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Children and Cell Phones: Time To Start Talking Sense

Fifteen years ago **Om Gandhi** pointed out that **children are exposed to higher levels of radiation from cell phones than adults**. He was right then and he is right today. Yet, no one could blame you for thinking otherwise.

In an **article** published in the May issue of *Harper's*, **Nathaniel Rich** uses this putative controversy, among a number of other examples, to make the case that confusion reigns in all aspects of cell-phone research. "The brain of a child absorbs a much greater amount of radiation from a cell phone than does the brain of an adult," he writes, adding immediately after, "No, it does not."

The truth is that there should be no controversy. Children do have higher radiation exposures and if cell phones are indeed doing us harm, then children are at greater risk than their parents.

"There is nothing complicated about why children absorb more radiation than adults," Gandhi told *Microwave News* from his office at the University of Utah not long ago. Children have thinner skulls and smaller ears than adults, he explained, and so the radiation has a shorter distance to travel from the phone to the brain. (Every millimeter of separation makes a big difference.) Because more radiation gets to the brain, the specific absorption rate (**SAR**), the preferred way to measure the radiation dose, increases. That's it. You don't need any complicated equations, or even a computer to see the big picture. "The higher SARs have nothing to do with sophisticated models," Gandhi said, "It's all about separation distance. This is something you can explain to your mother-in-law."

Gandhi's original 1996 graphics showing that 5-year-old and 10-year-old children have higher SARs than adults (reproduced below) have achieved iconic status. Ronald Herberman, the former director of the University of Pittsburgh Cancer Institute, and his colleague **Devra Davis** fashioned a three-dimensional model of Gandhi's pictures—with Gandhi's assistance—to emphasize the higher SARs and the deeper penetration of the radiation in a child's brain. They have exhibited it at **Congressional hearings**, on various TV shows and during myriad lectures and presentations. Their message, summarized by Herberman in a **memo** distributed to the some 3,000 members of the cancer institute's faculty and staff in July 2008, calls for precaution, especially with re-

(continued on p.2)

spect to children (see ***MWN*, July 2008**). "Do not allow children to use a cell phone, except for emergencies," Herberman advised because, "The developing organs of a fetus or child are the most likely to be sensitive to any possible effects of exposure to electromagnetic fields."

Much of the cell-phone industry is still in denial, however, and disputes the increased risk for children. In a brochure released earlier this year, the Mobile Manufacturers Forum (**MMF**), a leading cell-phone industry trade group, continues to insist that others have been unable to find support for Gandhi's conclusion. MMF's argument is tautological: It cites Gandhi's 1996 paper as evidence that that same 1996 paper is wrong. Then again, perhaps it does make sense. if industry's objective is to sow seeds of confus-ion, using Gandhi vs. Gandhi would be entirely appropriate.

Some of those who should be trying to set the record straight are dragging their feet. Take, for instance, **Michael Thun**, the American Cancer Society's (**ACS**) point man on cell phones. Last month, Thun told ***Parade*** magazine and its 75 million readers that, "If cell phones were harmful, then it is conceivable that children might be more vulnerable." Conceivable? No, it's a fact. As Gandhi points out: It's simple high school geometry.

Today, Gandhi has many supporters. Research groups in Brazil, France, Japan, Spain and Switzerland have all published papers showing that children have higher SARs. **Joe Wiart** of **France Telecom**, a major mobile-phone operator, should have put the issue to rest two years ago when he announced that he agreed with Gandhi. (The MMF neglects to cite **Wiart's paper** in its brochure.) "Children are not simply small adults," Wiart told us at the time. "Their skin and their skulls are thinner than those of adults, and their ears are smaller too. Given these differences, the higher SAR for children is not surprising" (see ***MWN*, July 2008**). The industry does not speak with one voice: One large company says Gandhi is right, while others fight on.

Even Niels Kuster, the director of the **IT'IS Foundation** in Zurich, who has feuded with Gandhi for more than a decade, has decided that he can no longer turn back the tide (see ***MWN*, N/D01, p.8**, and ***MWN*, M/J02, p.1**). Kuster's work is often been cited to make the case that children are no different than adults. One example: The MMF brochure points to **two Kuster papers** to bolster its argument. Kuster counters that he has been misunderstood. "In the 1990s, we were talking about *compliance*," he told *Microwave News*, "My position was never about whether or not children get more radiation exposure in the brain, but whether the phones meet exposure standards when used by children." Kuster told us that Gandhi's revelation is "trivial"—which is what Gandhi has been saying all along.

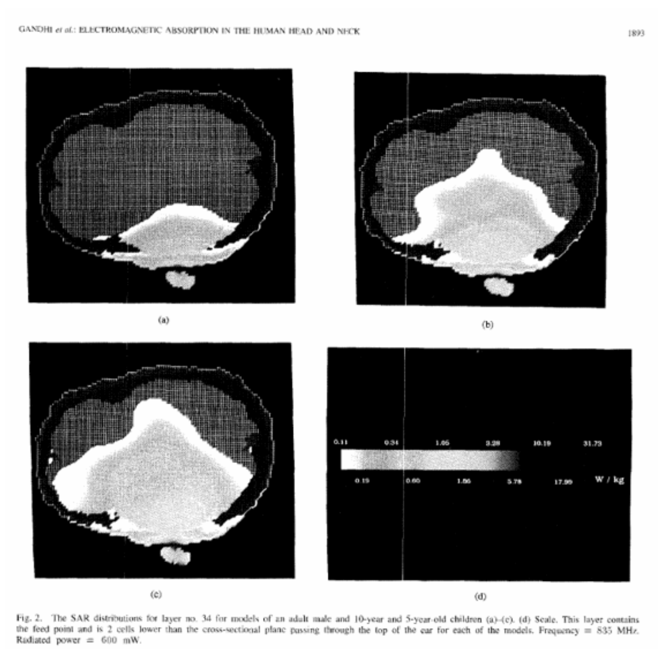

Figure 1: SAR distributions at 835 MHz for: (a) adult; (b) 10-year-old; (c) 5-year old. (d) is the SAR scale.
Source: **O. Gandhi *et al., IEEE Transactions on Microwave Theory and Techniques, 44,* p.1893, 1996**

Children's Brains Are Different

And there's more: Children also have a greater sensitivity to cell-phone radiation. For years, some have argued that young children are more vulnerable because their brains are still developing. This is Herberman's argument in favor of precaution, and, while plausible, there wasn't much hard data to back it up. Now, Andreas Christ of Kuster's lab has reported that the SAR in the bone marrow of children is more than ten times higher than that in adults. Or, to put it bluntly, the same amount of radiation packs ten times the punch inside a child's bone marrow as in his mother or father's bone marrow. The **new paper** came out last month in *Physics in Biology and Medicine.*

Christ and Kuster's finding could not have been a big surprise to those who follow the field. Last year, Azadeh Peyman and Camelia Gabriel, another veteran RF researcher who runs **MCL Technology Ltd.**, a testing firm in London, **showed** that some children's tissues have very different electrical properties than those of adults. These are known as dielectric properties and, in this context, refer to the **conductivity** (σ) and the **permittivity** (ε). (The SAR is directly proportional to the conductivity.) Peyman and Gabriel worked with samples from freshly killed pigs of different ages, which, they said, "are regarded as a good substitute for human tissues." They reported that the conductivity of a piglet's bone marrow was ten times higher than that of an adult pig. The reason for the big difference is that bone marrow has a higher water content in early life. The more water, the higher the conductivity, which in turn leads to a higher SAR. Christ and Kuster then used Peyman and Gabriel's new numbers to calculate the relative SARs in children and adults.

If Gandhi's contribution is about the importance of separation distance, the lesson from the Swiss and U.K. groups is about the importance of biophysical properties. Each tells us that the SARs are higher in children.

One remarkable aspect of the Peyman/Gabriel paper is that, having measured the dielectric properties, they did not take the next step and show that the SAR in a child's bone marrow would be higher. Peyman and Gabriel were working under a **~$600,000 (£408,000) research grant** from the U.K. mobile phone research program, known as **MTHR**. They could have done the same SAR calculation as Christ and Kuster, or at least pointed to and compared the conductivities. Yet, Gabriel and Peyman did neither. When asked why not, Gabriel replied that this would have required "speculation." Maybe so, but that was the problem they were hired to study. Another peculiar disconnect is that Peyman and Gabriel only looked at RF exposures from walkie-talkies, not cell phones. This too doesn't make much sense. When was the last time you saw a child talking into a walkie-talkie?

Gabriel and Peyman's decision not to draw the obvious inference about the higher SARs is all the more surprising because they had long known that the dielectric properties of bone marrow change with age. Back in 2001, **they had reported a similar change in rat tissues**—that time too, they didn't say a word about how it might raise the SARs. Yet, Gabriel realized its significance. "Children are not little adults," she told a meeting in Rome on **children and cell phones** the following spring. "We cannot afford not to do more research," she said (see ***MWN*, M/J 02, p.10**).

At about the same time that Gabriel was delivering her

The Arithmetic of SARs

The bone marrow of young pigs has a higher water content than adult bone marrow and, as expected, Peyman and Gabriel found that it has a higher conductivity. A little math might help understand why a higher water content in tissues this leads to higher SARs. Start with the basic equation for calculating the SAR:

$$SAR = \sigma E^2 / \rho$$

where σ = conductivity of the tissue; E = electric field,
ρ = density of the tissue

More simply, this means that the SAR is proportional to the conductivity:

$$SAR \sim \sigma$$

and therefore as the conductivity increases, so does the SAR.

Christ and Kuster only estimated the relative increase in SAR, which is proportional to the ratio of the conductivity of a child's bone marrow to an adult's:

$$\text{Relative SAR} \sim \sigma\,(\text{children}) / \sigma\,(\text{adults})$$

Actually, it's somewhat more complicated than this. Looking at the SAR equation, we can see that there are two other variables to consider: the electric field (E) and the density (ρ) of the sample. The electric field in the bone marrow depends on the permittivity (ε) of the tissue. Peyman and Gabriel showed that the permittivity of a child's bone marrow, like its conductivity, is also higher than an adult's. The net effect of this change is to further increase the SAR. As for the density of the tissue, there's no indication that it changes much with age, so, for our purposes, we can ignore it.

talk in Rome, Gandhi published a **new paper** that showed what Gabriel and Peyman must have already known but had not stated in print: The higher conductivity found in baby rats means higher SARs in young children. Gandhi minced no words about the necessity to follow up. These results point to "an urgent need" to validate the finding for rats in children, he pleaded.

Still, seven years later when Gabriel finally had the better data from pigs to support everyone's long-held suspicions that children might be at greater risk, she once again held back.

While Christ and Kuster have shown that the SAR is higher in a child's bone marrow, we still don't know the dose (the SAR). It may be ten times higher than in adults, but we need the actual number, or at least a range of SARs. "That's coming," Kuster said. "We have a **new research grant** from the Swiss National Science Foundation to look at SARs induced by phones in specific tissues."

Slicing and Dicing SARs

The SAR is a curious quantity for setting exposure limits because it cannot be directly measured. You can't stick a probe into a live brain, nor can you work with dead tissues—the electrical properties of the tissues change as soon as the organism dies. Instead, one is left with making physical models, called phantoms, or running computer stimulations.

A phantom is a primitive substitute for the human head. It's little more than a plastic shell filled with a liquid designed to mimic the dielectric properties of brain matter. A phantom makes no allowance for variations in types of tissue or for internal structure. Even so, making SAR measurements is more complicated than you might think. A **committee of the IEEE** spent six years developing a **protocol** on how they should be done. The protocol is a highly technical and generally impenetrable document that runs 148 pages, replete with opaque assumptions. [Here's a typical sentence: "A simple analytical model of an infinite half-space layered tissue model exposed to a plane wave was utilized to investigate the impact of impedance matching, scattering, standing waves, etc., on the peak spatial-average SAR."]

The process was run by industry insiders, who prefer to work out of public sight. Minutes of the committee meetings are secret—even the agendas are password protected. A couple of years ago when *Microwave News* asked to be on the committee's mailing list, representatives from the FDA and Motorola, who chaired the panel, said no.

The protocol includes recipes to make the synthetic brain liquid: Start with deionized water, add salt, sugar, hydroxyethyl cellulose, etc. This gross simplification of what must be the most complex piece of evolutionary engineering is a conceit. As Allan Frey pointed out in 1979: "There is a very real question whether [an SAR] has any relevance to the biological organism." Frey, a well-known RF researcher now semi-retired and living in Potomac, MD, took the RF research community to task for relying on "a concept whose time came and went in the 1950s." Its use, he said, is "grossly misleading and "cannot be justified." No one wanted to hear it. Today, over 30 years later, SARs are by far the most common measure of dose and the same criticisms continue to echo. "The brain is not a giant bowling ball filled with fluid—that's ridiculous," Devra Davis told us recently.

You can see the simplicity of the approach using phantoms in the graphics in Figure 2, taken from Christ and Kuster's new paper. They show SAR distributions based on measurements carried out under the IEEE protocol. Note how smooth the color contours are. No bumps, no discontinuities. The SARs go steadily down as you move away from the phone just as you would expect. There are a number of reasons why the pictures at 900 MHz and 1800 MHz are not the same: The radiation comes off the phone differently at the higher frequency and the dielectric properties of tissues vary with frequency. (The IEEE offers variations of the brain-fluid recipe for different frequencies.)

Computer models allow more complexity. By adapting MRI scans, representations of the head can have internal structure with a variety of different tissues, each with its own set of dielectric properties. Compare the Christ/Kuster phantom-based graphics with the pictures from computer models generated by Gandhi, Figure 3. He included 15 types of tissues. The simplicity is gone. Note especially the reddish areas inside the yellow zones in (b) and (c). They are regions of higher SARs called "hot spots," brought about by the mix of tissues. With phantoms, there are no hot spots.

The SAR is specified in energy per weight or volume of tissue, usually in watts per kilogram (W/Kg). The averaging volume for the SAR is a critical variable. For a given

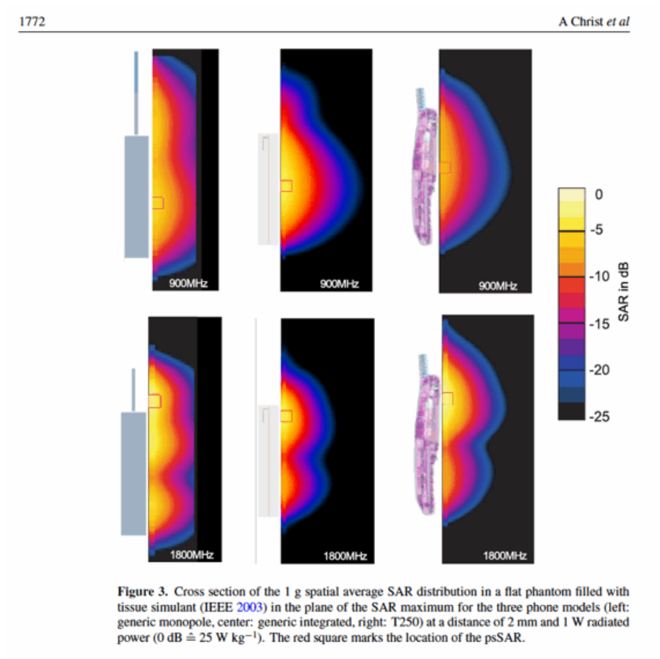

Figure 2: The yellow area has the highest SARs, followed by red, mauve and blue.
Source: **A. Christ *et al.*, *Physics in Medicine and Biology, 55,* p.1772, 2010**

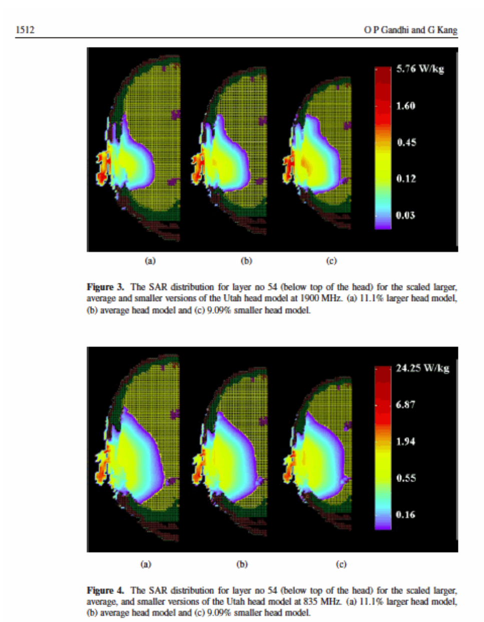

Figure 3: SAR distributions in different sized heads: (a) large); (b) average: (c) small.
Here the red areas have the highest SARs, followed by yellow, aqua and purple.
Source: **O. Gandhi and G. Kang, *Physics in Medicine and Biology, 47,* p.1512, 2002**

amount of energy, the larger the averaging volume, the smaller the SAR will be.

Here's one way to think about it: A bathtub is half-full of cold water when the hot-water tap is turned on for a couple of minutes. What's the temperature of the bath water? It will, no doubt, be much warmer right under the tap than at the other end of the tub. But what about the average temperature? It depends on the averaging volume. A teaspoon of water taken from right under the tap would be quite hot, but the temperature would go down as more and more of the surrounding cold water is included in the averaging volume. If you consider all the water in the bath, the temperature would be about the same whether you measured it before or after the tap was turned on. The reddish spots in the Gandhi graphics would fade away as more of the lower SAR areas (in yellow) are averaged in.

The SAR can be manipulated by changing the averaging volume. The **FCC** requires that SARs be averaged over 1g of tissue, while both the **IEEE** and **ICNIRP** specify a 10g average. Why 1g or 10g? It's an arbitrary decision with no cogent biological rationale to favor one over the other. Yet, it makes a big difference. A 1g average SAR is much stricter than a 10g average, as **Jim Lin**, the editor-in-chief of ***Bioelectromagnetics***, has long pointed out. The 1g SAR can be twice as high as the 10g SAR, or even higher (see ***MWN*, J/A00, p.8**, and ***MWN*, N/D00, p.3**). One implication of this is that European phones are built to a much looser radiation exposure standard than U.S. phones because their SAR limit is measured over 10g rather than the 1g in the U.S.

Alvaro de Salles of the Federal University of Rio Grande do Sul in Porto Alegre, Brazil, has put all this together in the table on p.7, taken from a paper he published a few years ago. The influence of the size of the head, the averaging volume and the dielectric properties, or parameters, are readily apparent.

Looking down any of the three columns, you can see the powerful diluting effect of increasing the averaging volume: Going from one voxel, the smallest volume for which an SAR is computed, to 1g and then to 10g, the SAR decreases by two-thirds or more. The SAR plummets when it's averaged over the whole head. If you look at the individual voxels, the peak SAR can be more than 30 times higher than the average over the entire head. The two columns on the left show how the "Gandhi effect" (the smaller head) raises the SAR. And the two columns on the right show how the higher dielectric properties of children's tissues also raise the SARs. In every case, the SARs for children are higher than their adult counterparts.

In an interview with *Microwave News,* De Salles summed it up this way: "The higher conductivity and higher permittivity in children's brain tissues, together with their thinner skulls and smaller heads, will lead to higher SARs in their brains compared to adults, as Om Gandhi and others, including myself, have described in many papers."

How can there be any doubt that children face a greater potential risk than adults.

Why Is It Taking So Long?

But that leaves the question as to why something so obvious is taking so long to acknowledge. After 15 years of feuding, a consensus is finally emerging that children have higher SARs. But even now, the MMF stands apart and many others continue to hedge. We can't explain the American Cancer Society's inability to talk sense, but for others, motives are easier to decipher—all you have to do is follow the money. (It's always about the money: see also our piece, **Industry Rules RF**.)

You need to look no further than the abstracts of the two papers on dielectric properties in children. Here's Peyman and Gabriel's **take-home message**: "No significant differences between the SAR values for the children of either age or for adults were observed." Gabriel and Peyman make it sound as if they didn't find anything of any importance. A more informative conclusion —"Children have higher SARs in biologically active tissues"— never made it into print.

And here's the last sentence of Christ and Kuster's **abstract**: "This study, however, confirms previous findings saying that there are no age-dependent changes of the peak spatial SAR when averaged over the entire head." Frankly, we don't know what that means. What was averaged over the entire head? (We asked both Christ and Kuster—twice each—for clarification and, though they were kind enough to respond, we are still as confused as ever, maybe more so.) Whatever they are trying to say, their message, like Peyman and Gabriel's, is that there's nothing much new to report.

Magicians call it misdirection. The facts are right, but

Electromagnetic Absorption in the Head of Adults and Children 357

Table 4
SAR—Quarter wavelength monopole (850 MHz), power = 600 mW

Model	Adult	10-year old child	
Electromagnetic parameters	Adult parameters	Adult parameters	Children parameters
		SAR values (W/kg)	
Peak SAR (one voxel)	3.68	5.97	6.20
1 g-SAR	1.8	2.38	2.89
10 g-SAR	1.7	1.74	2.05
Mean SAR (whole head)	0.149	0.193	0.191

Note: A **voxel** is a 3-dimensional **pixel**; It's the smallest volume for which an SAR is calculated.
Source: **A. De Salles *et al., Electromagnetic Biology and Medicine, 25,* p.357, 2006**

the emphasis is all wrong. Gabriel and Kuster are fixated on the peak SAR, a/k/a, the peak spatial SAR. That's the only number that counts as far as industry is concerned. The peak SAR determines whether a phone complies with a prescribed exposure limit (1.6 W/Kg over 1 g in the U.S. and 2.0 W/Kg over 10 g in Europe) and is allowed on the market. All the measurements and calculations on a given phone end up boiling down to this single number; you'll find it in fine print buried in the user's manual or on the manufacturer's Web site.

According to the prevailing dogma, if the maximum SAR is below the limit, the phone is safe. And industry insists on a corollary: A phone that is safe for adults, is equally safe for kids. The possibility that some internal tissues may be more sensitive is left out. Could higher SARs in bone marrow mean a greater health risk for children? That question is never addressed.

In order to understand how the misdirection works, we need one final, if technical, piece of the SAR story: The peak SAR will just about always be in the tissues closest to the phone. (Or, going back to the bathtub analogy, the temperature will always be highest under the tap.) That means that as long as compliance is the only objective, there is never any incentive to look at what might going on deeper in the brain. When the head is modeled as a homogeneous mass, like a liquid in a phantom, the peak will always be in the skin layer —it's a straightforward case of the radiation attenuating with distance from the transmitter. You can see this in the Christ/Kuster graphics (Figure 2); The small red squares mark the spots with the peak SARs. All six are at the interface of the phantom and the phone. Even if you consider variations in the dielectric properties of the tissues and run computer calculations, the maximum SARs will, except in the most unusual circumstances, be in the skin and nearby tissues. Gandhi's calculations show this too (see Figure 3; his maxima are in red), as do Peyman and Gabriel for walkie-talkies.

Peyman and Gabriel show their focus is on compliance in the final sentence of their paper. "[T]he peak 10 g averaged SAR in the child head phantoms caused by a walkie-talkie is calculated to be within the safety limits," they wrote. The impact of their new dielectric constants on the peak SAR is "marginal," they said. It had to be: The maximum SAR from the walkie-talkie is near the nose. The 10 g volume contains cartilage, skin and some air in the nasal cavity. While the dielectric properties of skin do change with age, the variation is much smaller than for bone marrow (40% vs. 1,000%).

The U.K. and the Swiss studies were funded by each government's mobile phone research program. But Gabriel and Kuster's bread and butter is servicing the telecom industry. Gabriel's **MCL Technology Ltd.** sells the phantoms and brain-tissue liquids used for compliance testing. As for Kuster, in addition to running the **IT'IS Foundation**, he is also the president of **SPEAG**, a high-tech, for-profit company that sells equipment (**the DASY System**) for measuring the fields inside a phantom, as well as **phantoms and associated brain liquids**. This does not run cheap.

A single DASY set-up can cost north of $100,000. SPEAG also has a software package, **SEMCAD**, that can calculate the SAR in tissues; Both Peyman/Gabriel and Christ/Kuster used SEMCAD.

When they work on research projects for health agencies, Gabriel and Kuster must walk a fine line between the needs of their funders and those of the industry. A research grant is a one-off affair, while the cell phone companies are long-term clients. Even IT'IS, which is a non-profit research outfit, has close ties to the industry. MMF's Secretary General, **Mike Milligan**, is on its **board of directors**. Over the years, representatives from **Alcatel**, **Ericsson**, **Motorola** and **Sunrise** have all served on the board at one time or another.

Given this context, the final conclusions in the Gabriel and Kuster abstracts are not so surprising. They are using their special code to be able to say that there's nothing to worry about and most outsiders are not going to understand the context. That helps assuage Gabriel and Kuster's long-term industry clients and associates. Christ and Kuster do point out that the SAR in bone marrow is ten times higher in children but then they throw in a few seeds of confusion (the bit about "no age-dependent changes.") As one close observer who has long worked in this field told us, "Those are the conclusions for the industry." (The person asked that his name not be used so that his work can continue.)

The entire cell phone health controversy is so riddled with industry money that only a few dare to address the implications for public health. We asked Alasdair Philips, a long-time activist, for his opinion. "My first thought after reading the new Christ/Kuster paper was for those youngsters, who use hands-free sets," he told us. "That's what the U.K. government advises and, though few actually listen, those who do and who carry their phones in their trouser pockets, might inadvertently be trading one risk for another," he said. "I would be concerned about the exposure of the long bones in their legs, as well as in their pelvises, because these have much larger amounts of marrow than the skull. A lot of important biology goes on in the bone marrow, and that includes producing blood cells." Philips is the founder of **Powerwatch** and an adviser to **Children with Leukaemia**, a charity.

Then we posed the same question to **Henry Lai** at the University of Washington in Seattle, another long-time microwave researcher. He took Philips's concerns one step further. "We should be looking at the SARs in each voxel," he said. "That's a much smaller volume than 1 g or 10 g, but there could still be up to 100,000 cells in each voxel. If the target is bone marrow, then the radiation is hitting red and while blood *and* stem cells. One small change may be all it takes."

In an e-mail exchange with *Microwave News*, Gabriel emphasized that, in fact, she is on the same track. "The exposure of the bone marrow is the single most important issue that needs to be pursued, not just for exposure to the head," Gabriel said. "I would like to see the exposure of the bone marrow in the limbs of children investigated."
