulses and the corresponding FAs).

 **TABLE I (**B1+ is in μT, SAR in W/Kg)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **avg****(B1+)**  | **max****SAR**  | **avg(B1+) for****FA=90°**  | **max SAR** **for****FA=90°, unit RF cycle** | **max SAR** **for****FA=90° RF pulse** |
| **Hugo,** **M, adult** | 0.52 | 0.68 | 7.2 | 130.3 | 20.9 |
| **Duke,** **M, 34** | 0.65 | 1.03 | 7.2 | 126.3 | 20.3 |
| **Ella,** **F, 26** | 0.68 | 0.93 | 7.2 | 104.2 | 16.7 |
| **Billie,** **F, 11** | 1.04 | 1.29 | 7.2 | 61.8 | 9.9 |
| **Dizzy,** **M, 8** | 1.32 | 2.10 | 7.2 | 62.4 | 10.1 |
| **Thelonius,****M,6** | 1.37 | 1.89 | 7.2 | 52.2 | 8.4 |
| **Roberta,** **F, 5** | 1.46 | 1.72 | 7.2 | 41.8 | 6.7 |

##### References

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