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Research of human kidney thermal properties for the purpose of cryosurgery

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Abstract. Calculation of the heat transfer is required to correctly predict the results of cryosurgery, cryopreservation, etc. One of the important initial parameters are the thermophysical properties of biological tissues. In the present study, the values of the heat capacity, cryoscopic temperature and enthalpy of the phase transition of the kidney samples in vitro were obtained by differential scanning calorimetry.

1. Introduction

Currently, cryosurgery is alternative thermal ablation method. The main advantages of this method are simplicity to perform, bloodlessness, painlessness and a short hospital stay. The disadvantages of cryosurgery are the complexity of predicting the cryoexposure results and a small amount of methodological information and general practical recommendations [1,2]. Therefore, the development of this method leads to the emergence of a number of scientific and technical issues.

To reach a certain temperature in the target area (the necrosis temperature) is necessary to obtain a positive result of cryosurgery. This requires preoperative planning, which consists in calculating the heat transfer in the tumor and the surrounding area under low-temperature exposure. To simulate it is necessary to know the values of parameters that are included in the mathematical model: thermophysical, biophysical, technical and geometrical [3,4].

One of the development directions of cryosurgery simulation is the measurement of the thermophysical properties of biological tissues in a wide temperature range (including pathological tissues). Obtaining adequate results of thermophysical calculation requires taking into account the features of biological tissues such as multicomponent, thermal properties anisotropy and temperature dependence. Thermophysical properties of water-containing materials significantly vary with decreasing temperature, but currently there is no information about the values of these properties for a whole variety of biological tissues in a wide temperature range below cryoscopic temperature. For this reason, there are used either constant values of thermophysical properties in the positive and negative temperature ranges or water/ice thermophysical properties for heat transfer modeling. According to the literature the use of ice properties results to an underestimation of freezing time, and the use of constant properties results to overestimation [5].

As a result of the literature analysis of the thermophysical properties data of biological tissues and methods for measuring them, it was decided to use differential scanning calorimetry to determine the specific heat, the enthalpy of phase transition and the cryoscopic temperature of biological materials, in



particular human kidney fragments in normal and pathological states. The results of these measurements can be used as input data for mathematical modeling and optimization of heat transfer.

2. Materials and methods

For the measurements, we used the differential scanning calorimeter DSC 204 F1 Phoenix with external cooling system.

The operating principle of the calorimeter is based on the measurement of the temperature difference between the research sample and the comparison sample. The resulting temperature difference is proportional to the heat flux absorbed or released by the research sample during its heating or cooling. The coefficient of proportionality is the calibration factor, which is determined during the preliminary calibration.

The measurement of the phase transition temperature consists in finding on the curve "heat flux-temperature" the starting point of the deviation from the monotonicity, determined by the intersection of the extrapolation of the low-temperature branch of the peak of the curve with the baseline.

Important parameter for measurements on a differential scanning calorimeter is the sensitivity factor K_s . The sensitivity coefficient K_s is proportional to the ratio of the differential scanning calorimeter signal to the specific heat and mass of the sample. The value of this coefficient is always the same for different substances under the same test and external conditions and is determined by:

$$K_s = \frac{DSC - DSC_0}{\beta \cdot m \cdot c_p}, \quad (1)$$

where DSC – the experimental signal from the sample, μV ;

DSC_0 – the experimental signal from an empty container (zero line), μV ;

β – the rate of temperature change in the measuring chamber of the calorimeter (5 K/min in the present study);

m – sample mass, kg;

c_p – specific heat of the sample, J/(g·K).

Thus, the specific heat of the sample is determined by the equation:

$$c_{pS} = \frac{DSC_S - DSC_0}{DSC_{CS} - DSC_0} \cdot \frac{m_{CS}}{m_S} \cdot c_{pCS}, \quad (2)$$

where subscripts S correspond to the research sample, subscripts CS correspond to the comparison sample [6,7].

Cryoscopic temperature is the temperature of formation of the first ice crystals in moisture-containing substances, particularly in biological tissues. Phase transition in such substances does not occur at a constant temperature, since water in biological tissues is in the form of solutions. Thus, the melting start temperature does not coincide with the cryoscopic temperature. All measurements on the differential scanning calorimeter are carried out in the heating mode, so the known standard calorimetric methods do not allow reliable measurements of the cryoscopic temperature of biological tissues. The complexity of measuring cryoscopic temperature in the cooling mode is a significant effect of supercooling processes in biological tissues. To determine the cryoscopic temperature, a new technique was used, developed by the laboratory staff in VNIHI [6,7].

Preventing supercooling by creating nucleation centers allows the cryoscopic temperature to be determined when the sample is frozen. This effect is possible with incomplete melting of a pre-frozen sample. Thus, a program including complete sample freezing and a group of defrost-freeze cycles allows calculating the cryoscopic temperature.

3. Results and discussion

Figure 1 compares the dependencies of the specific heat of human kidney samples on temperature obtained from all experiments. The character of the phase transition and its origin coincide in all experiments. In the low-temperature region, the heat capacity of the one sample is below the general trend by 5-8%. In the region of positive temperatures, the greatest difference between them is the heat capacity of samples with a malignant tumor.

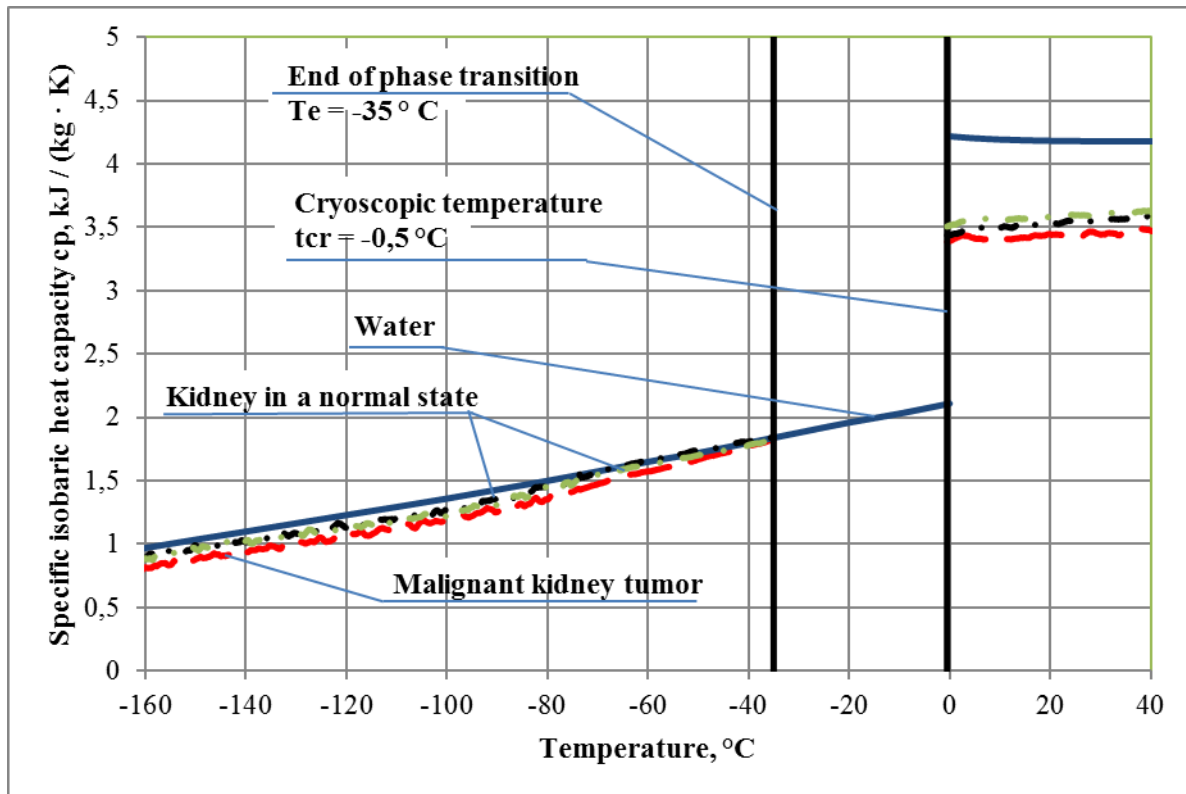


Figure 1. Specific heat of human kidney samples.

Cryoscopic temperature of kidney samples was found minus 0.5°C. Measurements of the heat capacity showed that the change in kidney heat capacity values at low temperatures has the same character as that of the water, but the values of the heat capacity of the kidney is 10-15% lower than that of water. The enthalpy of the phase transition is defined as the area bounded by the peak of the phase transition and the baseline (Figure 2). The average enthalpy of phase transition of human kidney tissue samples is 246 kJ / kg.

The specific heat of a malignant kidney tumor is lower than that kidney in a normal state. However, further research is required to assess the reliability.

4. Conclusion

In present study, the heat capacity, the enthalpy of the phase transition, and the cryoscopic temperature of the kidney samples were measured. The obtained measurements can be used for predict the results of cryosurgery, cryopreservation etc.

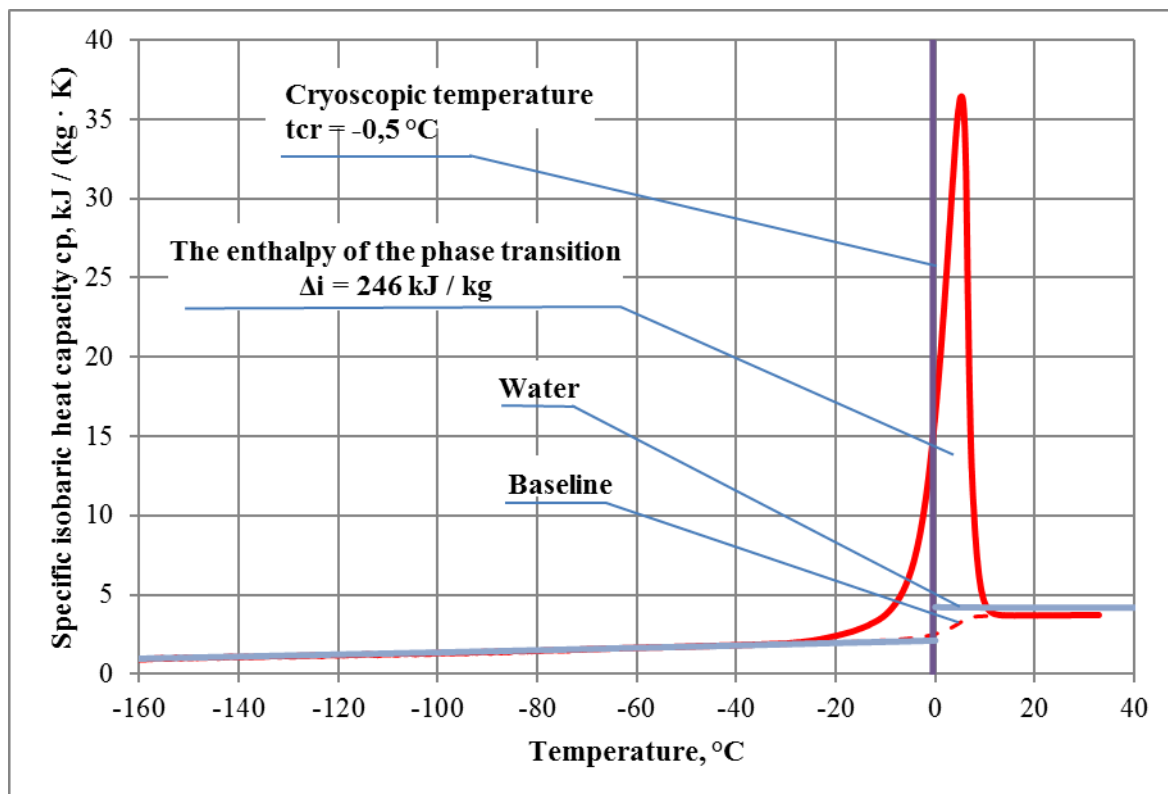


Figure 2. Definition of phase transition enthalpy.

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