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Project Summary

Effects of 200, 591 and 2450 MHz Microwaves on Cerebral Energy Metabolism

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Earlier work showed that levels of key biochemicals in the energy production system of rat brain are affected by exposure to 591 MHz microwave radiation at 13.8 mW/cm^2. The objectives of this study were to determine whether direct microwaves affect the biological system, and if they do, whether they are secondary to the hyperthermia produced in the tissue, to establish dose-response relationships for the effects, and to investigate different frequencies of exposure and modulation of the carrier signal. The fluorescence of reduced nicotinamide adenine dinucleotide (NADH) in the rat brain was measured *in vivo* during exposure to the microwave radiation, and adenosine triphosphate (ATP) and creatine phospate (CP) levels were measured chemically after exposure. An increase in brain temperature from 35.6 to 39°C caused no change in NADH fluorescence, an 11.8% reduction in the ATP level and a 28.8% decrease in the CP level. Microwave exposures at 200 and 591 MHz for 0.5 to 5 minutes at 13.8 mW/cm^2 caused no measurable increase in brain temperature; however, the maximum NADH fluorescence increase was 10% while ATP levels decreased by as much as 30%. CP levels decreased by up to 40% at 591 MHz but not at all at 200 MHz. Similar exposures at 2450 MHz produced no changes in any of the parameters measured. These results indicate frequency specific inhibition of brain energy metabolism. At 200 MHz, the mitochondrial NADH-to-ATP production pathway was inhibited. At 591 MHz both the NADH-to-ATP and the CP-to-ATP pathways were inhibited. At 2450 MHz, neither pathway was affected. The data support the hypothesis that microwave radiation directly inhibits mitochondrial energy production pathways in rat brain, and that tissue heating is not a factor.

This Project Summary was developed by EPA's Health Effects Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The question of whether microwave radiation can cause biological effects that are independent of tissue hyperthermia has been a continuing controversy for several years. While the matter is far from settled, several lines of evidence indicate a strong possibility of direct interactions which lead to potentially important biological changes. One such experiment provided the basis for this study. Exposure of a rat to 591 MHz microwave radiation at 13 8 mW/cm^2 produced changes in the levels of three key brain biochemicals, reduced nicotinamide adenine dinucleotide (NADH), adenosine triphosphate (ATP) and creatine phosphate (CP) Because the

principal compound, ATP, provides the energy necessary to drive many biological functions, any change in the biological system's capacity to produce this compound is extremely important.

The objectives of this study were threefold. The first was to establish whether or not tissue hyperthermia plays an obvious role in producing the biochemical changes. This was addressed by extensive dosimetry and by investigation of the effect of temperature on the *in vivo* processes. The second objective was to establish the dependence of the changes on the frequency of the microwave radiation and on modulation of the carrier frequency. Finally, wherever effects were found, dose-response relationships were developed.

Summary Text

Most of the microwave exposures were conducted by placing a rat in a stripline facing the source of the radiation. Experiments were conducted at frequencies of 200, 591, and 2450 MHz. The carrier signal at 591 MHz was also sinusoidally modulated at several frequencies between 4 and 32 Hz, and pulse-modulated at 250 and 500 pulses per second using 5 μsec pulses. Relative NADH levels were measured during exposure by uncovering a portion of the anesthetized rat's brain and placing a fiberoptic probe adjacent to it through which NADH fluorescence was measured by use of a time-sharing fluorometer. Following decapitation of the rat immediately after exposure, ATP and CP concentrations in the brain were determined chemically using established methods. Temperature controls were performed by wrapping the anesthetized rat in a heating blanket to maintain the desired brain temperature.

Incident microwave fields were measured at the rat's position in the stripline without the rat present. The tissue absorption of microwave radiation was measured by the temperature-rise technique using thermistor probes in the brains of dead rats.

The relationship of the three biochemicals measured is diagrammed in Figure 1. NADH oxidation results in electron flow in the respiratory chain of the mitochondrion which is coupled to ATP production. If ATP levels fall below normal, the CP-CP kinase-ADP→ATP reaction occurs rapidly to sustain the ATP pool. The CP pathway maintains normal levels of ATP until CP levels fall approximately 40%.

The results of the thermal controls demonstrated that when the rats were anesthetized with urethane, the NADH fluorescence was not affected, and ATP and CP levels decreased to new steady state levels as temperature was raised. A temperature rise from 35.6°C to 39.0°C decreased ATP concentration by 11.8% and CP concentration by 28.8%.

Dose-response curves for NADH fluorescence in microwave exposed rats are illustrated in Figure 2, plotted as a function of the incident field strength. These data show that at 200 and 591 MHz, the change in NADH fluorescence increased until exposures of 10-12 mW/cm^2 were reached, when the effect appeared to saturate. Additional exposures up to 40 mW/cm^2 confirmed this saturation level. No change in NADH fluorescence was found when the rats were exposed to 2450 MHz. As can be seen from the conversion factors in the figure, the energy absorbed by the rat head per unit time (specific absorption rate or SAR) varies with frequency and was actually highest at 2450 MHz where no change was observed. These results, coupled with those for the thermal controls, argue strongly against a tissue hyperthermia mechanism. If the NADH fluorescence data are plotted versus the electrical field strength in the brain tissue, a threshold of 3-4 volts/meter (V/M) is obtained at both 200 MHz and 591 MHz.

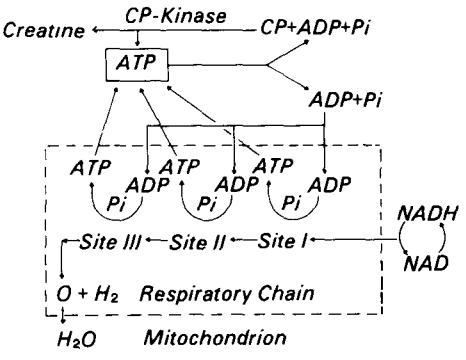

Figure 1. Interaction of CP, ADP, and NADH.

In Figure 3, typical NADH fluorescence curves are shown as a function of time of exposure together with the chemical data for ATP and CP concentrations determined after comparable exposure periods. For 591 MHz exposures, the changes in ATP concentration appear to mirror the changes in the NADH fluorescence. The CP concentrations changes were always greater than those for ATP, consistent with the normal functioning of the CP pathway. These data indicate an inhibition of the pathway that uses NADH to produce ATP, resulting in excess NADH and insufficient ATP. For 200 MHz exposures, the relationship of NADH fluorescence and ATP levels were similar to those of 591 MHz. However, at 200 MHz there was no decrease in CP concentration, even though ATP levels have dropped

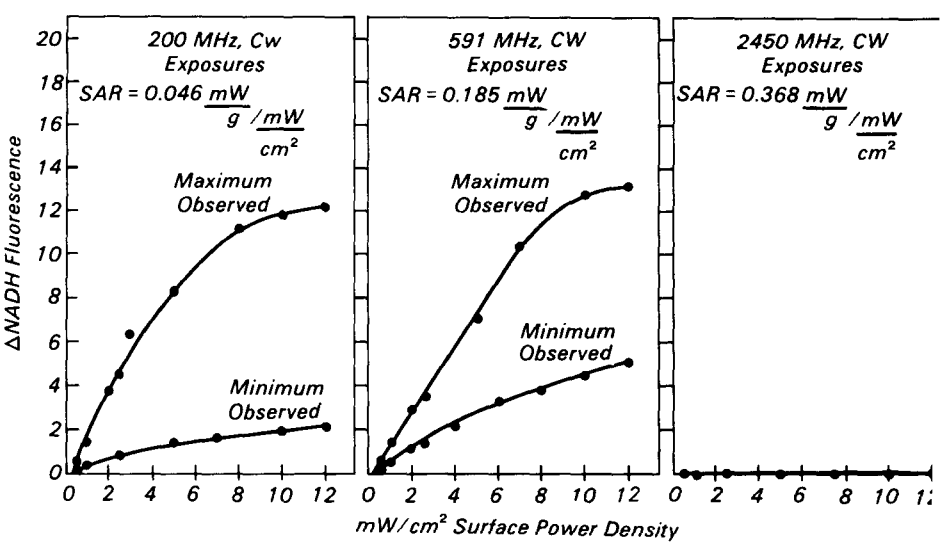

Figure 2. Changes in NADH fluorescence of rat brain vs surface power densities at 200, 591 and 2450 MHz, CW exposures in microstrip system.

significantly. This indicates an inhibition of both the NADH-to-ATP pathway and the CP-to-ATP pathway Again, for exposures at 2450 MHz there was no statistically significant changes in NADH fluorescence, ATP levels, or CP levels, indicating no inhibition of the system by this frequency. These results demonstrate a selective frequency-specific inhibition of the energy production system in rat brain.

NADH fluorescence has been measured for rats exposed to 591 MHz microwave radiation sinusoidally amplitude modulated at frequencies between 4 and 32 Hz. Results for amplitude modulation frequencies between 16 and 24 Hz were the same as for unmodulated 591 MHz microwaves At 4-12 Hz and 28-32 Hz, the increase in NADH fluorescence was about 10% smaller than for the unmodulated 591 MHz exposures. The significance of this difference is not known at this time

Rats also have been exposed to pulse modulated 591 MHz microwave radiation Five microsecond pulses at pulse repetition rates of 500 and 250 pulses/sec were employed. The NADH fluorescence changes measured at increasing average incident field strength were essentially the same as for the unmodulated 591 MHz exposures.

Conclusions

These data show a frequency-dependent effect of microwave radiation on energy metabolism in the rat brain. Under exposure at 591 MHz, the NADH-to-ATP pathway was inhibited, while at 200 MHz, this pathway, as well as the CP-to-ATP pathway, was inhibited. Apparently, at 2450 MHz no inhibition occurs The threshold for these effects in terms of field strength in the brain tissue was 3-4 V/m at both frequencies This corresponds to a threshold of less than 0 05 W/kg in terms of specific absorption rate. Because of the low threshold, and because the results are different from those for thermal controls, tissue heating is probably not the causative agent

Many enzymes in the system illustrated in Figure 1 (including CP-kinase) contain a metal atom which is involved with the enzyme's catalytic action The metal-enzyme complex normally has a high dipole moment. The results of this study are consistent with the hypothesis that a microwave induced dipole oscillation disrupts the rigid stereo-specificity requirements in certain enzymes, leading to inhibition of the system's function. These data indicate inhibition of at least two enzymes in the system.

The results of this study are consistent with a direct interaction of microwave radiation with the energy production system in rat brain, and are not consistent with a mechanism of tissue hyperthermia. For these reasons and because of possible effects on humans, it is necessary to understand the mechanism by which the effects are produced and the relevance to human exposure.

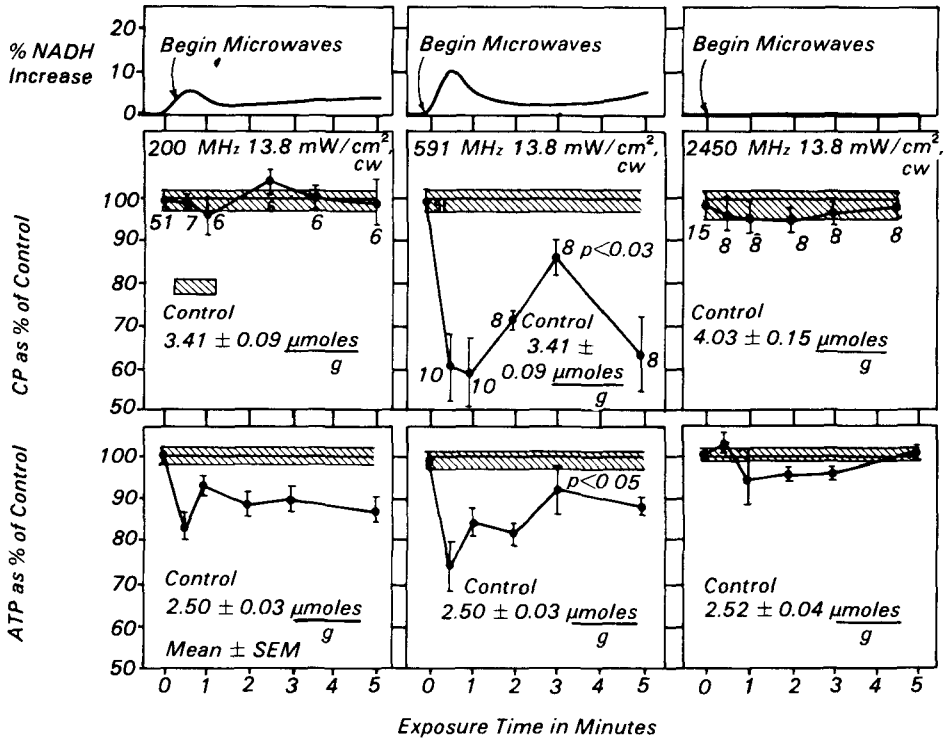

Figure 3. *Rat brain NADH fluorescence, [CP] and [ATP] at 200, 591 and 2450 MHz, CW, 13.8 mW/cm² surface power density vs time of exposure.*

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The complete report, entitled "Effects of 200, 591, and 2450 MHz Microwaves on Cerebral Energy Metabolism," (Order No. PB 83-116 913; Cost: $10.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650
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