Distribution of temperature along the phantom of the human leg under the influence of microwave radiation

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Abstract. In the article, the results of a study of the temperature distribution inside a phantom in the form of a human foot with a two-layer filling, simulating muscle and bone tissue are shown. Imitation of muscle tissue by dispersed pig meat (minced meat) and the bone by a wax cylinder was carried out. The temperature distribution profiles along the phantom during microwave heating with a power of 40 W in the time interval from 10 to 40 minutes are presented.

1. Introduction
The protection of public health in the Russian Federation is a priority of the country's social policy as a factor of national security, stability and welfare of society. Cold injury treatment is still relevant despite of many years of study in this issue [1–3]. The equipment for treating is objectively necessary due to climatic features of Russia where in most of the country cold season is up to six months. The noteworthy feature here is that difficulty of frostbite treatment exist in warmer regions. In 65% of cases of frostbite injury, even with prolonged treatment, patients have symptoms associated with permanent neurovascular damage [4]. Symptoms include cold sensitivity, paresthesia or numbness, pain and hyperesthesia.

Due to the lack of medical equipment for heating deep frostbite the creating of instrumentation and methods providing treatment at an early stage is very important. These studies on rabbits at Tomsk State University were started in 2006. The possibility of frostbite heating in a microwave chamber at a frequency of 2.45 GHz, which was approved for medical applications, was shown [5]. However, to start working with a human more detailed investigation is needed. First of all, it is necessary to investigate the heterogeneity nature of electromagnetic [6,7] and thermal fields in the capacity of heated limb to avoid local underheating and overheatings. The difficulty is in the prohibition to submit a person to this kind scientific experimentation. Therefore, it is imperative to create the phantom limb which would have dielectric properties as closely as possible to properties of human body.

One of the important advantages of the technique of heating deep frostbite of the extremities using microwave radiation in a multi-wavelength camera is the possibility of faster activation of deep-lying vessels, without which a positive treatment result is unattainable [8, 9]. In cases where the surface and near-surface vessels open, and the deep vessels remain ischemic, thrombosis, micro cracks, edema and, as a result, necrosis occur. At the same time, in order to obtain a positive result, the penetrating ability of microwave radiation alone is not enough. It is necessary to ensure uniform distribution of the thermal field throughout the limb volume, or, in extreme cases, to create conditions for the sequential heating of deeply located vessels from the limb that is not affected to cold injury. Do not forget that the microwave
field in a closed metal chamber is obviously heterogeneous, and this can play a significant role in cases where the surface and near-surface vessels open, and the deep-lying vessels are still closed. Hence the need for a more detailed study of the distribution of thermal fields in the volume of the limb, heated in a multiwave microwave chamber.

2. Experimental measuring technique of the temperature distribution in the phantom of the leg

To carry out this study, a phantom was chosen (Figure 1), which simulates a warmed limb [9] and allows one to freely cool and heat an obsessed person and measure the distribution of thermal fields in its volume.

To simulate muscle tissue, the volume of the phantom was filled with minced pork, as it is close to the dielectric constant of human tissue. As a simulation of the leg bone, a wax cylinder was used in the center of the phantom, the dielectric constant of the bone is 5.0–6.0 [10], the wax has close values of the dielectric constant of the bone 2.4–6.5 [11]. We research the phantom space corresponding to the lower leg and calf, which is the preferred zone for initial warming.

The studies were carried out in a microwave chamber (Figure 2) measuring 30×40×50 cm with an input aperture of 24 cm in diameter, equipped with a radioprotective sleeve, which eliminates unwanted microwave radiation into the surrounding space. The introduction of the temperature probe was carried out by a one-dimensional precision positioning system, which provide to measure the temperature distribution in the volume of the “muscle”.

The Figure 3 shows a block diagram of a system for recording the distribution of the phantom temperature in a microwave chamber.
As a source of microwave radiation, the generator unit SMVI-200 microwave physiotherapy apparatus, operating at a frequency of 2.45 GHz, with a power of 10 to 200 watts, was used. Using an LT-300 laboratory electronic thermometer the temperature inside the leg phantom was measured. Data exchange between the thermometer and the computer was carried out through RS-232/USB controller.

In Figure 4 shows the distribution of the temperature along the longitudinal axis of the phantom, obtained after loading the phantom with a cooled filler, as well as the result of successive sessions of its heating in the chamber at a fixed generator power.

From Figure 4 it follows that, with the indicated generator power of 40 W and a session duration of 10 minutes, each microwave heating session leads to a temperature increase of 1–3 ° C, which allows us to predict the integral heating time required to restore the lower leg vessels. It can be seen that the area of narrowing of the lower leg warms up much faster. Therefore, it is advisable to change the location of
the exciting antenna (in the above camera, the antenna is located on the wall opposite from the input aperture). In this case, it is located not only close to the narrowing of the lower leg, but also, more importantly, close to the foot, and rapid heating of which for the above reason is undesirable.

3. Summary
Thus, the study of the distribution of the temperature field along the longitudinal axis of the phantom of the ankle of the leg, placed in the microwave chamber, allows us to estimate the heating rate of muscle tissue and the degree of temperature heterogeneity caused by the complex geometry of the lower leg. It was shown that warming in the region of the tibia narrowing occurs faster, as a result, the temperature in this region is 3-4 °C higher, which should be taken into account when developing a schedule for warming the cold injury of the limb. It is also desirable to change the location of the microwave emitter located in the immediate vicinity of the foot and narrowing of the lower leg.

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