Temperature distribution in the phantom of limb in the microwave chamber with linear source of radiation

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Abstract. The paper presents results of temperature distribution in the phantom of limb under the microwave radiation. The authors have developed automated apparatus based on linear positioner and temperature detector. The apparatus is aimed at measuring the distribution of thermal field in phantom of a human hand. It was shown that impulse microwave radiation with a power of 40W during 6 minutes leads to uniform heating along longitudinal axis of phantom. The apparatus "SMVi-200" was used as a microwave source being normally applied for hypothermia treatment.

1. Introduction
The protection of public health in Russia is one of the key social policy areas. However, the research on the treatment of cold injuries remains a significant issue. The equipment for treating is still necessary due to Russian climate where in most of the country cold season lasts up to six months, as well as the problem of frostbite treatment still exists in warm regions. There were cases of massive cold injuries in India and Vietnam. There is a need to develop medical equipment and methods for deep frostbites heating due to the lack of such apparatus. The testings on rabbits began in 2006 at Tomsk State University, Russia. The possibility of frostbites heating in microwave chamber for medical purposes at a frequency of 2.45 GHz is shown [1]. However, to launch testing on people, more detailed investigations are required. Firstly, it is necessary to investigate the heterogeneous nature of electromagnetic and thermal fields to avoid local underheatings and overheating of a limb. It is imperative to create the phantom of limb, which would have dielectric properties as closely as possible to properties of human body. The main purpose of this research is to develop the apparatus that could provide uniform heating of the entire limb.

2. Experimental apparatus
The effect of high-frequency radiation on biological tissue is tissue heating due to released heat. The key factors affecting the radiation are as follows: flux density of radiation incident power, reflection and refraction coefficients at the "biological tissue-air" phase boundary and between individual layers, and linear attenuation coefficients. In this work, "SMVi-200" (MedTeko, Russia) apparatus-based experimental equipment is used to study the temperature distribution in the phantom of limb.

"SMVi-200" is an apparatus for the production of electromagnetic radiation, aimed at providing therapeutic intervention. The apparatus has a wide application in specialized physiotherapy departments, treatment, and preventive care establishments and hospitals.
The apparatus operates centimeter waves resulting in vascular distention and blood flow acceleration.

"SMVi-200" primarily provides anti-inflammatory effect, but also other effects such as catabolic, fibromodeling (under the high-intensity therapy), proliferative, and secretory (under the low intensity therapy). Therapeutic effect is reached due to applying microwaves that enhance blood flow and central nervous system microcirculation, enhance vessels and blood flow intensity, increasing concentration of oxygen in tissues. The result of apparatus operation is lymphodynamics intensification. "SMVi-200" cannot be used as an apparatus for frostbites treatment due to its design: the main function of the apparatus is local heating. However, it is possible to use "SMVi-200" as a microwave source. The apparatus operates at a frequency of 2.45 GHz and with a capacity from 10 to 200 W.

To investigate the temperature distribution in the phantoms of different sizes and configurations, the authors used an "automated temperature meter" [2] placed above the vertical microwave chamber.

![Experimental apparatus, SMVi-200 and automatized temperature meter placed vertically](image)

**Figure 1.** (a) Experimental apparatus, SMVi-200 and (b) automatized temperature meter placed vertically

The experiments conducted with isolated microwave chamber have shown that the apparatus construction for frostbites treatment needed further improvements [3]. The configuration (chamber sizes and mode of excitation) of forced air cooling of limb heated under microwave radiation was modified [4]. Air cooling was implemented since surface of phantom was heated more quickly than its internal volume due to "skin-effect". The cooling fan (2 in Figure 2b) was implemented into the chamber to provide phantom cooling. This allows reducing the temperature on the surface of phantom thereby ensuring deep heating and avoiding excessive heating.
Figure 2. Schematics microwave chamber with a) 30 cm in length, 1 - local radiator, b) 33 cm in length, 1 - whip antenna, 2 - air cooling system.

In addition, the width of the microwave chamber was increased by 3 cm in order to eliminate resonance. Radiator – the wave source – was also modified. The radiator became implemented along the longitudinal axis and positioned in the upper right corner (Figure 2b). The mentioned modifications were necessary because when radiator was placed near with area of fingers, overheating occurred.

Polypropylene pipe 50 cm in length and 10 cm in diameter filled with pork mincemeat was used as a phantom of a human limb (Figure 3). Preliminary studies on pork mincemeat have shown that the true part of dielectric constant is 50 and imaginary value is 16.9. These values are similar to the values of blood filled muscular tissue of human [5].

Figure 3. Polypropylene pipe 50 cm in length and 10 cm in diameter and its placement in vertical chamber.
3. Experimental

Figure 4 provides the results of temperature distribution measurements in phantom along longitudinal axis in the initial prototype of microwave chamber [4] and upgraded chamber [6]. The measurements were provided without heating (curve 1), and when heating the phantom within 6 min (curves 2, 3, 4). The temperature measurements were conducted for 4 times within 13 min for each measurement.

Figure 4a shows that during operation of microwave chamber with the radiator power of 40 W (pulse mode) on a frequency of 2.45 GHz, significant inhomogeneity of temperature is not observed, with the exception of the area contiguous to radiator.

4. Summary

The temperature measurements presented (Figure 4a, b) were conducted under the same conditions. According to Figure 4b, there is no overheating in fingers area (the back wall of the microwave chamber) in comparison with Figure 4a providing the initial position of microwave source. Therefore, the study on field distribution in cylindrical phantom has shown the possibility of obtaining a more
uniform field distribution in fingers area during frostbites treatment. Providing lower temperature will prevent premature heating of fingers blood vessels.

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