Exposure of Magnetic Bacteria to Simulated Mobile Phone-Type RF Radiation Has No Impact on Mortality

Charles G. Cranfield, Heinz Gregor Wieser, and Jon Dobson*

***Abstract*—The interaction of mobile phone RF emissions with biogenic magnetite in the human brain has been proposed as a potential mechanism for mobile phone bioeffects. This is of particular interest in light of the discovery of magnetite in human brain tissue. Previous experiments using magnetite-containing bacteria exposed directly to emissions from a mobile phone have indicated that these emissions might be causing greater levels of cell death in these bacterial populations when compared to sham exposures. A repeat of these experiments examining only the radio frequency (RF) global system for mobile communication (GSM) component of the mobile phone signal in a well-defined waveguide system (REFLEX), shows no significant change in cell mortality compared to sham exposures. A nonmagnetite containing bacterial cell strain (CC-26) with similar genotype and phenotype to the magnetotactic bacteria was used as a control. These also showed no significant change in cell mortality between RF and sham exposed samples. Results indicate that the RF components of mobile phone exposure do not appear to be responsible for previous findings indicating cell mortality as a result of direct mobile phone exposure. A further mobile phone emission component that should be investigated is the 2-Hz magnetic field pulse generated by battery currents during periods of discontinuous transmission.**

***Index Terms*—Mobile phones, magnetite, mechanism, transduction, radio frequency (RF).**

I. Introduction

MOBILE phones generate nonionizing radio frequency (RF) electromagnetic radiation generally at either 900 MHz or 1.8 GHz as well as lower frequency components associated with timedivision multiple access (TDMA) at 217 and 8.34 Hz, and a 2-Hz discontinuous transmission (DTX) component produced when the user is connected but not speaking [1]. The rapid proliferation of these devices throughout both the developed and the developing world has resulted in a public controversy surrounding possible health effects connected to their use. Though there are strict guidelines governing the power output of these devices, there have been many reports of nonthermal or athermal bioeffects from mobile phone-type exposure (e.g., [2], [3]). Experimental evidence has been presented which supports both sides of the debate [2]–[4].

A major issue which is not often addressed in electromagnetic compatibility research, however, is that of a transduction mechanism. In order to properly assess the validity of any experimental results demonstrating mobile phone bioeffects, it is necessary to understand the mechanism by which these effects may occur. Though this area of research has been highlighted by the World Health Organization's Electromagnetic Field (EMF) program, there are few theoretical mechanisms which have been proposed or thoroughly evaluated experimentally [5].

Mechanisms based on ferromagnetic transduction via nanoscale biogenic magnetite have a sound biophysical basis but have not been thoroughly evaluated experimentally. Magnetite is a ferrimagnetic iron oxide which can couple strongly to external electromagnetic fields due to its permanent magnetic moment. This material was first discovered in human brain tissue in 1992 and has since been confirmed to be present as a naturally occurring iron phase in many regions of the brain with particularly high concentrations in the meninges (the outermost region of the brain closest to the mobile phone when in use) [6]–[8]. Transduction of mobile phone signals via biogenic magnetite can be accomplished in two ways: 1) mechanical activation/disruption of normal cellular processes due to low-frequency battery current pulses [9] or 2) local deposition of energy due to ferromagnetic resonance [10].

The experiments presented here are based on the ferromagnetic resonance model and examine only the RF component of the mobile phone signal. In the ferromagnetic resonance model, the RF signal is coupled to the magnetization vector, causing it to resonate if the particle size and shape are consistent for resonance at the transmission frequency. This resonance excites vibrations in the magnetite crystal lattice, which could disrupt normal cellular function depending on the location of the magnetite within the cell.

Though ferromagnetic resonance represents one of the most plausible mechanisms for bioeffects, the model has not been tested experimentally on cells. This is primarily due to the fact that magnetite-bearing cells from the human brain have been neither isolated nor cultured. Magnetic and electron microscopic analyses of human brain tissue have revealed that biogenic magnetite in human brain tissue is similar to that produced by the magnetotactic bacterium *M. magnetotacticum* [6], [7]. Based on these findings, our group has investigated the possibility of using *Magnetospirillum magnetotacticum* as a proxy for testing ferromagnetic transduction models [11].

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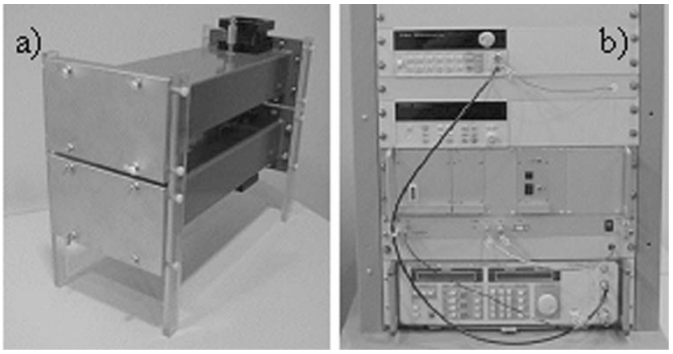

Fig. 1. The REFLEX system. (a) Two 1.8-GHz waveguides which fit into an incubator. (b) The control electronics.

TABLE I
RESULTS OF THE FIVE REFLEX EXPERIMENTAL RUNS ON THE CC-26 NONMAGNETIC BACTERIA

Experimental Run	Mean (Sham n=6)	Mean (Exposed n=6)	P
1	18.28±0.28	18.76±0.25	0.12
2	33.07±0.20	32.76±0.43	0.26
3	24.01±1.12	24.98±0.88	0.25
4	12.10±0.24	12.27±0.18	0.29
5	16.90±0.17	17.08±0.44	0.36

n = 6 sham and 6 exposed for each experimental run. Mean is the mean fluorescence ratio, which reflects cell mortality (lower ratios = higher mortality levels). P is the probability from a one-tailed Student's t-test

The presence and characterization of mechanosensitive ion channels and biomineralized intracellular magnetite in *M. magnetotacticum* make it an excellent system for examining these models. Here we present the results of the first experimental evaluation of the ferromagnetic resonance model.

II. METHODOLOGY

M. magnetotacticum [12], and the closely related nonmagnetic type of bacteria designated *strain CC-26* [13], were cultured in ATCC-revised magnetospirillum growth medium 1653 (MSGM) under anaerobic conditions at 30 °C in airtight glass tubes. Before each experiment, *M. magnetotacticum* samples were checked to confirm they were producing magnetite by observing their response to changes in magnetic fields under a light microscope and by transmission electron microscopy.

RF experiments were conducted using the REFLEX exposure system, which provides very well controlled dosimetry along with continual monitoring of temperature conditions during exposure [14] (see Fig. 1). This system consists of two 1.8-GHz waveguides housed in a CO_2 incubator with continuous temperature monitoring. Each waveguide holds six petri dishes. The signal unit consists of a RF signal generator (R&S SMY 02B) modulated by an arbitrary function generator (Agilent 33 120A) with a global system for mobile communication (GSM) frame generator which enables switching between DTX and non-DTX. RF exposure is controlled via a computer interfaced to the signal unit, which excites one of the waveguides at random, creating blind experimental conditions.

Three milliliters of equally concentrated magnetotactic bacterial cells or CC-26 cells were placed in 12 individual tissue culture petri dishes (40 mm × 12 mm). Each culture dish was sealed with laboratory film to make them airtight. The samples were then labeled with either a "1" or a "2" and appropriately placed into the two waveguides, also labeled "1" and "2." The waveguides were housed inside a temperature-controlled incubator set at 30 °C. The computer-controlled REFLEX exposure system was then programmed to produce a maximum 2-W/kg dose of 1.8-GHz RF radiation to one of the waveguides. This is done in a blind fashion so the experimenter does not know which waveguide has been excited until the assays are complete. Signals were pulsed at 217 Hz and included an 8-Hz component (every 26th pulse was blanked), and a 2-Hz DTX component 34% of the time, which corresponds to the average amount of time a phone is in DTX mode during a normal phone conversation. These signals are similar to those signals produced by mobile phone devices.

Exposure duration was 30 min, and exposure data were recorded onto the computer hard drive as an encrypted file. The file holds information on which waveguide is excited for each experiment as well as temperature monitoring data. The data were sent to the Institute for Information Technology in Society, Zurich, Switzerland [14], for decryption after the completion of each experiment.

Following exposure, or sham exposure, cell mortality was assayed. A 1-mL sample from each petri dish was loaded with 1.5 μL of each of the BacLight fluorescent viability kit components [Molecular Probes (Eugene, OR)—3.34 mM SYTO 9 solution in dimethyl sulfoxide (DMSO) and 20 mM propidium iodide solution in DMSO] and placed on an electric rocker for 15 min. Samples were then loaded into a cuvette and analyzed in a Perkin–Elmer LS50B fluorescence spectrophotometer. Excitation was set at 470 nm, and the ratio of integrated intensities between 510–540 nm and 620–650 nm was determined (i.e., green fluorescence/red fluorescence). This gives a ratio of live (green) to dead (red) cells.

A one-tailed Student's t-test was performed on the sham and exposed group for each experiment.

III. RESULTS

Results of the five runs conducted on the nonmagnetite-producing CC-26 bacterial strain did not show any consistent bioeffects due to RF exposure (see Table I). Cell mortality was not consistently higher in either group, and none of the experiments reached statistical significance using a one-tailed Student's t-test.

Results of the *M. magnetotacticum* magnetic bacteria samples also show no statistical difference between the exposed and sham exposed as determined by a one-tailed Student's t-test (see Table II).

IV. DISCUSSION

The results suggest that the RF signals produced by mobile phones do not affect the mortality of bacterial cells—whether they contain magnetite, as in the case of *M. magnetotacticum*, or not, as with the similar CC-26 strain of *Proteobacteria*. Even though the cell populations differed between experiments,

TABLE II
RESULTS OF THE FIVE REFLEX EXPERIMENTAL RUNS ON THE *M. MAGNETOTACTICUM* MAGNETIC BACTERIA

Experimental Run	Exposed (Sham)	Mean (Exposed)	P
1	18.33±0.18	18.33±0.14	0.49
2	21.75±0.47	22.65±0.30	0.07
3	21.13±0.32	21.32±0.26	0.33
4	16.05±0.35	16.03±0.22	0.48
5	18.14±0.10	18.32±0.09	0.11

$n = 6$ sham and 6 exposed for each experimental run. Mean is the mean fluorescence ratio. P is the probability from a one-tailed Student's t-test.

there was no difference recorded in cell numbers between corresponding sham and RF exposed samples. The ability of the Baclight cell viability kit to detect changes in cell viability was confirmed by the creation of a live/dead standard curve (results not shown).

These results differ from those published previously [15], which showed significant increases in cell mortality as a result of direct mobile phone exposure. There is a major difference in direct exposure from mobile phones and those emissions generated in the REFLEX waveguides. Real mobile phones also emit low-frequency magnetic field pulses generated by battery currents in the phones associated with TDMA and DTX. These fields are not reproducible in the waveguides. Although the RF signal in the REFLEX system is pulsed to simulate all GSM components, the cells are only exposed to a pulsed RF field and not a low-frequency magnetic field as is generated by the battery current pulses. Whether these magnetic fields are the major factor resulting in cell death of the magnetotactic bacteria in the previous study requires further evaluation.

In addition, cell mortality, though useful, is not the only possible end-point for research using this magnetic bacteria model of ferromagnetic transduction of RF energy. Recent publication of a draft genome for *M. magnetotacticum* on the Internet has made possible the search for alterations in gene expression as a result of RF exposure [16]. Of particular interest would be possible increased heat shock protein expression, which has been shown to be up-regulated in the nematode *C. elegans* as a result of athermal, mobile phone-type RF exposure [3].

These studies represent the first published research into possible interactions of mobile phone emissions [both RF and extremely low frequency (ELF)] and biogenic magnetite. Though results, even if positive, would not necessarily extrapolate to a deleterious effect in terms of human health, they would provide a much-needed plausible mechanism of interaction, which so far, is missing from the field of mobile phone research.

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