Differential Heating of the Cortex, Hypothalamus and Rectum in Three Species by 2450-MHz Microwaves

ABSTRACT

To assess the relationship between brain and rectal temperatures and superficial and deep brain temperatures after microwave induced hyperthermia, four rabbits, four guinea pigs and six rats were anesthetized with sodium pentobarbital (30 mg/kg) and were stereotaxically implanted with 22-gauge teflon microcatheters aimed at the preoptic area of the hypothalamus. In addition, a small opening (1-mm in dia) was burred through the calvarium to expose the dura, which allowed placement of another microwave thermocouple on the cortex. Animals were radiated in 2450-MHz field at dose rates of 30 to 40 mW/g until their rectal temperature reached a level between 42.5 and 43.0 °C. After radiation, rectal, hypothalamic and cortical temperatures were recorded at 30-sec. intervals for five minutes, 1-min. intervals for 10 minutes, and at 2-min. intervals for 15 minutes. In all three species, baseline cortical and hypothalamic temperatures were reliably lower than rectal temperatures. An analysis of variance confirmed that after microwave-induced hyperthermia, cortical temperature fleetingly exceeded rectal temperature ($p < .01$). Cortical temperature was significantly higher than hypothalamic temperature in guinea pigs and rats, but not in rabbits. These data indicate that the rectum, cortex and hypothalamus are differentially heated within and among differing species during microwave radiation. The degree of elevation of cerebral temperatures during whole-body irradiation in a multi-path field is believed to depend on a number of factors 1) the lower heat capacity of the brain due to its high lipid content 2) part-body resonant absorption by the head; and 3) anatomical, physiological and pharmacological differences among species.

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SUMMARY

An earlier study conducted in our laboratories revealed that immediately after intense microwave radiation of guinea pigs, cortical temperature exceeded that measured rectally, but fell toward baseline at a much more rapid rate. This observation is of interest in the light of a persistent tendency of the guinea pig's cortical temperature normally to be well below (∿2 °C) that of the body's core. Since the aim of the study was to assess the effects of hyperthermia on visually evoked electrocortical potentials, systematic study of the immediate and fleeting inversion was not undertaken. We report here data on the beginnings of a systematic, comparative analysis aimed at assessment of the generality of the inversion. Rats and rabbits in addition to guinea pigs have been observed as experimental subjects.

Brain and rectal temperatures just prior to and immediately after microwave radiation were recorded from four rabbits, four guinea pigs, and six rats--all visually pigmented, female, adults. The animals were lightly anesthetized with sodium pentobarbital (30 mg/kg i.p.) and stereotaxically implanted with Hamilton teflon microcatheters (KF 22 TF) aimed at the hypothalamus. The catheters were plugged at the distal terminus and calvarium with dental cement. During surgery, a small opening (1-mm in diam.) was burred through the calvarium to expose the dura 2-mm anterior to the bregmate junction and 2-mm to the right of the mid-saggital suture. After surgery, one Bailey Model 1T-2 microwave thermocouple could be acutely inserted into the catheter to measure hypothalamic temperature (target area: preoptic nucleus); another was located just under the dura to provide a reading of cortical temperature. A third thermocouple probe (Bailey Model RET/1) was inserted into the rectum. The thermocouples were connected to three Bailey Model BAT-8 digital electronic thermometers, which permitted simultaneous monitoring of rectal and hypothalamic temperatures.

Radiation by 2450-MHz microwaves took place in the multi-mode cavity previously described by Justesen, et al. (1971). The energy was electrically modulated as a bottom-clipped half-wave sinusoid at 60 Hz and was of sufficient intensity to result in dose rates between 30 and 40 mW/g. The anesthetized animals were irradiated for periods to 15 minutes until the rectal temperature reached a level between 42.5 and 43.0 °C. Upon cessation of radiation, cortical, rectal and hypothalamic temperatures were recorded at 30-sec. intervals for five minutes, at 1-min. intervals for ten minutes, and at 2-min. intervals for 15 min.

The baseline temperatures as shown in Figure 1 are considerably below normal levels (37.5 to 39 °C) as a result of dosing with sodium pentobarbital. An analysis of variance confirmed that mean baselines of cortical and hypothalamic temperatures were significantly lower than those of rectal temperatures ($p < .01$). Baseline means of hypothalamic

temperatures were lower than those of cortical temperatures of guinea pigs and rats, but hypothalamic temperatures of rabbits were not significantly lower than their cortical temperatures. Mean temperatures for the hypothalamus, cortex and rectum during baseline and after heating are presented in Table 1. Table 2 shows probability levels for mean-to-mean comparisons among hypothalamic, cortical, and rectal temperatures.

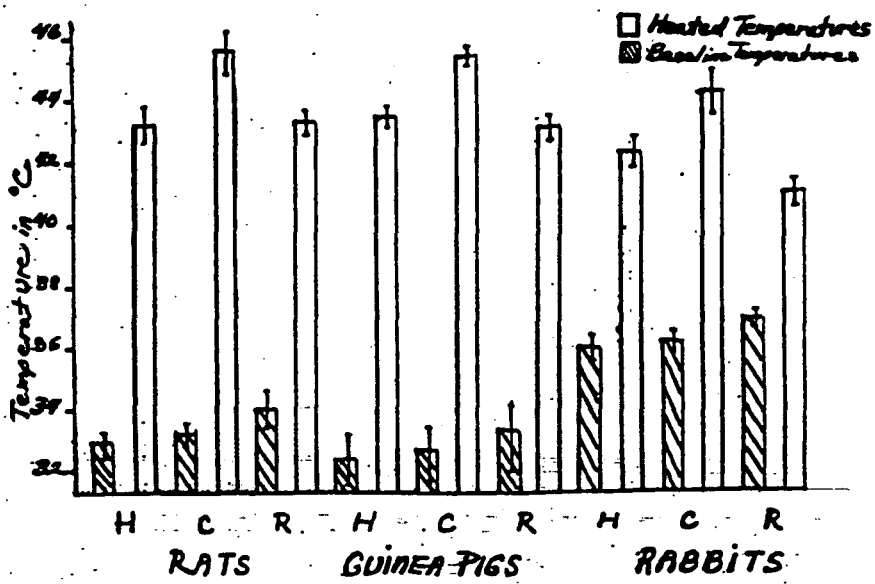

Figure 1: Hypothalamic (H), cortical (C), and rectal (R) temperatures of three species recorded prior to and after microwave radiation.

Table 1

Means of Temperatures at Baseline and after Heating for Three Species*

	Baseline Means °C			Heated Means °C		
	H	C	R	H	C	R
RATS	32.82	33.36	34.06	42.90	45.30	43.23
GUINEA PIGS	32.45	33.05	33.40	43.30	45.22	42.90
RABBITS	36.10	36.37	37.05	42.37	44.07	41.42

*H = hypothalamus, C = cortex, R = rectum

An analysis of variance performed on the data from all three species revealed that after microwave induced hyperthermia, cortical temperatures exceeded rectal temperature ($P < .01$); see Figure 1). However, hypothalamic temperature did not significantly differ from rectal temperature in guinea pigs and rats. In contrast, the rabbit's hypothalamic temperature was elevated significantly above its rectal temperature (see Tables 1 and 2).

An analysis of variance was also performed on the data to determine the rate at which rectal and brain temperatures decline after microwave heating. It was found that both cortical and hypothalamic temperatures fell reliably during the first recorded minute ($P < .01$), but fell at a relatively slow rate each minute thereafter. In contrast, rectal temperature fell much more slowly. There was no significant fall of mean rectal temperatures in any of the species during the first three minutes after termination of microwave radiation.

Table 2

Probability levels for comparisons between hypothalamic (H), cortical (C) and rectal (R) temperatures for baseline, and just after microwave heating

	Probability Levels (based on t tests for correlated means)		
	Baseline		Heated
RATS	<.05	H vs R	NS
	<.01	C vs H	<.001
	<.05	R vs C	<.01
GUINEA PIGS	<.05	H vs R	NS
	<.05	C vs H	<.02
	<.05	R vs C	<.02
RABBITS	<.05	H vs R	<.01
	NS	C vs H	NS
	<.02	R vs C	<.02

That baseline cortical temperature exceeded hypothalamic temperature in anesthetized guinea pigs and rats is probably due to the greater distance of the cortex from the hypothalamus, which is proximal to the circle of Willis in both species. Arterial blood serves to remove thermal energy from the brain, and this blood is cooled at the circle of Willis during the process of respiration. Presumably the greater the distance a brain structure is from the circle of Willis, the higher the temperature (Hayward and Baker, 1969). The lack of a difference between hypothalamic and cortical temperatures in the rabbit probably results from highly efficient dissipation of heat involving vasodilation and convection in the animal's large ears (Hayward and Baker, 1969). As noted previously, in all three species, cortical temperatures were far above rectal temperatures immediately after microwave radiation. At least two factors account for this finding: 1) the lower heat capacity of the brain due to its high lipid content and 2) part-body resonance. Gandhi (1979) has reported that in the far field of a plane wave a doubling of coupled energy can occur in the head of the rat at 2450-MHz. While whole-body resonant absorption is not observed in the multi-mode cavity, disproportionate uptake of energy (part-body resonance) is not excluded. That the temperature of the hypothalamus was not significantly elevated above rectal temperature in the guinea pig and rat is probably due to its close proximity to the circle of Willis. In contrast, hypothalamic temperature was significantly elevated above rectal temperature in the rabbit. This difference may result from a combination of factors including 1) relative mass as well as ratio of head to body mass 2) pharmacological differences in the rabbit's response to Na-pentobarbital and 3) the relative depth of penetration into deeper homologous structures by 2450-MHz energy.

A major reason for conducting this study was to assess the degree of invariance among rectal, hypothalamic and cortical temperatures after microwave-induced hyperthermia. Preliminary research has indicated that microwave radiation may be useful in arresting the growth of various neoplasms of the brain, and that rectal temperature under controlled conditions can provide an accurate prediction of brain (cortical) temperature in the rat. Since even electrically nonperturbing thermal probes cannot be placed in brains of animals with intracerebral tumors, as openings in the skull may relieve intracranial pressure and interfere with indices of mortality, we were interested in determining if the same

quantitative conditions of irradiation would yield the same good fit between rectal and brain temperatures in other species. As expected and confirmed, there are marked variations among rat, guinea pig, and rabbit.

REFERENCES

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