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Review paper

# Bioeffects of microwave—a brief review

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**Abstract**

Since the 18th century scientists have been intrigued by the interaction of electromagnetic fields (EMFs) and various life processes. Attention has been focussed on EMFs in different frequency ranges, of which microwave frequency range forms an important part.

Microwaves are part of the electromagnetic spectrum and are considered to be that radiation ranging in frequency from 300 million cycles per second (300 MHz) to 300 billion cycles per second (300 GHz), which correspond to a wavelength range of 1 m down to 1 mm. This nonionising electromagnetic radiation is absorbed at molecular level and manifests as changes in vibrational energy of the molecules or heat (Microwaves irradiating the community, *Hidden hazards*, Bantan Books publisher, Australia, 1991).

Identifying and evaluating the biological effects of microwaves have been complex and controversial. Because of the paucity of information on the mechanism of interaction between microwave and biological systems, there has been a persistent view in physical and engineering sciences, that microwave fields are incapable of inducing bioeffects other than by heating (Health Physics 61 (1991) 3). Of late, the nonthermal effects of microwaves on tissue responses are being documented (Physiol. Rev. 61 (1981) 435; Annals of New York Acad. Sci. 247 (1975) 232; J. Microwave Power 14 (1979) 351; Bioelectromagnetics 7 (1986a) 45; Bioelectromagnetics 7 (1986b) 315; Biologic Effects and Health Hazards of Microwave Radiation, Warsaw, Polish Medical Publication (1974) 289; Biologic Effects and Health hazards of the microwave Radiation, Warsaw, Polish Medical Publication (1974) 22; Multidisciplinory perspectives in event-related brain potential research, Washington DC, US Enonmental Protection Agency, (1978) 444).

The present article is an attempt to familiarise the reader with pertinent information regarding the effects, mainly athermal, of microwave irradiation on biologic systems, especially microorganisms.


*Keywords:* Microwave; Bioeffects; Athermal effect; Genetic mutation; Biotechnology

## 1. Thermal versus athermal effects of microwave irradiation

There is evidence that microwaves cause different biological effects depending upon field strength, frequencies, wave forms, modulation and duration of exposure (Rai et al., 1994a,b).

These effects were mainly attributed to microwave heating (Gandhi, 1987) but recent reports have shown or suggested that there are nonthermal microwave effects in terms of energy required to produce various types of molecular transformations and alterations.

One of the modern approaches to sterilisation in the food industry is the use of microwave irradiation. Microbiological studies involving microwave irradiation have resulted in the following two conflicting conclusions; cell death was solely the result of heat produced by microwave irradiation; death was due to not only heat but also microwave electric field. One of the main reasons for the above conflicting conclusions is the difficulty in keeping the temperature constant during the microwave irradiation. Keeping this in mind Siego Sato developed a new method for maintaining a constant temperature during microwave irradiation (Sato, 2001). No cell death was observed at 35 °C, whereas at 45, 47 and 50 °C, the death rates of *Escherichia coli* exposed to microwave irradiation were higher than those obtained in conventional heat sterilisation at the same temperature. Although the author could not specify the exact mechanism underlying the nonthermal effect of microwaves, the author proposed that the microwaves either caused ions to accelerate and collide with other molecules or caused dipoles to rotate and line up rapidly with alternating (2450 million times/s) electric field resulting in a change in secondary and tertiary structure of proteins of microorganisms.

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Michael Kozempel developed a continuous experimental microwave process to isolate thermal and nonthermal effects (Milligan and Brigid, 2000) to test the concept of nonthermal pasteurisation of liquids. The process combined rapid energy input to the food system using microwave, with rapid removal of thermal energy utilising an efficient heat exchanger concept. The combination of yeast, *Pedicoccus* sp. and *E. coli* K-12 were tested in water, beer, liquid whole egg etc. The temperature of the process was maintained at 35 °C or less with a total microwave exposure time of 3–8 min. It was observed that microwave energy in the absence of other stresses such as heat, pH or anti-microbials did not destroy microorganisms at low temperature.

Much effort has been devoted to studies that have attempted to demonstrate the existence of nonthermal effects of microwave irradiation by containing end-point temperatures below thermal death points of microorganisms under investigation. Early reports by Beckwith and Olsen (1931); Carpenter (1958); Fabian and Graham (1933); Fleming (1944); Nyrop (1946); Susskind and Vogelhut (1959); and Yen and Lui (1934), initiated this hypothesis for both procaryotes and eucaryotes. Culkin and Fung (1975) demonstrated that *E. coli* and *Salmonella typhimurium* could not survive in soups cooked at 915 MHz by microwave irradiation. They found that microbial destruction occurred at lower temperature and shorter time periods when compared to conventional heating methods. They also found varied effects based upon the intensity of the field strength at the top and bottom of the soup containers. They postulated that factors other than thermal effects might be involved in the effects of microwave irradiation on microorganisms.

Athermal physiological effects of continuous waves and modulated microwaves were studied on a *Cyanobacterium Nostoc* muscorum (Singh et al., 1994). The study showed that different microwave frequencies in continuous waves and modulated modes produced significantly different physiological effects on the algae. Water mediated bio-effects further presented additional proof that water had the capability to remember the imposed electromagnetic field characteristics for an extended period of time.

The effect of microwave modulated with square wave of different pulse repetition frequencies was studied on physiological behaviour of the *Cyanobacterium* (*Anabaena dolilum*) by Samarketu et al. (1996). The organism was directly exposed by inoculating the nutrient solution for an hour to microwave 9.575 GHz modulated with square waves of different pulse repeatation frequencies at incident power density 0.658 mW/cm$^2$. The study revealed that microwaves athermally induced different biological effects by changing the structures by differentially partitioning the ions, altering the rate and/or direction of biochemical reactions. Frequency dependent effect reveals that parameters like heterocyst frequency, filament length of the directly microwave exposed samples are directly correlated, whereas turbidity of cell suspension, protein, carbohydrate, chlorophyll a, carotenoids and phycocyanin of directly microwave exposed samples are inversely correlated with higher modulation frequencies. Moore et al. (1978) observed a reversible loss of virulence with virulent cells of *Agrobacterium tumefaciens* strain B6 upon exposure to microwave at a frequency of 10,000 MHz and an intensity of 0.58 mW/cm$^2$ for 30–120 min. The authors suggested a temporary change in one or more metabolic processes affecting virulence as a nonthermal microwave effect. A 30–60% decrease occurred in their ability to produce tumors on potato or turnip disks. The microwave exposure did not affect the viability of these bacteria or their ability to attach to a tumor binding site; neither did it induce thermal shock. Loss of virulence was reversible within 12 h.

Dreyfuss and Chipley (1980) attempted to characterise some of the effects of sublethal microwave irradiation in cells of *Staphylococcus aureus*. Upon exposure to microwave irradiation the activities of various metabolic enzymes such as Glucose-6-phosphate dehydrogenase, membrane ATPases, alkaline phosphatase, malate dehydrogenase, lactate dehydrogenase, cytochrome oxidase adenosine triphosphatase etc. were affected but the irradiation affected *S. aureus* in a manner quite different from conventionally heated cells. This thus indicates the athermal behaviour of microwave irradiation.

Subtle effects of low levels of microwave radiation which were not directly attributable to heat have been reported by researchers, mainly in Europe, since the 1950s. The occasional reports of head-ache, lassitude, stomach-ache pains, sleeplessness, irritability and other highly subjective symptoms suspected the nonthermal effects of microwave among workers in the vicinity of microwave generating equipments.

Low intensity of microwave has been found to modify behaviour without modifying the core temperature of experimental subjects (Justeen, 1979). Many physiological (Ray and Behari, 1990) and biochemical changes (Kunjlwar and Behari, 1993) have been reported in rats also after low level microwave exposure. Mammalian immunity has been found to be modulated by low levels of microwave (Budd and Czerski, 1985; Nageswari et al., 1991). Low intensity of microwave irradiation has in fact been considered as mild nonspecific "stressor" (Lu et al., 1980) with effects on total body (Lu et al., 1986) and reproduction (Lu et al., 1981). Acute low level of microwave has been reported to activate the endogenous opioids in the nervous system causing a decrease in the central cholinergic activity in the hippocampus and frontal cortex (Lai et al., 1986, 1987; Lai, 1992).

In our laboratory (Banik et al., 2002a,b) attempts have been made to study the effect of microwave irradiation on biomethanation by using a methanogenic bacterial strain (*Methanosarcina barkeri*-DSM 804) as inoculum. Microwave frequency ranging from 13.5 to 36.5 GHz was irradiated for 2 h on anaerobic microbial culture of *Methanosarcina barkeri*-DSM 804 to study growth character of the bacteria and its effect on biomethanation. From the study it was revealed that the cited frequencies of microwave are able to induce biomethanation by quicker generation of biogas and increasing quantity of methane in biogas. Study of growth dynamics revealed that microwave could increase growth rate of the bacteria and was most effective on biomethanation at 31.5 GHz frequency.

## 2. Microwave effect on cellular growth rate and properties

Grundler and co-authors (Grundler et al., 1977, 1982, 1988) observed that the growth rate of yeast *Sacharomyces cerevisiae* could either be increased upto 15% or decreased upto 29% by certain frequencies of microwave irradiation within 41.8–42.0 GHz.

Dardanoni and co-authors (Dardanoni et al., 1994) observed frequency and modulation dependent effects on the growth of the yeast *Candida albicans*. Microwave modulated at 1 KHz irradiation reduced growth rate by 15% at 72 GHz but not at 71.8 or 72.2 GHz. A 3 h continuous irradiation at 72 GHz increased the growth rate by about 25% over the control.

Levina and co-workers (Pakhomov et al., 2001) studied microwave effects on the development of the protozoan *Spirostum* sp. cell population. The study indicated that the irradiation affected the population's own growth control mechanism, and that the effect depended on the stage and other particulars of the population development.

Tambiev and co-workers (Pakhomov et al., 2001) observed that exposure for 30 min at 2.2 $mW/cm^2$ and 7.1 mm wavelength enhanced the growth of blue-green algae *Spirulina platensis* by 50%. They observed stimulatory effects are of considerable promise in biotechnology, where *S. platensis* is used for production of food protein and biologically active products.

Bulgakova and co-workers (Pakhomov et al., 2001) studied how microwave exposure of *S. aureus* affected its sensitivity to antibiotics with different mechanism of action. Irradiation either increased or decreased the antibiotic sensitivity and the probability of these opposite effects depended on the antibiotic concentration.

Sherb and co-workers (Pakhomov et al., 2001) showed changes in transmissivity of R-plasmids in various strains of *E. coli* and *S. aureus* upon 30 min exposure to 6.0–6.7 mm band of microwave irradiation.

Berzhanskaya and co-workers (Pakhomov et al., 2001) found a suppression of bioluminescence of *Photobacterium leiognathi* at 36.2–55.9 GHz microwave irradiation. Results of studies with *Enterobacter aerogenes* and *E. coli* B showed that microwave radiation inhibited or stimulated protein, DNA and RNA synthesis and cell growth.

## 3. Microwave irradiation studies on humans and animals

After several studies by Golantt, Mikhn, Novikov and Rodshtadt it could be suggested that peripheral receptors and afferent nerve signaling could be involved in the whole organisms response to a local microwave exposure. Chernyakov and co-authors were able to induce heat rate changes in anaesthetised frogs by microwave irradiation of remote skin areas. This data was then supported by the findings of Potekhina and co-workers where some frequencies from 53–78 GHz effectively changed the natural heart rate variability in anaesthetised rats (Pakhomov et al., 2001).

Teratogenic effect of microwave was performed with *Drosophila* flies by Belyaev and co-workers. The experiments involving microwave exposure suggested supposedly that microwave disturbed DNA-protein interactions, which determine the realisation of the ontogenetic program.

Liburdy and his group (Pakhomov et al., 2001) found that microwaves exposure (2450 MHz) of rabbit erythrocytes increased Na-passive transport only at membrane phase transition temperature of 17–19 °C and this permeability effect was enhanced for relative hypoxia which is characteristic of intracellular oxygen tension of less than or equal to 5 mm Hg.

The human body begins to significantly absorb electromagnetic radiation when the frequency exceeds about 15 MHz. This absorbtion varies for different parts of the body. In the frequency range of 70–100 MHz, which overlaps the TV and FM radio broadcast frequencies, the body acts as an efficient radiation antenna strongly absorbing these wave lengths (Pakhomov et al., 2001).

## 4. Genetic effects

A number of studies indicated that microwave could affect the fine chromosome structure and function of cell and cell tolerance to standard mutagens and lesion repairs. Recent work by Belyaev et al. (1993, 1994) pointed to the chromosomal DNA as a target for resonance interaction between living cells and microwave. Studies by Hellar and Teixeira (1959) are reported to have shown that low power microwave radiation could produce mutations in mammalian cells and insects. In the 1960s and 1970s researchers showed that protein, RNA and DNA absorbed 65–75 GHz radiation, and that microwaves were able to interfere with repair mechanisms or even to induce gene mutation in bacteria (Pakhomov et al., 2001).

## 5. Microwave therapy

In animals and humans local microwave exposure stimulated tissue repair and regeneration, alleviated stress reactions and facilitated recovery in a wide range of diseases. Microwave also alleviated the effect of X-rays at both cellular and organism level.

Diseases reported to be successfully treated with microwave are gastric, duodenal ulcers, cardiovascular diseases, respiratory sickness, tuberculosis, skin diseases etc. (Pakhomov et al., 2001).

## 6. Conclusion

1. In this review, we have found that microwave effects were established at all biological levels, from microbial cells to animals as well as the human system.
2. The study revealed that microwave could athermally induce different physiological effects.
3. The studies on the mechanism of microwave bio-interaction showed that microwaves act as promoting agents in inducing genetic changes in biosystem.

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