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REANIMATION OF RATS FROM BODY TEMPERATURES BETWEEN 0 AND 1° C BY MICROWAVE DIATHERMY

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We have previously shown the possibility of reanimating the adult rat cooled to a body temperature of 0–1° C (Andjus, 1951; Andjus & Smith, 1954, 1955). The reanimation procedures described consisted, basically, of re-establishing the heart beat by local heating of the praecordium as the first step in resuscitation. The heating was achieved either by application of a hot metal spatula to the chest wall, or by using a focused beam of light as the heating device. The burns inevitably produced during heating by both techniques were in a great number of cases compatible with complete reanimation and long-term survival. Nevertheless, the possibility was not ruled out that a proportion of the secondary delayed deaths occurring after reanimation could be partially attributed to the thermal injury of peripheral tissues.

Having at our disposal a magnetron microwave generator, we set out to investigate the possibility of using it for reanimation. It was hoped that burning of peripheral tissues would be avoided by the use of microwaves because of their satisfactory power of penetration. Furthermore, unlike the conventional diathermy apparatus which operates at a much lower frequency, it is possible with microwaves to achieve local heating of a small area.

METHODS

The magnetron microwave generator

The apparatus used for heating in present experiments was powered by a 500 W continuous wave magnetron, operating at a frequency of 3000 Mc/s feeding into an H_{01} mode waveguide. It was originally designed for rapid heating of frozen blood samples. It was available, however, when the animal experiments began and was therefore put into use, although a conventional pulsed magnetron could have been used. A more detailed description of the apparatus will be published elsewhere (Perkins, 1955).

To achieve preferential heating of the heart area, a grid extension of the waveguide was used, with an aperture (diameter 1in.) in its lower side. The animal was placed underneath the aperture.

A horn radiator was also used in the second series of experiments (Table 1) in order to produce a more even field distribution.

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Artificial respiration unit

In the first series of experiments artificial respiration was given using the same single hand bellows as described previously (Andjus & Smith, 1955). In the second series, however, an automatic apparatus was used. It consisted of an adjustable thyratron timing circuit, the relay contact operating a release valve connected to the compressed air supply.

Animals

Adult rats (160–200 g body weight) of the Medical Research Council hooded strain used in the present experiments were in every respect similar to the animals used in previous studies (Andjus & Smith, 1954, 1955).

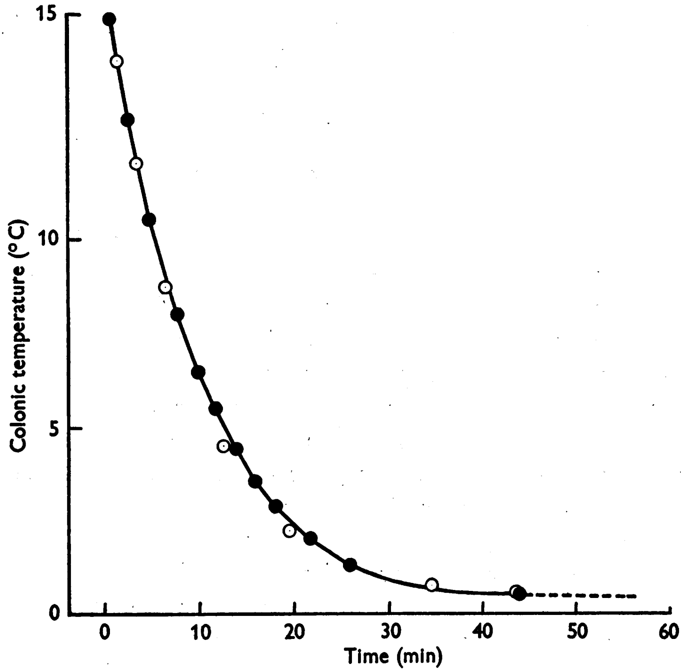

Fig. 1. Fall in colonic temperature during the second stage of cooling (rat covered with crushed ice). ○, rat (♂), 178 g, cooled after being killed by ether; ●, rat (♂), 176 g, revived after cooling.

Cooling

The cooling procedure was the same as described in previous papers. The first stage of cooling, lasting about 2 hr, aims at reducing the body temperature to about 18° C. This is achieved by the closed vessel technique. The rat is enclosed in a 2 l. jar, kept in a refrigerator at about 0° C. The developing oxygen lack and the accumulation of expired CO_2 are both factors inducing hypothermia. Below a body temperature of 18° C the 'cold narcotized' rat is cooled down to 0° C by covering it with crushed ice. During this second stage of cooling, the fall in body temperature is identical with that recorded in rat corpses (Fig. 1). During this stage the respiration and the heart beat stop.

Rewarming

We began the reanimation procedure when the colonic temperature ranged between 0 and 1° C, and 60 to 75 min after the temperature had fallen below 15° C. The temperature of 15° C was chosen because, soon after passing this point, heart beat and respiration cease, and the possibility of spontaneous recovery in a warm atmosphere is lost (Adolph, 1948).

The principle of preferential heating of the thorax was applied. It was achieved by placing the animal under the grid extension of the waveguide so that its chest lay beneath the aperture in the lower wall. The animal was fixed on a 'Perspex' plate by two clips holding its forelimbs.

The distribution of microwave energy in the area usually occupied by the animal was estimated by measuring the heating effect on a water load. A series of 10 c.c. Carrel flasks filled with water was distributed within that area, and the rise in temperature of the water was recorded after heating for 20 min. The results are shown in Fig. 2A, B. It can be seen that the maximum input of energy corresponds to the area usually occupied by the chest of the rat (Fig. 2A); furthermore, the left side of that area is more heated than the right (Fig. 2B).

The actual rise in body temperature during the reanimation procedure in a typical experiment is shown in Fig. 3. It is compared with the rise in temperature recorded from an experiment with a dead animal, killed before cooling. It is obvious that the temperature rises much more steeply in the chest than in the colon, and reaches about 30° C in 20 min. It can also be seen that the curves referring to the animal being reanimated start converging and deviate from the curves obtained from the corpse at the time when the heart beat reappears. The onset of circulation results in slowing down the heating of the thorax, while speeding up that of the abdomen. It also minimizes the danger of peripheral burning.

The chest is heated for a period of 15–20 min. The heart beat is usually re-established after the first 4–5 min (Fig. 3), while spontaneous respiration reappears towards the end of the heating period, when the colonic temperature has reached 15° C.

Artificial respiration is carried out right from the beginning of heating. It consists of blowing air rhythmically into the lungs (180–200 times per min) through a rubber tube applied to the nostrils. The rubber tube is connected either to a single hand bellows, or to the compressed air supply, the air current being rhythmically interrupted by the release valve. Artificial respiration is discontinued after spontaneous breathing is re-established.

Further rewarming of the reanimated rat from 15° C upwards is carried out as previously described (Andjus & Smith, 1955). The animal is immersed in a water-bath at 40° C until its body temperature reaches about 33° C. It is then placed in an incubator (28–32° C) for 3 days to convalesce, and afterwards transferred to the animal house.

RESULTS

Table 1 shows the final results of these experiments. They are compared with the results previously obtained by Andjus & Smith (1955).

It can be seen that it was possible to obtain 80–100% complete recovery in two series, of twenty-five rats each, by means of the technique described above. Furthermore, a single rat was reanimated 10 times after being cooled at intervals of 2–10 days each time to the same temperature level of 0–0·5° C. The effect of repeated cooling to, and reanimation from, zero has been studied in a number of animals, and the results will be published separately. Five rats revived by microwave diathermy have been kept under observation for 7 months. No obvious differences were noticed between them and their controls. Others have been used for precise psychological tests in order to assess the possibility of cerebral damage. The results will be published elsewhere in conjunction with Prof. R. W. Russell.

The results obtained by the new technique prove that the lack of complete success in previous experiments was due not to irreversible changes caused by cold, but to the inadequacy of the procedure hitherto used for reanimation.

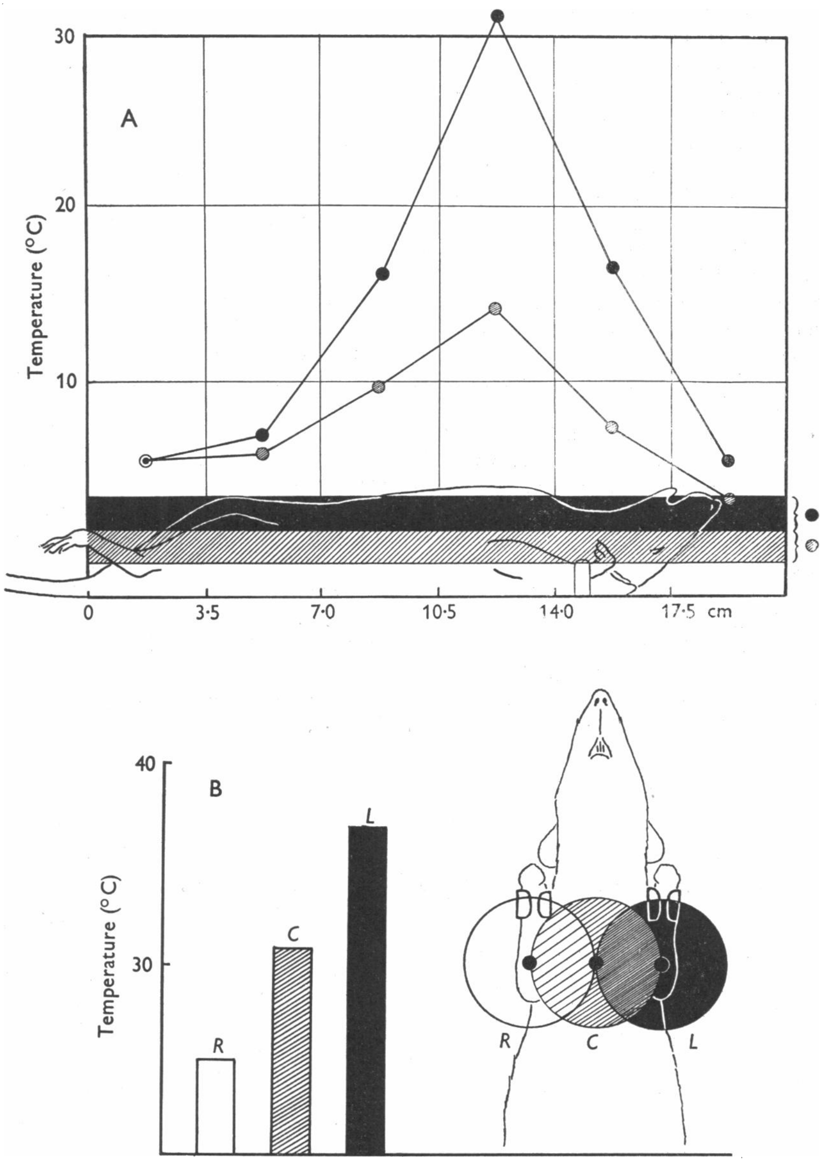

Fig. 2. Distribution of microwave energy in the area occupied by the animal. Estimation made by measuring the heating effect on a water load. Curves and columns in the diagrams are marked by the same shading as the corresponding heated areas.

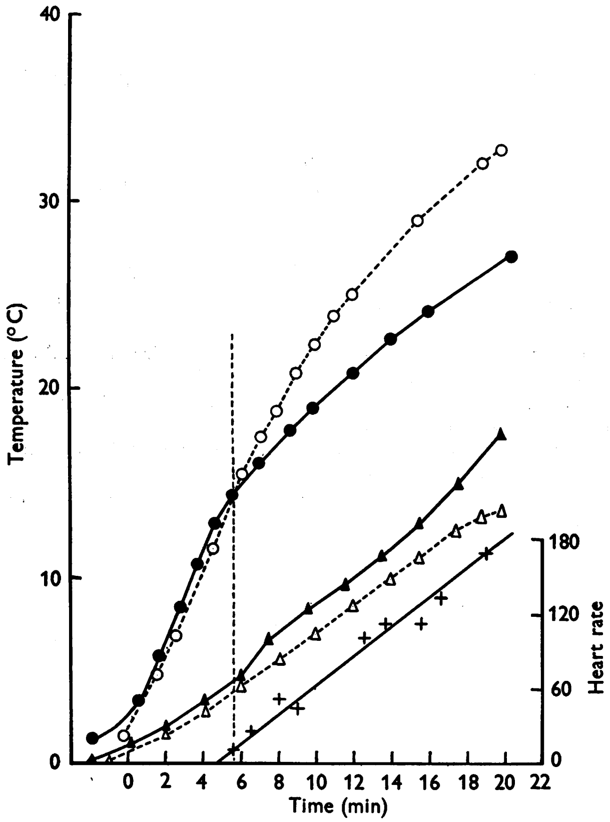

Fig. 3. Rise in temperature during heating by microwave diathermy. The chest temperature was taken in the oesophagus beneath the heart. The animal which was reanimated (plain lines) was killed afterwards, then cooled and used again for temperature measurements during heating (interrupted lines). ▲ and △, colonic temperatures; ● and ○, oesophageal temperatures; ×—× heart rate.

TABLE 1. Recovery of rats reanimated by different techniques

Series I of experiments, with the beam of light as the heating device, differed from series II only in that more intense heating was applied in the latter (see Andjus & Smith, 1955, for details about the first three series, marked with an asterisk in the table).

Microwave series I: horn radiator omitted; artificial respiration by the single hand bellows.

Microwave series II: horn radiator added to the waveguide; artificial respiration automatic.

Partial recovery: at least the heart beat re-established.

Secondary deaths: I, death occurring during rewarming. II, death overnight in the first 24 hr after reanimation; III, death within the first 10 days after reanimation.

Complete recovery: the animal regains its initial weight and continues growing.

Heating device	No. of rats	No. of experi-ments on each rat	Partial recovery (%)	Percentage secondary death I	II	III	Percentage complete recovery	Presence of burns
Hot spatula*	25	1	100	60	20	0	20	Yes
Beam of light I*	25	1	92	32	16	0	44	Yes
Beam of light II*	25	1	92	16	0	8	68	Yes
Microwaves I	25	1	100	20	0	0	80	Occasional
Microwaves II	25	1	100	0	0	0	100	No
Microwaves II	1	10	100	0	0	0	100	No

SUMMARY

80–100% of rats cooled to body temperatures of 0–1° C can be completely revived by the use of microwave diathermy.

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