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Study
on electromagnetic fields and thermal effects in the human body at exposure to cm/mm waves

1. Introduction

The study presented here is meant to prepare biological experiments in the range of cm/mm waves and deals with the following two central topics:

1. The study will elucidate the correlation between the power flux density meeting the human body and the distribution of the specific absorption rate (SAR) produced in the human skin and in the human eye. Only through gaining knowledge of this correlation we are able to draw conclusions on dose/effect relations in biological experiments if effects should be found.

2. The study will show the correlation between the power flux density meeting the human body and the heating effect of these fields. Based upon this knowledge we can safely differentiate between exposure scenarios with significant temperature increases in the tissue and exposure scenarios without thermal effects.

2. Limit values for the protection of people exposed to electromagnetic fields

There are numerous regulations worldwide aiming to protect people exposed to electromagnetic fields. In Europe, since 1999 exists the European Council Recommendation 1999/519/EC setting exposure limits for the general population (2). In the frequency range being of interest here, limit value recommendations primarily are based upon thermal considerations. The dosimetric basic quantity in the high-frequency range for frequencies above 10 GHz is a power flux density with a value of $S = 10\ W/m^2$.

3. Measuring dielectric properties of biological tissue

The numerical determination of electromagnetic fields in biological tissue requires knowledge of the dielectric properties of the different tissue types. The literature includes numerous studies dealing with measurements or model descriptions of dielectric parameters of biological tissue (3). However, for certain tissues in the human eye, no information is available. Therefore, we will conduct own complementary measurements in the frequency range of interest.

4. Calculation of electromagnetic fields in the skin and in the eye

For the calculation of the specific absorption rate (SAR) in the human skin in the frequency range of 3 - 100 GHz a one-dimensional layer model of epidermis, dermis, fat tissue and muscle tissue is generated. As a field source, a perpendicular, homogeneous, and even electromagnetic wave (HEW) with a power flux density of $S = 10\ W/m^2$ is selected. The set-up is shown in figure 1. The dielectric properties of the biological tissues are taken from corresponding literature (3).

The electromagnetic field distribution in the one-dimensional model of the human skin is calculated by means of a simple analysis procedure. Here, the factors of reflection and transmission between the different layers are determined and the forwards and backwards propagating even waves in due time overlap. In the upper skin layers (epidermis and dermis) with increasing frequency there is also an increase of the maximum local SAR. In the fat and muscle layers below, the SAR only increases up to a frequency of around 5 GHz, above that it steadily decreases. Above a frequency of 10 - 20 GHz practically the whole high-frequency power is absorbed by the upper two skin layers (epidermis and dermis).

For the calculation of the electromagnetic field distribution in the human eye a three-dimensional rotation symmetrical model is generated considering nine different tissues: cornea, front eye chamber, lens, iris, vitreous body, retina, capillary skin, sclera und optic nerve. The eye model is shown in figure 2. The experiment is conducted at a frequency of 77 GHz. The calculation of the electromagnetic fields in the eye model is performed by means of the Finite Difference Time Domain method (FDTD) (1). As field source, a homogeneous even electromagnetic wave with a power flux density $S = 10\ W/m^2$ is applied. As in the skin, also in the eye there is a sudden decrease of the specific absorption rate with increasing tissue depth. High SAR values primarily occur in the cornea, in the sclera and in the skin surrounding the eye. All other tissue types show significantly reduced SAR values.

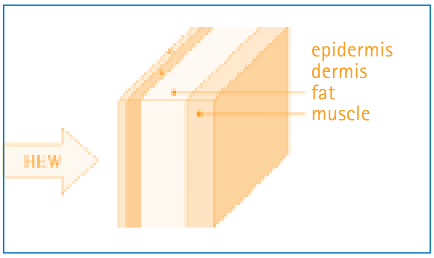

fig. 1: One-dimensional model of the human skin

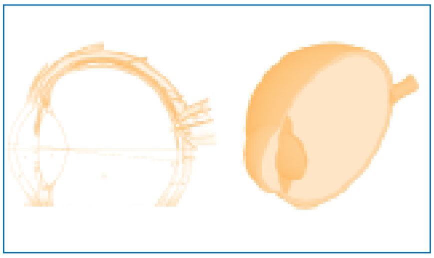

fig. 2: Sagittal section of the human eye (5) (left); Section of the simulation model of the human eye (right)

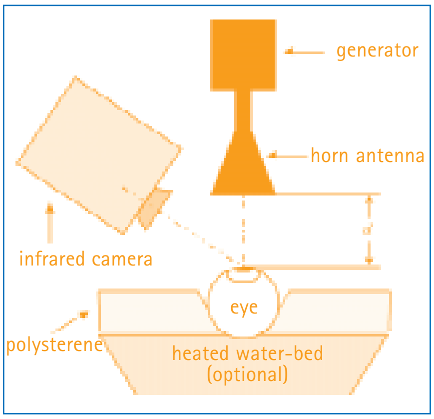

fig. 3: Measurement set-up for the in vitro temperature measurements in the pig eye (right)

5. Investigation of thermal effects

Figure 3 shows the measurement set-up for the in vitro temperature measurements in the eye. The experiment is conducted in fresh pig eyes. Surface temperatures are measured by means of a nitrogen-cooled infrared camera with a temperature solution in the range of 0.1°C. For exposure a set-up consisting of a generator and a horn antenna is applied, where the latter is perpendicular to the skin/to the eye. The generator has an initial power of 38 mW at a frequency of 77 GHz. As the power of the generator can not be altered, the distance d between the aperture of the horn antenna and the exposed object is varied to realise different power flux densities.

In addition, in vivo experiments in the surface temperature of the human skin of the test subject are performed. During these measurements a resting period of 15 minutes precedes the exposure in order to achieve a thermal balance in the subject. After that the exposure is continued until a new thermal balance has built up.

At a power flux density of 10 W/m² a maximum temperature increase of delta T $\leq$ 0.1°C is measured in the human skin and in the pig eye. At a ten times exceeded limit value maximum temperature increases of delta $\Delta T \approx 0.7$°C are detected. The measurement carried out as shown in fig. 3 shows no significant influence of the water-bed on temperature alteration.

Finally, as a plausibility check of measurement results a numeric assessment of the expected temperature increase in the skin is made at a frequency of 77 GHz. Here, heat transfer events in the human skin are described by the so-called bio heat transfer equation. Besides the metabolic heat production rate, the distribution of the specific absorption rate already established during electromagnetic analysis is considered and a solution by means of a simulation program with Finite elements (4) is determined. The results of the numeric analysis confirm the measured temperature values in the human skin.

6. Summary

The numeric calculations of the specific absorption rate in the human skin and in the human eye elucidate the penetration behavior of the fields in biological tissue. At a frequency of 77 GHz the interaction between the electromagnetic field and the body practically is limited to the upper two skin layers (epidermis and dermis). In the human eye the absorption of electromagnetic fields also primarily occurs at surface level; the highest values are found in the cornea. Thermal measurements at a frequency of 77 GHz show that temperature increases at power flux densities below the European limit value lie below 0.1°C.

Literature

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