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Effect of shape, size and electrical properties on specific absorption rate (SAR)

ORIGINAL ARTICLE

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***Abstract* - This paper presents the dependency of SAR distribution in human brain and eye on shape, size and electrical properties for different frequencies. Calculations were carried out using the Finite Difference Time Domain (FDTD) Method. The results indicate that the SAR distribution does not much depend on the shape and size but it depends mainly on the electrical properties of the tissues. There is a drop in magnitude of the SAR in the brain, when moving from a cubical model to the spherical model. There is a magnitude drop in the eye, when going from a spherical model to the cubical model. For both brain and eye, when the size is decreased, the volume is reduced and therefore the electromagnetic energy absorption goes up.**

The human eye at 2500 MHz was considered to observe how the electrical properties of the tissues affect the electromagnetic energy absorption in an organ. When relative permittivity is perturbed in small percentages with conductivity remaining unchanged; the value of the maximum SAR also changes by small values. However both these cases, when the electrical properties are changed, the location of maximum SAR remains unchanged. It is exactly at the center of the eye.

Keywords: *electromagnetic radiation; exposure levels; radiation absorption; FDTD method.*

I. INTRODUCTION

Distribution of the SAR inside an organ depends on the electric field distribution inside the organ due to incident RF signals. According to the literature [1,2], Theoretical estimates of the SAR distribution for RF signals of strength 1 V/m and having different frequencies ranging from 100 MHz to 3500 MHz was carried out examine when the RF energy is mostly absorbed inside the organs. From that the SAR distribution in brain is approximately the same for all frequencies and the highest SAR exposure levels can be found at the front layers of the brain. In the eye, from 100 to 900 MHz the highest exposure is at the front layers of the eye. At 900 MHz some peaks appear around the center of the eye and the highest can be found at 2500 MHz, the peak is exactly at the center [1,2]. Therefore this effort was to examine whether the electromagnetic energy absorption depends mainly on the shape or model, the size or the electrical properties of the organs.

II. METHODOLOGY

Calculations are based on an incident field of strength of 1 Vm^{-1}, as this value is close to the worst-case measured field strength [3,4]. For this work, brain & eye were taken into consideration. The initial model of the brain is taken as a cubical box model with the dimension of 20cm×20cm×20cm [5]. The eye is also taken as a spherical model with 18.75 mm in radius [6]. The SAR is evaluated for an incident field of 1 V/m for the brain using a cubical model and a spherical model to determine the effect of shape. A similar calculation is r epeated for the eye at a frequency of 2500 MHz when a prominent peak occurs.

The SAR is also evaluated using the spherical model of the brain for a reduced size of the brain and for the eye with the spherical model but having an increased size. Similarly the effect of the electrical properties on the SAR is examined by making perturbations to the values of ε and σ of the different body tissues.

All these calculations are carried out using the numerical technique called the Finite Difference Time Domain (FDTD) method [7-9]. As the most widely used technique for electromagnetic dosimetry problems is FDTD, this paper also reports results of SAR calculations based on FDTD method.

III. RESULTS

A. Shape Dependancy of Brain

The shape of the SAR distribution along the direction of wave propagation in the brain is very similar at all frequencies [2]. Therefore to observe the effect of shape are evaluated using the cubical box model and the spherical model of the brain at a frequency of 100 MHz which is a frequency at which the computational time is not too excessive. Figure 1 shows the SAR distribution in these two cases.

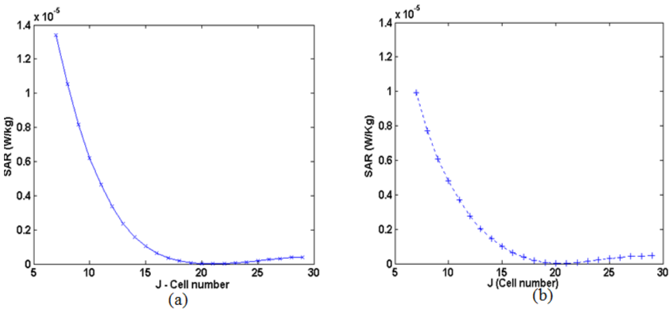


Figure 1. Variation of SAR_{1g} in the brain at 100 MHz using, (a) Cubical box model (b) Spherical model.

The shape of the SAR distribution is almost similar for the two shapes. However there is a difference in magnitude. At the front layer of the brain where the absorption is highest, the SAR_{1g} has a value of 1.34×10^{-5} W/kg for the cubical box model while it is 0.99×10^{-5} W/kg for the spherical model. As such there is a 26% drop in the maximum value of the SAR in the brain, from cubical box model to the spherical model. This may be a result of the plane wave front of the electromagnetic wave being incident on a plane surface in the cubical model while it is incident on a curved surface in the spherical model.
Some similarities have shown in literature [8] based on the form of SAR distribution, but only constrained to cubical model of brain.

SAR values at 2500 MHz are evaluated for the eye using a spherical shape and a cubical box shape. Figure 2 shows the SAR distribution in the two cases.

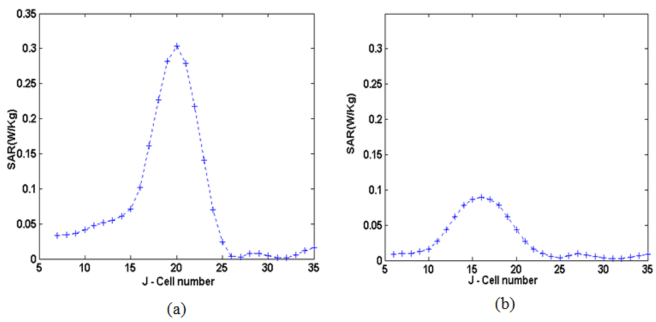


Figure 2. Variation of SAR_{1g} in the eye at 2500 MHz for, (a) Spherical model (b) Cubical box model.

Once again the shape of the curve is similar for both models. However with the spherical model, the peak SAR appears exactly at the center of the organ while with the cubical box model, that peak is slightly off the center. There is also a difference in magnitude: the SAR_{1g} value is 0.3080 W/kg with the spherical model and 0.1355 W/kg with the cubical box model with a drop in magnitude. The magnitude difference of the SAR maximum values from the two models can be understood by examining the incident plane wave front and the incident surface in the two cases.

The maximum SAR is at the centre of the front layer in the brain while it is at the center of the middle layer in the eye as indicated in Figures 3 and 4.

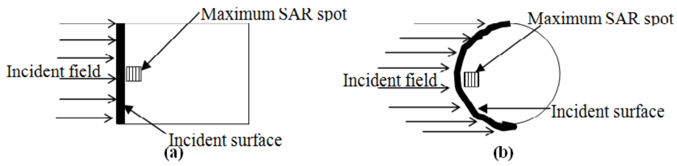


Figure 3. Maximum SAR spot and the incident surface of the brain with (a) cubical box model (b) spherical model.

In the case of the brain, the uniform plane electromagnetic waves are incident on a plane vertical surface when we consider the cubical box model while the waves are incident on a spherical surface for the spherical model. As a result, the cells that lie along the vertical plane are much closer to the maximum SAR spot than the cells that lie along the curved surface. Therefore the effect of the cubical box model on the maximum SAR is higher than that from the spherical model and this is what is observed from theoretical calculations of the SAR as shown in Figure 1.

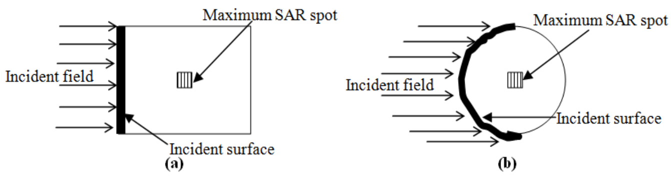


Figure 4. Maximum SAR spot and the incident surface of the eye with (a) cubical box model (b) spherical model

With the eye, the maximum SAR spot is at the center of the organ. Then the cells that lie along the curved surface are much closer to the maximum SAR spot than the cells that lie along the vertical plane. This is illustrated in Figure 4. Therefore the effect from the spherical model to the cell, which has the maximum SAR, is higher than the cubical box model. As such the maximum SAR is expected to be higher with the spherical model than with the cubical box model.

B. Size Dependancy of the Brain and Eye

To observe the effect of size, the SAR is recalculated for the brain using the spherical model with the brain size in diameter increased by 5% and decreased by 5% from its normal size. Figure 5 shows the variation of the SAR distribution before and after the change.

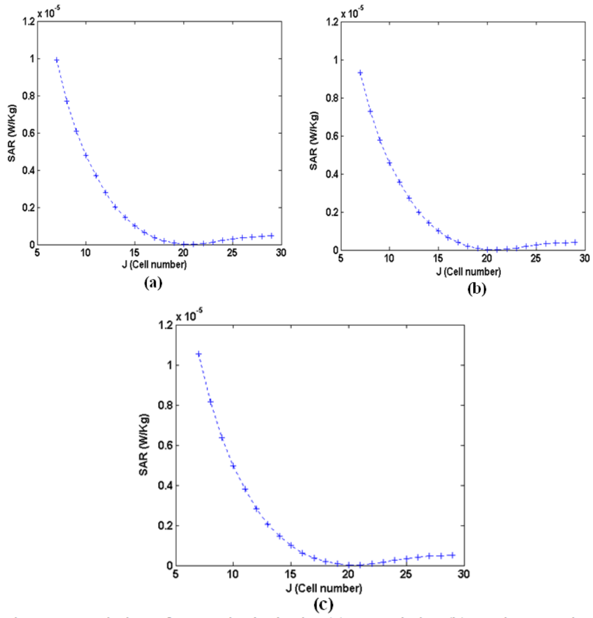
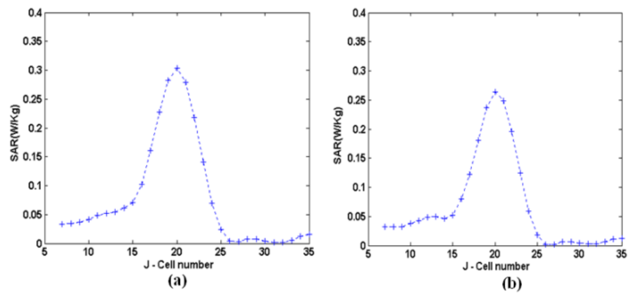


Figure 5. Variation of SAR_{1g} in the brain (a) normal size (b) 5% increased (c) 5% decreased

Once again, the shape of the SAR curve remains unchanged. However, there is a difference in magnitude, which is expected. The maximum SAR_{1g} values are, 9.93×10^{-6} W/kg, 9.33×10^{-6} W/kg and 10.57×10^{-6} W/kg for the normal size, for the increased size and for the decreased size respectively. Therefore in the case of the brain, the calculated maximum SAR_{1g} value decreases by 6.1% when its size is increased and it increases by 6.4% when the size is decreased. When the size becomes smaller, the energy absorption and hence the SAR will go up for the same incident field; similarly the SAR will go down when the size is larger.

SAR calculations are repeated for the eye at 2500 MHz using the spherical shape. Once again the size in diameter is increased by 5% and then decreased by 5% and the SAR distribution obtained. Figure 6 shows the variation of the SAR distribution.



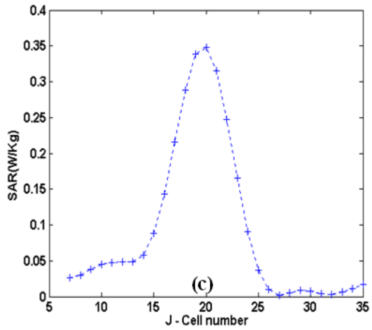


Figure 6. Variation of SAR_{1g} in the eye for (a) normal size (b) 5 % increased (c) 5% decreased

In this case also the general shape of the SAR distribution curve remains unchanged. However the magnitudes are different. They are; 0.3080 W/kg for the normal size, 0.2675 W/kg for the increased size and 0.3521 W/kg for the decreased size. As for the brain, this trend in the magnitude change is expected.

Therefore it implies that the specific features observed in the SAR distribution curves are not due to the shape or the size of any organ and therefore they must be due to the electrical properties.

C. Sensitivity of SAR on Electrical Properties

SAR values are recalculated to observe how the electrical properties of the tissues affect the electromagnetic energy absorption in an organ. For this purpose the human eye at 2500 MHz was taken into consideration as it gives the maximum energy absorption out of all body organs considered in this analysis. For the human eye at 2500 MHz, relative permittivity ε_r = 52.558, conductivity, σ = 2.0702 S/m [10]. Assuming and incident field of 1 V/m, the estimated SAR is 0.3080 W/kg.

ε_r and σ are given perturbations of 5% and 10% to observe the sensitivity of the SAR on electrical properties of the tissues. Observations are given in Table 1.

Table 1. Sensitivity changes for variations of Permittivity and Conductivity.

% change in σ / ε_r	*% change in SAR ε_r remaining constant*	*% change in SAR σ remaining constant*
-10	-11.5	-8.8
-5	-7	-3.2
0	0	0
+5	+2.2	+7.7
+10	+6.7	+12.7

The sensitivity curve of SAR for perturbations of electrical constants is shown in Figure 7.

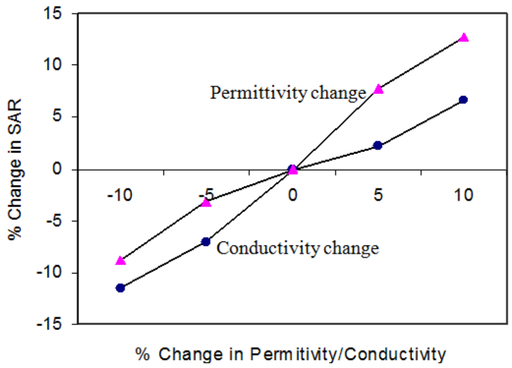


Figure 7. SAR sensitivity for perturbations of Permittivity and Conductivit

IV. CONCLUSIONS

The results indicate that the SAR distribution does not much depend on the shape and size but it depends mainly on the electrical properties of the tissues. However there are some differences in magnitude due to the shape and size variations.

There is a drop in magnitude of the SAR in the brain, when moving from a cubical model to the spherical model. There is a magnitude drop in the eye, when going from a spherical model to the cubical model. That is due to the effect of the wave front.

For both brain and eye, when the size is decreased, the volume is reduced and therefore the electromagnetic energy absorption goes up. On the other hand, when the size is increased, the volume is increased and therefore the em energy absorption goes down.

When ε_r is perturbed in small percentages with σ remaining unchanged; the value of the maximum SAR also changes by small values. The same trend is observed when σ is perturbed with ε_r remaining unchanged. These results are due to the complex dependency of ε_r and σ on SAR. However both these cases, when the electrical properties are changed, the location of maximum SAR remains unchanged. It is exactly at the center of the eye as shown in figure 8. The vertical axis of this figure gives the distance from the front surface of the eye in cell numbers and the data points show the locations of maximum SAR with respect to the electrical properties.

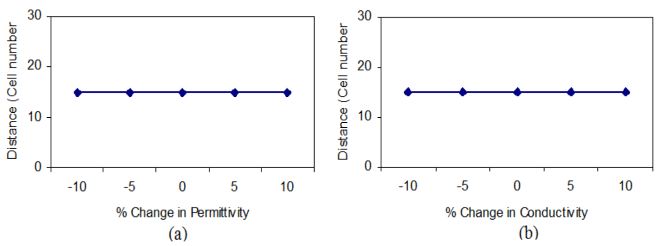


Figure 8. Locations of maximum SAR with respect to the percentage change in; (a) Permittivity with σ remain unchanged (b) Conductivity with ε_r remain unchanged.

Therefore it is clear that electromagnetic energy absorption depends mainly on electrical properties and not on the shape or the size.

For the future researches based on SAR distribution in human body organs, the above findings are more useful and can be extended for other body organs as well. Also the

V. DECLARATION

The authors have disclosed no conflicts of interest and the project was self-funded.

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