6. N. P. Chesnokova, Vopr. Med. Khim., No. 4, 497 (1976).
7. V. B. Brooks, J. Physiol. (London), 123, 501 (1954).
8. J. F. Eilbeck and W. G. Smith, J. Pharm. Pharmacol., 19, 374 (1967).
9. J. E. Fischer, S. H. Snyder, and J. H. Jaures, Ann. Surg., 175, 260 (1972).
10. A. C. Guyton, et al., Arch. Neurol. Psychiat., 57, 578 (1947).
11. P. A. Shore, A. Burkhalter, and V. N. Cohn, J. Pharmacol. Exp. Ther., 127, 182 (1959).

HARMFUL EFFECTS OF MICROWAVE (2400 MHz) IRRADIATION ON RATS AND SUBSEQUENT RECOVERY

V. S. Tikhonchuk

UDC 617-001.21:537-962

Threshold values of the power density (PD) and duration of microwave irradiation with a lethal effect of not more than 0.1% were determined in experiments on 2072 rats. The ratio between the rate of development of the harmful effect and recovery is close to an exponential function of PD of microwave irradiation. From earlier observations on mice and those now published, species differencies between mice and rats can be accepted. As regards the time of appearance of equal lethal effects, the half- and whole-recovery periods, and the ratio between the rates of injury and the rate of recovery depending on PD of microwave irradiation, mice are more sensitive than rats.

KEY WORDS: injury; recovery; species sensitivity; microwave irradiation.

Pathophysiological changes arising in rats during intensive microwave irradiation, causing death of the animals, have already been investigated experimentally [1, 2, 6, 7, 9]. The conditions of irradiation have been shown to influence the time of onset of death [8].

In the investigation described below a further study was made of the general tendencies of formation of lethal processes and recovery and the ratio between them in rats, and to compare these findings with results obtained previously [3, 5] on mice.

EXPERIMENTAL METHOD

The experiments were carried out on 2072 noninbred female rats with a mean weight of 220±12 g. The animals were irradiated in an anechoic chamber with microwaves (2400 MHz) with a power density (PD) of between 60 and 800 mW/cm^2, and in an ambient air temperature of 20-22°C. The inequality of the experimental microwave field did not exceed 2 dB. The mortality of the animals was studied. Empirical distributions were expressed algebraically.

EXPERIMENTAL RESULTS

Within the limits of the PD studied (60-800 mW/cm^2) the empirical distributions of lethal effects on the rats depending on the duration of microwave irradiation (Fig. 1) can be described sufficiently closely by equations of the type (probit analysis): $Y = 10.5566 \cdot X + 6.0070$; $Y = 20.3105 \cdot X + 2.0128$; $Y = 69.7311 \cdot X + 20.7204$; $Y = 20.4726 \cdot X - 6.6568$; $Y = 15.6766 \cdot X - 8.6621$; $Y = 15.2329 \cdot X - 14.1035$; $Y = 18.1849 \cdot X - 22.7886$, where Y is the lethal effect (in probits), and X the log of the irradiation time (in min). Just as in mice [5], with a decrease in PD the time taken to reach a prescribed effect was increased and the angle of slope of the distributions reduced. The existence of these two tendencies determines the exponential character of the relationships between PD and the duration of microwave irradiation for prescribed effects, for example 0.1, 50, and 99.9%: $\log Y = 2.6338 - 0.6918 \log X$; $\log Y = 2.7790 - 0.6741 \log X$; $\log Y = 2.9257 - 0.6549 \log X$ respectively, where log Y denotes PD (in mW/cm^2) and log X denotes the duration of microwave irradiation (in min). Analysis of these

Institute of Biophysics, Academy of Sciences of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR N. N. Zhukov-Verezhnikov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 88, No. 7, pp. 29-30, July, 1979. Original article submitted June 15, 1978.

0007-4888/79/8807-0703$07.50

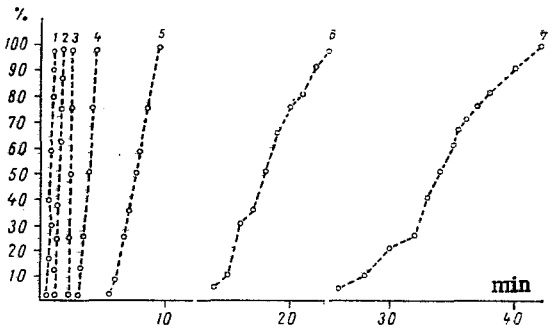

Fig. 1

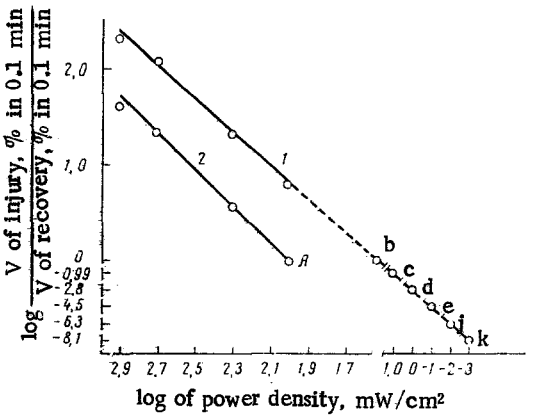

Fig. 2

Fig. 1. Mortality of rats as a function of irradiation time. Abscissa, irradiation time (in min); ordinate, mortality of rats (in %). 1-7) Empirical distributions for PD of 800, 500, 300, 200, 100, 80, and 60 mW/cm² respectively.

Fig. 2. Ratio of speed of injury to speed of recovery as a function of PD of microwave irradiation. 1, 2) Levels of injury and recovery equal to 0.1 and 99.9% and 50 and 50% respectively.

functional relationships indicates close correlation between the velocity characteristics of the lethal effects and recovery, and their dependence on PD and of the duration of microwave irradiation.

The presence of recovery reactions of animals with an increase in the time interval between single exposures to irradiation was demonstrated previously in mice [3] and rats[4]. For rats, with PD of 800, 500, 300, 200 and 100 mW/cm² the relationship between the lethal effects and intervals between single exposures, in min, was interpolated by the following equations (probit analysis): $Y = 8.4830\ X - 5.0486$; $Y = 5.4680\ X - 0.1803$; $Y = 6.9626\ X + 0.1669$; $Y = 6.8968\ X + 0.4743$; $Y = 7.2205\ X + 0.9657$ respectively, where Y is the survival rate (in probits) and X is log of the irradiation time (in min).

With comparable levels of lethal and recovery effects, for instance 0.1% mortality and 99.9% recovery, or 50% mortality and 50% recovery, the ratio between the speeds of development of these tendencies is a function of PD of microwave irradiation and can be described by the equation of an exponential function (Fig. 2): $\log Y = -2.7613 + 1.7690 \log X$ and $\log Y = -3.7714 + 1.8749 \log X$ respectively. Just as in mice, the higher the value of PD and the lower the mortality, the greater the absolute value of this ratio, but the difference is that the straight lines 1 and 2 are parallel (Fig. 2).

With equal speeds of the processes of injury and recovery ($\log V_{inj}/V_{rec} = 0$) the values PD (the projection of points A and B on the abscissa, see Fig. 2) was 102 and 36.4 mW/cm². In the last case mortality among the animals did not exceed 0.1% (for practical purposes it was zero). In rats, with PD values equal to and below 40 mW/cm², the ratio of the velocities of injury and recovery must therefore satisfy the condition: $\log (V_{inj}/V_{rec} \leq 0)$, the projection of the points C, D, E, J, and K on the ordinate (see Fig. 2; for values of PD of 10, 1, 10^{-1}, 10^{-2}, and 10^{-3} mW/cm²). This indicates that recovery processes become steadily more important than the effects of injury as the PD of microwave irradiation is reduced, and it formally explains the results obtained previously [8].

Earlier results [2-5] and the experimental facts described in this paper enable some general tendencies in the formation of processes of injury and recovery and the ratio between them to be assessed and compared, as a first approximation, in two species of animals, namely mice and rats. For each of these species it is possible to determine threshold values of PD and the duration of microwave irradiation at which the mortality effect does not exceed 0.1%. The relationship between these two values can be interpolated by an exponential function of the type: $\log Y = 2.4333 - 0.7408 \log X$ (for mice) and $\log Y = -2.7613 + 1.7690 \log X$ (for rats). With values of PD above 40 mW/cm² and with irradiation times in excess of the threshold, dependence of the effect (death) on irradiation time (when PD = const.) is obtained. Analysis of the equal effect (mortality) curves indicates formally the presence of recovery

reactions during the period of microwave irradiation, as has been confirmed experimentally [3, 4]. The speeds of formation of injury and recovery differ qualitatively in character for comparable injury and recovery effects. Expressed relative to one another they are a function of PD of microwave irradiation. With respect to the times of onset of equal injury and recovery effects, mice are more sensitive animals than rats.

LITERATURE CITED

1. A. N. Liberman, in: Work Hygiene and Biological Action of Radiofrequency Electromagnetic Waves [in Russian], Moscow (1972), p. 41.
2. E. A. Lobanova, Vopr. Radioélek. Ser. Obshchetekhn., No. 10, 61 (1960).
3. V. S. Tikhonchuk, Izvest. Akad. Nauk SSSR, Seriya Biol., No. 6, 920 (1977).
4. V. S. Tikhonchuk, Byull. Éksp. Biol. Med., No. 2, 170 (1978).
5. V. S. Tikhonchuk, Izvest. Akad. Nauk SSSR, Seriya Biol., No. 3, 459 (1978).
6. N. V. Tyagin, Byull. Éksp. Biol. Med., No. 8, 67 (1958).
7. H. Hines and J. Randall, Elect. Eng., 71, 879 (1952).
8. W. Deichmann, Indust. Med. Surg., 28, 212 (1959).
9. C. La Fond, Missiles and Rockets, 5, 23 (1959).