EXPOSURE AT UMTS ELECTROMAGNETIC FIELDS: STUDY ON POTENTIAL ADVERSE EFFECTS ON HEARING

EMFnEAR

Directorate C - Public Health and Risk Assessment

Health & Consumer Protection Directorate General

Grant Agreement: 2004127

INTERIM REPORT

Annex B

December 15, 2004 – March 15, 2006

EMFnEAR Publications

1. Galloni P., Parazzini M., Pinto R., Piscitelli M., Franzoni C., Ravazzani P., Marino C.,: Effects of UMTS related emissions on auditory system: evaluation of Distortion Product OtoAcoustic Emissions in exposed rats (EMFnEAR Project), *In proc. of the 28th Annual Meeting of the Bioelectromagnetics Society*, Cancun, Mexico, June 11-15, 2006;

2. Ravazzani P., "EMFNEAR Project: Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing",), *In proc. of the EHE'06 – International Conference on Electromagnetic Fields, Health and Environment*, Madeira, Portugal, April 27-29, 2006;

3. Parazzini M., Galloni P., Pinto R., Piscitelli M., Franzoni C., Marino C., Ravazzani P., "Effects of UMTS related emissions on the auditory system in exposed rats (EMFnEAR Project)", In proc. *International Conference and COST 281 Workshop on Emerging EMF-Technologies, Potential Sensitive Groups and Health*, Graz, Austria, April, 20-21, 2006

4. Parazzini M., Tognola G., Grandori F., Ravazzani P.: Numerical dosimetry in a model of the human inner hearing system exposed to 900, *In proc. of the 27th Annual Meeting of the Bioelectromagnetics Society BioEM 2005*, Dublin, June 19-24, 2005;

5. Ravazzani. P.: Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing. The European Commission EMFNEAR project, *In proc. of the 27th Annual Meeting of the Bioelectromagnetics Society BioEM 2005*, Dublin, June 19-24, 2005;

6. Ravazzani P., Parazzini M., Tognola G., "Potential effects of cellular phones on hearing: numerical dosimetry in the inner hearing system," *in Proc. of the XI National Symposium of Radio Sciences*, Poznan, April 7, 2005;

Effects of UMTS related emissions on auditory system: evaluation of Distortion Product OtoAcoustic Emissions in exposed rats (EMFnEAR Project)

P. Galloni*[1], M. Parazzini*[2], R. Pinto*[1], M. Piscitelli*[1], C. Franzoni*[2] , P. Ravazzani[2] and C. Marino[1]
[1]*Toxicology and Biomedical Sciences Unit, Enea Casaccia, Via Anguillarese 301, 00060 Rome, Italy;*
[2] *Biomedical Engineering Institute, CNR, Piazza Leonardo da Vinci 32, 20133 Milan, Italy.*

Objective: the EMF-nEAR project, started in 2004, addresses the evaluation of the potential health effects of UMTS phones on the hearing system of animals and humans. Within the project's activities, this study was performed with the goal of assessing possible effects on the inner auditory system of rats exposed to electromagnetic fields related to UMTS mobile devices. The cochlear functionality was investigated by Distortion Product Otoacoustic Emissions (DPOAE) measurements, known as indicator of the cochlea status: significant reductions in DPOAE amplitude are a sign of functional or structural damage in outer hair cells (OHC), i.e. the cochlear sensory epithelium.
Materials and Methods: according to the results obtained in our previous studies, performed within the GUARD project, established by the European Commission in the 5th Framework Programme, the experimental procedures were carried out as follows: animals (male Sprague-Dawley rats, weight of 250 gr.) were subjected to a localized exposure (right ear), simulating the use of a cellular phone, by 3 different sets of 4 loop antennas, one for sham and two for exposed animals. Animals were exposed 2 hours/day, 5 days/week, for 4 weeks, 10 W/kg of SAR, frequency of 1946 MHz; during the exposure rats were kept in plastic restrainers. The protocol should have to include also positive control animals, so different toxic agents at various doses were tested to gain the minor damage for the general health status of the animals beside the required impaired hearing function; thus kanamicin-treated (KM, 250 mg/kg, threshold dose) rats were also included. Eventually 4 groups of rats were scheduled: a RF-exposed group, a RF-exposed + KM group, a sham-exposed group, a KM only treated control group. DPOAE tests were carried out before, during (i.e. at the end of each week) and one week after exposure; the measurement sessions were performed keeping animals under general gas anesthesia (isoflurane in O_2, 1.5-2 %).
Results: the experiments were performed in blind mode with respect to the exposure conditions (sham or exposed). Data will be analyzed in terms of the differences in the DPOAE level between exposed and sham group, before and after UMTS exposure The statistical analysis of results is still in progress; following a rough preliminary examination, Only the ototoxic effect of KM seems to be clearly confirmed.

Acknowledgements: this study was founded by: EMF-nEAR Project **-** *Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing*, a project funded by the European Commission, Framework of the Programme of Community Action in the field of Public Health of the EC, DG Health and Consumer Protection, cont. n°2004127, Dec 2004 – July 2007.

EMFNEAR Project: Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing.

Ravazzani P.

Istituto di Ingegneria Biomedica, Consiglio Nazionale delle Ricerche, Piazza Leonardo da Vinci 32, 20133 Milano – **paolo.ravazzani@polimi.it**

Abstract

The possible effect of exposure to UMTS cellular phones on the hearing system in animals and humans is investigated in the course of the European Commission Project EMFNEAR Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing" (DG Health & Consumer Protection, 2004–2007). Aims of this paper is to present the main structures and first activities of the project

Keywords: UMTS Exposure; Hearing; in vivo and in Vitro

1. Introduction

Although in the last decade the European public concern was growing on the potential adverse health effects due to the use of mobile phones, among the studies addressing their potential health effects, only in 2002 a systematic multicenter research project was established by the European Commission (GUARD "Potential adverse effects of GSM cellular phones on hearing" FP5, QLK4-CT-2001-00150, 2002-2004) investigating the effects of GSM phones at 900 and 1800 MHz on hearing, actually a highly sensitive biological system to exogenous and endogenous agents and the first one to be affected by the microwaves.
Considering the crucial importance of the study of the effects at other frequencies and modulations and the diffusion of 3G technologies for mobile communications, specifically UMTS, the EMFNEAR Project "Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing" (DG Health & Consumer Protection, 2004–2007) aims to study the effects on the hearing of animals (Sprague-Dawley rats) and humans of UMTS cellular phones, assessing potential changes of audiological measures (otoacoustic emissions and auditory evoked potentials) of hearing functionality due to exposure.

2. Participants

Eight European partners are envisaged: *P. Ravazzani*, Scientific Coordinator, *L. Collet*, Université Claude Bernard Lyon1/ CNRS, Lyon, F, *M. Lutman*, ISVR, University of Southampton, UK, *C. Marino*, Section of Toxicology and Biomedical Sciences, ENEA, Rome, I, *M. Sliwinska-Kowalska*, Nofer Institute of Occupational Medicine, Lodz, Pl, *G. Tavartkiladze*, Department of Experimental and Clinical Audiology, Moscow, Ru, *G. Thuroczy*, National Research Institute for Radiobiology and Radiohygiene NIRR, Budapest, H, *I. Uloziene*, Kaunas University of Medicine, Kaunas, Lt.

3. Scientific Approach

The EMFNEAR project workplan is broken down in workpackages, that can be summarized as:

- Exposure and positioning systems. Localized exposure and positioning systems are used, allowing the setting of the level of SAR and exposure time.
- Exposure and measuring protocols. The effects of UMTS exposure on the auditory function of animals and humans are investigated by subjective and objective classical audiological tests.

- Data processing: All data obtained from the experiments are processed by the Central Data Processing Unit (CDPU), which will be in charge of data processing and analysis.
- Expected results of project EMFNEAR are: information on the adverse effects of UMTS phones on hearing, data on the minimum level of SAR and minimum exposure times for measuring changes or potential adverse effects, feedbacks to producers in order to reduce the potential hazards for hearing.

Acknowledgements

This work is partially supported by the European Project EMFNEAR "Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing" (DG Health & Consumer Protection", Agreement Number: 2004127, 2004–2007).

EFFECTS OF UMTS RELATED EMISSIONS ON THE AUDITORY SYSTEM IN EXPOSED RATS (EMFnEAR PROJECT)

PARAZZINI, M.[1], GALLONI, P.[2], PINTO, R.[2], PISCITELLI, M. [2], FRANZONI, C. [1], MARINO, C. [2], RAVAZZANI, P. [1]

(1) *Biomedical Engineering Institute, CNR, Piazza Leonardo da Vinci 32, 20133 Milan, Italy;*

(2)*Toxicology and Biomedical Sciences Unit, Enea Casaccia, Via Anguillarese 301, 00060 Rome, Italy;*

marta.parazzini@polimi.it

Abstract

64 male Sprague-Dawley rats were subjected to localized exposure to electromagnetic fields related to UMTS mobile devices. Animals were exposed 2 hours/day, 5 days/week, for 4 weeks, 10 W/kg of SAR, frequency of 1946 MHz. 4 groups of rats were scheduled: RF-exposed group; RF-exposed + KM group (i.e. kanamicin-treated rats, KM, 250 mg/kg of dose as ototoxic agent); sham-exposed group; KM control group (same dose as RF+KM group). The cochlear functionality was investigated by Distortion Product Otoacoustic Emissions known as indicator of the cochlea status. Blind mode with respect to the exposure conditions (sham or exposed) was applied. The results and their ongoing statistical analysis will be presented.

Introduction

The EMFnEAR project addresses the evaluation of the potential health effects of UMTS phones on the hearing system of animals and humans. Within the project’s activities, this study was performed with the goal of assessing possible effects on the inner auditory system of rats exposed to electromagnetic fields related to UMTS mobile devices.

The cochlear functionality was investigated by Distortion Product Otoacoustic Emissions (DPOAE) measurements, which are a well-known indicator of the cochlea status: significant reductions in DPOAE amplitude are a sign of functional or structural damage in outer hair cells (OHC), i.e. the cochlear sensory epithelium.

Aim of this paper is to present the first results related to the possible effects of UMTS exposure and of the combined exposure of ototoxic drugs (i.e. kanamicin, KM) and UMTS exposure on the auditory system of Sprague-Dawley rats.

Methods

The experimental procedures were carried out according to the results and experience obtained in our previous studies [1, 2] performed within the GUARD project.

A population of 64 male Sprague-Dawley rats that were 10 weeks old and weighed about 250–300 g at the time of the first test was used in this study. In the periods between the experimental sessions, the animals were fed ad libitum with pellets and water. All procedures adhered to internationally accepted guidelines for animal research [3].

4 groups of rats were scheduled: group 1 was treated with daily intramuscular injections of KM of 250 mg/kg body weight for 3 weeks and exposed to EMF; group 2 was treated with daily intramuscular injections of KM of 250 mg/kg body weight for 3 weeks (positive control group); group 3 was exposed to only EMF and group 4 was only sham exposed.

The groups subjected to the KM injections took the dose one hour prior the EMF exposure from the first day of exposure through three weeks.
The EMF exposed groups were subjected to a localized exposure near the right ear simulating the use of a mobile phones with a frequency of 1946 MHz, at a local SAR value of 10 W/kg. In both experiments, rats were exposed 2 hours/day, 5 days/week for 4 weeks.
During the exposure rats were inserted in perspex individual jigs with minimal stress. The temperature was controlled by an alcohol or mercury thermometer.
DPOAE tests were carried out before, during (i.e. at the end of each week) and one week after exposure; the measurement sessions were performed keeping animals under general gas anesthesia (isoflurane in O_2, 1.5-2 %). The experiments were performed in blind operating mode for all operators involved in rats handling procedures (exposure, DPOAE tests, statistical analysis).

Results
All animals were alive after the end of the experiments and all of them completed the EMF exposure, the KM injection, when necessary, and the recording sessions. Data were analysed and statistically compared in terms of the differences in the DPOAE level between the different groups of rats and across time of EMF-exposure/KM-treatments.
Comparing data recorded from only-UMTS and sham exposed animals, no statistically significant differences in the DPOAEs level were evidenced, throughout all the acoustic frequencies' spectrum analyzed.
Interestingly, a modification by co-exposure to RF electromagnetic field and KM was observed, revealing a statistically significant reduction of drug-induced ototoxicity throughout all the acoustic frequencies' spectrum analyzed.

Discussion
This very preliminary study shows that there were no effects on the cochlea functionality of Sprague-Dawley rats exposed to UMTS compared to sham exposed animals. On the contrary, a combined effect of ototoxic drugs (KM) and microwave exposure on the auditory system of exposed and drug treated animals was observed. However, these findings have to be confirmed on a larger number of animals.

Acknowledgements
This study was founded by EMFnEAR Project **-** *Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing* (European Commission, Framework of the Programme of Community Action in the field of Public Health of the EC, DG Health and Consumer Protection, 2004127, Dec 2004 - July 2007).

Literature
[1] Galloni, P., Parazzini, Piscitelli, M., Pinto, R., Lovisolo, G. A., Tognola, G., Marino, C., Ravazzani, P. (2005): Electromagnetic fields from mobile phones do not affect the inner auditory system of Sprague-Dawley rats. Rad. Res., vol. 164, no. 6, 798-804.
[2] Galloni, P., Lovisolo, G. A., Mancini , S., Parazzini, M., Pinto, R.,, Piscitelli, M., Ravazzani, P Marino, C. (2005): Effects of 900 MHz electromagnetic fields exposure on cochlear cells' functionality in rats: evaluation of Distortion Product OtoAcoustic Emissions. Bioelectromagnetics ,vol. 26, no.7, 536-547.
[3] N. Y. Acad. Sci. (1988): Interdisciplinary principles and guidelines for the use of animals in research, testing, and education. Academy of sciences, New York.

were placed at the midpoint of each end-ring element of the MRI coil. The computational analysis was performed at 64, 128, 300 and 400 MHz, which correspond to 1.5, 3.0, 7.0, and 9.4 T, for all sources. In addition, computation was included for the 900 MHz band used by some cellular telephone systems. In order to validate the algorithm used for SAR and temperature calculations, we had replicated the experiment where a muscle cylinder was exposed to a plane wave.

Results and Discussions

As expected, the computed SAR and temperature distributions were different for the plane wave, dipole and birdcage coil, in all cases. In addition to serving as a set of references for comparison, the results showed SAR and temperature distributions vary with the size of the sphere model, source type and frequency, as well as the distance of separation between the source and model. At low frequencies, the SAR has the characteristic of monotonic exponential decay from the surface to the center of the models. With increasing frequency, a standing wave like behavior becomes prominent as revealed by the corresponding oscillatory wave patterns.

In homogeneous spheres, the induced temperature distributions were closely related to SAR distributions since the spheres contained the same tissue with identical thermal properties. The situation would be different in an anatomically accurate human brain model. It is interesting to note that in all cases, the temperature elevations were slightly lower at the edges - because of the convective effect.

12-6

NUMERICAL DOSIMETRY IN A MODEL OF THE HUMAN INNER HEARING SYSTEM EXPOSED TO 900 MHZ. M. Parazzini, G. Tognola, F. Grandori, P. Ravazzani. Istituto di Ingegneria Biomedica CNR, Milano, Italy.

INTRODUCTION:. This paper presents the methodology and some preliminary results obtained in the evaluation of the RF EMF and absorbed power distribution produced by mobile phones at frequency of 900 MHz in a numerical model of human inner hearing system. The numerical method used in this work is the Finite Integration Technique (FIT), implemented by the software package Microwave 5 by CST GmbH.

MATERIAL AND METHODS: In this study an anatomical head model including the peripheral hearing (cochlea) and vestibular systems, generated from MRI image segmentation was used. Two different sets of MRI images were taken. From the first MRI data set (160 images, 256x256 pixels; 0.93x0.93x1mm) a 4 tissues numerical voxel-head model was obtained. This model was integrated using a second set of MRI images (60 images, 256x256 pixels; 1.01x1.01x0.8 mm) of the same subject, scanned using a specific acquisition protocol to enhance the signal coming from both inner ear and adjacent structures, from which a realistic representation of the cochlea and of semicircular canals of the vestibular system was obtained (in the following, the term vestibulus will be referred to both the cochlea and the vestibular system).

The radiation source was modelled as a ¦Ë/4 monopole on a conducting box at the working frequency of 900 MHz and a total radiated power of 1 W. The antenna was centred on the metal box. The metal box was covered with a dielectric insulator of 2 mm of thickness and ¦År = 2. The numerical simulations were performed with the phone placed so that its longitudinal axis followed an imaginary line from the entrance to the ear canal to the corner of the mouth, with the antenna feedpoint directly behind the opening of the auditory canal. The handset and the external layer of the head were in contact, therefore the distance between the monopole and the closest head surface, the pinna of the ear, was 1.5 cm. The interaction between the RF EMF and the vestibulus has been studied evaluating the spatial-peak distribution of the E, H and absorbed power in the target anatomical structure (vestibulus) and along a

series of lines passing through it (particularly one line going from the vestibular to the cochlear region, called Vestibular-to-Cochlea line and one line inside the cochlea from the apex to the base, called Apex-to-Base line) and along a straight line from one ear to the other on the medial plane of the head.
RESULTS: First of all, the influence of the presence of the vestibulus inside the head model on the EMF and SAR distributions has been evaluated comparing the results obtained with two models whose only difference was the presence or the absence of the vestibulus model. The absence of the vestibular model produces an underestimate in the SAR distribution. However, the differences in the SAR distribution are localized only in the ear region: the influence of the vestibulus model is therefore only local. As expected, the peak values in the contralateral ear are much more reduced compared to the one in the ear near the source.
The trend of E and H field distributions along the lines inside the vestibulus show an exponential decay along the Vestibular-to-Cochlea line and a quadratic trend along the Apex-to-Base line in the ear near the source, while the E and H field distribution in the contralateral ear is characterized by a quadratic trend along all the considered lines inside the vestibulus. As for the SAR distribution, the trend is an exponential decay along the Vestibular-to-Cochlea lines and a quadratic trend along the Apex-to-Base in both ears. Preliminary results relative to the effects of anatomical variability and changes in EMF characterization of the tissues should be also presented.
CONCLUSIONS: The results of this study clearly demonstrate that the dosimetry of radiofrequency fields in the hearing system, must be performed including a model of the hearing system itself.
As to the distribution of the fields inside the peripheral hearing system, the exponential decay trend of EMF and SAR suggests an higher EMF interaction in the vestibular region compared to the auditory region of the vestibulus, while the quadratic trend suggests an higher interaction in the basal and apical region of the cochlea compared to the middle one.
ACKNOWLEDGEMENTS: This work is partially supported by the European Project GUARD ¡°Potential adverse effects of GSM cellular phones on hearing¡± (FP5, QLK4-CT-2001-00150, 2002-2004), the European Project EMFNEAR ¡°Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing¡± (DG Health & Consumer Protection¡±, Agreement Number: 2004127, 2004¨C2007), the national project ALERT ¡°Studio degli effetti delle microonde a 900 e 1800 MHz sulla funzionalit¨¤ del sistema uditivo nell¡¯uomo e nell¡¯animale¡±(the Italian Consortium ELETTRA 2000) The authors thanks Dr. F. Baruzzi of Ospedale di Circolo di Varese for the MRI images and kind assistance.

12-7

AN OPTIMIZATION PROCEDURE TO DEVELOP SIMPLE NUMERICAL MODELS OF CELLULAR PHONES FOR AN ACCURATE EVALUATION OF SAR DISTRIBUTION IN THE HUMAN HEAD. S. Pisa[1], M. Cavagnaro[1], V. Lopresto[2], E. Piuzzi[1], P. Bernardi[1]. [1]Dept of Electronic Engineering, 'La Sapienza' Univ of Rome, Rome, Italy, [2]Section of Toxicology and Biomedical Sciences, ENEA Casaccia Research Center, Rome, Italy.

INTRODUCTION: The consolidated approach for compliance testing of mobile phones is based on experimental measurements, carried out using real phones and head phantoms. These phantoms are simplified models of the human head and they are not suitable to perform an accurate analysis of the SAR distribution in the various tissues and organs of the head. For this kind of analysis, a study based on numerical simulations, exploiting the availability of anatomically-based numerical models of the human head, is particularly useful. However, a numerical approach for studying the interaction between mobile phones and exposed subjects requires an accurate and realistic model of the mobile phone, which is rather difficult to be obtained. The use of FDTD codes with graded mesh or with subgridding makes

Human studies

P-C-81

EXPOSURE AT UMTS ELECTROMAGNETIC FIELDS: STUDY ON POTENTIAL ADVERSE EFFECTS ON HEARING. THE EUROPEAN COMMISSION EMFNEAR PROJECT. P. Ravazzani. Biomedical Engineering Institute, National Research Council, Milano, Italy.

INTRODUCTION:. Although in the last decade the European public concern was growing on the potential adverse health effects due to the use of mobile phones, among the studies addressing their potential health effects, only in 2002 a systematic multicenter research project was established by the European Commission (GUARD "Potential adverse effects of GSM cellular phones on hearing" FP5, QLK4-CT-2001-00150, 2002-2004) investigating the effects of GSM phones at 900 and 1800 MHz on hearing, actually a highly sensitive biological system to exogenous and endogenous agents and the first one to be affected by the microwaves (results of GUARD on animals and humans are presented in other abstracts during this Conference) .
Considering the crucial importance of the study of the effects at other frequencies and modulations and the diffusion of 3G technologies for mobile communications, specifically UMTS, the EMFNEAR Project "Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing" (DG Health & Consumer Protection, Agreement Number: 2004127, 2004–2007) aims to study the effects on the hearing of animals (Sprague-Dawley rats) and humans of UMTS cellular phones, assessing potential changes of audiological measures (otoacoustic emissions and auditory evoked potentials) of hearing functionality due to exposure.

PARTICIPANTS: Eight European partners are envisaged: P. Ravazzani, Scientific Coordinator, L. Collet, Université Claude Bernard Lyon1/ CNRS, Lyon, F, M. Lutman, ISVR, Univ of Southampton, UK, C. Marino, Section of Toxicology and Biomedical Sciences, ENEA, Rome, I, M. Sliwinska-Kowalska, Nofer Institute of Occupational Medicine, Lodz, Pl, G. Tavartkiladze, Dept of Experimental and Clinical Audiology, Moscow, Ru, G. Thuroczy, National Research Institute for Radiobiology and Radiohygiene NIRR, Budapest, H, I. Uloziene, Kaunas Univ of Medicine, Kaunas, Lt.

SCIENTIFIC APPROACH: The EMFNEAR project workplan is broken down in workpackages, that can be summarized as:
• Exposure and positioning systems. Localized exposure and positioning systems are used, allowing the setting of the level of SAR and exposure time.
• Exposure and measuring protocols. The effects of UMTS exposure on the auditory function of animals and humans are investigated by subjective and objective classical audiological tests.
• Data processing: All data obtained from the experiments are processed by the Central Data Processing Unit (CDPU), which will be in charge of data processing and analysis.
• Expected results of project EMFNEAR are: information on the adverse effects of UMTS phones on hearing, data on the minimum level of SAR and minimum exposure times for measuring changes or potential adverse effects, feedbacks to producers in order to reduce the potential hazards for hearing.

ACKNOWLEDGEMENTS: This work is supported by the European Project EMFNEAR "Exposure at UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing" (DG Health & Consumer Protection", Agreement Number: 2004127, 2004–2007).

Paolo Ravazzani
Marta Parazzini
Gabriella Tognola
Istituto di Ingegneria Biomedica CNR
Piazza Leonardo da Vinci 32
20133 Milano, Italy
paolo.ravazzani@polimi.it

XI NATIONAL SYMPOSIUM OF RADIO SCIENCES
Poznan, April 7 – 8, 2005

POTENTIAL EFFECTS OF CELLULAR PHONES ON HEARING: NUMERICAL DOSIMETRY IN THE INNER HEARING SYSTEM

Abstract: **This paper aims to present the application of numerical dosimetry techniques to the study of the effects of cellular phones on hearing. The estimation of the electromagnetic fields (both *E* and *B)* and the Specific Absorption Rate (SAR) distribution produced by mobile phones in the inner auditory system, modeled by segmentation and 3D-modeling of MRI images of a human head, will be presented.**

1. INTRODUCTION

This paper presents the methodology and some preliminary results obtained in the evaluation of the RF EMF and absorbed power distribution produced by mobile phones at frequency of 900 MHz in the inner hearing system inside a human head model. This model of the head and vestibulus (i.e., the system composed by the inner ear and the vestibular system), is generated from MRI image segmentation of a head of a young male subjects. The novelty is represented by the presence of a detailed electromagnetic characterization of the vestibulus.

The numerical approach used in this thesis is based on the Finite Integration Technique (FIT) developed by Weiland in 1977 (Weiland, 1977), implemented in the commercially available software package Microwave 4.3 by CST GmbH.

2. MATERIAL AND METHODS

The human head model

In this study an anatomical head model generated from MRI image segmentation was used. The magnetic resonance images (MRI) were obtained from the scan of the head of a young male subject. Two different sets of MRI images were taken. The first MRI data set was taken with the resolution of 1 mm along the height of the head and 0.93 mm for the orthogonal axes in the cross-sectional planes for a total of 160 images (256x256 pixels). The MRI scans of the head were converted into images involving 4 tissues types (skin, skull, cerebrospinal fluid CSF and brain) and a 4 tissues numerical voxel-head has been obtained.

The second MRI data set was taken with a resolution 0.8 mm along the height of the head and 1.01 mm for the orthogonal axes in the cross-sectional planes for a total of 60 images (256x256 pixels). These images were scanned using a specific acquisition protocol to enhance the signal coming from the inner ear and the adjacent structures.

Using an image processing similar to the previous one, a realistic representation of the vestibulus was obtained (Fig. 1).

Fig. 1 The anatomical model of the vestibulus: the semicircular canals on the left, the cochlea on the right and the beginning of the acoustic nerve behind.

The mobile phone modelling

Since the prevailing design of the 900 MHz cellular phones in the literature uses a monopole antenna and a nearly rectangular box, the following are the dimensions of the models here used (Okoniewski et al., 1996): an antenna length of 8.5 cm, a metal box of 15 (length) x 6 (width) x 3 (depth) cm. The antenna was centred on the metal box. The metal box was covered with a dielectric insulator of 2 mm of thickness and ε_r =2. The steady-state radiated power from the antenna was 1 W (i.e., the radiated power in the far field plus the power dissipated in the head).

In computing the transient response, the time-stepping is continued until the energy inside the calculation domain has decayed to a level approximately 30 dB below its peak value.

Type of numerical simulation

In this preliminary study the numerical simulations has been performed in a position called the "standard" position, i.e. that one in which the phone was placed so that its longitudinal axis followed an imaginary line from the entrance to the ear canal to the corner of the mouth, with the antenna feedpoint directly behind the opening of the auditory canal. The handset and the external layer of the head were in contact, therefore the distance between the monopole and the closest head surface, the pinna of the ear, if the model contained it, was 1.5 cm. Moreover, the contact between the handset and the model was physical, but not electrical, as the box was insulated with a thin dielectric.

Methods of data analysis

The spatial-peak distribution of the E and H inside the vestibulus has been evaluated along a series of lines passing through this anatomical structure (Fig. 2), and along a straight line from one ear to the other along the medial plane of the head. The 1-g average SAR value has been evaluated on the entire head model and along the lines previously described. In the following peak SAR 1 g will be referred to the peak of the 1-g average SAR distribution inside all the head, while SAR 1 g will be referred to the 1-g average distribution evaluated along the lines. Moreover, the SAR distribution inside the vestibulus has been evaluated calculating the SAR value at all points in the calculation domain included in the vestibulus model, both considering the entire vestibulus and considering its different regions, i.e. the vestibular system, the cochlea and the acoustic nerve. This SAR distribution inside the vestibulus has been evaluated without any "standard" mass average, i.e. 1 g or 10 g, because of the small volume of these anatomical structures.

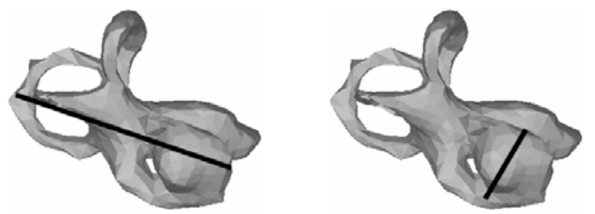

Fig. 2 On the left, a schematic view of the line Vestibular–to-Cochlea; on the right a schematic view of the line Apex-to-Base.

3. RESULTS

Fig. 6.3 shows the spatial-peak distribution of the E and H along lines inside the vestibulus for the ear near the source and along the line Ear-to-Ear, respectively, for the Standard900 simulation case. It must be underlined that these graphs don't show the temporal behaviour of the fields, but the distribution of the spatial-peak of the absolute value of E and H. The same calculations were performed in the contralateral ear. As one can expect, going from the ear close to the source to the contralateral one there is a decrease of a factor approximately equal to 10 on both the fields. In Fig. 6.4 the SAR 1 g distribution along the line Ear-to-Ear for frequency of 900 MHz is shown.

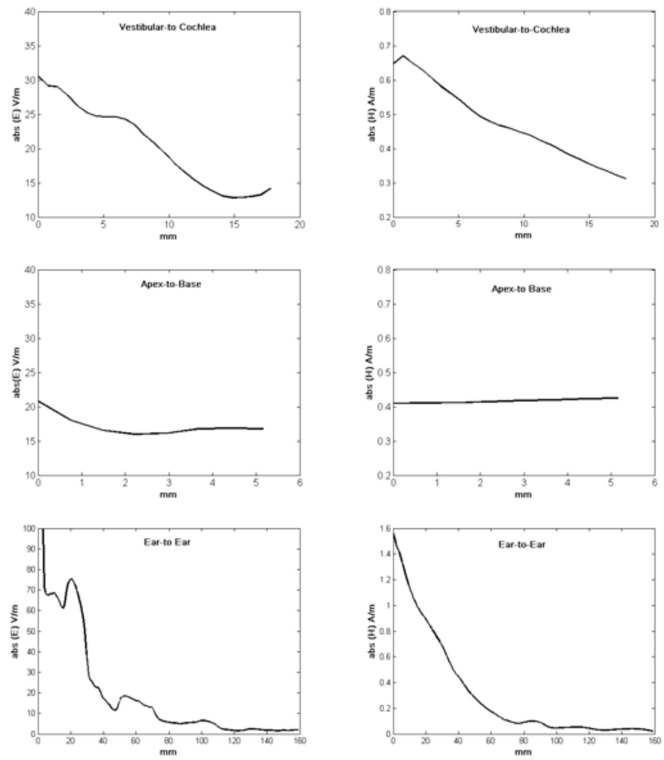

Fig. 6.3 E and H field distribution along the various lines for a frequency of 900 MHz.

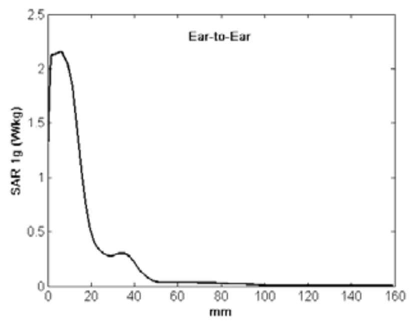

Fig. 6.4 SAR 1 g distribution along the line Ear-to-Ear) for frequency of 900 MHz.

Standard900 versus NoEar900

The EMF spatial-peak distribution and the SAR 1 g distribution along lines inside the vestibules near the source for the Standard900 and NoEar900 simulations were also estimated. The two simulations differ only for the human head model: the NoEar900 uses the same human head model but without description of the vestibulus. The trend of the spatial-peak distribution of the E and H is similar for both the simulations. The E field distribution is overestimated along both of the lines by the simulation NoEar900. In particular the mean percentage difference along the Vestibular-to-Cochlea lines is about of 64% and along the Apex-to-Base line is about of 83%. The H field distribution, instead, is underestimated by the NoEar900 simulation. However, these differences are small: the mean percentage difference along the Vestibular-to-Cochlea lines is about of 6% and along the Apex-to-Base line is about of 1%. Also, the SAR 1 g distribution inside the ear is underestimated by the NoEar900 model: the mean percentage difference along the Vestibular-to-Cochlea lines is about of 54% and along the Apex-to-Base line is about of 51%. This underestimation is much more evident when the comparison is performed on all the vestibulus and not only along some lines inside it. In fact the vestibulus SAR distribution evaluated in the NoEar900 model in the points in which there should be the vestibulus if it was included is underestimated of 75%. These differences in the EMF and SAR distribution are mainly localized in the vestibulus region. The differences between the E and SAR 1 g distribution are localized in the ear region (between 30 and 50 mm). As before, a positive difference for the E field distribution means an overestimate and a negative difference for the SAR 1 g distribution means an underestimate of the NoEar900 simulation as regard the Standard900 simulation. The mean percentage difference of the E, H, and SAR 1 g distribution along the Ear-to-Ear line is reduced to 18%, 4% and 16%, respectively, and the percentage difference between the peak SAR 1 g evaluated in all the head model collapses to 1.2%.

4. DISCUSSION

In this preliminary study the E, H and SAR distributions inside the vestibulus, when the head is exposed to a source of 900 MHz with 1 W of peak power has been evaluated. The novelty in the head model is represented by the presence of a geometric and electromagnetic characterization of the vestibulus. The vestibulus region is of special complexity with respect to EMF interaction and absorption because it is composed of complex 3D-tissue distributions, including air cavities, low-loss bone structure and wet tissues.

The results of this preliminary work suggest that the trend of E and H field distributions along the lines inside the vestibulus show an exponential decay along the Vestibular-to-Cochlea line and a quadratic trend along the Apex-to-Base line for the ear near the source. The quadratic trend of the E field suggests an exposition to higher value in the basal and apical region compared to the middle region of the cochlea; however, the mean difference between the value along the line in adjacent points are around 0.5 V/m and 0.29 V/m.

The EMF spatial-peak distribution in the contralateral ear is well reduced compared to the one in the Near ear (reduction factor from 10 to 40), because of the penetration of a wave in a lossy dielectric, and it is characterized by a quadratic trend along the lines inside the vestibulus considered in this thesis. This quadratic behaviour is probably due to an interference phenomenon that is more evident in the contralateral region.

As for the SAR distribution, the trend of the SAR 1 g distribution shows an exponential decay along the Vestibular-to-Cochlea lines and a quadratic trend along the Apex-to-Base, for both ears even if the values in the Far ear are extremely low (<4 mW/kg). As for the Ear-to-Ear line, the typical exponential decay trend, after the peak in the skin, was found.

A more detailed description of the absorption phenomenon at a vestibulus level has been obtained computing the vestibulus SAR distribution, showing that the vestibular system is characterized by a greater absorption in both of the ears. In the Near ear, this is probably due to the fact that it is closer to the source, while in the Far ear this is probably due to an interference phenomenon but it also possible that there is an effect of the geometry of the structure.

However, the distributions inside the Far vestibulus are much more homogeneous than the ones in the Near ear; in fact the differences between the mean SAR values inside the different region of the vestibulus are extremely low (less than 0.2 mW/kg).

The influence of the presence of the vestibulus inside the head model on the EMF and SAR distributions has been evaluated comparing the results obtained with two models whose only difference was the presence or the absence of the vestibulus model. Because of the low value obtained in the Far ear, the comparison has been performed only in the Near ear.

The exclusion of the vestibular model produces an overestimate in the E field distribution and an underestimate in the H field distribution. These effects are more effective on the E field. Moreover, the

E and H field distribution obtained without the vestibulus model appears smoother: this is probably due to the fact the lines are inside a much more homogeneous grid structure.

As for the SAR distribution, the effect is the opposite: the absence of the vestibulus model produces an underestimate in that region. This has been found both comparing the SAR 1 g distribution along the lines than the vestibulus SAR distribution. However, the percentage differences between the two SAR vestibulus distributions are greater than the ones between the two SAR 1 g distributions. This is due to the fact that the SAR 1 g is an average value that levels the differences. The increase in the SAR values is not surprising: the vestibulus, in fact, is a high conductivity tissue and therefore it is characterized by great energy absorption.

As final comment, the difference in the E, H and SAR distribution along the line Ear-to-Ear are localized only in the ear region: the influence of the vestibulus model is therefore only local and is probably due to the small dimensions of this anatomical structure.

5. ACKNOWLEDGEMENTS

This work was supported by fund from European Project GUARD “Potential adverse effects of GSM cellular phones on hearing” (FP5, QLK4-CT-2001-00150, 2002-2004), the European Project EMFNEAR “Exposure at UMTS electromagnetic fields: study on potential adverse effects on hearing” (DG SANCO, 2004-2007); the national project ALERT “Studio degli effetti delle microonde a 900 e 1800 MHz sulla funzionalità del sistema uditivo nell’uomo e nell’animale”(the Italian Consortium ELETTRA 2000) and the national project MIUR/CNR-ENEA “Salvaguardia dell’uomo e dell’ambiente dalle emissioni elettromagnetiche”.

REFERENCES

[1] T. Weiland, “A discretization method for the solution of the Maxwell’s equations for six-component fields”, Electronics and Communication, 31, pp. 116-120, 1977.

[2] S. Gabriel, R.W. Lau, C. Gabriel, “The dielectric properties of biological tissues: II. Measurements in the frequency range 10Hz to 20GHz”, Phys. Med. Biol., 41, pp. 2251-2269, 1996.

[3] M. Okoniewski, M.A. Stuchly, “A study of the handset antenna and human body interaction”, IEEE Trans. Microwave Theory Tech., 44, pp. 1855-1864, 1996.

[4] M. Parazzini, “Interactions between radio frequency electromagnetic fields produced by mobile phones and the auditory system: biological effects and numerical dosimetry”, PhD Thesis, Polytechnic of Milan, 2004.