DIELECTRIC PROPERTIES OF THE HUMAN BRAIN MEASURED LESS THAN 10 HOURS POST MORTEM

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ABSTRACT

After animal experiments gave a clear indication that the electric conductivity of brain tissue in the frequency range 800 to 2,450 MHz decreases after death, a measurement series on 20 human brains in the time period between 3 and 10 hours post mortem was performed. Analysis of the measurements obtained on fresh tissue yielded a mean value of grey matter conductivity which is slightly higher than values given in literature today. A comparison of mean conductivity versus post mortem age of the brain principally confirms the observations from the animal experiments, although the extent of decrease is in the range of the standard deviation of the measurements .

INTRODUCTION

The conductivity σ and the dielectric permittivity ε of human tissue are fundamental parameters in Radio Frequency (RF) dosimetry, because of their role in the field distribution inside the body. In addition, the electric conductivity σ is linked to the Specific Absorption Rate (SAR) by the equation:

$$SAR = \sigma \frac{|E|^2}{\rho}, \tag{1}$$

where SAR is the amount of absorbed RF power per unit mass of tissue, measured in Watts per kilogram. The other physical quantities in (1) are the electric field strength E inside the tissue and the mass density of the tissue ρ.

All dosimetric assessment systems used today, i.e., measurement systems and computer simulation programs, basically rely on the knowledge of the dielectric properties of body tissues. Results of RF dosimetry therefore can only be as accurate as the measured values of the dielectric properties of tissue.

Because of their importance, the dielectric properties of biological tissues have been studied for years. Among the most complete and today's best known publications are the papers published in 1996 [1], [2], and [3]. The papers present an exhaustive literature survey supplemented by measurements and the derivation of parametric models for many body tissues in the frequency range from 10 Hz to 20 GHz. However almost all the work mentioned above is based either on measurements on excised animal tissues about 2 hours after death or on human autopsy material obtained more than 24 hours after death. Only a few publications included in the literature survey of [1] reported measurements of animal tissues in vivo. The remaining important questions are: do the dielectric properties of human tissue change in the time immediately following death? If so, to what extent?

The rapid increase and public acceptance of modern mobile communication equipment in recent years have turned one of the scopes of RF dosimetry to the task of determining the SAR in the human head during mobile phone usage. Therefore accurate values of the dielectric properties of living human head tissues in the frequency range from 800 to 2,450 MHz are desirable. Because the living human head tissues are not accessible (except the outer skin), we started a twostep approach for determining the post mortal changes of the corresponding tissues in the frequency range of interest. In the first step, we have performed animal experiments on pigs, whereby we measured the dielectric properties of brain grey matter in the transition from life to death, as described in [4], [5]. In the second step, we have performed dielectric measurements on 20 human brains less than 10 hours after death, during routine autopsy procedure. In our work, we first concentrated on grey matter tissue, because it is the part of the brain most exposed by mobile communication equipment. The outer tissue layers of the human head have fundamental influence on the resulting RF absorption profile of the head and post mortal measurements on these other tissues, i.e., skull bone and skin will be considered in our future work.

MATERIALS AND METHODS

All measurements on human brains were performed during the routine autopsy procedure immediately after excising the brain. Only brains within 10 hours after death were included in the study. The excised brains were placed in a plastic dish and measurements of the dielectric properties in the frequency range from 800 to 2,450 MHz on the brain cortex (grey matter) were performed at 4 specific positions on the left and right temporal lobe (Fig. 1). The measurements were performed without the dura mater, however the arachnoidea was kept intact in the measurement region. The temporal lobe was chosen as target region because it is assumed to be the most exposed part of the brain during mobile phone usage. After the measurements, which took about 30 minutes the brains were examined according to the routine autopsy procedure and brains of patients who suffered from neurological diseases were excluded.

For all measurements an open ended coaxial probe (HP85070B) in combination with a vector network analyser (HP8722C) were used as measurement system (Fig. 2). Tissue temperature in close proximity to the measurement area was recorded using a Luxtron 790 fibreoptic temperature measurement device.

In total 20 brains (10 male and 10 female) which meet the 10 hours inclusion criteria were measured, i.e., measurements at 160 different locations were collected. The mean post mortal age of the tissue was 6.7 hours (min. 3 hours, max. 10 hours), standard deviation 1.6 hours. The average tissue temperature at the measurements was 21.35°C (min. 18°C, max. 25°C), standard deviation 1.57°C. Patients age at death was 70.4 years in average (min. 47.5 years, max. 87.6 years), standard deviation 9.9 years.

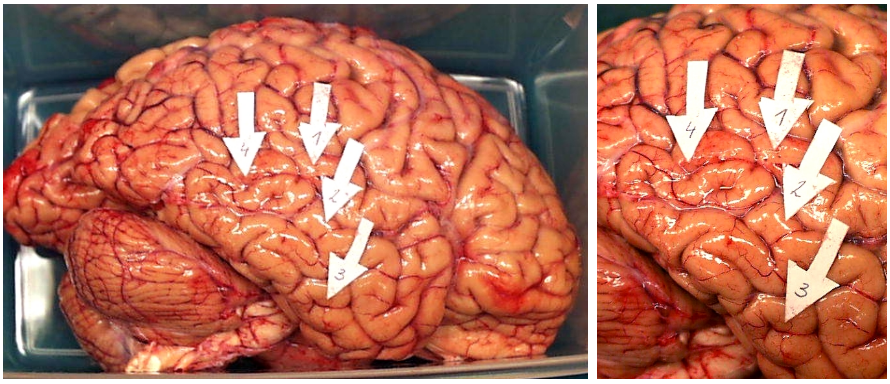

Fig. 1: Locations on the temporal lobe selected for the measurements of the dielectric properties.
left: global view of the brain; right: closeup of the temporal lobe.

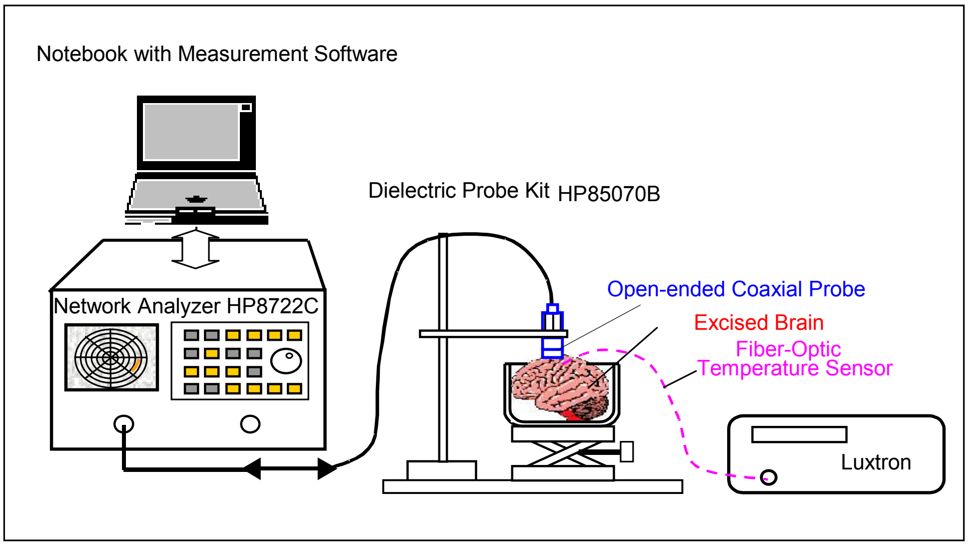

Fig. 2: Measurement Setup.

RESULTS

We report conductivity values in the following because of their relevance with respect to the maximum absorbed RF power in the given exposure situation. In addition, animal experiments [4], [5] showed a greater change for conductivity of brain tissue during the transition from life to death than for the permittivity.

Fig. 3 shows the raw measurement data for conductivity of grey matter samples at 900 and 1,800 MHz respectively. For each brain a mean value was calculated from 8 single measurement positions. The tissue temperature was different for each brain and ranged between 18 and 25°C. On the right side, the total mean ± standard deviation is given for all 20 brains, i.e., 160 single measurements. The data displayed in Fig. 3 shows a mean conductivity of 1.17 S/m (standard deviation 0.11 S/m) at 900 MHz and 1.64 S/m (standard deviation 0.13 S/m) at 1,800 MHz respectively. At a first glance, these conductivity values are in good agreement with the values used today in RF dosimetry. However it must be taken into account that the data presented correspond to an average tissue temperature of 21.35°C and grey matter conductivity is known to have a positive temperature coefficient [6], [7]. This indicates that the actual conductivity of living brain tissue at 37 °C is somewhat higher than shown in Fig.3. Unfortunately information about temperature coefficients of conductivity of brain tissue is very scarce. Our own measurements performed in vitro on a pig brain yielded 1.2 %/°C at 900 MHz and 0.8 %/°C at 1,800 MHz. Using these temperature coefficients for extrapolating the measured data to body temperature of 37 °C would lead to mean conductivity values of 1.39 S/m (standard deviation 0.14 S/m) at 900 MHz and 1.84 S/m (standard deviation 0.16 S/m) at 1,800 MHz respectively, which are higher than the values used today in dosimetric assessment.

Beside the positive temperature coefficient, a second effect which might increase the values of the data in Fig. 3, is a rapid post mortal decrease of conductivity. Animal experiments performed on pigs [4], [5] indicated an average decrease of grey matter conductivity of about 10 % to 15 % within the first 30 minutes after the death.

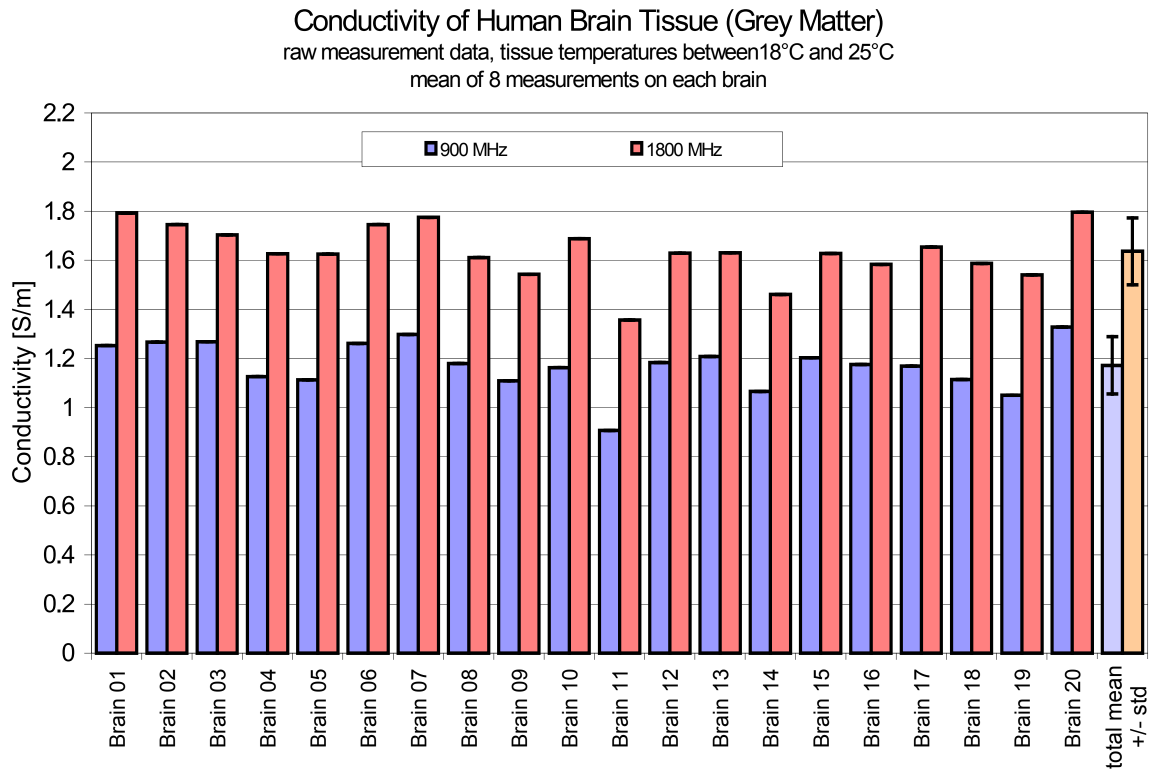

Fig.3: Conductivity measurements on 20 human brains less than 10 hours after death.

We cannot confirm this behaviour from the measurements on human brains, because it is not possible to have access to human brain tissue less than 3 hours after death.

DISCUSSION AND CONCLUSION

The conductivity values of fresh human brains (grey matter) measured between 3 and 10 hours post mortem in the frequency range from 800 to 2,450 MHz, indicated that the actual conductivity of living grey matter is higher than that used today in RF dosimetry, if a (frequency dependent) positive temperature coefficient is assumed. Additionally, assuming a 10 % decrease of conductivity in the first 30 minutes following death, as indicated by animal experiments, would lead to actual conductivity values of living grey matter which are higher than the values used today in the considered frequency range. If this could be confirmed this would have significant impact on RF dosimetry, however it must be taken into account that not only brain tissue conductivity has influence on the power absorption in the human head. Outer tissue layers as skin and especially skull bone have to be investigated with respect to their actual dielectric properties under living conditions. If these outer tissues show significant differences in their dielectric properties between the in vivo and the post mortem state, this would influence the absorption profile inside the human head.

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