EFFECTS OF LOW POWER MICROWAVES ON THE LOCAL CEREBRAL BLOOD FLOW OF CONSCIOUS RATS

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Local cerebral blood flow was measured in several different rat brain structures with a radioactive iodoantipyrine technique. Exposure to pulsed microwaves of either 1mW/cm^2 or 15 mW/cm^2 average power density increased the local cerebral blood flow in several different brain regions. The iodoantipyrine technique allows the use of conscious rats for both the microwave exposure and the regional determination of brain blood flow. Local cerebral blood flow increases of 10 to 144 percent occurred in 16 of the 20 brain regions sampled in both the 1 mW/cm^2 and 15 mW/cm^2 microwave exposed rats. The largest statistically significant increases occurred in the pineal, hypothalamus, and temporal cortex in the 1 mW/cm^2 exposed rats and in the pineal, temporal cortex, inferior colliculus, and medial geniculate in the 15 mW/cm^2 exposed rats. Our experiments demonstrating increased brain blood flow, along with the Wilson et al. experiments (Brain Res. in press) showing increased glucose consumption, confirm that low-power microwaves can cause metabolic changes in rat brains.

SUMMARY

Local cerebral blood flow was measured in several different rat brain structures with a radioactive iodoantipyrine technique. Exposure to pulsed microwaves of either 1 mW/cm^2 or 15 mW/cm^2 average power density increased the local cerebral blood flow in several different brain regions. The largest increases were in the pineal, inferior colliculus, medial geniculate, and temporal cortex. Alterations of cerebral blood flow in our present experiments indicate brain metabolism changes following low-level microwave exposure. The measurement of local cerebral blood flow in a conscious animal also provides another valuable technique for mapping the magnitude and extent of alterations in brain activity caused by varying microwave exposure parameters.

In 1955 the first method for quantitative determination of the rates of blood flow in discrete brain structures was reported; the method employed the radioactive gas tracer ^{131}I-triflouriodomethane along with the principles of inert gas exchange (S.S. Kety, Pharmacol. Rev, 3, 1, 1951). This radioactive gas was chosen because diffusional equilibrium between brain and blood is established almost instantaneously when it is administered. Two technical problems are encountered in the use of this technique of a volatile gas tracer: short half life and difficult assay. To overcome these problems, investigators have used ^{14}C-antipyrine as a nongaseous tracer; however, it provides values of local cerebral blood flow that are considerably below those obtained with radioactive gases (W.W. Eckman, et al., Am.J. Physiol., 229, 215, 1975). In addition, transfer of antipyrine from blood to brain is limited by its comparatively low diffusion at the cerebral vasculature. Recently, a new method has been developed that uses ^{14}C-iodoantipyrine and an audioradiographic assay (O. Sakurada, et al., Am. J. Physiol., 234, H59, 1978). The ^{14}C-iodoantipyrine has a higher oil/water partition coefficient than ^{14}C-antipyrine, is more permeable at the cerebrovsculature, and provides values of local cerebral blood flow that are comparable to those obtained with ^{131}-trifluoriodomethane.

The present blood flow experiments were performed with ^{14}C-iodoantipyrine measured by brain homogenization and liquid scintillation counting (K. Ohno, et al., Stroke, 10, 62,1979). Although scintillation counting does not give the structural resolution of audioradiography and densitometry, it is repeatable, fast, quantitative, and technically easier.

Male Wistar rats from the Walter Reed colony served as subjects in all experiments. The animals were provided food and water ad libitum until they had grown to a body weight of 250-320 g. All animals were prepared for the experiments by the insertion of polyethylene catheters into one femoral artery and vein under sodium pentobartibal (35 mg/kg, i.p.) anesthesia. After surgical preparation, the hindquarter of a rat was wrapped in a loose-fitting plaster cast and tied down to a styrofoam block. An animal was allowed to recover from the anesthesia for 4 hours or more before the experiment. Conscious rats could freely move their forequarters, head and neck, and appeared comfortable.

The rats were randomly selected and individually exposed for 30 min to one of three irradiation conditions: sham irradiated, pulsed microwaves of 1 mW/cm^2 average power density, or pulsed microwaves of 15 mW/cm^2. The day of the week, time of day, and body weight were balanced among test groups. A microwave anechoic chamber (2 m wide by 3 m high by 2 m long) maintained at $23 \pm 2^{\circ}C$ was used for exposures. All microwave exposures were at a frequency of 2.8 GHz, a pulse rate of 500 pps, and a pulse width of 2 μsec. Exposures were produced by a 40 kW pulsed microwave generator (Applied Microwave Laboratory, PH40) coupled to a standard gain horn. The field intensity was measured with a field intensity meter (National Bureau of Standards) and a isotropic radiation monitor (Narda Model-8300). Overall accuracy of reported average power density measurements is estimated to be better than $\pm$ 25%.

Within 5 min after sham or microwave exposure, the catheter in the femoral vein was connected to a 5-ml syringe, which was mounted in a constant-flow pump (Model 341, Sage Instruments, Inc.) and set to deliver at a rate of 0.78 ml min^{-1}. The femoral vein was then infused for 50s with isotonic saline containing 5 μC/ml of ^{14}C-iodoantipyrine (New England; specific activity = 50 mC/mmol). Periodically during infusion, 20-ml samples of arterial blood were collected into heparinized tubes, after which 10-ml aliquots were transferred to scintillation vials. The rats were decapitated 50 s after infusion began. Brain regions were dissected out (according to the method of Chiuek et al. (Brain Res, 145, 291, 1978) placed in tared scintillation vials, and weighed. The tissues and whole blood were dissolved at room temperature with 1.5-ml aliquots of a quaternary ammonium hydroxide tissue solubilizer (Solvene 350, Packard). Ten-ml aliquots of liquid scintillation mixture (Dimilume 30, Packard) were added to each vial, and the samples were subjected to routine liquid scintillation counting (Beckman LS-250).

Local cerebral blood flow, F was calculated from the equation first derived by Kety:

$$C_{brain}(T) = mF \int_0^T C_{blood}(t)\, e^{-mF(T-t)/\lambda}\, dt$$

where $C_{brain}(T)$ equals the tracer concentration (dpm/g) in the brain parenchyma (excluding intravascular concentration) at time T; m is a constant between 0 and 1 that represents the extent to which diffusional equilibrium between the tissue and blood is reached (for iodoantipyrine) m = 1); $C_{blood}(t)$ equals the tracer concentration (dpm/ml) in the arterial

blood as a function of time; λ equals the steady state, tissue: blood partition coefficient (0.8 for iodoantipyrine); t equals the variable time; and T is the time from initial infusion to decapitation. $C_{brain}(T)$, which represents intraparenchymal brain concentration of tracer, was obtained by subtracting intravascular from net regional radioactivity when the former quantity was taken as the product of regional blood volume and blood concentration at time T.

The results of the present study indicate that low-power pulsed microwave exposure effects the local cerebral blood flow in the conscious rat. Brain flow increases of greater than 10% (10% to 144%) occurred in 16 of the 20 brain regions sampled in both the 1 mW/cm^2 15 mW/cm^2 microwave exposed rats. The largest statistically significant increases occurred in the pineal, hypothalamus, and temporal cortex in the 1 mW/cm^2-exposed rats and in the pineal, temporal cortex, inferior colliculus, and medial geniculate in the 15 mW/cm^2-exposed rats.

The values of local cerebral blood flow for the control rats varied form 0.74 in the corpus callosum to 1.32 in the inferior colliculus. These values are slightly different from those of Sakurada et al (Am. J. Physiol, 234, H59, 1978), who used iodoantipyrine and audioradiography, but they are consistent with those of Ohno et al.(Stroke, 10, 62, 1979), who used iodoantipyrine and liquid scintillation. The data obtained from the two different measurement techniques are not directly comparable because brain regions listed in the liquid-scintillation technique contain several areas that were analyzed separately by the more discriminating autoradiography method.

Our experiments demonstrating increased blood flow, along with the Wilson et al.(Brain Res. in press) experiments showing increased glucose consumption, confirm that low-power microwaves cause metabolic changes in rat brains. The brain regions affected are not geographically group, as if microwave focusing of energy were the cause, but are spread throughout the areas of the brain. The primary regions affected were, but not limited to, the auditory structures. Work is in progress that will further map the effects of microwave parameters such a power and frequency on blood flow changes.