Conference Paper

Deep Temperature Measurements in Oncothermia Processes

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Temperature in depth of various model systems was measured, starting with muscle and other phantoms. It was shown that the temperature can be selectively increased in the target. In water-protein phantom, the protein coagulation ($>60^{\circ}\text{C}$) was observed selectively while the water temperature around it was a little higher than room temperature.

1. Introduction

Research of oncothermia has wide range of temperature measurements since its origin in 1988. Numerous experiments were done in various model systems and phantoms, including various ex vivo tissues and complex body parts of various animals [1]. Independently from Oncotherm, the temperature development was also measured in a complex meat phantom [2].

New model experiments have been recently performed to show the depth profile of heating and to be sure of the deep heating facility by oncothermia devices. Some devices use the size of the electrode pair for focusing, suggesting that the small electrodes have less penetration. Generally it is true in the radiative approach, but our impedance heating is different. We used the smallest available electrode (10 cm diameter) showing that even with this the impedance heating is effective in depth.

The problem of the controlled and focused heat delivery to deep-seated tissues is a long-standing problem of the local hyperthermia in oncology [3]. The multiple artificial methods to focus the temperature have numerous technical

and physiological problems. The energy could be focused in a planned and accurate way, but the temperature spreads naturally. One further problem is the physiological control in living objects, which is likely to act by negative feedback, limiting, or blocking the temperature increase during the actual heating process.

2. Methods

The early (twenty years old) phantom measurements have been repeated under much more modern conditions and have been checked with optical fiber thermosensing method, and also the outside heating profile has been controlled for visual pattern by a high-sensitivity thermocamera system. The in vivo models, as well as all the animal experiments, have used fluoroptic temperature measurements which were a Luxtron optical thermometer. We made measurements in various points of the phantoms in depth. The precise inserting of the sensors has been controlled by imaging technologies in large animals and humans. We used EHY-2000+ and a small electrode for the treatment.

FIGURE 1: Typical human thicknesses of various healthy volunteers. Volunteer 1 (male) is 177 cm tall, his weight is 90 kg, and his chest is 22 cm wide. Volunteer 2 (female) is 165 cm tall, her weight is 51 kg, and her chest is 20 cm wide. Volunteer 3 (male) is 173 cm tall, his weight is 58 kg, and his chest is 20 cm wide. Volunteer 4 (female) is 181 cm tall, her weight is 70 kg, and her chest is 21 cm wide.

We modeled various human sizes [4], orienting waists (thickness) as underweighted ~ 70 cm (~ 18 cm), healthy ~ 85 cm, (~ 21 cm) overweight ~ 114 cm, (~ 28 cm) obese ~ 152 cm (~ 33 cm), and used phantom thicknesses 15–32 cm depending on the patient's weight and the part of the body (see Figure 1). The thickness of an average patient is around 22 cm (see Figure 1), so the asymmetric solution is better for humans than the symmetric. Probably there are many animals (horses, cows, elephants, etc.), where the 22 cm is not enough, for these cases the symmetric solution is better. (We are using it in veterinarian solutions because of these specialties.)

First we measured in a 20 cm phantom column, taking care of the heat exchange with the environment and the cooling by the bolus and the waterbed. In the first experiment, the phantom was mixed pork paying attention to the muscle and fat tissue combinations, modeling the living body complexity well. The phantom was a 10 cm diameter and 20 cm long cylinder, placed on the treatment bed, and heated by 60 W (see Figure 2) (20 cm was chosen for thickness of an average cancer patient).

Other experiments targeted the selection process of oncothermia. Various phantom materials were placed in distilled water and the system was treated by oncothermia (Figure 3).

3. Results

The deep temperature was rapidly enhancing, reaching the 42°C (from 24°C), increasing 18°C , in the depth of 6 cm (see Figure 4). Approaching more the depth profile of the heating we measured the temperature in depths of 4, 8, 12, and 16 cm. The same phantom system was used with chopped pork (see Figure 5). The power was 75 W. The measured temperatures were controlled by fluoroptic (Ipitek product) and thermistor sensors (Tateyama product). The starting initial temperature was 24°C . After 1 h the top, sensor (4 cm depth) indicated over 54°C , while 53°C , 51°C , and 45°C were measured in the depths of 8, 12, and 16 cm, respectively. The down electrode was cooled by the waterbed having lost much from the heat. This temperature development was 30°C at the largest and

FIGURE 2: Typical experimental arrangement at EHY2000+ device. Experimental cylinder with the temperature sensors (a), well-tuned device (b), the muscle phantom on the treatment bed (c), and muscle phantom with temperature sensors (d).

FIGURE 3: Various phantom arrangements to study the selection solutions. A piece of liver of pork (a), egg-white in rectangular water-tank (b), egg-white in cylindrical water-tank (c), and caviar in water-tank (d).

FIGURE 4: The temperature in depth was increased considerably. The outside temperature is of course lower, due to the cooling of the outside air on room temperature (22°C). The highest temperature in 6 cm depth (red temperature sensor in the thermo-picture) was 42°C , which was reached from 25°C at start (17°C increase made by 60 W, 60 min).

21°C at the smallest values. Without waterbed the down-cooling was not effective, and the phantom was heated higher.

The most realistic geometry was used when we put the experimental phantom to 31 cm height, simulating an obese patient (see Figure 6). The in-depth measurements show definite increase in the temperature over 45°C (from 27°C)

in depth of 24 cm applied 100 W heating power. The well-increased temperature (peak) in depth of ~ 10 cm is well observed in the thermo-picture.

The phantom experiments for demonstrating the selection process had shown the selection mechanism of oncothermia well. The liver experiment has shown a high temperature increase inside of the liver piece (Figure 7).

FIGURE 5: Depth profile with (a) and without (b) waterbed cooling effect. The temperature was the same in both systems, when the heating time was 60 min and 40 min in case of waterbed and without waterbed cooling of the system. The deepest temperature, however, was over 45°C, (18°C increase) in 16 cm depth.

The same selectivity was measured on egg-white in plastic bag surrounded with distilled water in two different-shape water-tanks (Figures 8 and 9). The temperature was as high as the temperature when the protein coagulation happens ($T > 60^\circ\text{C}$), while the water temperature was only slightly increased (2°C over room temperature of 24°C) by the heat from the coagulated egg-white. The same was observed on the caviar phantom, when the balls were individually “cooked” without increase of the temperature of the surrounding water (Figure 10).

4. Conclusion

Oncothermia is an effective deep heating method for tumor lesions, increasing the temperature in a safe, controlled and well-targeted way. Phantom measurements proved the possibility of the selection when the local temperature can go up to ablative regime, without heating up the nontargeted volume. This is the basis of oncothermia selection and is expected to be effective in nanoscopic range at the membrane of the malignant cells.

FIGURE 6: The phantom column, its thermo-picture during the treatment, and the thermosensors (“O”-Oncotherm-Tateyama system, “I”-Ipitek system for control). The thermo-picture shows a temperature distribution which has a maximum in depth of ~ 10 cm. The high temperature increase is proven in depth of as much as 24 cm.

FIGURE 7: On the picture on the left the section of the pork can be seen. It can be seen clearly that the proteins on the inner part of the liver coagulated quicker and better than the proteins on the peripheries. On the picture on the right it can be seen that the temperature inside the liver raised up to more than 40°C while the temperature of the distilled water around raised only by 5°C.

FIGURE 8: Coagulation of egg-white starts in its inner volume, while the water around it remains cold (room temperature).

FIGURE 9: The development of the egg-white coagulation is well seen in the cylindrical water-tank. The coagulation starts from the inside of the egg-white while the water outside remains cold.

FIGURE 10: The caviar pieces are cooked, while the water had no temperature increase from room temperature.

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