SAR prediction in Adults and Children by combining measured B1+ maps and simulations at 7.0T.

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Running title: SAR in Adults and Children at 7.0 T

**Abstract.**

*Purpose.*To predict local and global Specific Absorption Rate (SAR) in individual subjects

*Materials and Methods.* SAR was simulated for a head volume coil for two imaging sequences: axial T1-weighted “Zero” Time-of-Echo (ZTE) sequence, sagittal T2-weighted FLuid Attenuated Inversion Recovery (FLAIR). Two head models (one adult, one child) were simulated inside the coil. For 19 adults and 27 children, measured B1+ maps were acquired, and global (head) SAR estimated by the system was recorded. We performed t-test between the B1+ in models and human subjects. The B1+ maps of individual subjects were used to scale the SAR simulated on the models, to predict local and global (head) SAR. A phantom experiment was performed to validate SAR prediction, using a fiberoptic temperature probe to measure the temperature rise due to ZTE scanning.

*Results.*  The normalized B1+ standard deviation in subjects was not significantly different from that of the models (p>0.68 and p>0.54). The rise in temperature generated in the phantom by ZTE was 0.3 °C; from the heat equation it followed that the temperature-based measured SAR was 2.74 W/Kg, while the predicted value was 3.1 W/Kg.

*Conclusions.* For ZTE and FLAIR, limits on maximum local and global SAR were met in all subjects, both adults and children. To enhance safety in adults and children with 7.0 T MR systems, we suggest the possibility of using SAR prediction.

*Keywords*: ultra high field Magnetic Resonance, SAR, safety, RF full-wave simulations, B1 mapping

**INTRODUCTION**

The management of Specific Absorption Rate (SAR) is a critical issue in MR, especially at ultra-high field (UHF) strength. In fact, at UHF, the energy deposition due to the radiofrequency (RF) field increases and its distribution inside the subject becomes extremely inhomogeneous (1-4). The increase of RF energy deposition and of its spatial variability at UHF is due to the higher operating frequency of the UHF MR system.

MR systems provide an estimation of the global SAR in the subject under test during the exam. During MR exams, global SAR exposure is monitored and must remain below the regulatory limit imposed by the International Electrotechnical Commission (IEC), as given in the standard IEC-60601-2-33. The limit for the head is 3.2 W/kg during any 6-minute time average (5); head SAR limit is based not on whole body weight but on the mass of the head. Head SAR estimation is obtained through empirical formulation, which takes into account the forward and reflected power during MR acquisition, and patient parameters (6). If the global SAR remains below the limit, then the maximum head local SAR should also remain at a safe level, i.e. below the IEC limit of 10 W/kg during any 6-minute time average (5), being the local SAR defined as the SAR averaged over any 10 g of tissue. SAR limits are intended to limit the increase of tissue temperature to safe values, i.e. temperature is the critical parameter (5).

This estimation presents drawbacks, which include the following: i) the monitoring of forward and reflected power is performed in real time, but offers no capability for SAR prediction; ii) global SAR is determined by empirical formulation and thus it is not subject-specific since subject anatomy and subject position with respect to the transmitting coil are not taken into account; iii) local SAR is not evaluated. Moreover, it has been shown that global SAR estimation routines differ from system to system: thus, they should not be taken as the primary and only way to evaluate MR safety (7, 8).

While many B1+ field-mapping techniques exist, subject-specific SAR measurements are not available on current MR systems; thus, electromagnetic simulations must be performed for RF fields and SAR analysis. Subject-specific anatomic simulations models would require acquisition and segmentation images of each subject before the MR in question (9, 10): however, such an approach is rarely feasible and therefore models are used instead. This practice introduces a mismatch between real and simulated data, which can be compensated by simulating and comparing different human models (2, 11).

The purpose of this work is to predict local and global subject SAR exposure in two 7.0 T imaging sequences in both adults and children by combining electromagnetic simulations on two generic anatomic human head models (one adult and one child) with subject-specific B1+ maps measured in vivo.

**METHODS**

***Electromagnetic simulations.*** The Finite Integration Technique (FIT) in the CST MW Suite (CST-Computer Simulation Technology AG, Darmstadt, Germany) was used. We simulated a 1H quadrature birdcage head coil manufactured by Nova Medical (Wilmington, MA, USA), operating at 298 MHz. In simulations, a human head model derived from the 2×2×2 mm3 voxel-size anatomic human model Ella (woman, 59 kg), (Virtual population, IT’IS Foundation, Zurich, Switzerland) was placed inside the coil, as shown in Fig 1. The coil elements (copper flat strips having width of 2.5 cm and thickness of 35 μm) were equally spaced along a circle of diameter of 29.5 cm, and were connected through two copper end-rings (having width of 1 cm). A quadrature feed with 4 sources of 1W, equally spaced azimuthally by 2, with a relative electrical phase shift of 2, was simulated.

B1+ was calculated in the axial slice crossing the corpus callosum and in the central sagittal slice. The maximum local SAR [W/kg] (local SAR we report the SAR averaged over 10g) was calculated in the entire head; the global SAR [W/kg] (global SAR we report the SAR averaged over the head) was calculated as well.

The maximum local and global SAR for a given sequence applied on a given slice were then determined by a scaling factor which accounts for all the sequence-related parameters: TR, number and waveform of RF pulses, and the corresponding nominal Flip Angle (FA) averaged on the slice (which are related to the nominal B1+, i.e. B+1,nominal). The two sequences addressed in this study were: 1) Axial “Zero” Time-of-Echo (ZTE) sequence (“SILENT”) (12, 13) with central slice crossing the corpus callosum and 2) Sagittal FLAIR (14) with central slice through the mid-sagittal plane. Details of each sequence are given in the next sub-sections. The ratio *r*SAR between maximum local and global SAR was also computed. Next, we simulated various positions of the head model inside the coil: i) rotating the head at 15°, 30°, 45° from the original position on z-axis; ii) moving the head of ±1cm along the 3 axes.

We repeated the simulations with a different human head, derived from the 2×2×2 mm3 voxel-size anatomic human model Billie, girl, 35 kg, (Virtual population IT’IS Foundation, Zurich, Switzerland).

An overview of the details of anatomic models described above is given in Table 1, while details of the segmented tissue can be found in (15).

Further simulations were performed by placing a homogeneous sphere of radius 90 mm in the center of the coil. The sphere had dielectric constant = 52 and conductivity = 0.55 S/m (thus mimicking the white matter of the human brain (16)). B1+ was calculated in the axial slice crossing the center of the sphere, while the maximum local (10g) and global SAR [W/kg] were calculated in the entire sphere. Simulations were repeated decreasing the radius of the sphere to 88 mm, 86 mm and 84 mm, respectively.

To allow comparison with the actual phantom experiments (see the correspondent sub-section), simulations were performed also with a cylindrical phantom having height of 12.5 cm and radius of 3 cm, positioned in the center of the coil and with its axis parallel to the birdcage axis, with dielectric constant = 77.52 and conductivity = 1.886 S/m. B1+ was calculated in the axial slice through the center of the cylinder. The maximum local (10g) SAR [W/kg] was calculated in the entire cylindrical phantom for SILENT sequence prescribed axially and centered on the center of the cylinder.

***Phantom experiments.***AGE MR950 7T human system (GE HealthCare, Milwaukee, WI, USA) equipped with the birdcage coil mentioned above (operating in quadrature) and with a 32-element receiving array was used. A cylindrical phantom having height of 12.5 cm and radius of 3 cm was placed in the center of the coil, with its axis parallel to the birdcage axis. The phantom was prepared by dissolving agar (7 g/L), NaCl (10 g/L) and CuSO4 (1 g/L) in hot water and then allowing the solution to cool and solidify in the cylindrical plastic former. The recipe was taken from (17); the density of the mixture is 1054 kg/m3, the heat capacity is 4200 J/kg/°C, the dielectric permittivity is 77.52, the conductivity is 1.886 S/m (all these values are given in (17)). The heat equation for a thermally insulated and nonperfused material with an internal heat source (in our case, SAR) can be written as:

 [1]

where c is the heat capacity and ΔT is the temperature rise after a time of Δ*t* (8).

The ΔT generated by SILENT, prescribed axially and centered on the center of the cylinder, was measured with a fiberoptic temperature probe (Neoptix Canada LP, Quebec, Canada, temperature resolution: 0.1 °C) placed at the location of anticipated maximum local SAR. Scan duration Δ*t* was 462 s. The temperature sensor was inserted radially, near the surface of the phantom, on the central axial plane. Before performing the measurement, the phantom was equilibrated to room temperature; thermal insulation was achieved by inserting the phantom in an extruded polystyrene cavity and turning off the patient ventilation fan (8). Thus, by applying eq [1], a temperature-based measurement of SAR was determined. The temperature sensor had a length of approximately 2 cm; since the mass of 2 cm3 of the agar solution is approximately 10 g, we can assume that the temperature-based measurement of SAR corresponds to a measurement of 10g SAR .

We also acquired a B1+ magnitude map (|B+1,map|) in the axial slice crossing the center of the phantom using a Bloch-Siegert sequence (18). Bloch-Siegert parameters are given in the next sub-section. For the slice where |B+1,map| was measured, a coefficient *C*,proportional to average(|B+1,map|)/B+1,nominal, was calculated (note that |B+1,map| is obtained from measurements, while B+1,nominal is obtained from the nominal FA). The coefficient *C* was then used to scale the maximum local simulated SAR for the SILENT sequence, allowing phantom local SAR prediction. Since *C* refers to B1+, SAR scaling must be performed with a multiplication by *C*2 (19).

***In-vivo measurements.***AGE MR950 7T human system (GE HealthCare, Milwaukee, WI, USA) equipped with the birdcage coil mentioned above (operating in quadrature) and with a 32-element receiving array was used. The first 46 patients who completed the scanning protocol of studies "133/11" and "133/11A" (Italian Ministry of Health DGDFSC 0035162-P-09/05/2013 and DGDFSC 0028690-P-08/04/2014) concerning adult and pediatric patients, respectively, with cortical dysplasia and epileptogenic tumors (20, 21) were included in the analysis.

Participants were 19 adults (aged 18-42 y; weight ranging between 46 kg and 100 kg; 14 subjects with cortical dysplasia and 5 with epileptogenic tumors; 10 males and 9 females) and 27 children (aged 9-17 y; weight ranging between 27 kg and 95 kg; 19 subjects with cortical dysplasia and 8 with epileptogenic tumors; 16 males and 11 females). Subjects were placed in the scanner in supine position, head first, as in simulations (Figure 1). Written informed consent was obtained from all adult subjects, and from parents or guardians of all children. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The research project was approved by the Ethical Committee of Meyer Children’s Hospital, Firenze, Italy and it was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

For each subject: we recorded age and weight. We acquired B1+ magnitude maps (|B+1,map|) with a Bloch-Siegert sequence (18) centered on slices corresponding to those used in the simulations: parameters TR=33 ms, TE=15 ms, bandwidth=15.6 kHz, slice thickness=3.5mm, matrix-size 64x64, square FOV 22 cm, 2 averages (acquisition time: 9 s per slice). For the axial slice, we calculated the average of |B+1,map| and standard deviation of |B+1,map| for a FA=90° sinc-pulse. We also recorded the values of global (head) SAR estimated by the system during the two 3D whole-brain sequences that were common to all subjects (the other sequences in the scanning protocol were tailored to each case, and they targeted different brain regions).

The two sequences assessed were: 1) Axial “Zero” Time-of-Echo (ZTE) sequence (“SILENT”) (12, 13), 384 FA=4° hard pulses of duration=12 μs and 5 inversion and saturation pulses per TR (TR=525 ms), TE=16 μs, post-segment time of delay TD=2 s, FOV=192x192x192mm3, data matrix=192x192x192 (resulting in a spatial resolution of 1x1x1mm3); 2) Sagittal FLAIR (14), 240 FA=120° hard pulses of duration=336 μs per TR (TR=8 s), TE=122.4 ms, TI=2048 ms, FOV=202x202x155.4 mm3, data matrix=288x288x222 (resulting in a spatial resolution of 0.7x0.7x0.7mm3).

***SAR prediction by combining B1+ in-vivo measurements with electromagnetic simulations.*** For each subject and for each slice where |B+1,map| was measured, a coefficient *C*,proportional to average(|B+1,map|)/B+1,nominal, was calculated (note that |B+1,map| is obtained from measurements, while B+1,nominal is obtained from the nominal FA). The subject-dependent coefficient *C* is then used to scale the SAR obtained through electromagnetic simulations on the generic anatomic models, predicting both local and global SAR; in this context, the choice to use SAR simulated in Ella or in Billie is made on a subject-weight basis; specifically for subjects whose weight was ≥ 47 kg (the average weight between Ella and Billie) we used SAR simulated in Ella, while for the others we used SAR simulated in Billie. Since *C* refers to B1+, SAR scaling must be performed with a multiplication by *C*2 (19). The predicted maximum local SAR was derived by multiplying the predicted global SAR by the correspondent *r*SAR

***Statistical Analysis.***We calculated the relative error between predicted SAR and temperature based SAR measurement in phantom. To validate the birdcage coil model for the head simulation studies, we calculated the normalized standard deviations (the ratio between standard deviation and average) of B1+ magnitude map were calculated in each subject; such normalized standard deviations were compared to those in either Ella (for subjects heavier than 47kg) or Billie (for subjects lighter than 47 kg) with a t-test..

For adults (age ≥18 years) and children we calculated the maximum, minimum, average and standard deviation of age and weight. For adults and children and for each sequence, we calculated the maximum, minimum, average and standard deviation of predicted global SAR*.* The lines of regression of both estimated and predicted global SAR with respect to the subject weight were also determined.

**RESULTS**

The measured ΔT generated in the cylindrical phantom by SILENT was 0.3 °C; therefore from eq [1] the temperature-based SAR measurement was 2.74 W/Kg. The predicted phantom maximum local SAR (10 g) for SILENT sequence was 3.1 W/Kg. The relative error between predicted SAR and temperature based SAR measurement was 11%.

Fig 2 shows: the measured |B+1,map| for a FA=90° sinc-pulse axial slice, acquired on the scanner for 8 subjects (selected arbitrarily among the participants, for demonstration purpose only); the simulated B+1 magnitude for a FA=90° sinc-pulse, axial slice, in Billie and Ella. For visual comparison, the B+1 fields were normalized to the correspondent maximum value in the slice center. Weights, ages, average and standard deviation of B+1 magnitude before normalization are given in the insert. Concerning the average of B+1 magnitude before normalization, the values which refer to Billie and Ella are equal to 7.2 μT, i.e. the B+1,nominal for the FA=90° sinc-pulse (having length of 3.2 ms); conversely, the values which refer to the 8 subjects vary from 6.55 μT to 6.97 μT.

The average of normalized standard deviations of B+1 magnitude in all participants heavier than 47 kg was 0.209, and was not significantly different from 0.211 found in Ella (t-test, p>0.68). The average of normalized standard deviations the B+1 magnitude in subjects whose weight was < 47 Kg was 0.196, and was not significantly different from 0.200 obtained in Billie (t-test, p>0.54).

Table 2 shows the highest values with respect to model positions inside the coil, obtained for maximum and global SAR in Ella and Billie after scaling the simulations to achieve the B1+ magnitude average value of 1 μT in the axial or sagittal slices. Table 3 shows the highest values with respect to model positions obtained for maximum and global SAR in SILENT and FLAIR sequence in Ella and Billie. The highest *r*SAR is 3.4 for Ella and 3.2 for Billie.

The SAR analysis performed on generic anatomic models is then combined with the subject-specific |B+1,map|. In Fig 3a and Fig 3b we report the values of global SAR predicted by our method and estimated by the MR system for the SILENT sequence in 19 adults and 27 children; Fig 3d and Fig 3e refer to the FLAIR sequence. Fig 3c and Fig 3f show the values of global SAR predicted by our method and estimated by the MR system for both sequences with respect to weight. The slope of the regression lines are 0.011 W/kg for the SILENT estimated global SAR (offset=0.88 W/kg) and 0.017 W/kg for the FLAIR estimated global SAR (offset=0.95 W/kg). The slope of the regression line for the SILENT predicted global SAR (offset=2.17 W/kg) can be assumed equal to 0, being the maximum difference (in the weight range here considered) <1/200 of the offset. Also the slope of the regression line for the FLAIR predicted global SAR (offset=2.59 W/kg) can be assumed equal to 0, being the maximum difference (in the weight range here considered) <1/200 of the offset.

Table 4 summarizes the minimum, maximum, average and standard deviation of the age, weight and predicted global SAR for the 19 adults and 27 children used in this study. Fig 4 shows the predicted maximum local SAR for both sequences for all the subjects.

Table 5 refers to the simulations using homogeneous spheres with different radii: specifically, the second and third column of Table 5 show the global and maximum local SAR after scaling the simulations to achieve the same B1+ magnitude average value of 1μT. In the spheres here simulated, *r*SAR oscillates slightly (<3%) around the mean value of 1.36.

**DISCUSSION**

SAR regulatory limits do not distinguish between adults (age ≥18 years) and children, but particular care must be paid when scanning juvenile subjects due to the lack of data on children SAR exposure at UHF in the literature. We predicted, for a 7.0 T system, the global (head) and local subject-specific SAR exposure for two 3D whole-brain sequences, namely SILENT and FLAIR, by combining B1+ in-vivo measurements (that have a short acquisition time: 9 s per slice) with electromagnetic simulations. We introduced a safety margin by choosing the worst-case simulated SAR. Limits on maximum local and global SAR were met in all subjects, both adults and children. The FLAIR sequence resulted more SAR demanding than the SILENT sequence.

The ratio *r*SAR quantifies the hot spots, i.e. the locations where the maximum local SAR occurs; *r*SAR is calculated through simulations. The *r*SAR in Ella and Billie is more than twice the *r*SAR in spheres. A high *r*SAR , i.e. *r*SAR>3.13 (where 3.13 is the ratio between the maximum local SAR limit = 10 W/kg and the global head SAR limit = 3.2 W/kg), can occur at 7.0 T; this is due to the operating frequency which gives a wavelength in tissue comparable with the head dimensions and results in major field distortions. Hot spots depend on each head’s unique features and on its position inside the coil. In our simulations we found that the highest *r*SAR is 3.4 for Ella (very similar to what was reported in (22), where a different anatomic model has been used) and 3.2 for Billie; such *r*SAR>3.13 implies that maximum local SAR limit can be reached before global SAR limit.

A good agreement was bserved between the temperature-based measured SAR on phantom and the predicted one, with a relative error of 11%. The residual discrepancy may be related to the temperature resolution of the probe and to approximations in the heat capacity value of the agar solution (17).

Simulated and measured B+1,map had the same qualitative appearance; all the simulated and measured maps exhibited the typical central focusing effect and a slight left/right asymmetry, observed also in (23) where a similar coil with a different human head model obtained through a manual segmentation was used. Despite subjects had different weight, size and age, the normalized standard deviation of their |B+1,map| was not significantly different from the normalized standard deviation of the maps obtained with Ella and Billie. Specifically, the average normalized standard deviation in subjects heavier than 47 kg was not significantly different from that of Ella (t-test, p>0.68), and in patients whose weight was < 47 Kg it was not significantly different from that of Billie (t-test, p>0.54).

|B+1,map| for FA=90° gives the field, produced by the MR scanner after RF power calibration, for maximum signal intensity (4), since RF power is calibrated from a projection of the slice signal intensity. The high dielectric constant of human tissues (15) leads to very inhomogeneous B1+ maps, which explains why |B+1,map| values can differ from B+1,nominal. B1+ maps were acquired in each subject to calculate the coefficient *C* to be used in scaling the simulations. From electromagnetic theory it can be demonstrated that the same coefficient holds for scaling both the magnetic and the electric field, while *C*2 holds for SAR, being the SAR proportional to the square of the electric field (22); the ratio *r*SAR instead is not affected by simulation scaling. The use of B1+ maps for scaling the simulations does not require any information about transmitted power, reflected power, or power lost in the transmitting chain.

From the simulations we observe that: for the axial slice (and, thus, in calculations related to SILENT sequence) SAR is higher in Billie (this is in agreement with what reported in (15)); for the sagittal slice (and, thus, in calculations related to FLAIR) SAR is higher in Ella.

By considering the global SAR predicted by our method, we observed that SAR exposure does not increase with subject weight; this finding is consistent with what was reported in (11). To be thorough, we also reported the values of global SAR estimated by the system, and we observed that, according to these data, the SAR exposure seems to increase with subject weight. This finding is consistent with what was previously reported in (24), however it should be noted that the MR system estimates global SAR by means of an empirical formulation using data that are not directly accessible by the experimenters, such as the reflected RF power and the fraction of subject’s mass that is exposed to RF (in our case, the head) (6). For example, in our scanner the head mass exposed to RF is determined directly by the system using an equation (whose details are not disclosed to the vendor’s customers) that combines subject weight and coil parameters. This type of empirical formulae for estimating SAR assume homogeneous loads and unperturbed magnetic field; however, such assumptions are not valid for human heads using a 7.0 T birdcage coil, and the RF fields generated by the coil inside the heads are highly inhomogeneous.

To simulate SAR exposure, we used two different anatomical models. While there was a substantial difference in age and weight of the two models, they do not represent the true anatomical variability of clinical patients, Here, Ella and Billie were used because they were felt to be representative of the worse case SAR scenarios for adults and children, respectively (15). One limitation of our study is the fact that the variation of dielectrical properties of tissues with age was not considered. However, Wang et al. (25) have shown that variation of dielectrical properties of tissues with age does not affect significantly the SAR (i.e., less than 10% in the extreme case). Further, a phantom experiment for validating the SAR prediction has been performed on a homogenous cylinder, while validation of the birdcage coil model for the head simulation studies has been performed using a limited number of subjects; experiments on anthropomorphic phantoms and a higher number of subjects would increase the confidence of SAR prediction. The present study has been performed using the 7.0 T system of one single vendor equipped with a quadrature head coil; moreover, only two sequences have been considered.

In conclusion, here we suggest to predict SAR exposure by combining B1+ in-vivo measurements with electromagnetic simulations; in case limits are exceeded by predictions, appropriate actions can be taken before further scanning, such as by decreasing RF power and/or increasing TR (where possible). Although we are aware that there is no abrupt physiological change at the age of 18 years, throughout the paper we maintained the regulatory distinction between adults and minors to highlight that the use of the studied sequences at 7.0 T is safe, concerning SAR exposure and according to our predicted local and global SAR, in both adults and children.

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**Table 1.** Anatomic human models used in this paper

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Model** | **gender** | **age [y]** | **weight [kg]** | **height [m]** | **Head maximum axis [mm]** | **Number of tissues used in the model** |
| **Ella** | Female | 26 | 58.7 | 1.63 | 214 | 76 |
| **Billie** | Female | 11 | 35.4 | 1.47 | 194 | 75 |

**Table 2.** Maximum and global SAR in Ella/Billie after scaling the simulations to achieve the B1+ magnitude average value of 1 μT in the axial/sagittal slices.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Max(SAR) [W/kg]**  **after scaling axial B1+ to 1 μT** | **Global (SAR) [W/kg]**  **after scaling axial B1+ to 1 μT** | **Max(SAR) [W/kg]**  **after scaling sag B1+ to 1 μT** | **Global (SAR) [W/kg]**  **after scaling sag B1+ to 1 μT** |
| **Ella (adult)** | 1.73 | 0.56 | 1.76 | 0.57 |
| **Billie (child)** | 1.85 | 0.68 | 1.54 | 0.51 |

**Table 3.** Maximum and global SAR in Ella/Billie in SILENT/FLAIR sequence

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Max local SAR,SILENT**  **[W/kg]** | **Global SAR, SILENT**  **[W/kg]** | **Max local SAR, FLAIR**  **[W/kg]** | **Global SAR, FLAIR**  **[W/kg]** |
| **Ella (adult)** | 7.6 | 2.47 | 9.48 | 3.07 |
| **Billie (child)** | 8.2 | 2.8 | 8.3 | 2.85 |

**Table 4.** Minimum (min), maximum (max), average (avg) and standard deviation (std) of the age, weight and predicted global SAR for the 19 adults and 27 children used in this study. The two sequences here considered are axial SILENT; sagittal FLAIR

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **age [y]** | **weight [kg]** | **SILENT, predicted global SAR [W/kg]** | **FLAIR, predicted global SAR [W/kg]** |
| adults, min  adults, max  adults, avg  adults, std | 18  42  29.1  6.5 | 46  100  67.5  16.4 | 1.83  2.35  2.2  0.15 | 2.45  2.68  2.58  0.07 |
| children, min  children, max  children, avg  children, std | 9  17  12.4  2.2 | 27  95  50.7  17 | 1.9  2.34  2.2  0.12 | 2.44  2.73  2.58  0.08 |

**Table 5.** Maximum and global SAR in homogeneous spheres with different radii after scaling the simulations to achieve the B1+ magnitude average value of 1 μT in the central axial slices.

|  |  |  |
| --- | --- | --- |
|  | **Global (SAR) [W/kg]**  **after scaling axial B1+ to 1 μT** | **Max(SAR) [W/kg]**  **after scaling axial B1+ to 1 μT** |
| Sphere 90 mm radius | 0.412 | 0.575 |
| Sphere 88 mm radius | 0.404 | 0.549 |
| Sphere 86 mm radius | 0.398 | 0.545 |
| Sphere 84 mm radius | 0.390 | 0.526 |

**Figure Legends**

Fig. 1. left) Ella’s head inside the MR quadrature birdcage coil (accessible diameter of 29.5 cm). The 4 red cones displayed in the superior part indicate the 4 sources. right) Sagittal view of Ella’s head inside the birdcage coil (red dots: slice crossing the corpus callosum)

Fig 2. Measured |B+1,map| for a FA=90° sinc-pulse [normalized unit], axial slice, FOV= 22 cm x 22 cm, acquired on the scanner for 8 subjects; the simulated B+1 magnitude for a FA=90° sinc-pulse, axial slice, FOV= 22 cm x 22 cm, in Billie and Ella. For visual comparison, the B+1 fields were normalized to the correspondent maximum value achieved in the central region. Weights, ages average and standard deviation of B+1 magnitude are given in the insert (before normalization). The 8 subjects shown in this figure have been selected arbitrarily among the participants for demonstration purpose only.

Fig 3. (a,d)- Global SAR predicted by the proposed method and estimated by the system for SILENT and FLAIR sequence in 19 adults; (b,d) Global SAR predicted by the proposed method and estimated by the system for SILENT and FLAIR sequence in 27 children; (c,f) global SAR predicted by the proposed method and estimated by the system for SILENT and FLAIR sequences with respect to subjects weight; linear fit plots are also given.

Fig 4. Predicted maximum local SAR for SILENT and FLAIR for all the subjects.

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