Combined Effect of Ambient Temperature with Radiofrequency Electromagnetic Radiation in Rabbit

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Introduction

There has been an increasing interest in synergistic effects observed after combined action of various agents. Many studies have shown that numerous physical and chemical agents combined with hyperthermia can interact in a synergistic manner when the effect produced by both agents used in combination exceeded the expected results from simple summation of the every effect produced by heat and the particular agent [1]. It was found that ambient temperature had a profound effect on the thermoregulatory responses to radiofrequency electromagnetic radiation (RFR) in various animals [2] and humans [3]. An extensive quantitative investigation of synergistic interaction of ambient temperature and microwaves has been published for rabbit heating [4]. It would be of interest to estimate whether or not the general features of the combined action revealed with unicellular organisms can be expressed for animals exposed to microwave power combined with a higher environmental temperature.

Materials and Methods

The RFR exposure system as well as some materials and methods used in this study have already been described [4]. Nevertheless some important points should be mentioned. Exposure to RFR were performed in a temperature-controlled anechoic chamber with dimensions of ~6.5 (length) x 5.0 (width) x 3.5 (height) m, lined with commercial microwave absorbing material. The air temperatures in the chamber were 22±0.2℃, 30±0.2℃, 38±0.2℃. Animals used were Shinella rabbits with body masses of 2.5 to 3.2 kg both males and females at an age of 60 days. They were housed individually at an ambient temperature of 22℃, with a relative humidity of 50 per cent under natural lighting. Rabbit chow and water were provided ad libitum. Animals were pre-handled and gentled for 10 days prior to exposure. The body temperature was allowed to equilibrate in the chamber for at least one hour before irradiation. Rabbits were individually exposed to 7-GHz microwave radiation The irradiation was carried out in the far zone and E-orientation at (55±5)% humidity. All experiments were performed with the animals without general anesthesia. In this study, rectal temperature was measured in rabbits during exposure to 7-GHz microwave radiation at an ambient temperature of 22, 30 or 38℃. Experiments were performed on 40 rabbits. Rabbits were individually irradiated to the following power flux density (PFD): 0, 10, 15, 20, 30 and 100 mW/cm^2 whose corresponding specific absorption rates (SAR) were 0.75, 1.12, 1.50, 2.25, and 7.5 W/kg, respectively.

Results and Discussion

The observed temperature increment after simultaneous action of high ambient temperature and RFR exposure was in most cases greater than that expected for additive effects of these factors. It means that the synergistic interaction between microwave energy and thermal load induced by high ambient temperature is observed. To estimate the effect of synergy, used was the synergistic enhancement ratio k which can be determined by the ratio of temperature increments observed in experiments after simultaneous action of both factors $\Delta T(RFR+30^oC)$ to that expected for additive summation of thermal effects from microwaves alone $\Delta T(RFR+22^oC)$ and high ambient temperature $\Delta T(30^oC)$ estimated for any identical duration of exposure:

$$k = \frac{\Delta T(RFR+30^oC)}{\Delta T(RFR+22^oC)+\Delta T(30^oC)}, \qquad (1)$$

It is worth noting that the increment of rectal temperature exhibited by animals exposed to microwaves alone was estimated after irradiation at a comfort temperature (22℃). The synergistic enhancement ratio, determined by Eq. 1, shows how many times temperature increment after simultaneous application of both modalities exceeds the sum of increments expected from individual action of each agent. To calculate the synergistic enhancement ratio we approximated some part of experimentally obtained heating curves by straight lines. The colonic temperature was not increased immediately after the beginning of low intensity exposure but approximately after 1 hr. As soon as we used only linear part of heating curves we can use heating rate, dT/dt, calculated all over the straight parts of heating curves instead of temperature increment. Then Eq. 1 can be rewritten as

$$k = \frac{dT/dt(RFR + 30^oC)}{dT/dt(RFR + 22^oC) + dT/dt(30^oC)}. \quad (2)$$

Table 1 summarizes heating rates estimated for different conditions of exposure. It is evident that raising ambient temperature from 20 to 30C in the most cases would greatly enhance rabbit heating because of reduced rabbit's ability to dissipate heat accrued from RFR exposure. Basing on the data presented it can be concluded that the observed temperature increment after simultaneous action of high ambient temperature and RFR exposure was in most cases greater than that expected for additive effects of these factors. It means that the synergistic interaction between microwave energy and thermal load induced by high ambient temperature is observed.

Table 1. Heating rate and synergistic enhancement ratio (k) after different conditions of rabbit exposure

PFD, mW/cm^2	SAR, W/kg	dT/dt at 22°C	dT/dt at 30°C	N_2/N_1	k
0	0	0	0.067	–	–
10	0.75	0.033	0.6	2.0	6.0
15	1.12	0.067	1.1	1.0	8.2
20	1.5	0.23	1.7	0.29	5.7
30	2.25	0.74	3.3	0.09	4.1
100	7.5	6.9	7.6	0.01	1.1

Fig. 1 shows the dependence of the synergistic enhancement ratio on power flux density, calculated on the basis of Eq. 2 and the results presented in Table 1. It is clearly seen that the synergy takes place for some power densities while for others the interaction is small or only additive. It means that the synergistic interaction of microwave energy with high environmental temperature was observed for rabbits only within a definite ratio of incident power densityof electromagnetic radiation. One can see that there is an optimal intensity for which the highest synergy is achieved. It is of interest that just such a dependence of synergy on the intensity of various physical agents should be expected on the basis of mathematical model developed to predict the effectiveness of synergistic interaction of various environmental agents [5,6]

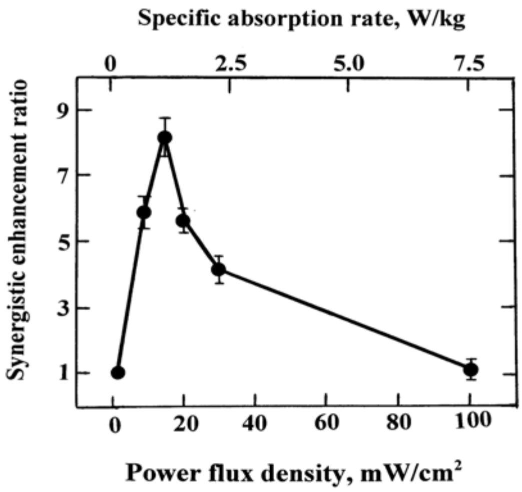

Fig. 1. Relationship between the synergistic enhancement ratio and power flux density after simultaneous action of microwave (7 GHz) exposure and high environment temperature (30°C) on rabbit heating.

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