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Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality

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ABSTRACT

Children's brains are more susceptible to hazardous exposures, and are thought to absorb higher doses of radiation from cell phones in some regions of the brain. Globally the numbers and applications of wireless devices are increasing rapidly, but since 1997 safety testing has relied on a large, homogenous, adult male head phantom to simulate exposures; the "Standard Anthropomorphic Mannequin" (SAM) is used to estimate only whether tissue temperature will be increased by more than 1 Celsius degree in the periphery. The present work employs anatomically based modeling currently used to set standards for surgical and medical devices, that incorporates heterogeneous characteristics of age and anatomy. Modeling of a cell phone held to the ear, or of virtual reality devices in front of the eyes, reveals that young eyes and brains absorb substantially higher local radiation doses than adults'. Age-specific simulations indicate the need to apply refined methods for regulatory compliance testing; and for public education regarding manufacturers' advice to keep phones off the body, and prudent use to limit exposures, particularly to protect the young.

1. Introduction

With many nations having more mobile phones than people, and the rapidly increasing use of wireless transmitting devices by infants, toddlers and young children, it is important to consider children's unique absorption of radiofrequency (RF), also called microwave (MW) non-ionizing radiation (Gandhi et al., 1996; de Salles et al., 2006; Wiart et al., 2008; Christ et al., 2010) and potential health impacts.

Standards for wireless devices have not changed since 1997, and are based on the assumption that the only adverse effect to be avoided is heat (Gandhi et al., 2012). Mobile phones are certified to be within RF radiation regulatory limits using robot-assisted determination of peak spatial Specific Absorption Rate (psSAR) – i.e. maximum dose rate – within a phantom of a large, adult male head and body, the Standard Anthropometric Mannequin (SAM). The plastic SAM head mold, filled with a homogeneous liquid to simulate dielectric characteristics of soft tissues at the frequency of the device being tested, is assumed to be valid for those with younger and smaller heads (U.S. Federal Communications Commission (FCC) Office of Engineering and Technology, 1997; IEEE International Committee on Electromagnetic Safety (SCC39), 2005), to test compliance with outdated standards set for exposure to the entire head. This ignores human anatomy, and the fact that the brain and eyes are target tissues where such radiation can be especially biologically important. Studies have consistently indicated that children's brains absorb substantially higher peak doses than adults (Morris et al., 2015; Foster and Chou, 2016).

Anatomically-based, age-appropriate mathematical models of younger heads with thinner skulls and higher water content were used to examine specifics of psSAR averaging volume and dielectric constants within specific regions of the head. Specific regions include the eye and brain, to aid interpretation of international standards (Institute of Electrical and Electronics Engineers, 2013; Gosselin et al., 2014; International Commission on Non-Ionizing Radiation Protection, 1998; Peyman et al., 2009). Age-appropriate simulations are used to advance the understanding of the exposure of critical parts of the brain to RF radiation using models over a broad range of ages (from 3 to 34 years) (Fernandez-Rodriguez et al., 2015) from cell phones used against the ear, as well as in front of the face to view virtual reality (Google, n.d.).

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2. Materials and methodology

2.1. Cell phone model

A dual band (900 MHz and 1800 MHz) model was used (Garzon et al., 2013), with a common cell phone case 109 × 60 × 13.9 mm and a Planar Inverted "F" Antenna (PIFA) in the top position. This antenna is widely used in modern phones. With the exception of virtual reality modeling, the phone was in the "touch" position (touching the cheek, with the antenna over the ear). Although manufacturers specify that wireless devices should be kept a minimum distance from the body in order to ensure meeting exposure standards, in this work the phone was modeled as it is commonly used, against the skin, with dimensions from phone to brain as indicated below. Virtual Reality (VR) modeling was carried out for a system similar to the Google Cardboard (Google, n.d.) in which the cell phone is positioned in front of the eyes. The distances between the antenna (inside the phone) and the eye lens are: 31.37 mm for Thel and 46.64 mm for Duke, based upon the dimensions of the anatomical models.

2.2. Head models

Head models of the 8 and 10 year old boys, developed by Porto Alegre/Environmental Health Trust (PAEHT) for this work, were obtained via segmentation of Computerized Tomography (CT) images of specific children after approval by the ethics committee of the Mae de Deus Hospital in the "Parecer n° 556/12 do Comité de Ética em Pesquisa do Hospital Mãe de Deus CEP/HMD," in Porto Alegre, Brazil. All other head models belong to the "Virtual Family" (VF) developed by the Swiss National Institute of Technology Research (IT'IS) in collaboration with the U.S. Food and Drug Administration. The VF, representing average dimensions and anatomy for the gender and age, have been detailed elsewhere (Gosselin et al., 2014). SAM, the homogenous head model employed by telecommunication testing worldwide is based on a male with a head weighing about 11 pounds, representing the 90th percentile of U.S. military recruits in 1989.

The models are: 3 year-old boy (Indy from VF; 13 mm distance antenna to brain (atb)), 5 year-old girl (Roberta from VF; 20 mm atb), 6 year-old boy (Thelonious from VF; 23 mm atb), 8 year-old girl (Eartha from VF; 29 mm atb), 8 year-old boy (David developed by PAEHT; 23 mm atb), 10 year-old boy (Diego developed by PAEHT; 24 mm atb), 11 year-old girl (Billie from VF; 26 mm atb), 14 year-old boy (Louis from VF; 19 mm atb), 26 year-old woman (Ella from VF; 29 mm atb), 34 year-old man (Duke from VF; 32 mm atb) and SAM (8 mm atb) (Institute of Electrical and Electronics Engineers, 2013). In the Diego, Duke, Louis and Thelonious simulated versions, the pinna has not been identified.

psSAR simulations were repeated in triplicate for a range of ages, grid sizes, and dielectric parameters, employing standard protocols as summarized below.

2.3. Dielectric parameters

Adult parameters obtained from the work of Gabriel (1996) are regularly used for this purpose in medical applications. Age specific parameters for children were estimated based on accepted methods by correlating age specific measurements in pigs (Peyman et al., 2009) with Gabriel data (Gabriel, 1996) and interpolating using the following equation:

$$P(a) = \left[\frac{P_{50} - P_{10}}{12 - 4} \times a + \left(P_{50} + \frac{P_{50} - P_{10}}{12 - 4} \times 12\right)\right] \times \left(\frac{P_H}{P_{250}}\right)$$

where,

P is one of the dielectric parameters (permittivity or conductivity) of a given tissue;

a is the age (in years) for which the parameters are being adjusted (a must be in the range 4–12 years);

P_{250}, P_{50} and P_{10} are the parameter values measured in pigs (Peyman et al., 2009) weighing 250 kg, 50 kg and 10 kg corresponding to human ages of 18 (and adults), 12 and 4 years respectively;

P_H, is the value of the parameter published in Gabriel (1996), which is widely accepted as "adult human parameters."

2.4. Simulations

Software – SEMCAD X 14.8. Hardware – aXware TESLA C1060@ Intel i5 – 3470 CPU 3.20 GHz, 32 GB RAM. Grid characteristics – voxel dimensions: from 0.002 to 0.07 wavelength (0.67–23.3 mm in surrounding space); grading and relaxation ratio: 1.2 minimum padding: 0.2 wavelength (6.67 cm of free space around the head); total model size: from 4 M to 54 M cells. Source characteristics – frequency: 900 MHz; power delivered: 250 mW; bandwidth: 200 MHz and harmonic (0 Hz); typical simulation length: 40 periods. Simulation time – from 30 min to 5 h depending on the grid adjustment (dimensions and orientation) and frequency bandwidth. Validation – Loss and radiated power > 240 mW (@ Pdel = 250 mW). Uncertainties were estimated by varying simulation parameters (e.g. refining the mesh) and measuring the power budget. All psSAR values are in W/kg.

3. Results

When cell phones are held close to the head most of the energy (more than 80%) from the transmitting antenna is absorbed by the head. When the phone is used for virtual reality viewing, the head absorbs 50% of the energy.

3.1. Averaging volumes

Different averaging volumes are used in RF radiation regulatory limits, with North American standards referencing a cube of tissue weighing 1 g (U.S. Federal Communications Commission (FCC) Office of Engineering and Technology, 1997), while the International Commission on Non-Ionizing Radiation Protection (ICNIRP) relies on a 10 g volume ("Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). (International Commission on Non-Ionizing Radiation Protection", 1998). psSAR in the whole head (ear and/or skull) as well as in the brain varies inversely with averaging volume (Fig. 1), as smaller volumes are on average closer to the antenna. Another consequence is that the SAM head psSAR values are higher than values calculated using anatomical models, by approximately 1.7-fold in 10 g of tissue and 1.4-fold in 1 g of tissue. Several factors contribute to this trend: the SAM head model has no skull so psSAR is measured in simulation fluid that mimics soft tissues (bone absorbs RF radiation less avidly than the brain); the SAM head has a non-absorbing space simulating a compressed 6 mm thick pinna, while the anatomical models have uncompressed pinnas ranging from 5 mm in Indy to approximately 2 cm in Duke, and these outer ears do absorb radiation; and the relatively large head model of SAM presents a flatter surface adjacent to the antenna, compared with the smaller, rounded heads of the anatomical models.

Consistent with previous reports (Kang and Gandhi, 2002), the averaging volume employed in the modeling is correlated inversely with the calculated maximum tissue dose or psSAR (Fig. 1). Averaging the SAR over 10 g of tissue with a 2 W/kg maximum SAR (consistent with the ICNIRP recommendation) permits over 3-fold greater radiation absorption in the skull ("head" per regulatory standards), compared with averaging over 1 g of tissue with a 1.6 W/kg maximum SAR (consistent with current FCC/FDA methods). Furthermore, averaging SAR over 0.1 g – one-tenth the smallest mass in current use – yields a tissue dose up to 6 times that calculated for the commonly used 10 g mass standard.