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Review

Why children absorb more microwave radiation than adults: The consequences

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ABSTRACT

Computer simulation using MRI scans of children is the only possible way to determine the microwave radiation (MWR) absorbed in specific tissues in children. Children absorb more MWR than adults because their brain tissues are more absorbent, their skulls are thinner and their relative size is smaller. MWR from wireless devices has been declared a possible human carcinogen. Children are at greater risk than adults when exposed to any carcinogen. Because the average latency time between first exposure and diagnosis of a tumor can be decades, tumors induced in children may not be diagnosed until well into adulthood. The fetus is particularly vulnerable to MWR. MWR exposure can result in degeneration of the protective myelin sheath that surrounds brain neurons. MWR-emitting toys are being sold for use by young infants and toddlers. Digital dementia has been reported in school age children. A case study has shown when cellphones are placed in teenage girls' bras multiple primary breast cancer develop beneath where the phones are placed. MWR exposure limits have remained unchanged for 19 years. All manufacturers of smartphones have warnings which describe the minimum distance at which phone must be kept away from users in order to not exceed the present legal limits for exposure to MWR. The exposure limit for laptop computers and tablets is set when devices are tested 20 cm away from the body. Belgium, France, India and other technologically sophisticated governments are passing laws and/or issuing warnings about children's use of wireless devices.

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Abbreviations: MRI, magnetic resonance imaging; MWR, microwave radiation; CNS, central nervous system; FDTD, finite-difference, time-domain; GBM, glioblastoma multiforme (also called glioblastoma); cm, centimeter.

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1. Introduction

Here we discuss: how the amount of MWR can be calculated, children's greater absorption of MWR compared to adults' adsorption, MWR's listing as a Class 2B (possible) carcinogen, the existing legal limits for human exposure to MWR, and that the existing legal limits do not incorporate the greater exposure to children.

1.1. Computer simulation

The finite-difference, time-domain (FDTD) computer algorithm has been the best way to simulate the amount of absorbed MWR in tissues for many decades. In 1997 the U.S. Federal Communications Commission (FCC) stated, "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. FDTD method 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 computer technology, it has become possible to apply this method to near-field applications for evaluating handsets" [1].

1.2. Children's greater absorption of MWR

There are multiple studies showing that children absorb more MWR than adults. In 1996 a study reported that the absorbed MWR penetrated proportionally deeper into the brain of children age 5 and 10 compared to adults' brains [2].

In 2008 Joe Wiart, a senior researcher for French telecom and Orange reported that the brain tissue of children absorbed about two times more MWR than adults' brain tissue [3].

A 2009 study reported the CNS absorption by children is "significantly larger (∼2×) because the RF [MWR] source is closer and skin and bone layers are thinner", and "bone marrow exposure strongly varies with age and is significantly larger for children (∼10×)" [4].

In 2010, Andreas Christ and team reported children's hippocampus and hypothalamus absorbs 1.6–3.1 times higher and the cerebellum absorbs 2.5 times higher MWR compared to adults'; children's bone marrow absorbs 10 times higher MWR radiation than in adults, and children's eyes absorb higher MWR than adults [5]. These calculations were based on porcine measurements taken from sacrificed animals.

1.3. Microwave radiation is a Class 2B (possible) carcinogen

After 30 experts from 14 countries reviewed the science, the World Health Organization's (WHO's) International Agency for Research on Cancer (IARC) declared that RF-EMF [MWR] is a Class 2B (possible) carcinogen [6]. It was a near unanimous declaration (one dissenter).

Including MWR, there are 285 agents listed by WHO's IARC as Class 2B carcinogens [7]. Exposures to almost all of these agents are regulated. Some of the commonly recognized agents are: carbon black, carbon tetrachloride, chloroform, DDT, lead, nickel, phenobarbital, styrene, diesel fuel, and gasoline.

Like these other Class 2B Carcinogens, should anyone, particularly children, be exposed to MWR?

1.3.1. Children are at increased risk when exposed to carcinogens

Children are at greater risk from exposure to carcinogens than adults, and the younger the child, the higher the risk [8–10].

1.4. Exposure limits

In 1996, the FCC adopted the IEEE 1991[11] standard with some details from the 1986 NCRP Report [12] as exposure limits in the United States. Nineteen years after the FCC exposure limits were published, based on documents published 24 and 29 years previously, the legal exposure limit has remained unchanged. Yet during these decades an enormous body of scientific studies was published reporting risk well below the legal exposure limit.

The Institute of Electrical and Electronic Engineers (IEEE) is an industry professional organization, as is the National Council on Radiation Protection (NCRP). Neither organization had medical or public health expertise.

In European countries and a few other countries, the exposure limits are based on the 1998 "Guidelines" of the International Commission for Non-Ionizing Radiation Protection (ICNIRP) [13]. These "Guidelines" were based on publications from 1984, 1987, 1991, and 1993 [page 494]. That is the "Guidelines" were based on publications up to 31 years ago, Similar to the IEEE and NCRP, ICNIRP is an organization without medical or public health expertise. It is accountable to no government and its funding sources are not transparent.

1.4.1. The 19 year old IEEE and 17 year old ICNIRP exposure limits are based on a false premise

The exposure limits are premised on an assumption that the only biological effect from MWR exposure is acute (short-term) heating sufficient to cause tissue damage. There is no consideration of the effects from chronic (long-term) exposures. There are many scientific papers that report biological impacts tied with non-thermal (no measurable temperature change) effects. Indeed, the 480-page IARC Monograph 102 that documents the science that led to the declaration that MWR is a Class 2B (possible) carcinogen is a virtual compendium of such papers [14].

1.4.2. FCC compliance requirements do not comport with current testing systems

The FCC requires "For purposes of evaluating compliance with localized SAR guidelines, portable devices should be tested or evaluated based on normal operating positions or conditions" [15]. But phones are not tested in pants or shirt pockets. As a result *every* cellphone manual has warnings that the phone should be kept at various distances from the body otherwise the human exposure limits can be exceeded.

Here are two of many examples:

(1) The BlackBerry Torch 9800 Smart Phone warns, "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)." "Lower abdomen" is an oblique reference to testicles and "abdomen of pregnant women" is an oblique reference to the fetus.

(2) The iPhone 5's manual is embedded within the phone: Users must go to "Settings," and scroll down to "General," then scroll to the bottom to "About," go to "Legal," scroll down to "RF [MWR] Exposure" where it reads, "To reduce exposure to RF energy, use a hands-free option, such as the built-in speakerphone, the supplied headphones, or other similar accessories. Carry iPhone at least 10 mm away from your body to ensure exposure levels remain at or below the as-tested [exposure limit] levels."

1.4.3. There is a 20 cm distance rule for tablets and laptop computers

"For purposes of these requirements mobile[1] devices are defined by the FCC as transmitters designed to be used in other than fixed locations and to generally be used in such a way that a separation distance of at least 20 cm is normally maintained between radiating structures and the body of the user or nearby persons" [16].

Clearly, this 20 cm rule contradicts the "normal operating position" regulation in the description "a separation distance of at least 20 cm is normally maintained." Indeed, "laptop" computer directly implies that it is to be placed on a lap which is not 20 cm distant from the user.

The growing use of tablets by young children in schools contradicts these normal tested conditions as well, as these children have shorter arms that do not allow them to hold devices 20 cm from their bodies.

2. Materials and methods

We have performed a review of the peer-reviewed cellphone exposure epidemiology from 2009 to 2014, and cellphone dosimetry since the 1970s from a previous paper [17], along with relevant governmental and other policy documents, manufacturers' manuals and similar documents.

3. Results

3.1. Early development

Here we present evidence of harmful effects from exposure to MWR during early developmental stages both in animals and in humans.

3.1.1. Fetal exposures

A study from Yale University School of Medicine exposed mice in utero to MWR [18]. The study reported that these mice were hyperactive and had impaired memory "due to altered neuronal developmental programming. Exposed mice had dose-responsive impaired glutamatergic synaptic transmission onto layer V pyramidal neurons of the prefrontal cortex." During pregnancy the mice were irradiated by a cellphone positioned above each cage positioned over the feeding bottle at a distance of 4.5–22.3 cm from each mouse depending on the location of the mouse within the cage. Controls were under the same condition but the phone was not active. The observed effects were

[1] The FCC defines laptop computers, tablets and similar devices as "mobile devices" in comparison to "portable devices" which are cell and cordless phones and similar devices; the former falls under the 20 cm rule, the latter has no such rule.

similar to attention deficit hyperactivity disorder (ADHD) in children.

A Turkish study reported on a 900 MHz in utero exposure of rats [19]. "The results showed that prenatal EMF exposure caused a decrease in the number of granule cells in the dentate gyrus of the rats ($p < 0.01$). This suggests that prenatal exposure to a 900 MHz EMF affects the development of the dentate gyrus granule cells in the rat hippocampus."

A Chinese study investigated effects of MWR emitted by cellphones on rat CNS, in vitro (cortical neuronal cells) and in vivo (rat's brain) [20]. Neuronal cells had a significantly higher death rate at power densities of 0.05 mW/cm^2 and above. In vivo results show increased apoptosis with DNA fragmentation.

3.1.2. Myelination

A myelin sheath covering neurons acts as an insulation of the electrical activity of neurons. In human embryos, the first layer develops from mid-gestation to 2 years of age and continues into adolescence [21]. Myelination of the brain is not complete until early adulthood.

There are two studies with reported degeneration of the myelin sheath after MWR exposure:

A 1972 study from Poland reported myelin degeneration and glial cell proliferation in guinea pigs and rabbits from a 3 GHz exposure [22].

In 1977 Switzer & Mitchell reported a 2.45 GHz exposure in rats increased myelin degeneration in rat brains at 6 weeks after exposure. They concluded "The results of our study and related investigations by others indicated that exposures to low-intensity MW irradiation can result both in transient and in long-term structural anomalies in CNS tissue and may result in various hematologic irregularities" [23].

3.2. Children and adolescents

Aydin et al. in a study of cellphone use by children and adolescents (median age 13 years), reported a significant risk of brain cancer and a significant exposure–response relationship for >2.8 years since first cellphone subscription, OR = 2.15, CI = 1.07–4.29, p-trend = 0.001 for increasing risk with increasing time since first subscription with operator recorded use data (billing records) [24]. Yet the study's conclusion states, "The absence of an exposure–response relationship either in terms of the amount of mobile phone use . . . argues against a causal association." It is unclear why the conclusion directly contradicts the published results. The study was funded in part by cellphone companies.

A Swedish study reported when first cellphone use began as a teenager or younger there was a significant ipsilateral risk of brain cancer, OR = 7.8, CI = 2.2–28, $p < 0.01$, and an almost identical ipsilateral risk from cordless phone use, OR = 7.9, CI = 2.5–25, $p < 0.001$ [9].

A Korean study found risks for ADHD in first grade (ages 7–8) children and followed them to ages 12–13 [25]. "The ADHD symptom risk associated with mobile phone use for voice calls but the association was limited to children exposed to relatively high [blood] lead [levels]." With an average time per cellphone call of ½ to <1 min, OR = 5.66, CI = 1.31–24.51 and for 1+ minutes per call, OR = 7.20, CI = 1.37–37.91, p-trend = 0.02. For children playing games for 3+ minutes/day a significant risk for ADHD, OR = 1.94, CI = 1.30–2.89, $p < 0.001$, and p-trend < 0.001 in the lower blood lead level group.

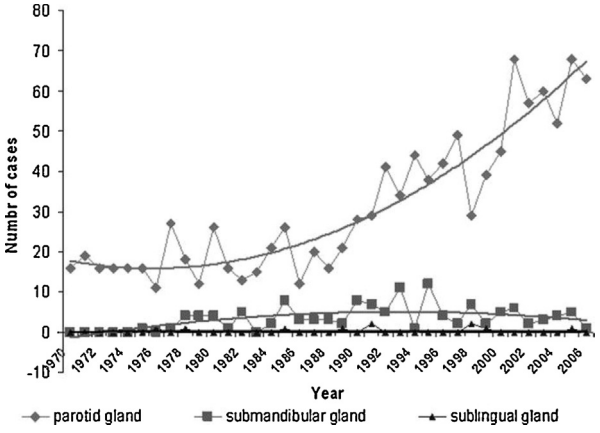


Fig. 1. Increase of parotid gland tumors relative to other salivary gland tumors in Israel.

Elsewhere it has been shown the low-level exposures to MWR increases the permeability of the blood–brain barrier [26–28]. This suggests children exposed to lead who use cellphone might have increased blood lead levels in the brain.

3.2.1. Breast cancers resulting from placement of cellphones in bras

A case study reported 4 women who placed cellphones in their bras. Two were diagnosed at age 21, with one who had begun placing her cellphone in her bra at age 15. This resulted in multiple primary breast cancers immediately beneath where the cellphone were placed [29].

3.2.2. Parotid gland tumors

The parotid gland is a large salivary gland in the cheek immediately next to where a cellphone is held to the ear.

A Chinese study reported statistically significant increased risks of 10- to 30-fold [30]. With more than 10 years since first use of a cellphone, the risk of epithelial parotid gland cancer, OR = 10.631, CI = 5.306–21.300, $p < 10^{-10}$; similarly the risk for mucoepidermoid carcinoma, OR = 20.72, CI = 9.379–45.821, $p < 10^{-13}$, and for average daily use of >3.5 h, OR = 30.255, CI = 10.799–90.456, $p < 10^{-10}$.

An Israeli Interphone study found significant risk of parotid gland tumors [31]. "For ipsilateral use, the odds ratios in the highest category of cumulative number of calls and call time without use of hands-free devices were 1.58 (95% confidence interval: 1.11, 2.24) and 1.49 (95% confidence interval: 1.05, 2.13), respectively."

Another Israeli study showed that among the 3 salivary glands, the only increase was the parotid gland [32]. "The total number of parotid gland cancers in Israel increased 4-fold from 1970 to 2006 . . . whereas two other salivary gland cancers remained stable." Fig. 1 illustrates the enormous

increase in parotid gland tumors relative to other salivary gland tumors.

A newspaper in Israel reported "[S]alivary gland cancer, which researchers suspect to be linked to cellphone use, was disproportionately common among young patients. One fifth of those patients were under 20" [33].

3.2.3. Sperm damage

Perhaps more than any other adverse health effect from exposure to MWR, damage to sperm is the most documented including in vitro, in vivo and human epidemiological studies.

A 2005 study with data collection from November 2002 to March 2004 examined the motility of sperm. "The proportion of slow progressive motile sperm increased with increase of the duration of the daily transmission time $p < 0.01$" [34].

A study of cellphone usage among men who attended an infertility clinic concluded, "Use of cell phones decrease the semen quality in men by decreasing the sperm count, motility, viability, and normal morphology. The decrease in sperm parameters was dependent on the duration of daily exposure to cell phones and independent of the initial semen quality" [35].

A Japanese study reported "This study has indicated significant decrease in sperm count [$p = 0.004$] and motility [$p = 0.003$] ... because of exposure to MP [Mobile Phone] emission, respectively" [36].

An Australian study investigated how sperm cells are damaged by cellphone MWR. Its conclusions stated "RF-EMR [Radio Frequency-Electro Magnetic Radiation] 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 well-being of their offspring" [37].

Professor Stanton A. Glantz is a Professor of Medicine at the University of California, San Francisco Medical School. He is also author of a renowned graduate level statistics textbook, *Primer of Biostatistics, Seventh Edition* [38]. Referring to the above four studies on sperm damage from MWR he concludes:

> "Taking all the information we have discussed on cell phones and sperm allows us to confidently conclude that exposure to cell phones adversely effects sperm."

A study of temperature controlled human sperm placed 3 cm beneath a laptop computer connected to Wi-Fi for 4 h [39] reported, "Donor sperm samples, mostly normozoospermic [normal sperm], exposed ex vivo during 4 h to a wireless internet-connected laptop showed a significant decrease in progressive sperm motility and an increase in sperm DNA fragmentation." The study concluded "Ex vivo exposure of human spermatozoa to a wireless internet-connected laptop decreased motility and induced DNA fragmentation by a nonthermal effect. We speculate that keeping a laptop connected wirelessly to the internet on the lap near the testes may result in decreased male fertility."

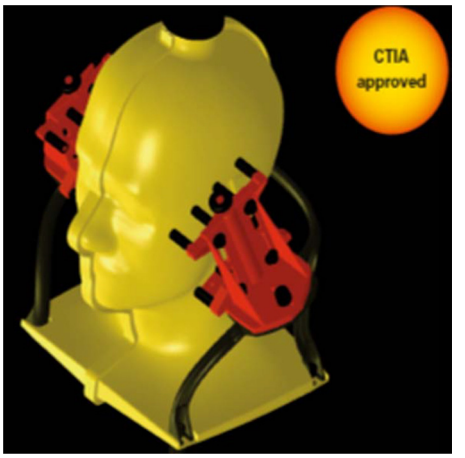


Fig. 2. SAM Phantom. The red devices are clamps to hold the cellphone in a specified location. "CTIA" is the Cellular Telecommunications Industry Association.
Source: Speag Phantom Product Flyer.

3.3. Tumor latency times

The *average* time between exposure to a carcinogen and the diagnosis of a resultant solid tumor is 3 or more decades. Brain tumors, like lung cancer and many other solid tumors have, *on average*, long latency times [8,40]. Therefore, it may be several decades before tumors induced by current MWR exposures in children are diagnosed. For example, the Israeli study showing brain tumor risk was inverse with age had long latency times [8]. In contrast the Aydin et al. study had relatively short latency times [24].

4. Discussion

4.1. Wireless device exposure limit certification

The FCC has approved two processes to certify that a wireless device meets the required exposure limit:

(1) The computer simulation process, and
(2) The Specific Anthropomorphic Mannequin (SAM) process.

The computer simulation process is discussed above.

The SAM process is based on a plastic mannequin representing the top 10% largest U.S. military recruits in 1989. Any head smaller than SAM will absorb more MWR (~97% of the U.S. population) [17]. A liquid with the average adult absorption properties of the 40 tissues of the head is poured into a hole at the top of this head. A robotic arm with an electric field probe is positioned within the mannequin such that the location of the highest electric field is located within any one cubic centimeter volume. A cellphone to be certified is clamped to either side of SAM (see Fig. 2). The electric fields values are used to calculate the maximum spatial peak Specific Absorption Rate (SAR) for any 1 g of

Table 1
A comparison of the capability to measure SAR using the computer simulation certification process or the SAM certification process for various exposures.

Attribute	SAM process	FDTD process	Comments
Children's exposure	No	Yes	Multiple ages
Pregnant women's exposure	No	Yes	1, 3 and 9 months
Female exposure	No	Yes	
Specific tissue parameters	No	Yes	
3-D resolution	~1 cm^3	<1 mm^3	
Relative cost	Higher	Lower	
Medical implant exposure	No	Yes	
Testicle exposure	No	Yes	
Female breast exposure	No	Yes	With and without wire frame bra
Eye exposure	No	Yes	With and without wire frame eyeglasses
Thyroid gland exposure	No	Yes	With and without metal necklace
Parotid gland exposure	No	Yes	With and without dental braces

Adapted from Gandhi et al. [17].

tissue (equivalent to 1 cm^3 volume). If the maximum SAR is at or below the U.S. exposure limit of 1.6 W/kg the phone is certified for sale without regard to the ±30% tolerance of the SAM certification process [41].

Table 1 compares the capabilities of the two cellphone certification processes.

As can be seen in Table 1 the SAM process is not capable of determining the MWR absorption as measured by SAR in every category except the relative cost and volume resolution. Nevertheless, the SAM process has been *exclusively used* to certify every cellphone to date.

4.2. Cellphone manual warnings and 20 cm distance rule

In spite of an FCC regulation "For purposes of evaluating compliance with localized SAR guidelines, portable devices should be tested or evaluated based on normal operating positions or conditions" [15], this regulation is ignored by the FCC. Holding a cellphone at a defined distance from your body is not "based on normal operating positions"!

For laptop computers, tablets and similar devices, an exposure limit that begins at a distance of 20 cm is not "based on normal operating positions." Indeed the very term "laptop" computer defines the normal operating position, which when placed on the lap is not 20 cm distant.

4.3. Increasing brain cancer incidence

There are studies showing an increased risk of brain cancer from wireless phone use. It is a current problem. The worst brain cancer, glioblastoma, has increased in the United States, and Denmark. Brain cancer incidence has increased in Australia in recent years. These results are based on brain cancer incidence from each country's cancer registries.

A United States study examined 3 cancer registries (Los Angeles County, California and SEER 12[2]) [42]. It examined incidence rates between years 1992–2006 and reported the Average Percent Change (APC) during those years. "RESULTS: Increased AAIRs [Age-Adjusted Incidence Rates] of frontal (APC +2.4–3.0%, $p \leq 0.001$) and temporal (APC +1.3–2.3%, $p \leq 0.027$) lobe glioblastoma multiforme (GBM) tumors were observed across all registries . . . The AAIR of cerebellar GBMs increased according to CCR (APC +11.9%, $p < 0.001$)."

The Danish Cancer Registry issued a press release that stated, "The number of men who are diagnosed with the most malignant form of brain cancer (glioblastoma), has almost doubled over the past ten years" [43].

The Australian study reported, "an overall significant increase in primary malignant brain tumors was observed over the study period from 2000 to 2008 (APC, 3.9; 95%CI, 2.4–5.4), particularly since 2004 (overall AAPC, 3.9; 95% CI, 2.6–5.2)" [44].

4.4. Selling toys for infants and toddlers

The iPad, tablets, laptop computers and cellphones are not children's toys. Within 20 cm of the device, the exposure limit can be exceeded with iPads and laptop computers. Figs. 3–5 are examples of toys for sale (there are many more similar toys).

4.5. Digital dementia

Digital dementia also referred to as FOMO (Fear Of Missing Out) is a real concern. A science publication's review



Fig. 3. An iPad placed within a rattle. Note the device is immediately over the boy's testicles.

[2] SEER 12 is cancer registry data maintained by the National Cancer Institute (NCI) using 12 States of the United States.



Fig. 4. 2-in-1 iPotty with Activity Seat for iPad.



Fig. 5. An iPad for entertaining a baby.

article describes the problem in great depth [45]. An empirical study of the problem was published in 2013 [46].

4.6. Governmental warnings

Many countries have issue warning about children's cellphone use. Some examples are:

Turkey 2013:
Governor Aksoy Huseyin, of the Samsun province announced he would launch a cellphone campaign to bring awareness of their hazards.

Belgium 2013:
The Public Health Minister bans cellphone sales for children under 7 years old. Advertisements are also banned during children's TV programs.

Australia 2013:
The federal government created a fact sheet providing citizens ways to reduce exposure from wireless devices. The agency advises parents to limit children's exposure to cellphones.

France, 2010
Laws make advertising cellphones to children under the age of 12 illegal.

5. Conclusions

The risk to children and adolescent from exposure to microwave radiating devices is considerable. Adults have a smaller but very real risk, as well.

(1) Children absorb greater amount of microwave radiation (MWR) than adults;
(2) MWR is a Class 2B (possible) carcinogen as is carbon black, carbon tetrachloride, chloroform, DDT, lead, nickel, phenobarbital, styrene, diesel fuel, and gasoline. It seems clear that we would not expose children to these other agents, so why would we expose children to microwave radiation?
(3) Fetuses are even more vulnerable than children. Therefore pregnant women should avoid exposing their fetus to microwave radiation.
(4) Adolescent girls and women should not place cellphones in their bras or in hijabs.
(5) Cellphone manual warnings make clear an overexposure problem exists.
(6) Wireless devices are radio transmitters, not toys. Selling toys that use them should be banned.
(7) Government warnings have been issued but most of the public are unaware of such warnings.
(8) Exposure limits are inadequate and should be revised such that they are adequate.

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