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Deep temperature measurements in oncothermia processes

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Abstract

Temperature in depth of in various model-systems was measured, starting with muscle and other phantoms. Temperature was measured by flouroptical system (Luxtron) in the various points of the phantoms. It was shown that the temperature can be selectively increased in the target. In water-protein phantom the protein coagulation (>60 °C) was observed selectively while the water temperature around it was a little higher than the room temperature.

Keywords: oncothermia, temperature, penetration-depth, hyperthermia, selectivity, phantom

Introduction

Research of oncothermia has wide range of temperature measurements from 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 complex meat-phantom [2].

New model-experiments were performed recently to show the depth profile of heating and be sure on the deep heating facility by oncothermia devices. Some devices are using the size of the electrode pair for focusing, telling that the small electrodes have less penetration. It is true generally in the radiative approach, but our impedance heating is different. We had 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. Further problem is the physiological control in living objects, which likely acts by negative feedback, limiting or blocking the temperature increase during the actual heating process.

Methods

The early (twenty years old) phantom measurements have been repeated under much more modern conditions, and have been checked with optical fiber thermo sensing method, and also the outside heating profile was controlled for visual pattern by a high-sensitivity thermo-camera system. The in-vivo models, as well as all the animal experiments, have used flouroptical temperature measurements in depth. The precise inserting of the sensors was controlled by imaging technologies in large animals and humans.

We had 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 pictures below), 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 for these specialties).

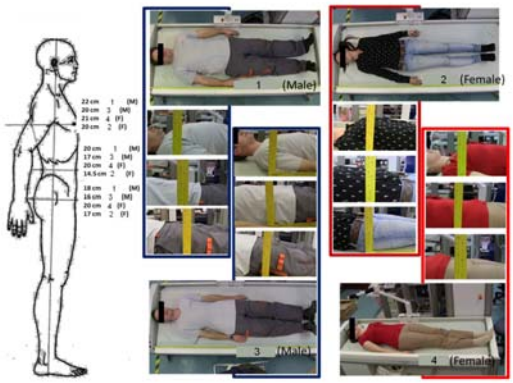


Figure 1. Typical human thicknesses of various healthy volunteers

First we measured in a 20cm phantom column, taking care on the heat-exchange with the environment and the cooling by the bolus and the water-bed. In the first experiment the phantom was mixed pork-meat taking care about 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 a thickness of an average suffering cancer patient.)

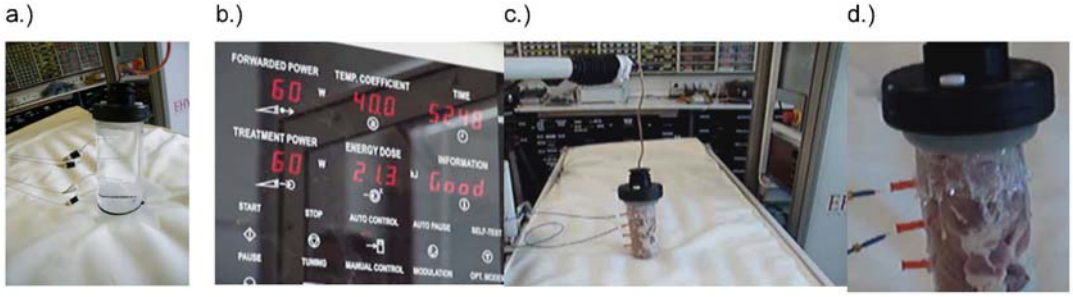


Figure 2. Typical experimental arrangement at EHY2000+ device. Experimental cylinder with the temperature sensors (a) Well turned device (b). The muscle phantom on the treatment bed (c) Muscle phantom with temperature sensors (d)

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

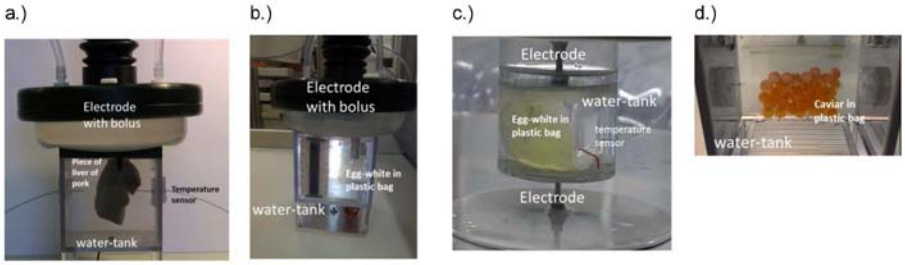


Figure 3. Various phantom arrangement for study the selection solutions. A piece of liver of pork (a), egg-white in rectangular water-tank (b), egg-white in cylindrical water-tank (c), caviar in water-tank (d)

Results

The deep temperature was rapidly enhancing, reaching the 42°C (from 24°C) increasing 18°C up, in the depth of 6 cm, (see Figure 4.).

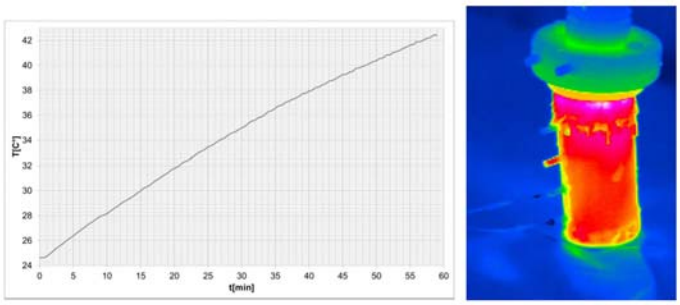


Figure 4. The temperature in depth was increased considerably. The outside temperature is of course lower, due to the cooling of the outside air on room temperature (22°C). The highest temperature in 6 cm depth (red temperature sensor in the thermo picture) was 42°C, which was reached from 25°C at start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

Approaching more the depth profile of the heating we measured the temperature in depths of 4, 8, 12, 16 cm depth. The same phantom system was used with chopped pork meat, (see Figure 5.) The power was 75 W. The measured temperatures were controlled by fluorooptical (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 other depths of 8, 12 and 16 cm was developing 53°C, 51°C and 45°C. (The down electrode was cooled by the water-bed having much a loss of the heat. This temperature

development was 30°C the largest and 21°C the smallest values. Without water-bed the down-cooling was not effective, and the phantom was heated higher.

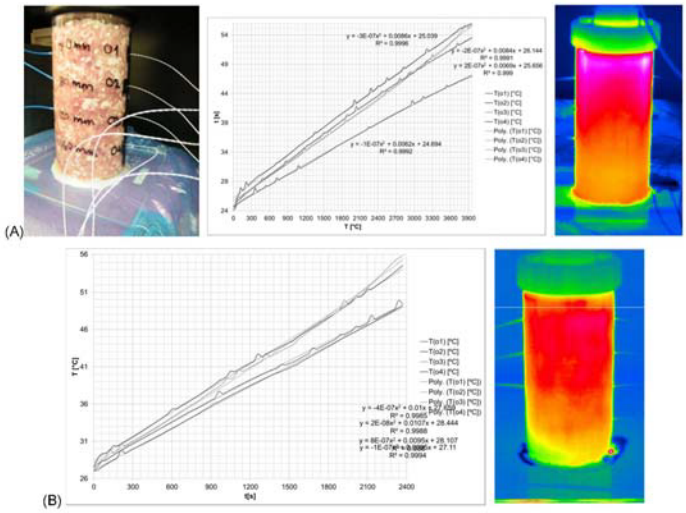


Figure 5. Depth profile with (A) and without (B) water-bed cooling effect. The temperature was about the same in both systems, when the heating time was 60 min and 40 min in the canse of water-bed and without water-bed cooling of the system. The deepest temperature however was over 45°C, (18°C increase) in 16 cm depth

The most realistic geometry was used when we put the experimental phantom 31 cm height, simulating an obese patient, (see Figure 6.). The in-depth measurements show definite increase of 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 observable on the thermo picture.

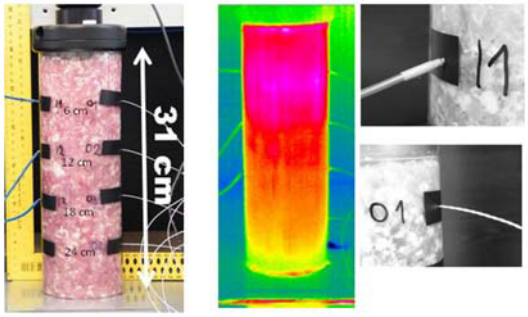
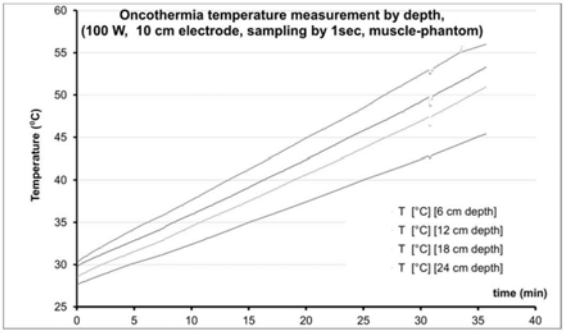


Figure 6. The phantom column, its thermo-picture during the treatment and the thermo sensors ("O" - Oncotherm-Tateyama system, "I" - Ipitek system for control). The thermo-picture shows a temperature distribution which has a maximum in depth of ~10 cm. The high temperature increase is proven in depth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



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

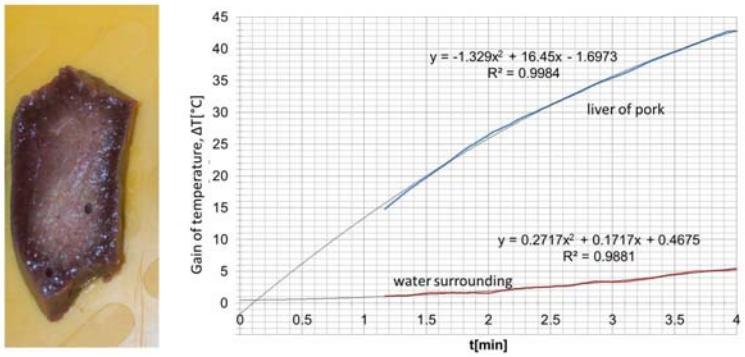


Figure 7.

The same selectivity was measured on egg-white in plastic bag surrounded with distilled water in two different-shape water-tanks (figure 8. and figure 9.). The temperature was as high as the protein coagulation happen (T>60 °C), while the water temperature was only slightly up (2°C over the room temperature 24°C), by the heat form 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, see Figure 10.

Figure 8. Coagulation of egg-white starts in its inner-volume, while the water around remains cold

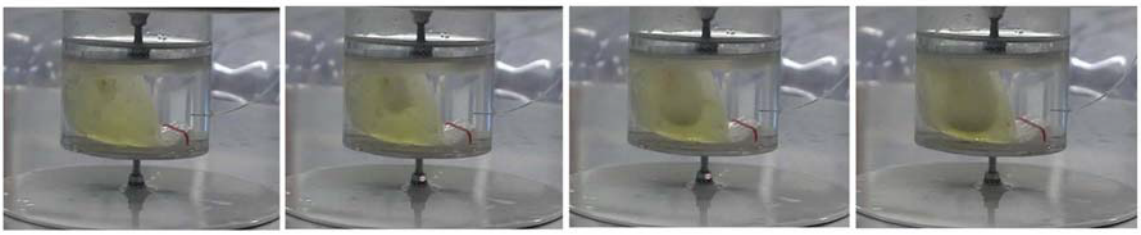


Figure 9. The development of the egg-white coagulaton is well seen in the cylindrical water-tank. The coagulation starts inside of the egg-white, the watr outside remains cold

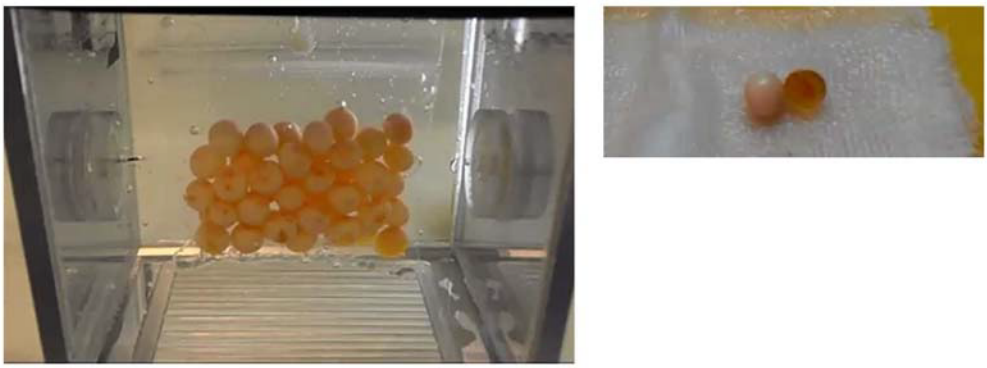


Figure 10. The caviar pieces are cooked, while the water had no temperature increase from room-temperature

Conclusion

Oncothermia is an effective deep heating method for tumor-lesions, increasing the temperature by 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 non-targeted volume. This is the basic of oncothermia selection and is expected to be effective in nanoscopic range at the membrane of the malignant cells.

Acknowledgement

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