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Exposure Limits: The underestimation of absorbed cell phone radiation, especially in children

Om P. Gandhi[1], L. Lloyd Morgan[2], Alvaro Augusto de Salles[3], Yueh-Ying Han[4], Ronald B. Herberman[2,5] & Devra Lee Davis[2]

[1]Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, Utah, USA, [2]Environmental Health Trust, Teton Village, Wyoming, USA, [3]Electrical Engineering Department, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, [4]Department of Epidemiology and Community Health, School of Health Sciences and Practice, New York Medical College, Valhalla, New York, USA, and [5]Intrexon Corp., Germantown, Maryland, USA

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The existing cell phone certification process uses a plastic model of the head called the Specific Anthropomorphic Mannequin (SAM), representing the top 10% of U.S. military recruits in 1989 and greatly underestimating the Specific Absorption Rate (SAR) for typical mobile phone users, especially children. A superior computer simulation certification process has been approved by the Federal Communications Commission (FCC) but is not employed to certify cell phones. In the United States, the FCC determines maximum allowed exposures. Many countries, especially European Union members, use the "guidelines" of International Commission on Non-Ionizing Radiation Protection (ICNIRP), a non governmental agency. Radiofrequency (RF) exposure to a head smaller than SAM will absorb a relatively higher SAR. Also, SAM uses a fluid having the average electrical properties of the head that cannot indicate differential absorption of specific brain tissue, nor absorption in children or smaller adults. The SAR for a 10-year old is up to 153% higher than the SAR for the SAM model. When electrical properties are considered, a child's head's absorption can be over two times greater, and absorption of the skull's bone marrow can be ten times greater than adults. Therefore, a new certification process is needed that incorporates different modes of use, head sizes, and tissue properties. Anatomically based models should be employed in revising safety standards for these ubiquitous modern devices and standards should be set by accountable, independent groups.

INTRODUCTION

History of Exposure Testing, Guidelines, and Standard-Setting

August 1974

In 1974, a study determined that at certain frequency ranges resonance increased the absorbed radiation by up to nine times higher than that previously assumed for humans (Gandhi, 1974).

Address correspondence to L. Lloyd Morgan, Environmental Health Trust, P.O. Box 58, Teton Village, WY 83025 USA; E-mail: Lloyd.L.Morgan@gmail.com

1975

In 1975, behavioral studies were performed on food-deprived rats that had learned to bar press for food rewards in order to determine what exposure levels to non-ionizing radiation (NIR) might impair their ability to work for food reward and therefore be deemed as hazardous. The exposure metric used was the specific absorption rate (SAR), the amount of power absorbed per unit mass of tissue (Watt per kilogram). It was determined that trained rats stopped working for food at a whole body average SAR exposure of 4 W/kg (D'Andrea et al., 1975). This level of exposure increased core body temperatures measured with rectal thermometers. It was deduced that the absorbed electromagnetic power was the reason that food-deprived rodents stopped working for food.

September 1982

The American National Standards Institute (ANSI) published the first exposure NIR exposure standard, which incorporated a 10-fold safety factor for humans exposed to electromagnetic fields between 300 kHz and 100 GHz. No reason per se was given for the size of the safety factor other than there was a consensus (ANSI, 1982, p. 14).

In the ANSI standard concerns were expressed that the standard might not be sufficiently protective. "It was recognized that the specific absorption rate (SAR), which provides the basis for limiting power densities, does not contain all of the factors that could be of importance in establishing safe limits of exposure. First, other characteristics of an incident field such as *modulation frequency* and *peak intensity* may pose a risk to health." [emphasis added] Further, the ANSI standard noted that the database they used did not "provide evidence to recommend special provision for modulated fields" (ANSI, 1982, p. 14; see "In-Vivo and In-Vitro Studies" section below).

ANSI adopted a standard for whole body exposure of 0.4 W/kg averaged over 6 min, and a 20-fold greater spatial peak SAR exposure over any 1 gram of tissue of 8 W/kg averaged over 6 min. Effectively, this allowed much higher exposures within the small area of the brain than are permitted over the body. No reason was given for allowing this. The ANSI standard noted the resonant frequency (70 MHz) "results in an approximate sevenfold increase of absorption relative to that in a 2450 MHz field" (ANSI, 1982, p. 12). The intent of this standard was to protect "exposed human beings from harm by any mechanism, including those arising from excessive elevation of temperature." (ANSI, 1982, p. 12, italics in the original)

The ANSI standard called for a review of the standard every 5 years (ANSI, 1982, p. 11).

1987–1988

ANSI, not having medical expertise, handed over the setting of exposure limits to the Institute of Electrical and Electronic Engineers (IEEE), a professional society of electrical and electronics engineers from the electronics industry as well as academia. IEEE is not chiefly a medical, biological, or public health organization.

September 1991

In 1991, IEEE first revised the ANSI standard (IEEE, 1991), which has not changed substantially since then, although minor revisions were provided by Standard C95.1 in 2005–2006, and these changes were not adopted by the FCC. It established a two-tier system: one for the general population within an "uncontrolled environment," and one for workers in a "controlled environment," the latter defined as "locations where there is exposure that may be incurred by persons who are aware of potential for exposure as a concomitant of employment ... where ... exposure levels may be

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[up to a whole body SAR of 0.4W/kg for any 1 gram of tissue averaged over 6 minutes and a peak spatial SAR of 8 W/kg for any 1 gram of tissue averaged over 6 minutes]."

For the general population, the IEEE revision of the ANSI standard reduced the average whole-body and spatial peak SAR by a factor of 5. This reduction was recommended because of concerns that the general population includes a wide range of ages, vulnerabilities and health status, and in some circumstances, the potential of 24/7 exposures. In explanation of this reduction of general population exposure guidelines, the IEEE standard noted, "To some, it would appear attractive and logical to apply a larger ... safety factor ... for the general public. Supportive arguments claim subgroups of greater sensitivity (infants, the aged, the ill, and disabled), potentially greater exposures (24 hr/day vs. 8 hr/day) ..., [and] voluntary vs. involuntary exposures. Non-thermal effects, such as efflux of calcium ions from brain tissues, are also mentioned as potential health hazards." (IEEE, 1991, p. 23) For the general population the standard revised the whole body average SAR exposure to 0.08 W/kg averaged over 30 min and the spatial peak SAR for any 1 gram of tissue to 1.6 W/kg averaged over 30 min (IEEE, 1991, p. 17).

Because the resultant Specific Absorption (SA) is identical for the general population in an uncontrolled environment, as it is for workers in a controlled environment (0.08 W/kg*30 min = 0.4 W/kg*6 min), the "larger safety factor" for the general population is non-existent.

The IEEE language concerning the 20-fold larger spatial peak SAR when compared to the whole body SAR went further than the ANSI standard it replaced. The IEEE standard stated, "... spatial peak SARs may exceed the whole-body averaged values by a factor of more than 20 times." (IEEE, 1991, p. 25)

Twenty years later this standard remains unchanged, despite minor alterations in 2005–2006.

1992

In 1992, ANSI adopted the 1991 IEEE standard. It was referred to as, ANSI/IEEE C95.1-1992, but a copy is no longer publicly available (C.K. Chou, Personal Communications, July 18, 2011).

October 1997

In 1996, the FCC published the first U.S. regulations on maximum allowable cell phone radiation adopting the ANSI/IEEE C95.1-1992 standard, which became effective on October 15, 1997. FCC's Bulletin 65 described how to evaluate compliance to the FCC regulations for human exposure to electromagnetic fields (Cleveland et al., 1997). The FCC exposure limits were, and remain, identical to the 1991 IEEE standard. The FCC SAR adopted values were:

(1) For occupational exposures, "0.4 W/kg as averaged over the whole-body and spatial peak SAR not exceeding 8 W/kg as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the hands, wrists, feet, and ankles where the spatial peak SAR shall not exceed 20 W/kg, as averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube) [averaged over 6 minutes]."
(2) For the general population exposures, "0.08 W/kg as averaged over the whole-body and spatial peak SAR not exceeding 1.6 W/kg as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 4 W/kg, as averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube) [averaged over 30 minutes]."

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Once again, the "larger safety factor" for the general population compared to workers was non-existent. It should be noted that these exceptions did not include the ear (also referred to as the pinna). As we shall see in "The SAM Cell phone Certification Process," section below, this exclusion of the ear is important.

December 1997

Four months later, the FCC published Supplement C, which provided among other details, additional information for "portable devices" (AKA cell phones) certification. The introduction states, "Currently, industry groups and other organizations are working to develop standardized product test procedures to evaluate RF exposure compliance with ... SAR limits" (Chan et al., 1997, p. 1). [See June 2001 below.] As this was prior to the adoption of the SAM cell phone certification process, Supplement C notes several concerns about the existing cell phone certification process:

(1) "The lack of standardized test positions for evaluating handsets can result in difficulties in determining RF compliance with SAR limits;" (Chan et al., 1997, p. 1–2).
(2) The liquid used to simulate the average electrical properties of an adult head had not been standardized at this time, "The permittivity and conductivity of simulated liquid tissues prepared for SAR evaluation must be measured to ensure that they are appropriate ... These parameters are usually measured periodically or before each SAR evaluation to determine if it is necessary to add appropriate amounts of water ..." (Chan et al., 1997, p.12).
(3) "Most test facilities use separate head models for testing handsets on the left and right side of the head. While some models included ears and others do not, a few have also used a spacer to represent the ear" (Chan et al., 1997, p. 12).

While there was a standardized method to certify the specific SAR for each cell phone, it was not repeatable from one certification facility to the next.

An alternate certification process within Supplement C was computer simulation. "Currently the finite-difference time-domain (FDTD) algorithm is the most widely accepted computation method for SAR modeling. This method adapts very well to the tissue models which are usually derived from MRI or CT scans, such as those available from the visible man projects [see "Virtual Family" discussion below]. FDTD offers great flexibility in modeling the inhomogeneous structures of anatomical tissues and organs. The FDTD method has been used in many far-field electromagnetic applications during the last three decades. With recent advances in computing technology, it has become possible to apply this method to near-field applications for evaluating handsets" (Chan et al., 1997, p. 16).

April 1998

In 1998, a non governmental organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998), provided "guidelines." ICNIRP followed IEEE's lead by adopting the same two-tier system except that both the general public and occupational exposures were averaged over 6 min. ICNIRP far-field guideline was, "A whole-body average SAR of $0.4 \mathrm{Wkg}^{-1}$ has therefore been chosen as the restriction that provides adequate protection for occupational exposure. An additional safety factor of 5 is introduced for exposure of the public, giving an average whole-body SAR limit of $0.08\,\mathrm{Wkg}^{-1}$." For general public exposures, the maximum spatial peak SAR = 2.0 W/kg averaged over 10 g, with occupational exposures, SAR = 10 W/kg (ICNRIP, 1998, p. 509).

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Many governments set or recommend exposure limits based on ICNIRP's "guidelines". For example, the United Kingdom's Health Protection Agency (HPA) states on their web page, "There is no explicit UK legislation that limits people's exposure to electromagnetic fields, including the radio waves used in mobile telephony," then goes on to state, "The Recommendation incorporates the restrictions on exposure of the general public advised by ICNIRP in its 1998 guidelines" (HPA, 2010).

The ICNIRP guidelines made no recommendation about how to certify a cell phone. It noted, "These guidelines do not directly address product performance standards, which are intended to limit EMF emissions under specified test conditions, nor does the document deal with the techniques used to measure any of the physical quantities that characterize electric, magnetic, and electromagnetic fields. Comprehensive descriptions of instrumentation and measurement techniques for accurately determining such physical quantities may be found elsewhere (NCRP, 1981, 1993; IEEE, 1992; DIN VDE, 1995)" (ICNIRP, 1998, p. 2).

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June 2001

In 2001, the FCC's Supplement C was revised (Means and Chan, 2001). For the first time, a standardized and repeatable, although not necessarily accurate, industry-designed (see December 1997 above) cell phone SAR certification process was available (the SAM cell phone certification process). Yet, the FCC continued to offer the alternative computer simulation certification process, repeating the language from the December 1997 edition (with minute language changes), and then added, "The FDTD method offers great flexibility in modeling the inhomogeneous structures of anatomical tissues and organs" (Means and Chan, 2001, p. 13).

CHRONIC EXPOSURE EFFECTS

All exposure limit standards and/or guidelines rested on avoiding acute heating effects originally observed in food-deprived rats (Chou et al., 2006). Chronic effects from levels of NIR that did not induce a measurable change in temperature were not taken into account. However, the intent of the ANSI standard was to protect the "exposed human being from harm by *any* mechanism," not just heating. The IEEE standard increased safety margin was to protect "subgroups of greater sensitivity" from "24 h/day involuntary exposures," and from "non-thermal effects, such as efflux of calcium ions from brain tissues." Then and now, there were many studies showing important effects from chronic non-thermal NIR exposure (See September 1991 above; and BioInitiative Working Group, 2007).

The following studies reported findings of harmful effects, but this is not a comprehensive list. There are studies, often industry funded (Huss et al., 2007), that reported no significant effects. The purpose of this section is to describe the multitude of studies that suggest there is a problem.

In-Vivo and In-Vitro Studies

An extensive number of experimental studies below the exposure limits indicate that pulsed digital radiation from cell phones induces an array of biological impacts ranging from blood-brain barrier leakage to brain, liver, and eye damage in prenatally exposed offspring of rabbits and rats, to genotoxic effects on human cells (e.g., Nittby et al., 2009; Salford et al., 2003; Adlkofer, 2004; Schwarz et al., 2008; Guler et al., 2011; Mulak et al., 2011; Tomruk et al., 2010; Odaci et al., 2008).

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When human fibroblast cells were exposed to GSM modulated cell phone radiation, the REFLEX project found that genotoxic effects began at SAR = 0.3 W/kg (Adlkofer, 2004, Fig. 94, p. 135). Another REFLEX study exposed human fibroblast cells to UMTS modulated cell phone radiation found effects beginning at SAR = 0.05 W/kg (Schwarz et al., 2008). In these studies, a UMTS modulated signal has a 6-fold lower genotoxic threshold than a GSM modulated signal. But, other studies were not consistent with this finding. This suggests that the concerns of the 1982 ANSI that "other characteristics of an incident field such as modulation frequency and peak intensity may pose a risk to health" were prescient, as the pulsed nature of signals may be more important than their power.

Brain Cancer Studies

While some studies of brain cancer from chronic cell phone use find no increase in risk, these studies generally have followed people who have used cell phones for a relatively short time. Where long-term, heavy use of cell phones has taken place for over a decade, several epidemiologic case-control studies have found significantly increased risks of brain cancer. The largest brain cancer case-control study was the 13-country, government and industry-funded Interphone study with 2,708 cases and 2,972 controls for glioma, the most serious among many brain cancer types, restricted to ages 30–59 years. (The Interphone Group, 2010). It examined the risk from cell phones, but not the risk from cordless phones. The second largest brain cancer case-control study was done in Sweden without industry funding by Dr. Lennart Hardell's team. This study had 1,251 brain cancer cases and 2,438 controls (Hardell et al., 2011) and examined the risk for all malignant brain tumors, not just glioma, from both cell phones and cordless phones, ages 20–80 years.

In May 2010 the Interphone study published its first pooled results from all 13 countries. It reported no overall increased risk of brain cancer (glioma only) among short-term cell phone users, but found a more than doubled risk of brain cancer when cell phones were used for 10 or more years compared to short-term users (1–1.9 years), OR = 2.18, 95% CI = 1.43–3.31 (The Interphone Group, 2010).

In contrast, the Hardell et al. 2011 study found risk of malignant brain tumor from use of cell and cordless phones (wireless phones) for $>$ 5–10 years, with $>$ 195 cumulative hours, OR = 1.4, 95% CI = 1.1–1.8, and for $\geq$ 10 years of use, OR = 2.4, 95% CI = 1.7–3.2. Also, it found a strong dose-response risk for all brain cancer types. For every year since first use of a wireless phone, the risk increased by 5.4%, OR = 1.054, 95% CI = 1.036–1.073. Perhaps, most alarming was the risk found by age at first use. When use began as a teenager or younger the risk of astrocytoma from cell phone with $>$ 195 cumulative hours and $\geq$ 10 years or use, which was more than 3-fold (OR = 3.1, 95% CI = 2.1–4.4, $p = 2.5*10^{-8}$).

One meta-study found a doubled risk of brain cancer when cell phones are used ipsilaterally (cell phone use on same side as tumor location) for 10 or more years, OR = 2.0, 95% CI = 1.2–3.4 (Hardell et al., 2008). Another meta-study found for $>$ 10 years of ipsilateral use nearly doubled for risk of brain cancer, OR = 1.9, 95% CI = 1.4–2.4 (Khurana et al., 2009).

The overall Principal Investigator (PI) of the Interphone Study, Dr. Elizabeth Cardis, along with the Israeli Interphone PI, Dr. Siegal Sadetzki, published a commentary, *Indications of possible risk in mobile phone studies: should we be concerned?* Based on the evidence of increased brain tumor and acoustic neuroma risk, they concluded, "Simple and low-cost measures, such as the use of text messages, hands-free kits and/or the loud-speaker mode of the phone could substantially reduce exposure to the brain from mobile phones. Therefore, until

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definitive scientific answers are available, the adoption of such precautions, particularly among young people, is advisable" (Cardis and Sadetzki 2011).

These findings and more resulted in the International Agency for Research on Cancer (IARC) finding that RF radiation (30 kHz–300 GHz) is a Class 2B carcinogen ("a possible human carcinogen") (Baan et al., 2011). RF sources include: cell phones, cordless phones, Bluetooth, amateur radio, cell phone base stations, wireless routers, Wi-Fi, Wi-Max, baby monitors, and Smart Meters.

Salivary Gland Tumors

An Israeli Interphone study found a significant risk for parotid gland tumors (a salivary gland in the cheek, below the ear) from > 266.3 cumulative hours of ipsilateral cell phone use, OR = 1.49, 95% CI = 1.05–2.13, with the heaviest users (>4,479 cumulative hours) having more than a two-fold increased risk of non-malignant parotid gland tumors, OR = 2.42, 95% CI = 1.14–5.11 of this tumor (Sadetzki et al., 2008).

A Swedish Interphone study of parotid gland tumors found a borderline significant risk for ≥10 years of ipsilateral use, OR = 2.6, 95% CI = 0.9–7.9, p = 0.078 (Löon et al., 2006).

Scientists working with the Israeli Dental Association in 2009 reported "a sharp rise in the incidence of salivary gland cancer in Israel that researchers believe may be linked to the use of mobile phones . . . Among salivary gland cancer cases, researchers found a worrying rise in the number of cases of malignant growth in parotid glands." "Most oral cancer patients were over 70, with only 2.7 percent under the age of 20." (Even, 2009).

From 1970–2001, parotid gland tumors in Israel had averaged 37 cases per year. From 2002–2006, the cases increased by 65% to an average 61 cases per year (Czerninski et al., 2011). Fig. 1 from this study shows the number of cases per year for the 3 types of salivary gland tumors (parotid, submandibular, and sublingual glands) with smoothed trend lines. Only the parotid gland trend line grew over time. However, the figure suggests a break-point analysis would be even more informative as the data suggest a flat trend from 1970 to the early 1990s, and then a sharp upward linear trend afterwards.

Male Fertility

There is a robust and growing literature in both animals and humans that chronic exposures to cell phone radiation, far below existing standards significantly impairs sperm morphology, motility, viability, and count. Often, the mobile phone is placed in the trouser pocket which may lead to significant exposure of the scrotum in men.

One human study found a significant 59% decline in sperm count in men who used cell phones for four or more hours per day as compared with those who did not use cell phones at all (Agarwal et al., 2008). Included in their study were deleterious effects on sperm viability, motility, and morphology (Agarwal et al., 2008).

A study from Hungary found deterioration of human sperm motility associated with self-reported cell phone radiation exposure (Fejes et al., 2005). An Australian study found genotoxic effects on mice sperm (Aitken et al., 2005), while other studies from this group have reported similar effects on human sperm.

A recent study of mice exposed for 6 months to cell phone base station radiation reported, "The exposure of male mice to radiofrequency radiations from mobile phone (GSM) base stations at a workplace complex and residential quarters caused 39.78 and 46.03%, respectively, in sperm head abnormalities compared to 2.13% in control group. Statistical analysis of sperm head abnormality score showed that there was a significant ($p < 0.05$) difference in occurrence of sperm head abnormalities in test animals. The major abnormalities observed were knobbed hook, pin-head and

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FIGURE 1 SAM Phantom. Source: Speag Phantom Product Flyer. "CTIA" is Cellular Telecommunications Industry Association.

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banana shaped sperm head. The occurrence of the sperm head abnormalities was also found to be dose dependent" (Otitoloju et al., 2010). The researchers reported sperm abnormalities at 489 mV/m (workplace), and 646 mV/m (residential) compared to exposure limits of 41,000 mV/m and 58,000 mV/m, respectively (ICNIRP, 1998).

Lastly, a study of human sperm warns, "RF-EMR in both the power density and frequency range of mobile phones enhances mitochondrial reactive oxygen species generation by human spermatozoa, decreasing the motility and vitality of these cells while stimulating DNA base adduct formation and, ultimately DNA fragmentation. These findings have clear implications for the safety of extensive mobile phone use by males of reproductive age, potentially affecting both their fertility and the health and wellbeing of their offspring" (De Iuliis et al., 2009).

Leukemia

Two studies have found that chronic cell phone use increased the risk for leukemia. Adjusting for leukemia risk factors, including benzene, solvents, pesticide exposures at work or home, and working or living near power lines, a study in Thailand, found a 3-fold risk of leukemia from GSM cell phone use (OR = 3.0, 95% CI: 1.4–6.8) and more than a 4-fold risk for any lymphoid leukemia (OR = 4.5, 95% CI: 1.3–15) (Kaufman et al., 2009).

A British study found borderline significant risks of leukemia from >15 years of cell phone use for acute myeloid leukemia (AML), OR = 2.08, 95% CI = 0.98–4.39, p = 0.051, and for all leukemia, OR = 1.87, 95% CI: 0.96–3.62, p = 0.060 (Cooke et al., 2010).

TWO CELL PHONE SAR CERTIFICATION PROCESSES

The SAM Cell Phone Certification Process

Specific Anthropomorphic Mannequin (SAM) is a plastic head mannequin (Beard and Kainz, 2004), based on the 90th percentile of 1989 United States military recruits (Gordon et al., 1989). While the exposure limit standard considered body sizes "from small infant to large adult," (ANSI, 1982, p. 14) only a large adult male that weighed about 220 lb (100 kg) and was 6 foot 2 in (188 cm) in height was used for cell phone compliance testing.

The SAM cell phone certification process uses:

(1) a plastic head mannequin with an opening at the top of the head (Fig. 1);
(2) a liquid whose electrical permittivity and conductivity parameters are equivalent to the average electrical parameters of the 40 tissue types in a head;
(3) a robotic arm (Fig. 2) with a small electric field probe attached (the effective 3-dimensional resolution is limited by the dimensions of the probe).

For cell phone certification a liquid is poured into the head with the average permittivity and conductivity of the head tissues. A cell phone is affixed to either side of the mannequin with a tapered flat spacer used instead of the ear, and the robotic arm measures the electric field within the volume of the mannequin with a resolution of somewhat better than 1 cm^3. The SAR values are calculated from the electric field measurements along with the 3-D location of each measurement and the properties of the liquid. The resulted SAR value has a tolerance of $\pm 30\%$ (IEEE 2003, p. 55). Thus a cell phone certified at the exposure limit of 1.6 W/kg could be as large as 2.08 W/kg.

The Computer Simulation Certification Process

For the computer simulation certification process, the revised FCC Supplement C publication states, "Currently, the finite-difference time-domain (FDTD) algorithm is the most widely accepted computational method for SAR modeling. This method adapts very well to the tissue models that are usually derived from MRI or CT scans such as those currently used by many research institutions. The FDTD method offers great flexibility in modeling the inhomogeneous structures of anatomical tissues and organs (Means and Chan, 2001, p. 13)."



FIGURE 2 Robotic arm with electric field probe. Source: Speag DASY 52 Info Sheet.

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The Food and Drug Administration (FDA), which has ultimate responsibility for U.S. cell phone safety, has a "Virtual Family" based on MRI scans that indicate different brain tissue properties for use with computer simulation. "Family" members currently include: a 5-year old girl, a 6-year old boy, an 8-year old girl, an 11-year old girl, a 14-year old boy, a 26-year old female, a 35-year old male, an obese male adult, and 3 pregnant women with fetuses at 3rd, 7th, and 9th months of gestation. Additional "family" members are under development (Christ et al., 2010b). "[T]he Virtual Family is already used by more than 200 research groups worldwide." (http://www.itis.ethz.ch/research/virtual-population/virtual-population-project/, accessed 28 Dec. 2010).

Fig. 3 illustrates the members of the "Virtual Family."

"The development of the [Virtual Family] models was carried out in cooperation with the Center for Devices and Radiological Health of the U. S. Food and Drug Administration (FDA), Silver Spring, MD, USA; the Austrian Research Centers GmbH, Seibersdorf, Austria; the University of Houston, TX, USA; the Hospital of the Friedrich-Alexander-University (FAU), Erlangen, Germany; and Siemens Medical Solutions, Erlangen, Germany" (http://www.itis.ethz.ch/services/population-and-animal-models/population-models/, accessed December 10, 2010).

The FCC also regulates medical implants in concert with the FDA. Because metal implants can interact with exogenous electromagnetic fields, computer simulation is also used to calculate resultant interactions.

In order to use the FDTD computer simulation process to certify that cell phones meet the SAR exposure standards the FDTD computer simulation model of the cell phone submitted for certification is required. Because such models are required for product development, they are available.

RESULTS (SAM CELL PHONE CERTIFICATION PROCESS IN COMPARISON TO FDTD COMPUTER SIMULATION PROCESS)

Because any head size smaller than SAM receives a larger SAR, children receive the largest SAR relative to adults modeled with the SAM process. Gandhi et al. (1996) reported that for 5- and 10-year old children, using only head size differences compared to an adult, the children's SAR was 153% higher than adults. Wiart et al. (2008) employed MRI scans of children between 5 and 8 years of age and found approximately 2 times higher SAR in children compared to adults, and Kuster et al. (2009) reported that the peak SAR of children's CNS tissues is "significantly larger ($\sim$2x) because the RF source is closer and skin and bone layers are thinner." de Salles et al. (2006), using scans of a 10-year old boy's head with children's electrical tissue parameters found that differences in head size and other parameters increased the SAR by 60% compared to an adult. Peyman et al. (2001) found the relative permittivity of an adult brain was around 40 while a young child's brain is from to 60–80, resulting in a child's SAR being 50–100% higher than an adult's independent of head size. Han et al. (2010) provided additional analyses of the underestimation of spatial peak SAR with the SAM process.



FIGURE 3 The Virtual Family. http://www.itis.ethz.ch/services/population-and-animal-models/population-models/ (accessed December 10, 2010).

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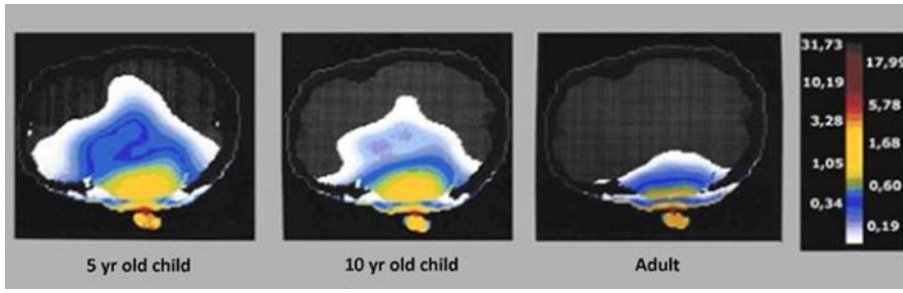


FIGURE 4 Depth of absorption of cell phone radiation in a 5-year old child, a 10-year old child, and in an adult from GSM cell phone radiation at 900 MHz. Color scale on right shows the SAR in Watts per kilogram (Gandhi et al., 1996).

Not only are children exposed to a higher SAR, but also the relative volume of the exposed and still developing child's brain is far greater than in adults. Fig. 4 shows the depth of the cell phone's radiation absorption into the brain is largest for the 5-year old penetrating far beyond the mid-brain. For 10-year old children the penetration of radiation is less, but still beyond the mid-brain, and for the adult, the penetration is much less, and ends well before the mid-brain (Gandhi et al., 1996).

Of course, while no models have been developed for toddlers or infants who may be using or playing with cell phones today, their absorption would be even greater than that of a 5-year old, because their skulls are yet thinner and their brains are yet more conductive and far less developed.

A recent study (Christ et al., 2010a) details the age dependence of electrical properties on the brain, concluding that:

> "Exposure of regions inside the brains of young children (e.g. hippocampus, hypothalamus, etc.) can be higher by more than 2 dB–5 dB [1.6–3.2 times] in comparison to adults."
>
> "Exposure of the bone marrow of children can exceed that of adults by about a factor of 10. This is due to the strong decrease in electric conductivity of this tissue with age."
>
> "Exposure of the eyes of children is higher than that of adults."
>
> "Because of differences in their position with respect to the ear, brain regions close to the surface can exhibit large differences in exposure between adults and children. The cerebellum of children can show a peak spatial average SAR more than 4 dB [2.5 times] higher than the local exposure of the cortex of adults."

Increased exposure to the eyes and cerebellum was suggested in a 1998 study of far-field exposures at resonant frequencies to the head and neck (Tinnisword et al., 1998). The authors noted, "[T]he highest absorption is in the neck as the currents generated in the head have to flow into the body through the constricted volume of the neck concentrating them (i.e., increasing the current density) and as a result increasing the SAR." A figure (see figure 5 below) from this article suggests that there is a significantly increased SAR to the thyroid gland.

However, with a dearth of U.S. research funds provided for cell phone research, no studies have examined the exposure of the thyroid gland when using a cell phone.

Another study analyzed relatively greater absorption of children and adults smaller than SAM and concluded, "The results suggest that the recommended ICNIRP reference levels need to be revised" (Bakker et al., 2010), and proposed "fine-tuning" the ICNIRP guidelines.

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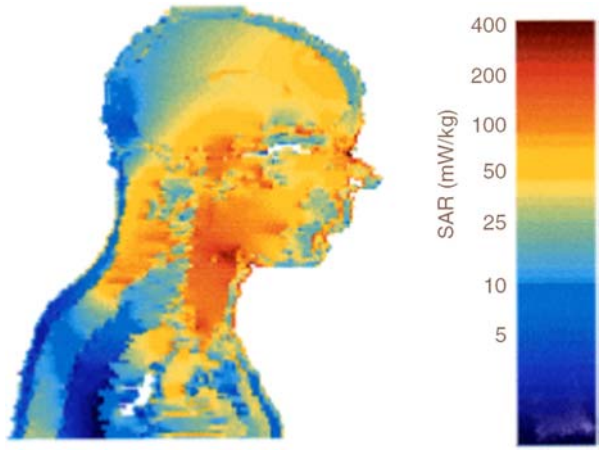


FIGURE 5 The SAR distribution in the head and neck at 207 MHz under isolated conditions. Far-field power density = 1 mW/cm^2 (adapted from Figure 6; Tinniswood et al., 1998).

The spacer used to imitate the ear in the SAM mannequin also results in an underestimation of the SAR. Radiation decreases as the square of the distance from the antenna increases in the far field, and in the near field, radiation decreases as the cube of the distance from the antenna increases. This means that even a small increase in distance has a large effect. Gandhi and Kang (2002) found that incorporating a plastic ear model (or "pinna") with a 10 mm spacer gave artificially lowered SARs, which are up to two or more times smaller than for realistic anatomic models that hold cell phones directly to the ear. In two studies, the use of plastic spacers results in an underestimation of the SAR by up to 15% for every additional millimeter of thickness of such spacers (Gandhi and Kang, 2002, 2004).

"A mobile phone compliant with the ICNIRP standard of 2.0 W/kg SAR in 10 g of tissue may lead to a 2.5 to 3 times excess above the FCC standard of 1.6 W/kg in 1 g of tissue (i.e., 4–5 W/kg in a cube of 1 g of tissue)" (Gandhi and Kang, 2002).

When the back of a cell phone (typically where the transmitting antenna is located) was placed in a shirt pocket while using a cell phone with a headset, a 2002 study found that the SAR increased by up to 7-fold (Kang and Gandhi, 2002). This suggests when a cell phone is in a shirt pocket the surface of the heart muscle closest to the skin could be absorbing substantial cell phone radiation.

Table 1, adapted from Table 2 of Han et al. (2010), summarizes the various findings. ICNIRP, based on its 1998 Guidelines, relies on a larger 10-g volume and a higher 2 W/kg SAR for limiting brain exposures compared to the FCC's 1-g standard.

DISCUSSION

The FDTD computer simulation process, based on MRI/CT scans, employs anatomically correct head sizes, and allows for inclusion of 80 tissues types with accurate 3-dimension locations, with the electrical properties of each tissue type used to calculate the cell phone's SAR to a resolution of 1 mm^3 or better.

In contrast, the SAM process, uses a large male head, and assumes the inside of human head is homogenous via a liquid with the average electrical properties of the head. Of course a real head has an ear, not a 10 mm plastic spacer. For this reason the consumer booklets with the information of the functions, etc. of the mobile phone usually contain a page with safety information stating that the phone must not be placed closer than 10 or 15 or even 25 mm to the body. Because the

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TABLE 1 Summary of the results confirming that children absorb more radiated electromagnetic energy from cell phones resulting in higher specific absorption rate (SAR) as compared to adults (adapted from Table 3, Han et al 2010).

Author, Year	Highlights of results
Gandhi et al. (1996)	Deeper penetration of absorbed energy for models of 10- and 5-year old children; peak 1-g SAR for children up to 53% higher than adults.
Wiart et al. (2008)	1-g SAR of brain tissues of children is about two times higher than adults.
Kuster (2009)	Spatial peak SAR of the CNS of children is " significantly larger (~2x) because the RF source is closer and skin and bone layers are thinner"; " bone marrow exposure strongly varies with age and is significantly larger for children(~10x)"
DeSalles et al. (2006)	The 1-g SAR for a 10-year old boy is about 60% higher than for the adults.
Peyman et al. (2001)	Children's SAR is 50–100% higher than an adult's SAR.
Christ et al. (2010a)	Hypocampus and hypothalamus receive 1.6–3.1 higher SAR in children compared to adults; children's bone marrow receive 10 times higher SAR than adults; children receive higher SAR to the eyes than adults; children's cerebellum receive > 2.5 time higher SAR than adults.
Tinnisword et al. (2008)	Far-field whole body SAR highest in neck particularly where thyroid gland is located.
Bakker et al. (2010)	Recommended ICNIRP reference levels be revised
Kang and Gandhi (2002)	Up to 7 times SAR when back of cell phone in a shirt pocket is closest to skin.
Gandhi and Kang (2002)	10 mm spacer on SAM artificially lowers SAR. Deeper penetration of absorbed energy for smaller heads typical of women and children; peak 1-g SAR for smaller heads up to 56% higher than for larger heads.
	Plastic spacer used on SAM for ear (or pinna) decreases SAR by 15% per millimeter.
	ICNIRP's 2 W/kg, 10 g spatial peak SAR results in 2.3–3 times high SAR than FCC's 1.6 W/kg, 1 g spatial peak SAR
Wang and Fujiwara (2003)	Compared to peak local SAR in the adult head, we found "a considerable increase in the children's heads."
Martinez-Burdalo et al. (2004)	As head size decreases, the percentage of energy absorbed in the brain increases; so higher SAR in children's brains can be expected.

10 mm plastic spacer used in testing artificially lowers the calculated SAR for every phone, these booklets make no statement about keeping the device at a distance from the head.

The existing SAR cell phone certification process systematically underestimates exposure for any head smaller than SAM model, and also assumes that the head is homogenous. In fact, tissues and organs in the head vary substantially in density and capacity to absorb radiation and this variation changes inversely with age of children. Only 3% of the U.S. population has a head the size of SAM and no one has a uniformly consistent brain with dielectrically homogenous tissue. Adoption of the FDTD approach would generate standards that reflect the anatomic properties of the brain and correct for this systematic underestimation of the SAM cell phone certification process. Table 2 compares attributes of the SAM cell phone SAR certification process and the FDTD computer simulation cell phone SAR certification process.

For all of the reasons presented in this analysis, the existing cell phone SAR certification process does not adequately protect 97% of the population, i.e., those with heads smaller than SAM. Because children absorb more cell phone radiation than adults, this lack of adequate protection is even of more concern with their growing use of cell phones.

In addition, to these major problems, contemporary cell phones do not comply with the existing certified SAR value when held directly at the head or kept in a pocket. According to manufacturers' advisories, cell phones can exceed the FCC exposure guidelines as commonly used. Here are some examples of manufacturer's warnings:

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TABLE 2 Comparison of cell phone certification processes.

Attribute	SAM Process	FDTD Process	Comments
Children's exposures	No	Yes	Male & female, multiple ages
Pregnant women's exposure	No	Yes	1, 3 & 9 months
Female exposure	No	Yes	
Small male exposure	No	Yes	
Large male exposure	Yes	Yes	
Electrical tissue parameters	Average of all tissues	Specific for each tissue	
3-D Resolution	1 cm^3	1 mm^3	
Relative cost	High	Low	
Medical implant modeling	No	Yes	
Testes exposure	No	Possible	
Eye exposure	No	Possible	
Thyroid gland exposure	No	Possible	

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(1) BlackBerry Torch: "To maintain compliance with FCC, IC, MIC, and EU RF exposure guidelines when you carry the BlackBerry device on your body, ... keep the BlackBerry device at least 0.98 in. (25 mm) from your body ..." "To reduce radio frequency (RF) exposure ... keep the BlackBerry device at least 0.98 in (25 mm) from your body (including the abdomen of pregnant women and the lower abdomen of teenagers ...," i.e., implicitly indicating the importance of keeping it away from teenage boys' testicles (BlackBerry, 2010, p. 23).
(2) Nokia 1100: "This product meets RF exposure guidelines ... when positioned at least 1.5 cm away from the body ... and should position the product at least 1.5 cm away from your body." (Nokia, 2003, p. 63)
(3) Motorola V195 GSM: "keep the mobile device and its antenna at least 2.5 cm (1 in) from your body." (Motorola, 2008, p. 70)

The FCC directive states, "For purposes of evaluating compliance with localized SAR guidelines, portable devices should be tested or evaluated based on *normal operating positions* or conditions (Cleveland et al., 1997, p. 42)." [emphasis added] In fact, phones are only tested with a spacer next to the ear or hip and are not tested in the ways that people commonly operate them, i.e., in their trouser or shirt pockets. Moreover, no tests simulate use by the 97% of the population with heads smaller than SAM.

The 5-fold reduction in SAR exposure limits for the general population in the IEEE standard, and adopted by the FCC, was intended to protect the most "sensitive": "infants, aged, the ill and disabled." However, no such reduction exists when SA is considered.

Finally, The FDTD resolution of brain tissues and organs is by three orders of magnitude higher than the resolution of SAM (the dimensions of the electric field probe cannot be made much smaller without losing too much sensitivity). There is a need to protect the most "sensitive" users because, due to curvature of tissue layers but also due to differences in dielectric properties of adjacent tissues and their geometry, "hot spots" (small brain volumes with intense energy absorption), the result of focusing, could occur.

CONCLUSIONS

(1) Because, the SAM-based cell phone certification process substantially underestimates the SAR for 97% of the population, especially for children, the SAM-based certification process should be discontinued forthwith.

(2) An alternative FDTD computer simulation cell phone certification process is immediately available and provides three orders of magnitude higher resolution than the SAM-based system for the head.
(3) The anatomically based "Virtual Family" includes sensitive groups such as small children, pregnant women, and the fetus.
(4) Advisories found in cell phone manuals violate the FCC compliance guidelines, because they do not take into account customary use of phones in pockets and held directly next to the head.
(5) The SAM-based cell phone certification process is unable to address exposure to sensitive tissues such as the testes or the eyes, while the FDTD method can addresses exposures to such sensitive tissues.
(6) Because billions of young children and adults with heads smaller than SAM are now using cell phones extensively, and because they absorb proportionally greater cell phone radiation, it is essential and urgent that governments around the world revise approaches to setting standards for cell phone radiation, to include sufficient protection of children.
(7) Cell phone for which SAR values were certified prior to June 2001 were not required to be replicatable between different certification facilities (see "December 1997") above.

We have shown that children and small adults absorb significantly more cell phone radiation than SAM estimates. Accordingly, contemporary cell phone standards for all of the world's more than five billion cell phones do not protect the young or the 97% of the population with heads smaller than SAM. Until SAR standards have been revised, Israel (Azoulay and Rinat 2008), Finland (YLE.fi 2010), France (Lean, 2010), India (India eNews, 2008), and the U.K (BBC, 2000) recommend limited use by children, using wired headsets, hands-free kits, texting, and keeping the mobile phone away from the head and from the body to substantially lower exposures with current cell phones.

Governments all over the world should urgently require that industry sell cell phones that work only with headsets (sans speakers and microphones). Then users would have to employ wired or other hands free devices for headphones with the result that the cell phone would be kept away from their heads while talking on cell phones.

The long-term impact of cell phone radiation is a matter that merits major research investment and serious public scrutiny. Anatomically based models should be employed in revising safety standards for these ubiquitous modern devices. Standard setting should not be the province of non-governmental, non-accountable agencies, such as ICNIRP which has been heavily funded by industry, but should be carried out by governmental agencies accountable to the public or by independent experts accountable to governments.

Declaration of Interest
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