EFFECT OF MICROWAVE FIELDS ON RABBIT VAGUS NERVES AND SUPERIOR CERVICAL GANGLIA

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Abstract

Rabbit vagus nerves and superior cervical ganglia were exposed in vitro to CW and pulsed 2450 MHz fields in a waveguide circulated with temperature-controlled Ringer's solution. No significant change in characteristics was observed at absorbed power densities of 0.3-1500 W/kg for CW, and 0.3-220 kW/kg peak for pulsed fields as long as temperature was maintained at a constant non-noxious level.

Summary

The use of electromagnetic (EM) power in medicine has existed since EM sources have been available to man.[1] The first work on the therapeutic application of microwaves started at the Mayo Clinic in 1946. Since then, microwave diathermy has been used to relieve pain and reduce muscle spasm and joint stiffness. However, the effects of microwaves have received only limited quantitative examination until recent years. The increasing medical potential for the use of microwaves in medicine, such as the rewarming of human blood or frozen tissues, differential hyperthermia in cancer treatment, transcutaneous stimulation of nerves by implanted diodes, etc., have made contra-indication, precautions and dosimetry increasingly important. Although the most obvious effects of microwaves are thermal in nature, which are desirable in most of the medical applications, evidence is also being sought for the explanation of possible non-thermal effects. In vitro experiments with waveguide apparatus were designed to study the effects of microwaves on isolated tissues. With isolated tissue preparations, it is possible to minimize the temperature effect by surrounding the exposed tissue with a temperature-controlled bathing solution. Since only small amounts of isolated tissues are pulled through the waveguide in regions of known field configuration and magnitude, quantitative dosimetry is easily achieved. Also, with the stimulating and recording apparatus outside the waveguide, artifacts due to field enhancements or EM field interaction with preamplifiers can be eliminated. In addition, the waveguide exposure apparatus can simulate a whole range of low to high intensity exposure conditions with readily available low power sources monitored by conventional power meters.

Reports from this laboratory have shown that no changes in conduction characteristics were observed for peripheral nerves exposed to both CW and pulsed fields[2] and ganglion in CW fields[3], as long as the temperature of the tissue was kept constant. However, in previous experiments, nerves were only exposed to electric fields parallel to the nerve axis. The present paper reports additional work on the effects of CW and pulsed 2450 MHz fields applied perpendicular to the axis of vagus nerves and superior cervical ganglia of rabbits.

Previously, only myelinated fiber response was studied. In this work, the effect of microwave fields on the conduction of unmyelinated fibers is also clarified. Anatomically, unmyelinated fibers differ from myelinated fibers by their wrapping of Schwan cells. Unmyelinated fibers are also distinguished from myelinated fibers by their slow conduction rates, high electrical threshold, and long spike duration. The vagus nerve consists of both myelinated and unmyelinated fibers. It is, therefore, a preferable preparation for a simultaneous study on the effects of microwave fields on both types of fibers. Its easy accessibility and lack of branches at the neck region of the animal donor also make it a convenient preparation to use in the experiments.

Superior cervical ganglion is the largest ganglion of the sympathetic trunk with cell bodies and numerous synaptic junctions. There are both cholinergic and adrenergic nerves releasing acetylcholine and catecholamines, respectively, at the synapses.[4] The effect of microwave fields on the electrical characteristics of the neuron cell body and the two types of synaptic transmission can be conveniently studied by using the superior cervical ganglion.

Rabbits (4-6 kg) of either sex were anesthetized with urethane (1.5 g/kg, IV). Depending on the particular experiment, about 6 to 10 cm of either vagus nerve or superior cervical ganglion with cervical sympathetic (preganglionic) and internal carotid (principal post-ganglionic) nerves was removed from the neck region. The isolated tissue was immersed in the bathing solution at room temperature. The connective tissue of the vagus nerve or the sheath of the ganglion was then carefully removed in order to allow free diffusion of glucose and oxygen, etc. The bathing solution, consisting of 136.8 mM NaCl, 5 mM KCl, 1 mM $MgCl_2$, 2 mM $CaCl_2$, 12 mM $NaHCO_3$, 1 mM NaH_2PO_4, and 11 mM glucose was prepared for each experiment. This solution, when gassed with 95% O_2 + 5% CO_2, had a pH of 7.3-7.4 at 37°C. The complex dielectric constant of the solution, measured in a coaxial slotted line, was found to be (74.3-j20.5). The corresponding field penetration depth of 1.65 cm was used for the calculation of absorbed power density at the nerve.

A silver plated S band WR 284 waveguide was equipped with inlet and outlet ports for circulating fluids, as shown in Fig. 1. The waveguide was pointed upward with a plexiglass solution reservoir on the top edge of the waveguide to prevent overflow. A 1.2 cm thick quarter wave dielectric matching slab of Emerson Cuming Stycast Hi K 500 F K=6 was milled to the size of the inner waveguide and pushed to the level of the circulating ports. Leakage was prevented by sealing it with vacuum grease at the contact. A VSWR value of 1.08 was measured at room temperature. The 6 cm depth of solution reduced reflections from the solution-air interface to negligible values in the region of the tissue. For tissue preparations with average dielectric constants close to that of the bathing solution, the absorbed power density is a simple exponential function of distance from the dielectric-solution interface. For TE_{10} mode, the spatial power distribution in the waveguide is a function of sine square with maximum power at the center of the waveguide. The maximum absorbed power density at x cm from this

interface can be calculated by the formula:

$$P = \frac{4\alpha(P_I - P_R)}{\rho A} e^{-2\alpha x}$$

where P = absorbed power density in the nerve (W/kg), P_I = incident power (W), P_R = reflected power (W), ρ = density of the tissue, A = cross-sectional area of the waveguide, and $1/\alpha$ = depth of field penetration in the Ringer's solution. Four 3 mm diameter holes were drilled in the four walls of the 24 cm^2 cross-sectional waveguide at a distance of x = 1 cm above the dielectric interface. Four plexiglass chambers were glued on the outside walls of the waveguide to accommodate stimulating and recording electrodes for nerve axis locations either perpendicular or parallel to the electric fields. The stimulating electrode located on one end of the tissue exterior of the waveguide was platinum and the recording electrode was 0.9 mm polyethylene suction electrode which could be placed at one end of the tissue in the waveguide. The platinum wire in the bathing solution filled suction electrode was always at the outside of the waveguide. Stimulation current pulses of 0.3 msec and 0.3-30 mA were provided to the nerves once every 2 seconds. The temperature of the Ringer's solution was held at 37° within $\pm$ 0.02°C by a constant temperature circulator with 1.3 liter/min circulation rate. The temperature of the solution was monitored at the outlet of the waveguide with a thermocouple. The true temperature at the center of the waveguide 1 cm above the dielectric material during various radiation levels was calibrated by a liquid crystal fiber optic temperature probe.[5] The maximum temperature rise during irradiation was about 1°C limited by the maximum pumping rate of the solution. CW and pulsed power sources, operating at 2450 MHz with incident and reflected powers measured by means of a directional coupler and a power meter were used to feed the waveguide. The waveguide, suction electrode, and directional coupler were enclosed in a grounded screened chamber to eliminate the interference from power lines and nearby equipment.

The vagus nerves were exposed to each power level for 10 min separated by 5 min intervals with no applied power. The superior cervical ganglia were exposed for only 5 min at a time since their viability had a shorter lifetime. In one series of experiments, the isolated preparation was exposed to pulsed power with calculated average power absorption densities of 0.3, 3, 30 and 220 W/kg in the tissue. The pulse widths were 1 μsec and 10 μsec with recurrence rates of 1000 and 100 pps, respectively. Therefore, the peak absorbed power densities in the nerves were 0.3, 3, 30 and 220 kW/kg which are equivalent to 328, 1037, 3278 and 8876 V/m in the tissue. Continuous waves with absorbed power densities of 0.3, 3, 30, 300 and 1500 W/kg were used. When the isolated tissue was positioned perpendicular to the electric field, only the portion of the tissue at the center of the waveguide was exposed to the above absorbed power densities. Compound action potentials were recorded on tape and reduced off-line by a computer of average transients. Arrangement of the apparatus is shown schematically in Fig. 2. Tests for possible direct stimulation of nerves and ganglia by microwave fields were also performed using maximum available absorbed power densities of 1500 W/kg average for CW and 220 kW/kg peak for pulsed fields. Electrical stimulation was removed during these tests.

Exposure of vagus nerves and superior cervical ganglia did not result in either amplitude or conduction velocity changes of compound action potentials during the time that the temperature of solution was held constant for either CW or a pulsed irradiation (Figs. 3,4). No direct stimulation of nerves by either CW or pulsed fields was observed. The conduction characteristics of the neurons were independent of electric field polarization. At high applied power levels, the induced action potential showed a slight increase in conduction velocity consistent with the 1°C bathing solution temperature rise. This effect was reproduceable raising the temperature of the solution by resetting the temperature controller.

Acknowledgment

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References

1. Guy, A.W., J.F. Lehmann, and J.B. Stonebridge, "Therapeutic applications of electromagnetic power," Proc. IEEE, vol. 62, no. 1, pp. 55-75, January 1974.

2. Chou, C.K. and A.W. Guy, "Effect of 2450 MHz microwave fields on peripheral nerves," IEEE-G-MTT, Int. Microwave Symp. Digest, Boulder, Colorado, pp. 318-320, June 1973.

3. Courtney, K., J.C. Lin, A.W. Guy, and C.K. Chou, "Microwave effect on rabbit superior cervical ganglion," IEEE MTT-S, Int. Microwave Symp. Digest, Atlanta, Georgia, pp. 104-105, June 1974.

4. Akert, K. and P.G. Waser, Ed., "Mechanisms of synaptic transmissions," Progress in Brain Research Vol. 31, 1969.

5. Johnson, C.C., C.H. Durney, and J.L. Lords, "Liquid crystal fiber optic temperature probe for the measurement of electromagnetic power absorption in tissues," IEEE MTT-S, Int. Microwave Symp. Digest, pp. 32-34, Atlanta, Georgia, June 1974.

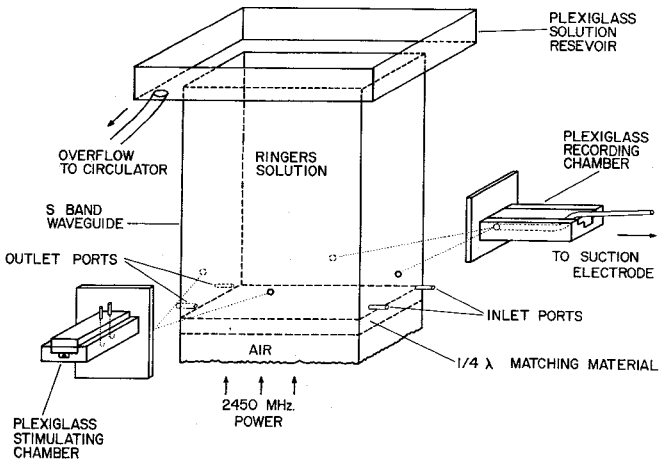

Figure 1. Waveguide showing matching material, circulating ports, stimulating and recording assemblies.

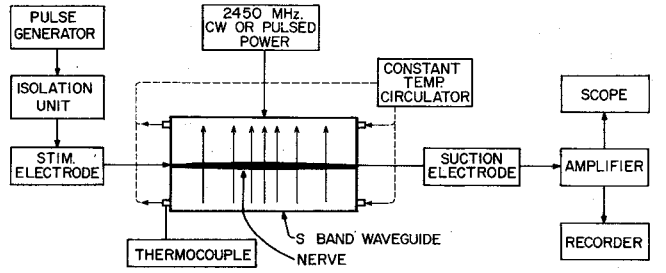

Figure 2. Apparatus for microwave radiation of isolated nerve in vitro.

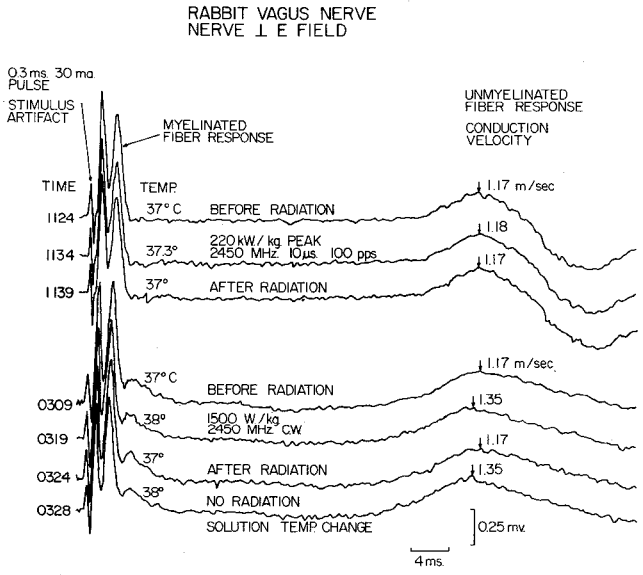

Figure 3. Compound action potentials of isolated rabbit vagus nerve exposed to 2450 MHz CW and pulsed fields.

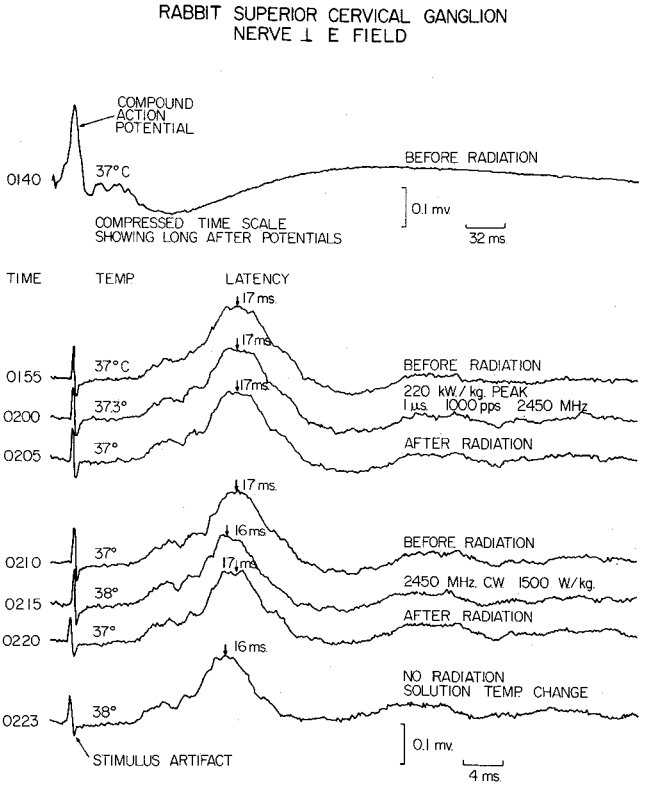

Figure 4. Compound action potentials of isolated rabbit superior cervical ganglion exposed to 2450 MHz CW and pulsed fields.