EXPERIMENTAL STUDY OF THE EFFECT OF AN ULTRAHIGH-FREQUENCY ELECTROMAGNETIC FIELD ON THERMAL CONDUCTIVITY OF LIVING TISSUES

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Nontraumatic cryosurgical techniques are finding ever-increasing application in the treatment of many malignant and benign neoplasms [3]. However, the capacity for low-temperature destruction of space-occupying pathological formations is very limited: the superficial part dies but the deep part continues to grow [1]. An experimental method of potentiating cryogenic destruction by preliminary exposure of the region to be frozen to microwaves, in the form of an ultrahigh-frequency electromagnetic field (UHF-EMF), has been developed in the Pediatric Surgical Clinic of the N. I. Pirogov Second Moscow Medical Institute. Clinical experience confirms the beneficial effect of the UHF-EMF of enhancing cryodestruction [6]. The influence of UHF-EMF on living tissues varies, but in the opinion of most investigators, the points of application of this field are dipole structures, the main part of which consists of bound water [2]. Under the influence of microwaves polar molecules are brought into an excited state and resonance phenomena arise. Changes may also take place in the zone of hydration, with rupture of intramolecular bonds. The "packing" of water is disturbed, so that the volume occupied by the aqueous phase may be increased, and in turn, this leads to an increase in size of the water lattice [4]. All this destabilizes the structure of water and makes it more mobile and more sensitive to various influences, including the action of cold. The depth of freezing and, consequently, the depth of cryonecrosis of living tissue, are mainly determined by its thermophysical properties (TPP). The ability of living tissue to conduct heat in the steady state is characterized by its thermal conductivity (λ). The higher its value, the deeper the freezing. Present-day computerized methods of mathematical prediction of the temperature field can give the desired result only provided that TPP of neoplasms in vivo is known [7]. It has been shown [8] that cryogenic treatment is an individual matter in each particular case. If the cryosurgical procedures are carried out under identical conditions (equality of temperatures, time, rate of cooling, geometry and size of the working part of the cryosurgical instrument, identical nosologic forms and identical dimensions of the structures), repeatability of the results of treatment was not observed in 50% of cases [7]. The primary reason for this is that each type of biological tissue as a whole and of neoplasms in particular is characterized by strictly individual ability to conduct heat, and ultimately this determines the efficiency of the cryodestruction process.

The aim of this investigation was to study changes in thermal conductivity of living tissue as a result of exposure to a UHF-EMF, and also to determine the optimal conditions for exposure to the UHF-EMF to achieve maximal cryonecrosis.

EXPERIMENTAL METHOD

The test object was rabbit liver, for of all tissues, this has a TPP which is closest to that of vascular tumors (hemangiomas), and it can thus serve as a model of such a tumor [5]. The source of the UHF-EMF was a "Plot" apparatus, with wavelength of 33 cm, diameter of source 3 cm. There were three series of experiments. The experiments of series I were carried out on isolated liver tissue in vitro. Standard specimens 1.5 cm in diameter and

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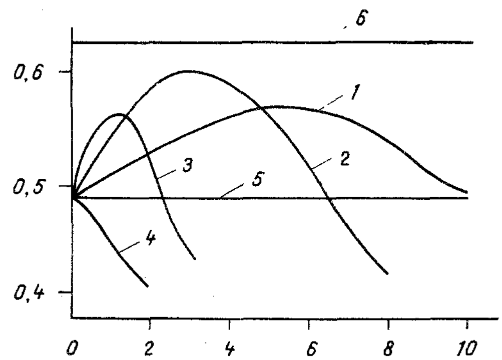

Fig. 1. Thermal conductivity λ of rabbit liver in vitro, depending on power (ω) and duration (τ) of irradiation. Abscissa, τ (in min); ordinate, λ [in W/(m·K)]. 1) ω 5 W; 2) ω 10 W; 3) ω 15 W; 4) ω 20 W; 5) λ of normal liver; 6) λ for water.

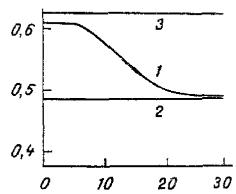

Fig. 2. Thermal conductivity of rabbit liver depending on time elapsing after irradiation (parameters of UHF-EMF: 10 W, exposure 3 min). 1) λ for rabbit liver after exposure to UHF-EMF; 2) λ for normal rabbit liver; 3) λ for water. Remainder of legend as to Fig. 1.

0.3 cm high were prepared. Specimens were irradiated in cellophane packs (to prevent dehydration) for up to 10 min, in steps of 1 min; the dose rate was 5, 10, 15, and 20 W. Altogether 900 specimens were studied. In the experiments of series II, to study the after-reaction of exposure to the UHF-EMF, rabbit liver tissue was irradiated in vivo, after which the animals were killed after intervals of 5 min until 30 min after irradiation. The power of the UHF-EMF was 10 W, and the duration of exposure 3 min (the conditions were chosen on the basis of the results of the experiments of series I). Standard specimens were prepared from the irradiated liver. Altogether 680 were tested. The value of λ of the specimens was determined on an apparatus based on a mass-produced ITÉM-1 instrument, which was specially modernized for measuring biological tissues (from the "Etalon" Factory, Aktyubinsk). Calibration measurements on standard specimens, conforming to the state standard, showed that the error of measurement of λ did not exceed 5%. In the experiments of series III, on liver tissue which had not been isolated, in vivo, the value of λ was determined on an experimental bench, by the use of heat-flow transducers, designed and tested at the Institute of Technical Thermophysics, Academy of Sciences of the Ukrainian SSR, Kiev. The power of the UHF-EMF was 5, 10, 15, and 20 W, and the duration of exposure up to 10 min, in steps of 1 min. Altogether 32 rabbits underwent the procedure. Unirradiated specimens of liver and also the liver of intact living rabbits served as the control (series III).

EXPERIMENTAL RESULTS

Determination of thermal conductivity in vitro showed (Fig. 1) that for a higher value of λ to be achieved and, consequently, for cryodestruction to be maximized, exposure to the UHF-EMF must be adequate as regards both duration and power (10 W for 3 min). Exposure to a UHF-EMF of 5 W did not increase λ to the desired value even after 5 min, whereas higher powers (15 and 20 W), while inducing a predominantly thermal effect and (quite quickly) coagulation of the tissues, could not increase the value of this parameter to the necessary

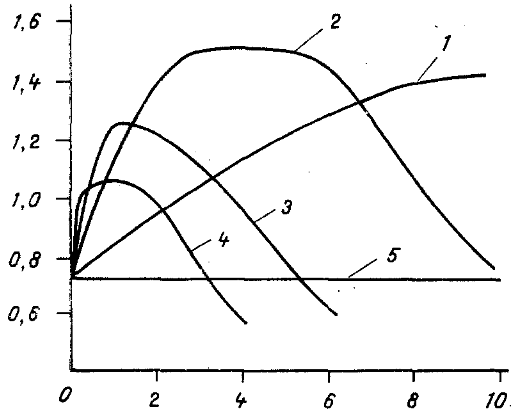

Fig. 3. Thermal conductivity of rabbit liver in vivo, depending on power and duration of irradiation. Legend as in Fig. 1.

level in the first minute. The study of the after-reaction of exposure to the UHF-EMF (see the thermal conductivity data in Fig. 2) showed that this reaction lasts not more than 30 min; during the first 5 min, moreover, it was maintained at a high level, after which it fell sharply. It can accordingly be concluded that the optimal time for cryodestruction is immediately after irradiation in the UHF-EMF and in the first 5 min thereafter.

Determination of thermal conductivity in vivo (Fig. 3) showed that when the blood flow was preserved thermal conductivity was increased as a result of exposure to UHF-EMF far higher than without exposure, although the general rules characteristic of isolated tissue still held good. Optimal conditions of exposure to UHF-EMF, according to the results of investigation of λ in vivo, were 10 W for 3-5 min. An experimental study of the volume of rabbit liver tissue dying as a result of cryonecrosis showed that its value after combined exposure to UHF-EMF and cryogenic destruction was on average 40 times higher (6-8 times in depth) than in the case of cryodestruction alone. It was observed that if cryodestruction was carried out 30 min after irradiation with the UHF-EMF, no effect of enhancement of cryodestruction was found, whereas after 5 min, the effect was completely preserved.

Thus as a result of microwave irradiation the thermal conductivity of living tissue is considerably increased. This largely explains the effect of enhancement of cryodestruction as a result of combined exposure to the UHF-EMF and cryogenic action. Determination of thermal conductivity of living tissue after irradiation in the UHF-EMF indicates that scientifically based optimal conditions of exposure to the UHF-EMF can be recommended for the achievement of maximal enhancement of cryodestruction.

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