

# Recent Advances in Bioelectromagnetics Research on Mobile Telephony and Health—An Introduction

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**Abstract**—It is not widely known that biological and health effects of radiofrequency (RF) energy have been studied for about 50 years. Currently, there are about 1500 published studies related to RF health research, covering various disciplines from biophysics to epidemiology, usually defined as bioelectromagnetics research. All these studies can be found at WHO EMF database (<http://www.who.int/peh-emf/en/>). Current international EMF safety guidelines, established by the International Commission on Nonionizing Radiation Protection (ICNIRP) and IEEE, are based on this extensive research database.

Recent advances in multidisciplinary bioelectromagnetics research addressing mobile telephony and health issue have significantly increased our knowledge about fundamental scientific questions in this area. Improved dosimetry and exposure design have made it possible to conduct well-controlled biomedical experiments. Several carefully conducted theoretical biophysical analyses have also increased our understanding about the responses of cell macromolecules to RF energy. However, inconsistent molecular biological findings have raised questions whether the observed changes are real and whether they have any significance on human health. In this regard, part of the biomedical research community has forgotten a fundamental rule that an observed effect cannot be considered established if it has not been independently replicated and confirmed by other researchers. RF energy—cancer link has been rejected by recent carefully conducted animal studies. However, inconsistent epidemiological findings and misinterpretation of epidemiological data continue to create confusion in mobile telephony—cancer debate in many countries. Studies on other health endpoints than cancer have not either been able to confirm any adverse health effects in humans, such as effects on central nervous system (CNS) at low RF exposure levels. The weight of scientific evidence shows that RF energy does not cause adverse health effects in humans below the internationally accepted RF exposure guidelines, such as established by ICNIRP and IEEE.

## 1. Introduction

By the end of year 2005, it has been estimated that there will be about two billion mobile subscriptions, and by the year 2010 the amount will increase up to about three billion. Huge advances have been made in the research and development in the wireless communications technology during the past two decades. However, the rapidly increased use of mobile phones and establishment of mobile base station networks has led to concerns that RF energy could possibly cause some unexpected adverse health effects in humans. It has been suggested, for example, that mobile phone use induces brain tumors or promotes brain cancer development, or have other unknown effects on central nervous system. These concerns have led to extensive media debates and also—sometimes—hasty sciencepolitical decisions to initiate extensive biomedical research programs in several countries around the world.

There has been an extensive research effort to investigate the effects of RF energy on human health. The research has been ongoing for about 50 years and has produced a large database, such as the one coordinated by WHO EMF project. When analyzing this extensive research database, it is essential to understand what the weight of scientific evidence tells us about biological and health effects following RF exposure instead of looking at outcomes of single studies. The objective of this paper is to summarize the current research conclusions related to bioelectromagnetics research on mobile telephony and health. This review will not cover all the research findings in detail but will highlight three important questions: 1) is RF energy from mobile telephony able to cause cancers in humans; 2) is RF energy from mobile telephony able to cause adverse effects in human central nervous system; 3) are so-called “non-thermal” biophysical interactions possible at mobile telephony frequencies.

## 2. The Radiofrequency (RF) Database

The WHO database on biological and health effects of RF energy is extensive and global. It comprises more than 2500 scientific publications from countries around the world. About 1000 of these are reviews, engineering studies and non-peer-reviewed articles. As shown in Table 1, almost 1500 published papers in the database

satisfy criteria for use as a basis to assess the possible public health impacts of exposure to RF fields. Table 1 shows the number of entries in the database for each of the following types of scientific studies on RF fields: epidemiological, human, animal, and cellular studies. In addition, there are about 300 studies are estimated to be published in the near future including 213 ongoing studies and 90 reported-but-not-published studies.

Although all peer-reviewed studies in the RF database (Table 1) are considered relevant to the mobile phone issue, there are also a large number of studies in this database related to mobile telephony frequencies as shown in Table 2. In this table, the number of studies in each of the four types of scientific investigations is shown. There are 673 studies listed in the database using mobile telephony-specific signals, and 412 of these have been completed. All of the literature in the RF database is available to the public on the WHO website shown in Tables 1 and 2.

Table 1: Peer-reviewed papers describing biological and health effects of RF exposure.

- *All studies are listed on the WHO web site under “citation listings”:* <http://www.who.int/peh-emf/research/database/en/>

Research Study Type	Ongoing	Reported but not Published	Published
Epidemiology	39	7	215
Human Studies	61	18	139
Animal Studies	54	33	717
Cellular Studies	59	32	376
<b>Totals</b>	<b>213</b>	<b>90</b>	<b>1447</b>

Table 2: Mobile telephony relevant studies in the WHO database.

- *These studies are listed on the WHO web site:* <http://www.who.int/peh-emf/research/database/en/>

Research Study Type	Ongoing	Reported but not Published	Published
Epidemiology	34	5	64
Human Studies	57	17	82
Animal Studies	47	23	170
Cellular Studies	52	26	96
<b>Totals</b>	<b>190</b>	<b>71</b>	<b>412</b>

### 3. RF Energy and Cancer

Today there seems to be a some kind of overreliance on what can be expected from epidemiological studies. This has particularly become evident when epidemiological studies related to mobile telephony and health have been misinterpreted in massmedia. It is often falsely interpreted that correlation between two factors, such as mobile phone use and cancer, means also that there is a cause-effect relationship. This relationship does not appear plausible when analyzing critically scientific data, both qualified epidemiologic and laboratory animal data.

Recent reviews of the published epidemiology studies [1–3] have not been able to establish a link between RF exposure and cancer. Many of the epidemiological studies have had serious problems in experimental design and exposure assessment. More reliable data will be available when a current large multi-centre case-control study (INTERPHONE), directed by the International Agency for Research on Cancer (IARC), will be completed during year 2006. The weight of evidence from the epidemiological studies indicates no adverse health effects and this conclusion is strongly supported by results from long-term animal cancer studies, many of which have well-defined RF exposure data useful for risk analysis [4]. The weight of scientific evidence of the long-term animal cancer studies indicates no effect on survival or body weight at exposure levels less than 4 W/kg, which is regarded as the exposure threshold for adverse effects in animals. These results provide strong evidence that

RF exposure does not cause life shortening diseases or general toxicity at exposure levels within ICNIRP limits which are set well below the adverse effect threshold of 4 W/kg [4].

A large amount of research has also focused on possible genotoxic effects in vitro following RF energy exposure although it is widely accepted that RF energy quanta are not capable of causing molecular damage in cell macromolecules, such as in DNA. Vijayalaxmi and Obe [5] have reviewed the scientific literature pertaining to the genotoxicity of RF energy in somatic cells, with the specific endpoints of DNA strand breaks, chromosomal aberrations, micronuclei formation, and sister chromatid exchanges. From their examination of 53 studies, the authors conclude that the weight of evidence shows that RF EMF is not genotoxic, and that many of the studies reporting positive results may have had experimental deficiencies. Meltz [6] has reviewed studies focusing on cancer-related bioeffects in mammalian cell systems and concludes that the weight of evidence available indicates that, for a variety of frequencies and modulations, low RF energy exposure levels do not cause genotoxic effects.

The bioelectromagnetics science community has also intensively debated whether RF fields are capable of causing other specific molecular biological effects than genotoxic which could be related to cancer. Main focus has been on the reports claiming that RF energy is able to interfere with the heat shock protein (HSP) metabolism [7]. It has been speculated that the reported effects are due to “non-thermal mechanisms”. However, the explanations have remained vague because of lack of plausible biophysical interaction mechanism explaining the molecular biological effects which have not either been successfully replicated in other laboratories [8]. Cotgreave [9] concludes in his review paper that issues concerning the risks to human tissues from RF emissions in vivo are still clouded by a number of inconsistencies and controversies in the literature with respect to HSP response, which must be clarified by novel research. Moreover, the use of high-throughput screening techniques (HTST) such as proteomics or transcriptomics to “identify possible molecular targets” of RF energy are still very immature and are currently not useful for RF health risk assessment.

#### 4. RF Energy and Central Nervous System

Intensive discussions—both scientific and non-scientific—have been ongoing about the potential effects of mobile telephony signals on human central nervous system. It has, for example, been proposed that RF exposure alters important physiological functions in the brain such as brain electrical activity, sleep and blood flow [10, 11].

In a review by D’Andrea et al., [12] the authors conclude: ... “the diverse methods and experimental designs as well as lack of replication of many seemingly important studies prevents formation of definitive conclusions concerning hazardous nervous system health effects from RF exposure. The only firm conclusion that may be drawn is the potential for hazardous thermal consequences of high-power RF exposure.”

It has also been proposed that mobile phones may affect the human cognitive performance [13, 14]. However, replication studies with improved methodology [15], including better statistical design, have failed to replicate the original findings. An important methodological point appears to be inclusion of sufficient amount of subjects in the experiments to avoid false positive data when a large number of psychophysiological endpoints are investigated.

It has also been speculated that children with still a developing nervous system would be more vulnerable to RF emissions from mobile phones. This is not supported by scientific facts. From the exposure point of view, carefully conducted theoretical dosimetry studies have shown that there is no evidence for a correlation between energy absorption and head size [16, 17]. Other factors such as shape of the head, tissue distribution and antenna position are more important factors affecting specific absorption rate (SAR). “Child issue” is not either supported by biomedical evidence. Recent well-designed human experimental studies have found no significant differences in cognitive performance as measured by reaction time and accuracy in children exposed to RF fields typically used in mobile telephony [18, 19].

#### 5. RF Biophysical Interaction Mechanisms

The bioelectromagnetics science community has for several years debated whether there would other RF biophysical interaction mechanisms than thermal. Unfortunately, even fundamental research findings in this field are often overlooked in speculative debates. A thermal mechanism depends only on the amount of energy absorbed and thus its frequency dependence is predictable. The amount of energy absorbed will depend on the electrical properties of the tissue and the geometrical interaction with the biological object, both of which will cause well-established frequency variations. There is no modulation dependence for a thermal mechanism. A non-thermal mechanism, on the other hand, would be expected to exhibit frequency dependent responses, modulation dependent responses or both. The current 400 mobile telephony studies cover a wide range of frequencies and modulations and do not support the hypothesis that there is frequency dependent or modulation

dependent response. This conclusion is further magnified by several biophysical analyses and reviews showing that other biophysical mechanisms than thermal are not plausible at mobile phone frequencies.

Foster and Repacholi [20] have concluded: “Modulation introduces a spread of frequencies into a carrier waveform, but in nearly all cases this spread is small compared to the frequency of the carrier. Consequently, any nonthermal (field-dependent) biological effects related to modulation must result from interaction mechanisms that are fast enough to produce a response at radiofrequencies. Despite considerable speculation, no such mechanisms have been established. Existence of “non-thermal interactions at radiofrequencies are not either supported by rigorous biophysical analyses of Pickard [21] and Adair [22].

A special target for discussion has been the DNA molecule and whether RF energy would be capable of causing vibrational modes in this macromolecule and thereby leading, for example, to molecular damage. Even fundamental physics shows that this mechanism does not appear plausible since the RF photon quantum energy is far too low to cause breaks in chemical bonds and/or conformational changes in macromolecules such as in DNA and proteins. Prohofsky [23] has shown in a theoretical study that that absorption of RF energy below several hundred GHz would not be resonantly absorbed into an intramolecular mode for macromolecules such as DNA. The absorption would be into bulk modes of the material in which the molecule is embedded. The thermalization of the RF energy would be primarily to this bulk material, rather than to a single molecule.

## 6. Conclusions

The weight of scientific evidence of the epidemiological and long-term animal cancer indicates that long-term RF exposures do not induce tumors or promote cancer development. Studies on other health endpoints than cancer have not either been able to establish any adverse health effects in humans, such as effects on central nervous system (CNS) at low RF exposure levels. Theoretical biophysical studies to date and lack of replicable biological effects strongly suggest that the only plausible interaction mechanism at mobile telephony frequencies and emission levels is thermal. The weight of scientific evidence shows that RF energy does not cause adverse health effects in humans below the internationally accepted RF exposure guidelines, such as established by ICNIRP.

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