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Children Absorb Higher Doses of Radio Frequency Electromagnetic Radiation From Mobile Phones Than Adults

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ABSTRACT The greater vulnerability of children to the effects of environmental hazards has raised concerns about their exposure to and the resultant absorption of mobile phone radiation. Foster and Chou (2014) reviewed published studies that used computer models of radio-frequency electromagnetic fields to estimate and compare the tissue dose rate in the heads of children and adults using mobile phones. Their review confuses exposure with absorption, and the study results conclude erroneously that children are not more exposed than adults. We show that their review was not executed systematically. There are discrepancies between text summaries and the graphed ratios of child: adult peak special specific absorption rate, in line with the author's hypothesis that children have the same or lower tissue dose than adults. Even the underlying precept of their review is flawed, as the results of deterministic models are treated as random variables. In fact, model results are entirely determined by the underlying assumptions and the structure of the model. Models are included in their unsystematic review that do not consider differences in dielectric constants among different tissues, or across ages, while other models that consider such differences are not included. In this paper, we discuss the differences between exposure and tissue absorption and re-examine the results presented by Foster and Chou. Based upon our review, we suggest an alternative interpretation of the published literature. In an Appendix, we discuss modeling of tissue dose in the context of governmental safety certification processes.

INDEX TERMS Blood-brain-barrier (BBB), certification process, children, dosimetry, exposure-limits, EMR (electromagnetic radiation), FACTS (**F**inite difference time domain **A**natomically **C**orrect **T**issue **S**pecific), FDTD (finite-difference, time-domain), RF (radio frequency) SAM (specific anthropomorphic mannequin), SAR (specific absorption rate), virtual family (VF), WTDs (wireless transmitting devices).

I. INTRODUCTION

In recognition of the unique sensitivity of children to environmental health hazards, the U.S. Environmental Protection Agency, in 1996, adopted a National Agenda to Protect Children's Health from Environmental Threats [1], and in 1997 established an Office of Children's Health [2] dedicated to determining how to ensure that environmental policies adequately protect children. Although considerable attention has been paid to reducing chemical hazards in environments frequented by the young, relatively little focus has been applied to physical hazards such as those posed by radio-frequency electromagnetic radiation (RF-EMR) emitted by mobile phones and other wireless transmitting devices (WTDs).

To the extent that RF-EMR poses a risk, is that risk uniquely elevated in children? Foster and Chou [3] argue that children have the same exposure to the brain as adults, and face equal risks, based on their review of studies comparing the intracranial dose rates of absorbed RF-EMR in adults and children. Others, for example Gandhi [4], contend that children have proportionally greater intracranial peak tissue dose given their thinner skulls and the higher water content of their cerebral tissues. Moreover, the rapid rate of growth and development, and incomplete myelination of the brain, make children uniquely susceptible to the effects of radiation [5], [6].

The current study considers the methods used by Foster and Chou [3] to identify and abstract data from relevant studies. The results of these studies, as presented by Foster and Chou, were examined in detail in an effort to understand why their conclusions differ from those drawn by other authors.

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II. EXPOSURE VERSUS DOSE

The distinction between exposure and dose is fundamental to environmental health research. When considering a potentially toxic substance, exposure is the amount of that substance that is ingested, inhaled, or deposited on the body. In the case of radiation, such as RF-EMR, exposure is the duration and intensity of radiation that reaches the surface of the body. The term "tissue dose," on the other hand, refers to the amount of radiant energy absorbed by a specific tissue, and the "dose rate" is the energy absorbed per unit time.

The Specific Absorption Rate (SAR), which is the focus of the Foster and Chou analysis, is a measure of the tissue dose rate of microwave radiation, *not* exposure. The dose is the specific absorption (SA), typically measured in Joules per kilogram (J/kg). The reports assembled by Foster and Chou compare estimated dose rates in the heads of adults and children using simulation models that, by design, have the *same exposure*. Thus the flaws in this paper begin with its title, "*Are Children More Exposed to Radio Frequency Energy From Mobile Phones Than Adults?*" This is an important question, but the topic their paper actually reviews should be restated as: are peak RF-EMR doses from mobile phones higher in children than adults? Thus, the paper's title conflates exposure and dose.

III. REVIEW METHODOLOGY

Recognizing that this is an article on tissue dose rate, the following section considers whether Foster and Chou provide a systematic, comprehensive, meaningful, and objective review consistent with current scientific practice.

A literature review, whether qualitative or quantitative, involves, at a minimum, three principal steps: 1) literature search and report selection, 2) abstraction of study attributes and results, and 3) analysis of abstracted data. The use of meta-analysis is desirable whenever possible [7]–[9].

A. STUDY SELECTION

The validity of a scientific review is rooted in the comprehensive identification of relevant research. Missing or excluding potentially relevant studies opens the door to bias, but bibliographic search strings and methods used to assemble the Foster and Chou review were not presented. Studies were selected "that permit a direct comparison of SAR in heads of children and adults from use of mobile phones ... limited to dosimetric issues [of] age-related differences ... [3]." Twenty-three studies were reviewed, all of which use finite difference time domain (FDTD) calculation methods.

The major differences among the selected studies involve the design of the simulation models, which have evolved steadily with the growth in computing power. Early models were relatively simplistic, using spheres [10] and cylinders as crude approximations of the human head. All of these early models required the simplifying assumption that human tissue was a uniform, undifferentiated substance, characterized by a single set of dielectric constants, and child head models were merely scaled down adult models. As a result, the only differences between the tissue dose in adult and child models resulted from either the position of the phone or the penetration into additional anatomical regions resulting from the smaller head size. Refinements in recent years using the Talairach atlas (available since 1988) allow for model improvements based on high-resolution characterization of brain tissues, including adjustments for higher water content in younger brains, which, as a result, absorb RF-EMR more avidly [11].

In 2005, investigators at the U.S. Food and Drug Administration working together with researchers at the Swiss IT'IS Foundation developed a set of digital human models of the entire body, not just the head, with organs and tissues in anatomically correct locations [12]. These models, which became known as the Virtual Family (VF), incorporated tissue-specific parameters for conductivity and permittivity, and a series of researchers have introduced other **F**DTD **A**natomically **C**orrect, **T**issue **S**pecific (FACTS) models [13].

By coupling data from high-resolution MRI scans of a broad range of subjects, researchers around the world, including teams in Brazil [14] and Korea [15], have added to the library of available FACTS models. Currently the VF has more than a dozen different models, including male and female children of various ages, men, women and even pregnant women at 1, 3, 7 and 9 months gestation [13]. Additional models continue to be introduced. Absorption related parameters are derived from empirical measurements of dielectric parameters in animal tissues of various ages immediately after death. The models and WTD antennae can be configured in any possible position, to predict the effects of exposure of tissues of various sensitivities.

Foster and Chou acknowledge that, prior to the introduction of FACTS models, simulations "were not designed to explore the effects of human variability on SAR, which on the basis of [36] and other studies are considerable."

Despite the fact that this statement seems to suggest that these older models would not be suited to identifying differences in tissue dose, Foster and Chou included many such studies. Of the 22 distinct studies (2 are companion studies [24], [25]) in their Table 2, only ten used FACTS models [20]–[24], [26], [28], [29], [31], [35]. Foster and Chou lumped these FACTS models together with ten older, less sophisticated models spanning 19 years (1994-2012), which simply used scaled down, non-FACTS models of adult heads to model children without any consideration for the models' limitations.

B. DATA ABSTRACTION

To summarize a series of studies concisely, reviewers must distill the findings of any particular study into a few numbers. If the process of abstracting three or four statistics to characterize an entire paper is not done according to a clear, systematic protocol with meticulous attention to detail, a strong potential for bias is introduced.

The papers that were selected by Foster and Chou reported modeling exercises that differed in important ways.

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TABLE 1. Comparisons of qualitative study results from Foster and Chou [3] as summarized in their Table 2 and the quantitative results depicted in their Figure 1.

Papers Listed in Foster and Chou Table 210.5		Child/Adult Tissue Dose from Foster and Chou Table 2	Child/Adult psSAR based on Foster & Chou, Figure 1 [3]				Model Adult/Child (ages)*
			$psSAR_{1g}$		$psSAR_{10g}$		
Year	Authors		Low Band	High Band	Low Band	High Band	
1996	Gandhi 5 y [16]	>1	1.5	0.9	NR	NR	MRI/Scaled†
	Gandhi 10 y	>1	1.1	0.8	NR	NR	
2002	Gandhi & Kang [17]	>1	0.95	0.75	NR	NR	MRI/Scaled
2003	Anderson et al. [10]	>1	1.3	NR‡	1.25	NR	3-layers spherical
2003	Wang & Fujiwara [18]	>1	1.25	NR	1.25	NR	MRI/Scaled
2005	Hadjem et al. [19]	>1	0.75	0.9	0.95	0.85	MRI/MRI & Scaled
2005	Wiart et al. [20]	>1	0.95	0.9	0.9	1.05	FACTS/MRI & Scaled
2006	de Salles et al. [14]	>1	1.6	1.7	1.15	1.65	?/Scaled
2008	Wiart et al. [21]	>1	0.9	0.6	1.25	1.05	FACTS/FACTS
2011	Wiart et al. [22]	>1	Excluded from Figure 1				FACTS/FACTS (Fetus, 5, 8, 12)
2012	Lu & Ueno [23]	>1	Excluded from Figure 1				FACTS/FACTS (6,11)
2010	Christ et al. [24], [25]	>1	NR	1.1§	NR	NR	FACTS/FACTS
1998	Schönborn et al. [26]	≅1	1.1	0.95	0.95	1.05	FACTS/MRI (3, 7)
2005	Bit-Barbik et al. [27]	≅1	0.9	NR	0.95	NR	?/Scaled
2005	Christ et al. [28]	≅1	NR	NR	0.95	1.1	FACTS/FACTS (3)
2009	Peyman et al. [29]	≅1	Excluded from Figure 1				FACTS/FACTS (3, 7), walkie-talkie
2010	Hadjem et al. [30]	≅1	Excluded from Figure 1				NR / NR (9, 15)
2011	Keshvari&Heikkila[31]	≅1	0.9	0.5	0.75	0.75	FACTS /Scaled
1994	Dimbylow&Mann[32]	≅1	1.05	0.75	0.95	0.75	Phantom/Scaled
2002	Lee et al. [33]	<1	0.9	1.0	0.9	1.0	MRI & CT/ Scaled (5 ages)
2006	Beard et al. [34]	<1	1.0	0.8	0.75	0.75	1 phantom; 2 MRI/ Scaled?
2004	Martinex-Burdalo et al[35]	Unclear	0.9	1.0	0.9	1.0	MRI/ Scaled
2005	Keshvari & Lang [36]	Unclear	NR	NR	0.6	0.75	FACTS/Scaled (2)

* This column describes the technique used to generate the adult model/child model. MRI=model anatomy generated from MRI, FACTS model is a FDTD Anatomically Correct Tissue Specific Model. Where relevant, the age of the child used to generate models is listed.
† Child model scaled proportional to an adult model.
‡ Not reported.
§ Table 2 of Foster and Chou lists two studies with this author for 2010 [24], [25], but only one description mentions a specific comparison of child and adult doses. We have assumed this is the paper referenced in their Figure 1.

These include: the precise positioning and nature of the radiation source; the ages of the simulated heads; the degree to which different tissue characteristics are considered (if at all); and most importantly, the specific choice of anatomical simulation model. A table summarizing these variables for the collection of studies would have been extremely informative.

Table 1 of the current paper summarizes the literature selection, modeling designs and summary of results depicted Figure 1 and Table 2 of Foster and Chou [3].

C. INCONSISTENCIES BETWEEN TABLE 2 AND FIGURE 1 IN FOSTER AND CHOU

Comparison of Foster and Chou's Table 2 and Figure 1 suggests a pattern of inconsistencies and errors in extracting information. Although their Table 2 includes almost no numerical data, a careful reading of the text summaries allows classification of most studies according to which age group had a higher peak tissue dose rate. Based on these determinations, as shown in Table 1 of this paper, 11 of 22 distinct studies [10], [14], [16]–[24] concluded tissue doses were higher in children, 7 found no difference [26]–[32] and only 2 found higher doses in adults [15], [33]. In 2 cases the text summaries were unclear [34], [35]. In other words, studies reporting higher doses in children outnumber those reporting higher doses in adults by a ratio of more than five to one, according to the text summaries of the study results provided by Foster and Chou in their Table 2.

Figure 1 from Foster and Chou does not accurately reflect the information provided in their Table 2. Figure 1 from their paper depicts 57 ratios of child/adult psSAR as abstracted from 19 studies. Of these values, 14 (25%) indicate higher peak dose in children, 17 (30%) found little or no difference (0.95 – 1.05), and 26 (46%) found higher peak dose in adults. Of all the values in Figure 1 from Foster and Chou [3], 60% were greater than 1.00. Yet, according to Table 2, the percentage of studies that concluded that psSAR was higher in

children was 57% while only 10% concluded that doses were higher in adults. Figure 1 indicates psSAR ratios both above and below unity for many studies, yielding ambiguous results. For two studies summarized as reporting higher absorption in children, all of the values in their Figure 2 represent higher peak dose in adults [17], [19]. Because the authors did not pool results quantitatively, the reader can not make conclusions with respect to whether or not the combined studies suggest the ratio of peak dose for children as compared to adults is significantly different from 1.0.

Four of the studies listed in Table 2 were omitted from Figure 1 including two that found higher doses in children [22], [23] and two that concluded there were no differences between adults and children [29], [30]. The reasons for this omission are unclear.

Wiart et al. [22] stated that peripheral brain tissue had "... higher exposure with children than with adults." Lu and Ueno [23] conclude that "[t]he induced SAR can be significantly higher in subregions of the child's brain." Both of these quotes were taken directly from Table 2 in Foster and Chou, but their Figure 1 shows results from neither paper.

For at least two papers [17], [19], none of the results in Figure 1 from Foster and Chou corresponds to the summary of findings in their Table 2. In referring to Gandhi and Kang [17], their Table 2 states that the model of the child's head has "peak 1 g SARs that may be up to 50-55% higher compared to the SARs for the larger [adult] model particularly for a PCS frequency of 1900 MHz [High Band]." In contrast, the bar graph in Figure 1 shows the ratio of Child/Adult $psSAR_{1g}$ values <1.0 in both the Low and High Bands.

According to Foster and Chou's Table 2, Hadjem et al. [19] estimated that, for two child head models, the peak 10 gm SAR in the brain "is slightly more significant [higher] than that for the adults one." Their Figure 1 implies that adults have higher dosage rates.

In other words, four studies were described in Table 2, but omitted from Figure 1 and at least two other studies had results reported in Figure 1 that were not consistent with Foster and Chou's own description of the results in Table 2. Our Table 1 suggests additional contradictions between their Table 2 and Figure 1.

Readers who rely on the visual summary of findings in Figure 1 will infer that the majority of studies found higher peak doses in adults. Readers diligent enough to sort through the dense text of Table 2, will reach the opposite conclusion.

More important to the issue at hand is that many of the models cited by Foster and Chou do not take into account differences in the dielectric characteristics of the tissues of children, compared with adults [29], [37]. Without this, models only consider children as small adults. This all but assures that there will be little difference in peak tissue dosage between children and adults, except to the extent that children's smaller heads lead to higher doses in particular anatomical regions of the brain when compared to the larger adult head.

D. ANALYSIS OF STUDY RESULTS

There are two approaches to combining numerical results abstracted from a group of comparable individual studies. The first is to employ the statistical models commonly used in meta-analysis, which pool results of experimental studies mathematically using the standard error of the effect estimates. The modeling studies reviewed by Foster and Chou are not experimental, so their results cannot be pooled using standard meta-analytical techniques.

Results from deterministic models, such as those reviewed by Foster and Chou [3], can be systematically compared based on study characteristics. Steady improvements in model sophistication and dramatic increases in memory and processing speed of computers would lead one to expect more accurate results from more recent models. Of the five studies using sophisticated FACTS models for both adults and children and published in the past ten years, four found higher peak dose rates in children.

Of 22 paragraphs devoted to discussing differences among models, Foster and Chou [3] devote nine to an extended discussion of two models that are 14 and 20 years old. Of the fifteen models published in the past ten years, less than half are mentioned in the discussion.

The reason Foster and Chou chose to criticize the work of a particular author is suggested by their discussion of Penetration Depth, in which they focus almost exclusively on Gandhi's 2002 Figure 3 image of RF-EMR absorption in the brain at different ages. They assert, "A similar set of false-color figures ... showed SAR patterns in all three differently sized head models that extended about the same distance into the head." This is true, as would be expected, because the child's head is smaller (scaled down from an adult's head). This study predated FACTS models, which account for differences in dielectric properties between young and older heads. The apparently controversial message of this image is that RF-EMR penetrates proportionally deeper into the brain of a child than an adult. If, as Foster and Chou assert, absorption is the same in the pediatric and adult brains, then the smaller size of a child's head will guarantee higher doses to tissues deeper in the brain. Much of their argument relies on a paper [27], co-authored by Chou in 2005, a ten-year-old study which relies on a simple, scaled down model of the adult head.

IV. DISCUSSION

In their Discussion, Foster and Chou state: "In summary, simple generalizations found on the Internet about 'kids absorbing more RF energy than adults from cell phones aren't supported by available dosimetry studies.'" The textual summaries of study findings, as provided by Foster and Chou in their Table 2, appear to support exactly the opposite conclusion. These 25 words represent the only part of the Discussion section that refers directly to the topic of the paper—the differences between tissue doses in adults and children.

The remainder of their Discussion argues that none of this is relevant because compliance testing (as discussed in

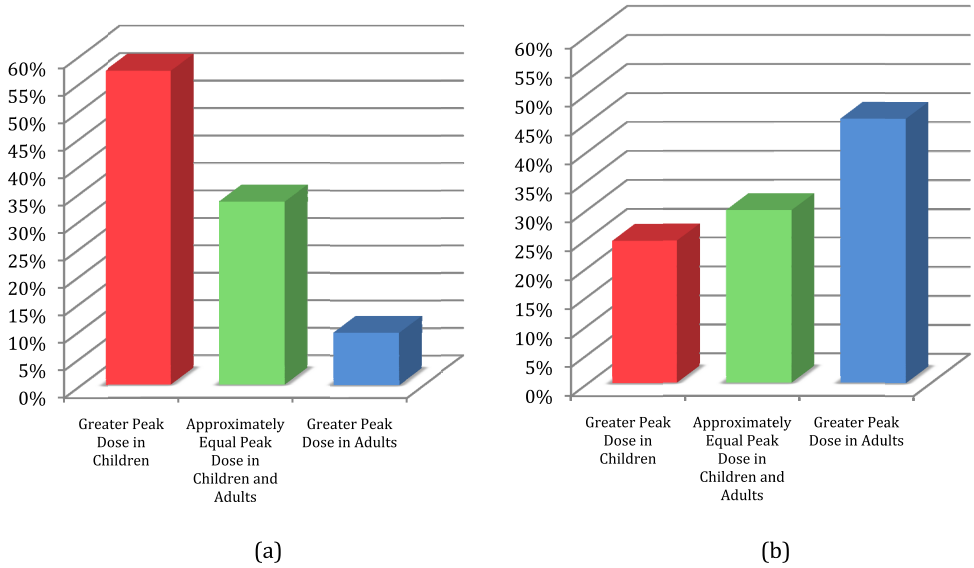

FIGURE 1. (a) Numerical results of original studies as abstracted by Foster and Chou [3]. (b) Summaries of study findings as quoted by Foster and Chou [3].

detail in the Appendix of the current paper) is so susceptible to slight differences in model conditions, particularly phone position, that the calculated tissue doses have no real world relevance. They further argue that worst-case testing grossly overestimates true exposure. These points are, frankly, red herrings and reintroduce the confusion created by the inaccurate title.

Current safety certification of WTDs relies on the Standard Anthropometric Model (SAM), a physical model of an adult head. To draw the conclusion that children have higher doses from a given exposure than adults would both invalidate that certification process and suggest the need for stronger safety standards. This would be expensive and problematic for the telecommunications industry, particularly the makers of WTDs.

The Appendix shows that the current cell phone certification is vastly inferior to an FCC approved FDTD computer simulation certification process that has never been employed to certify phones but is regularly used to evaluate medical devices.

V. CONCLUSION

Foster and Chou [3] review 23 studies that model the penetration and absorption of RF-EMR from cell phones and other MTD's. Figure 1a categorizes the conclusions drawn by the authors of those studies as quoted by Foster and Chou [3]. Based on these summaries, 57% of studies concluded that children had higher peak doses than adults. As shown in Figure 1b, only 25% of the numerical results of these studies as abstracted by Foster and Chou [3] concluded that Children had a higher peak dose.

The chance of this pattern occurring by chance is negligible (p=0.005 based on chi-squared test). There are only two possible alternative explanations for this systematic discrepancy. It is conceivable that the authors of the original studies misrepresented their findings, but the fact that there were many different authors involved and these were all peer-reviewed papers makes this kind of widespread systematic error unlikely. The alternative is that the values abstracted by Foster and Chou do not correctly represent the actual results of these studies.

In response to new evidence documenting children's vulnerabilities to Non-Ionizing Radiation (NIR), the Belgian government has made it illegal to provide a mobile phone to a child age 7 or younger [40]. Similar legislation is under consideration in France, India, Israel and other high-tech nations to reduce exposures to WTDs [41].

Even if children and adults had the same tissue dose for a given exposure, the effects of that same dose on the developing brain of a fetus or young child would almost certainly be greater. Younger brains are faster growing and can therefore be more vulnerable to any toxic agent, whether chemical or physical. In addition, the insulating layer of myelin, which acts to protect nerve cells, is far less developed in the child, the skull is thinner, the immune system is still developing and cells are reproducing far more rapidly than in adults. All of these vulnerabilities increase susceptibility to neurological insult. Neurologists, toxicologists and brain scientists agree that the developing brain is acutely and uniquely sensitive to hazardous exposures [5].

Higher doses in children are even more important in light of evidence that has emerged over the past 15 years suggesting adverse effects from radiofrequency radiation that are completely unrelated to heating. These may include: increased permeability of the blood-brain-barrier (BBB) [42], [43],

genotoxic effects on human cell lines [44], brain cancer [45]–[47], acoustic neuroma [48]–[50], and sperm damage [51]–[53]. In 2013, the World Health Organization's International Agency for Research on Cancer (IARC) classified RF-EMR as a possible (2B) human carcinogen [54].

In light of explosive growth in usage rates and rapid technological change in wireless devices, the American Academy of Pediatrics [55] supports "reassessment of radiation standards for cell phones and other wireless products and the adoption of standards that are protective of children and reflect current use patterns." The U.S. GAO has also recommended that the FCC reassess its exposure limits in light of new evidence [56].

In sum, the review by Foster and Chou suffers from the following weaknesses.

1. There is no clear protocol specified for the identification of studies and the extraction and summary of data.
2. There are major, systematic discrepancies between the summaries of study results in Foster and Chou's Table 2 and the data presented in their Figure 1.
3. The authors spend almost half of their discussion focusing on papers that are more than a decade old, but say nothing about half of the studies published in the past decade, most of which contradict their primary conclusion.

APPENDIX
RF-EMR EXPOSURE LIMITS AND COMPLIANCE TESTING

In order to give some context to the concerns about compliance testing raised by Foster and Chou [3], we present a brief overview of RF-EMR exposure standard-setting and compliance assessment.

A. RF-EMR EXPOSURE LIMITS

Two RF-EMR exposure limit standards are in general use. The FCC 1996 standard [58] was substantially based on the Institute of Electrical and Electronic Engineers (IEEE) C95.1, 1991 standard with minor input from National Council on Radiation Protection and Measurements (NCRP) Report No. 86. The other, standard primarily used in the European Union (E.U.), was authored by the International Commission on Non-Ionizing Radiation (ICNIRP) [59], [60].

For the general U.S. public the maximum permissible specific absorption rate in any 1 g of tissue (SAR_{1g}) is 1.6 W/kg averaged over 30 minutes. In contrast, the corresponding exposure limit for the general public in the E.U. (ICNIRP) in any 10 gram cube of tissue is 2 W/kg averaged over 6 minutes. The maximum SAR increases as the tissue weight and volume decrease [61], so the E.U. limit allows roughly 2 to 3 times greater exposure than the U.S. limit [21].

B. COMPLIANCE TESTING – TWO FCC APPROVED METHODS

Applicants requiring certification of wireless transmitting devices (WTDs) by the FCC and/or those E.U. agencies adhering to the ICNIRP guidelines are permitted to use either a finite-difference time-domain (FDTD) Computer Simulation Process, or the Specific Anthropomorphic Mannequin (SAM) physical model to certify that WTDs do not exceed the exposure limit [62].

FIGURE A-1. SAM Phantom. "CTIA" is the Cellular Telecommunications Industry Association. Source: SPEAG Phantom Product Flyer.

C. SAM COMPLIANCE TESTING

A cell phone set to transmit at maximum power is affixed to either side of the mannequin's head (red plastic in Fig. A-1), offset by a distance to simulate the ear. The robotic arm probes SAM to find the highest electric field within any 1 cm^3 (1 g) cube, or 10 g, for the 1 and 10 g standards respectively.

SAR is calculated from electric field measurements and the properties of the liquid. Uncertainty in SAR determinations has been stated as ±30% [63].

Modern WTDs can operate simultaneously on different frequencies for both speech and other data, but devices are tested on one frequency at a time.

In 1994, Niels Kuster worked with Motorola colleagues at their Florida research center a submersible electric field probe required for the SAM Certification Process. Shortly thereafter, he created a commercial manufacturing company in Zurich to produce the test system that is now widely used around the world. SPEAG was founded in December 1994 as a spin-off company of the Swiss Federal Institute of Technology (ETHZ) by Kuster and colleagues. Schmid & Partner Engineering was one of the founders of the IT'IS Foundation, and has remained a major sponsor of this research institute [64].

SPEAG is the brand name used by Schmid & Partner Engineering AG for the hardware and software required for the SAM Certification Process. SAM models have been extended to adult phantoms of other body parts, that may be posed. SPEAG also provides FDTD modeling software and services [65].

D. COMPARISON OF SAM AND FDTA COMPLIANCE ANALYSIS

The FDTD Computer Simulation Process is approved for FCC compliance, but according to government websites is not used for WTDs [66], [67]. It is, however, used by the U.S. Food and Drug Administration's (FDA) Center for Devices and Radiological Health (CDRH) to evaluate the

TABLE A-1. 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 gestation
Female exposure	No	Yes	
Female breast	No	Yes	
Small male exposure	No	Yes	
Large male exposure	Yes	Yes	
Testes exposure	No	Yes	
Dielectric tissue parameters	Average of all head tissues	Specific for each tissue	
3-D resolution	~1 cm^3	<1 mm^3	
Medical implant modeling	No	Yes	
Eye exposure	No	Yes	
Thyroid gland exposure	No	Yes	

safety of medical implants by relying on anatomically based models for persons of varying ages and sizes [68], [69].

Compared with the homogenous fluid-filled SAM head phantom, the FDTD Computer Simulation Process using FDTD Anatomically Correct, Tissue Specific (FACTS) models provides fine-grained resolution of RF-EMR absorption in tissues in any volume within the body, of any age or sex, with any location of the WTD (e.g., adjacent to a pregnant abdomen, or in a trouser pocket in proximity to a testicle).

Table A-1 compares the attributes of the two FCC approved certification processes.

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