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Electromagnetic fields: from dosimetry to human health

Study of the influence of the laterality of mobile phone use on the SAR induced in two head models

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ABSTRACT

The objective of this paper is to investigate and to analyse the influence of the laterality of mobile phone use on the exposure of the brain to radio-frequencies (RF) and electromagnetic fields (EMF) from different mobile phone models using the finite-difference time-domain (FDTD) method.
The study focuses on the comparison of the specific absorption rate (SAR) induced on the right and left sides of two numerical adult and child head models. The heads are exposed by both phone models operating in GSM frequency bands for both ipsilateral and contralateral configurations. A slight SAR difference between the two sides of the heads is noted. The results show that the variation between the left and the right sides is more important at 1800 MHz for an ipsilateral use. Indeed, at this frequency, the variation can even reach 20% for the SAR10g and the SAR1g induced in the head and in the brain, respectively. Moreover, the average SAR induced by the mobile phone in the half hemisphere of the brain in ipsilateral exposure is higher than in contralateral exposure. Owing to the superficial character of energy deposition at 1800 MHz, this difference in the SAR induced for the ipsilateral and contralateral usages is more significant at 1800 MHz than at 900 MHz. The results have shown that depending on the phantom head models, the SAR distribution in the brain can vary because of differences in anatomical proportions and in the geometry of the head models. The induced SAR in child head and in sub-regions of the brain is significantly higher (up to 30%) compared to the adult head.
This paper confirms also that the shape/design of the mobile and the location of the antenna can have a large influence at high frequency on the exposure of the brain, particularly on the SAR distribution and on the distinguished brain regions.

1. Introduction

In the past few years, the development of mobile communication devices has been one of the most important outcomes in the application of the electromagnetic (EM) theory. Correspondingly, significant efforts have been devoted to quantify the interaction between wireless terminals and biological tissues such as preventing brain tumours that might be caused by the EM radiation from mobile phones [1–3].

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As stated in many previous studies, the estimation of the SAR in the brain induced by a wireless communication system is very complex since the exposure depends on many parameters (side of phone use [4], source characteristics [5,6]: design and location, usage [7], morphology [8], frequency [8,9], etc.).

In this work, we computed and we investigated the electromagnetic radiations and the SAR from mobile phones having different antenna types/positions models held on both (left and right) sides of the head. For this purpose, a comparison is performed concerning those parameters (side of use, antenna position) between an adult human head and a child head. The SAR is the most appropriate parameter for determining EM effect exposure in the very near field of a radio-frequency (RF) source [10]. The local SAR (W/kg) at any point in the human head is defined as:

$$\mathrm{SAR} = \frac{\sigma E^2}{2\rho}$$

E represents the peak electric field strength in the body tissue (V/m); σ is the tissue conductivity (S/m), and ρ is the mass density of the tissue (kg/m^3). The quantification of the power absorbed by the biological tissues is obtained in this study using an electromagnetic field solver that employs the FDTD method [11].

This paper is organised as follows: Section 2 introduces the head phantoms with both different mobile phone models investigated in the numerical simulations. Section 3 analyses first the influence of the laterality on the SAR values and second the absorption's power in a brain exposed at 900 MHz and 1800 MHz radio-frequencies. It includes also the study of the SAR apportionment in each lobe of the brain. Sections 4 and 5 discuss the sensitivity of the SAR to the morphology of the head and to the antenna position in the phone box.

2. Numerical simulations

In this study, the quantification of the EM interaction of a human head and a mobile phone is investigated using the well-known finite-difference time-domain (FDTD) method. This numerical method is used to determine the power absorbed by brain tissues of the head model and to compute thereafter the SAR.

In order to evaluate the influence of the side of use of the mobile phone, two 3D anatomically correct MRI-based heterogeneous head models are used: the Duke head (34 years old, an adult from the Virtual Family) [9] and a Louis head (14 years old, a child from the Virtual Family) [12]. To assess the influence of the laterality use on the exposure of the brain in its different parts, the mobile phone is positioned against the head model for the cheek/tilt positions [13,14] on both sides of the head (right/left sides). Focusing on the influence of the antenna position of the mobile phone effects, two different phone models having dual-band – 900 MHz/1800 MHz – antennas were investigated. The phones have different dimension and antenna location characteristics. The first model (Phone 1) is a slide phone used in close configuration [107 mm × 51 mm × 18 mm] having a patch antenna mounted on the back-side of the upper part of the printed circuit board (PCB). The second model is a bar phone (personal digital assistant model) (Phone 2) [117 mm × 58 mm × 13 mm], whose antenna is mounted on the back-side of the bottom part of the PCB. Detailed characterisations of the phone models as well as their validations are available in [6].

FDTD simulations were performed at the two common telecommunication carrier frequencies of 900 and 1800 MHz. In this paper, we calculated:

- the "SAR 10 grams" (SAR10g), which represents the maximum SAR value averaged around a cube of 10 g;
- the "contiguous SAR 1 gram" (SAR1g) in the brain tissues, which is estimated by averaging the local maximum SAR and adding the highest SAR volume in a brain tissues till a mass of 1 g is reached;
- the average SAR (avgSAR), calculated by averaging over all the cubes of 1 mm inside a specific anatomical brain structure;
- the absorbed power in each brain structure, which was also evaluated for both left and right phone use configurations.

Note that the SAR values were normalised to the SAR10g equal to 1 W/kg obtained with the SAM phantom in cheek position at 900 and 1800 MHz.

3. Laterality influence analysis

There exist many parameters that influence the estimation of the SAR induced by a mobile phone in the brain tissues. The phone use side (laterality) is one of these important parameters. It was therefore of great interest to analyse the exposure of brain structures induced by a handset for both ipsilateral and contralateral configurations.

In order to analyse the influence of the laterality of phone use on the exposure, the left and the right sides were considered separately for both standard phone positions (cheek/tilt positions) IEC 62209-1 [14]. The SAR distribution and the energy absorbed in the right and left hemispheres for six different anatomical brain structures were calculated at both frequencies (900 MHz and 1.8 GHz).

The six different brain structures investigated in this study are designed for the right and the left sides as follows: temporal-right (Temp-R), temporal-left (Temp-L), frontal-right (Front-R), frontal-left (Front-L), parietal-right (Parie-R),

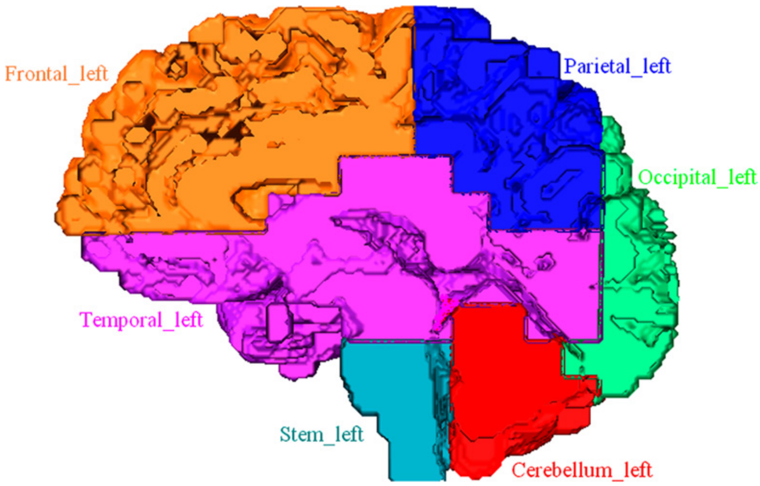

Fig. 1. Sagittal cut of the brain with 1-mm resolution (left brain structures).

Table 1
SAR10g IEEE (SAR10g-head) induced in Duke and Louis heads for both phones and both frequencies.

		900 MHz		1800 MHz	
		Cheek R[a]/L[b]	Tilt R/L	Cheek R/L	Tilt R/L
Phone 1	SAR10g-Duke (W/kg)	0.47/0.5	0.29/0.31	0.73/0.9	0.83/1.00
	SAR10g-Louis (W/kg)	0.67/0.68	0.42/0.43	0.87/0.9	0.94/0.99
Phone 2	SAR 10g-Duke (W/kg)	0.64/0.61	0.40/0.38	0.69/0.88	0.40/0.46
	SAR10g-Louis (W/kg)	0.78/0.78	0.56/0.59	0.8/0.86	0.47/0.5

[a] R: right side;
[b] L: left side.

parietal-left (Parie-L), occipital-right (Occip-R), occipital-left (Occip-L), cerebellum-right (Cereb-R), cerebellum-left (Cereb-L), stem-right (Stem-R), and stem-left (Stem-L) (see Fig. 1).

3.1. SAR10g IEEE in the head

In the laterality analysis, our calculations indicate a slightly greater SAR when the two phones are used on the left side of the head compared to the right side for both cheek and tilt positions at 900 MHz. This finding is available for both head models.

For the Duke head, the SAR over 10 g in the head in cheek position for Phone 1 (respectively for Phone 2) reaches 0.47 W/kg (0.54 W/kg) for a right-side use and 0.5 W/kg (0.61 W/kg) for the left-side use at 900 MHz. However, this variation is more significant at 1800 MHz. Indeed, for cheek position, the SAR10g induced by Phone 1 (respectively by Phone 2) is equal to 0.73 W/kg (0.69 W/kg) for the right-side use and 0.9 W/kg (0.88 W/kg) for the left-side use. At this frequency, we find that the SAR over 10 g in the head varies from around 20% between right-side and left-side uses in the cheek and tilt position for both phone models.

For Louis head, we find that at 900 MHz for both phone models, the SAR10g values are practically the same, while at 1800 MHz, the induced SAR is generally slightly higher when the phone is held in the left side of the head (around 6%), as can be seen in Table 1.

3.2. SAR1g in the brain

A summary of the values of SAR1g in the brain for both mobile phones and for both frequencies are given in Table 2. These results show also that the SAR over 1 g in the brain can vary, depending on the side of the head where the mobile phone is used. We can notice that this variation is more important at 1800 MHz for the both head models, specifically for Phone 1 in both standard positions. The difference can even reach 20% from a right-side use to a left-side use.

3.3. Discussion

From the results that have been shown in the previous subsections, we thus find that the SAR distribution induced by a phone used on the left or the right side is not exactly the same whatever the phone type and the head models used.

Table 2
SAR1g in the brain induced in the Duke and Louis heads for both phones and both frequencies.

		900 MHz		1800 MHz	
		Cheek R[a]/L[b]	Tilt R/L	Cheek R/L	Tilt R/L
Mobile 1	SAR1g-Duke (W/kg)	0.27/0.29	0.25/0.27	0.44/0.61	0.48/0.60
	SAR1g-Louis (W/kg)	0.36/0.35	0.30/0.33	0.49/0.56	0.51/0.61
Mobile 2	SAR1g-Duke (W/kg)	0.28/0.31	0.13/0.14	0.16/0.2	0.11/0.15
	SAR1g-Louis (W/kg)	0.33/0.32	0.28/0.28	0.20/0.22	0.13/0.15

[a] R: right side;
[b] L: left side.

Table 3
Depth of the ears of both head models.

	Duke head	Louis head
Right ear	28 mm	21 mm
Left ear	25 mm	20 mm

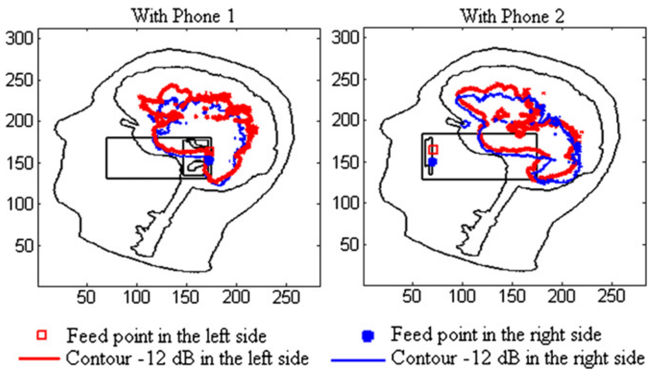

Fig. 2. −12-dB contour in the brain region for the right and left sides of the Duke head at 1800 MHz for Phone 1 and Phone 2. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

Comparing results for two frequencies, we note that the variations between the left and the right side are more significant at 1800 MHz. They may reach 20% for the SAR10g and the SAR1g. The SAR variation between the two sides of the head for an ipsilateral configuration could be explained by the difference in the shape of both ears (as mentioned in Table 3) and by the asymmetry of the antenna (Fig. 2).

Fig. 2 plots the contour of the 12 dB level at 1800 MHz obtained by projection (the thin blue line and the bold red line correspond to the contour when the phone is held respectively on the right and left sides of the head) for each excitation point position for both sides. The red and blue points in the figure indicate the location of the feed point of the antenna for each mobile phone used. We observe that the SAR distribution is sensitive even to the design of the antenna and especially to the small changes in the antenna feed point location.

Furthermore, we observe from Tables 1 and 2 that the difference between both sides is higher for the adult head than for the child head, because the difference in the shape of the right and left ears of the Duke head is more important than in the Louis head (Table 3).

3.4. Average SAR and power absorbed in different anatomical brain structures for ipsilateral and contralateral uses

In this subsection, the absorbed energy and the average SAR calculated in specific anatomical brain structures were estimated for both ipsilateral and contralateral configurations.

Comparing average SAR values in different anatomical brain structures for a phone held on the right and on the left sides of the head, we can observe at 900 MHz a slight difference for an ipsilateral use between the right and the left sides of the brain. This difference is even more important at 1800 MHz for both phones (see Tables 4 and 5). For example, for the Duke head, the difference between the right and the left side for Phone 1 in cheek and tilt positions in the temporal lobe is less than 5% at 900 MHz, but exceeds 20% at 1800 MHz. Note also that the same kind of difference is observed for the SAR induced in the other brain structures.

For the Louis head, at 1800 MHz, the average SAR values obtained in the left anatomical brain structure can be up to 20% higher than those obtained in the right side (Table 5).

Table 4
Distribution of average SAR in some anatomical brain structures for Phone 1 held on the left side and on the right sides of the Duke head.

Phone 1	900 MHz		1800 MHz	
	Cheek R/L	Tilt R/L	Cheek R/L	Tilt R/L
AvgSAR-Temp-R	$0.49 \times 10^{-1}/0.2 \times 10^{-2}$	$0.39 \times 10^{-1}/0.22 \times 10^{-2}$	$0.51 \times 10^{-1}/0.77 \times 10^{-3}$	$0.52 \times 10^{-1}/0.83 \times 10^{-3}$
AvgSAR-Temp-L	$0.2 \times 10^{-2}/0.5 \times 10^{-1}$	$0.21 \times 10^{-2}/0.41 \times 10^{-1}$	$0.63 \times 10^{-3}/0.64 \times 10^{-1}$	$0.65 \times 10^{-3}/0.67 \times 10^{-1}$
AvgSAR-Front-R	$0.93 \times 10^{-2}/0.2 \times 10^{-2}$	$0.75 \times 10^{-2}/0.17 \times 10^{-2}$	$0.13 \times 10^{-1}/0.65 \times 10^{-2}$	$0.89 \times 10^{-2}/0.45 \times 10^{-3}$
AvgSAR-Front-L	$0.19 \times 10^{-2}/0.94 \times 10^{-2}$	$0.12 \times 10^{-2}/0.8 \times 10^{-2}$	$0.72 \times 10^{-3}/0.16 \times 10^{-1}$	$0.49 \times 10^{-3}/0.91 \times 10^{-2}$
AvgSAR-Parie-R	$0.48 \times 10^{-2}/0.13 \times 10^{-2}$	$0.66 \times 10^{-2}/0.19 \times 10^{-2}$	$0.29 \times 10^{-1}/0.63 \times 10^{-3}$	$0.32 \times 10^{-1}/0.6 \times 10^{-3}$
AvgSAR-Parie-L	$0.11 \times 10^{-2}/0.49 \times 10^{-2}$	$0.16 \times 10^{-2}/0.68 \times 10^{-2}$	$0.49 \times 10^{-3}/0.32 \times 10^{-1}$	$0.52 \times 10^{-3}/0.37 \times 10^{-1}$
AvgSAR-Cereb-R	$0.89 \times 10^{-2}/0.8 \times 10^{-3}$	$0.11 \times 10^{-2}/0.91 \times 10^{-3}$	$0.21 \times 10^{-1}/0.45 \times 10^{-3}$	$0.34 \times 10^{-1}/0.1 \times 10^{-2}$
AvgSAR-Cereb-L	$0.1 \times 10^{-2}/0.85 \times 10^{-2}$	$0.94 \times 10^{-3}/0.1 \times 10^{-2}$	$0.34 \times 10^{-3}/0.27 \times 10^{-1}$	$0.82 \times 10^{-3}/0.38 \times 10^{-1}$

Table 5
Distribution of average SAR in some anatomical brain structures for Phone 1 held on the left side and on the right side of the Louis head.

Phone 1	900 MHz		1800 MHz	
	Cheek R/L	Tilt R/L	Cheek R/L	Tilt R/L
AvgSAR-Temp-R	$0.49 \times 10^{-1}/0.22 \times 10^{-2}$	$0.48 \times 10^{-1}/0.22 \times 10^{-2}$	$0.23 \times 10^{-1}/0.90 \times 10^{-3}$	$0.23 \times 10^{-1}/0.90 \times 10^{-3}$
AvgSAR-Temp-L	$0.23 \times 10^{-2}/0.48 \times 10^{-1}$	$0.23 \times 10^{-2}/0.49 \times 10^{-1}$	$0.746 \times 10^{-3}/0.28 \times 10^{-1}$	$0.75 \times 10^{-3}/0.27 \times 10^{-1}$
AvgSAR-Parie-R	$0.42 \times 10^{-2}/0.99\times 103$	$0.61 \times 10^{-2}/0.15 \times 10^{-2}$	$0.5 \times 10^{-2}/0.83 \times 10^{-3}$	$0.93 \times 10^{-2}/0.76 \times 10^{-3}$
AvgSAR-Parie-L	$0.98 \times 10^{-3}/0.42 \times 10^{-2}$	$0.14 \times 10^{-2}/0.62 \times 10^{-2}$	$0.70 \times 10^{-3}/0.6 \times 10^{-2}$	$0.65 \times 10^{-3}/0.13 \times 10^{-1}$
AvgSAR-Cereb-R	$0.11 \times 10^{-1}/0.12 \times 10^{-2}$	$0.11 \times 10^{-1}/0.11 \times 10^{-2}$	$0.2 \times 10^{-1}/0.70 \times 10^{-3}$	$0.22 \times 10^{-1}/0.71 \times 10^{-3}$
AvgSAR-Cereb-L	$0.12 \times 10^{-2}/0.10 \times 10^{-1}$	$0.12 \times 10^{-2}/0.11 \times 10^{-1}$	$0.60 \times 10^{-3}/0.24 \times 10^{-1}$	$0.61 \times 10^{-3}/0.26 \times 10^{-1}$

This is one more time, the difference is due to the morphology of the ear and the asymmetry of the antenna, as it has been mentioned and explained in the previous section.

The left and right hemispheres' exposures differ structurally and functionally for ipsilateral and contralateral configurations. For example, for Phone 1 in cheek position at 1800 MHz, the average SAR values (the absorbed power proportions) induced in the right temporal lobe for ipsilateral and contralateral uses are respectively 0.51×10^{-1} and 0.7×10^{-3} W/kg (64.2% and 0.7%). There are 0.64×10^{-1} and 0.63×10^{-3} W/kg (74% and 0.9%) in the left temporal lobe (see Table 4). We find also closer values of the average SAR than between left and right side uses for ipsilateral and contralateral configurations in other brain structures.

We can also observe in Tables 4 and 5 that, for both phone models, the difference between average SAR values in each anatomical structure for a right- or a left-side use in contralateral configuration is always more important at 1800 MHz (this finding is also verified with Louis head for both phone models). It is therefore important to note that the absorption of the RF EMFs is lower on the side of the head opposite to the phone use side than on the side of use, because of the attenuation of the RF radiation through different tissues. This attenuation is higher at 1800 MHz because the absorption is more superficial than at 900 MHz. This is explained by the fact that the depth of penetration into the brain tissues decreases with increasing frequencies.

3.5. Distribution of RF energy emitted in the different anatomical structures of the brain

For cheek and tilt positions, whatever the used head models and the operational frequency, the RF energy absorption is always the highest in the temporal lobe on the side of the head where the phone is held. As illustrated in Fig. 3 and as observed in previous studies [15,16], more than 60% of the power is absorbed in the temporal structure for both phones (Phone 1 and Phone 2) at 900 MHz and 1800 MHz for cheek and tilt positions. The second-highest SAR values are obtained in the parietal or the frontal lobes. The occipital lobe and brain stem are generally less exposed (they absorb less than 5% of the total absorbed power in the brain) because these structures are located further back in the brain, with an exception for the cerebellum. In this case, depending on the antenna location and the frequency, we can remark that the cerebellum may be more exposed than the frontal and the parietal lobes when Phone 1 is used (see Table 2). This is true particularly for the tilt position at 1800 MHz with the antenna on the top, because the antenna is positioned very close to the cerebellum tissues. These results are comparable to results obtained in previous studies that were based on SAR measurements performed in a homogeneous phantom and extrapolated to heterogeneous models [5,17].

4. Influence of head models

The comparison of SAR induced in both adult and child heads from different types of phone models shows that exposure varies greatly between the two heads. From all the results that have been illustrated in the previous section, it has been pointed out that the SAR values (SAR over 10 g in the head, SAR over 1 g in the brain and the average SAR in the different

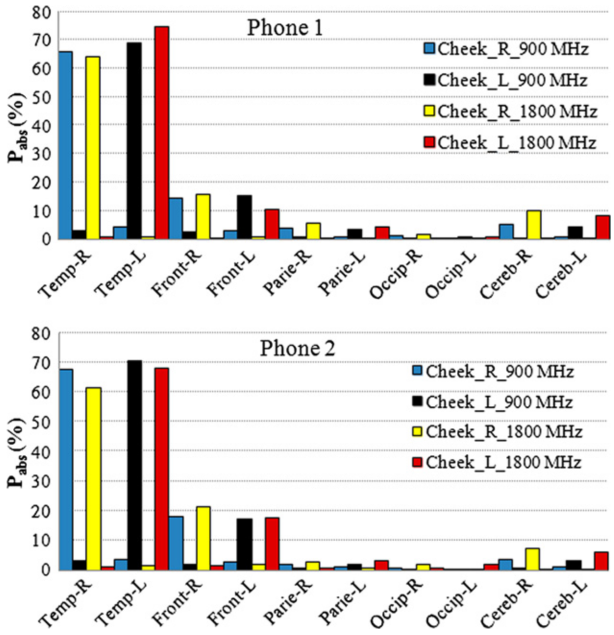

Fig. 3. Total power absorbed ratios in the different anatomical brain structures of the Duke head in cheek position.

anatomical structures) induced in the child head (Louis head) are always higher and more significant compared to an adult head model (Duke head), whatever the mobile phone model used and the operational frequency. We observe from Tables 1 and 2 that the SAR induced in the child head can increase by about 30% at 900 MHz and by less than 15% at 1800 MHz for both phone models. This higher exposure rate is due to differences in anatomical proportions. In fact, the depth and the thickness of head tissues in the case of the child head are lower than in the adult head's case, as reported previously in [7,15,18].

5. Dependence on the frequency of the antenna location effects

In comparing the results obtained with the two mobile phone models, it appears that Phone 1 induces generally a higher SAR values (SAR10g, SAR1g and the avgSAR) than Phone 2, more specifically at 1800 MHz. At this frequency, the SAR induced remains very low for Phone 2. These results confirmed that the SAR distribution is strongly affected by the antenna location at high frequencies because the current and the energy are more concentrated near the antenna feed point location; as reported in previous studies [5,9,15]. This is why we obtained a decrease in SAR induced by Phone 2, which has its antenna on the bottom of the case.

Results have also illustrated that the maximum SAR is always obtained in cheek position when operating at 900 MHz for both phones and both head models. It tends to decrease in tilt position, compared to cheek position, when the phone is held on the left or on the right side of the head. Conversely, when the phones are operating at 1800 MHz, the SAR induced by Phone 1 tends to increase in tilt position compared to cheek position, and the SAR induced by Phone 2 tends to decrease. This phenomenon depends furthermore on the frequency band and the location of the antenna, as clarified previously. This is explained by the fact that in the 900 MHz frequency band, the maximum of the SAR is approximately located above the centre of the phone box. In tilt position, the maximum of the RF energy is moved away from the head; hence a decreased SAR is generated. Inversely, in the 1800 MHz frequency band, the RF currents are located around the antenna. When the phone is moved away from the head in tilt position, it brings the energy even closer to the head. It generally occurs when the antenna is located on the top of the phone box, as is the case of Phone 1.

6. Conclusion

To analyse the influence of the laterality of the phone use on the SAR distribution at GSM frequencies, two human head models exposed to both phone models RF EMF in the standardised "cheek" and "tilt" positions were investigated. We used the well-known FDTD method in order to perform this analysis. The study showed that the SAR induced in the head and in the brain can vary slightly depending on the side of use of the mobile phone. This is mainly due to the asymmetry of the head and also to the design and the asymmetry of the antenna. The frequency can also have an influence. Indeed, the variations were more significant at 1800 MHz with the phone models used in this study. At this frequency, the variation between both sides of the head can reach 20%. For all performed simulations, the results demonstrated that an ipsilateral configuration always induces a higher exposure of the brain than a contralateral one. The absorption of the RF EMFs is indeed lower on the side of the head opposite to the phone use side than it is on the side of use. This decrease is due to the attenuation of the RF radiations through different tissues. This attenuation is higher at 1800 MHz, because the absorption is more superficial than at 900 MHz. We conclude also from the results of the SAR distribution in the different anatomical brain structure that the maximum SAR was always located in the temporal lobe. The absorption in the temporal lobe was found to be more than 60% of the total absorbed power, whatever the head model used. The second-highest exposed areas were generally the parietal, the frontal lobes or the cerebellum, depending on the antenna location and the frequency band. We found that the SAR induced by a mobile phone depends closely on the antenna location at high frequency.

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References

[1] E. Cardis, L. Richardson, I. Deltour, B. Armstrong, M. Feychting, C. Johansen, M. Kilkenny, P. McKinney, B. Modan, S. Sadetzki, J. Schuz, A. Swerdlow, M. Vrijheid, A. Auvinen, G. Berg, M. Blettner, J. Bowman, J. Brown, A. Chetrit, H.C. Christensen, A. Cook, S. Hepworth, G. Giles, M. Hour, I. Iavarone, A. Jarus-Hakak, L. Klaeboe, D. Krewski, S. Lagorio, S. Lonn, S. Mann, M. McBride, K. Muir, L. Nadon, M.E. Parent, N. Pearce, T. Salminen, M. Schoemaker, B. Schlehofer, J. Siemiatycki, M. Taki, T. Takebayashi, T. Tynes, M. Van Tongeren, P. Vecchia, J. Wiart, A. Woodward, N. Yamaguchi, The INTERPHONE study: design, epidemiological methods, and description of the study population, Eur. J. Epidemiol. 22 (2007) 647–664.
[2] A. Ahlbom, M. Feychting, S. Lonn, Mobile phones and tumor risk: interpretation of recent results, Radio Sci. Bull. 314 (2005) 30–33.
[3] N. Varsier, K. Wake, M. Taki, S. Watanabe, E. Cardis, J. Wiart, Categorization of mobile phones for exposure assessment in epidemiological studies on mobile phone use and brain cancer risk, IEEE Trans. Microw. Theory Tech. 56 (2008) 2377–2383.
[4] S. Joachim, Lost in laterality: interpreting "preferred side of the head during mobile phone use and risk of brain tumour" associations, Scand. J. Public Health 37 (2009) 664–667.
[5] N. Varsier, K. Wake, M. Taki, S. Watanabe, Influence of use conditions and mobile phone categories on the distribution of specific absorption rate in different anatomical parts in the brain, IEEE Trans. Microw. Theory Tech. 57 (2009) 899–904.
[6] Y. Pinto, A. Ghanmi, A. Hadjem, E. Conil, T. Namur, C. Person, J. Wiart, Numerical mobile phone models validated by SAR measurements, in: Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP2011), pp. 2585–2588.
[7] A. Hadjem, E. Conil, A. Gati, M.F. Wong, J. Wiart, Analysis of power absorbed by children's head as a result of new usages of mobile phone, IEEE Trans. Electromagn. Compat. 52 (4) (November 2010) 812–819.
[8] E. Conil, A. Hadjem, F. Lacroux, M.F. Wong, J. Wiart, Variability analysis of SAR from 20 MHz to 2.4 GHz for different adult and child models using FDTD, Phys. Med. Biol. 53 (2008) 1511–1525.
[9] A. Christ, W. Kainz, E.G. Hahn, K. Honegger, M. Zefferer, E. Neufeld, W. Rascher, R. Janka, W. Bautz, J. Chen, B. Kiefer, P. Schmitt, H.P. Hollenbach, J.X. Shen, M. Oberle, D. Szczerba, A. Kam, J.W. Guag, N. Kuster, The Virtual Family—development of anatomical cad models of two adults and two children for dosimetric simulations, Phys. Med. Biol. 55 (2010) N23–N38.
[10] CENELEC, Basic standard for the measurement of specific absorption rate related to human exposure to electromagnetic fields from mobile phones (300 MHz–3 GHz), Standard EN 50361, CENELEC, Brussels, 2001.
[11] A. Taflove, S.C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 2nd ed., Artech House, Boston, MA, 2000.
[12] A. Christ, M. Zefferer, B. Bühlmann, M.C. Gosselin, E. Cabot, E. Cherubini, N. Kuster, Recent advances in numerical modeling and dosimetry of children and pregnant women, in: FGF Workshop: Radiofrequency Fields and Health – Conclusions After 17 Years Work of the Research Association for Radio Applications (FGF), Stuttgart, Germany, 23–25 Nov. 2009.
[13] IEEE, Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques, IEEE 1528, The Institute of Electrical and Electronics Engineers, Inc., New York, 2003.
[14] IEC, Human exposure to radio frequency fields from handheld and body-mounted wireless communication devices—Human models, instrumentation and procedures: Part 1. Procedure to determine the specific absorption rate (SAR) for handheld devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz), IEC 62209, IEC, Geneva, 2005.
[15] J. Wiart, A. Hadjem, M.F. Wong, I. Bloch, Analysis of RF exposure in the head tissues of children and adults, Phys. Med. Biol. 53 (2008) 3681.
[16] N. Kuster, J. Schuderer, A. Christ, P. Futter, S. Ebert, Guidance for exposure designs of human studies addressing health risk evaluations of mobile phones bioelectromagnetics, Bioelectromagnetics 25 (2004) 524–529.
[17] E. Cardis, M. Kilkenny, International case-control study of adult brain, head and neck tumors: results of the feasibility study, Radiat. Prot. Dosim. 83 (1999) 179–183.
[18] A. Hadjem, D. Lautru, N. Gadi, I. Bloch, C. Dale, M.F. Wong, V.F. Hanna, J. Wiart, Influence of the ear's morphology on specific absorption rate (SAR) induced in a child head using two sources models, in: 2005 IEEE MTT-S International Microwave Symposium Digest, 12–17 June 2005, pp. 1327–1330.