NON-PERTURBING TEMPERATURE PROBE AND THERMOGRAPHY MEASUREMENTS IN MICROWAVE DIATHERMY

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ABSTRACT

In support of the BRH proposed microwave diathermy standard, temperature measurements in fat-muscle phantoms using thermography and a non-perturbing temperature probe were investigated. These probe data indicate significant thermography errors.

I. Introduction

The proposed microwave diathermy standard heating effectiveness requirement calls for a Specific Absorption Rate (SAR) of at least 235 W/kg to be deposited in standard planar and cylindrical phantoms.[1] The purpose of this paper is to describe the techniques for measuring temperature in these planar, simulated, fat-muscle phantoms with a minimally perturbing temperature probe, and to compare these results against measurements made with a thermographic camera.

II. Experimental Setup

a. Thermography

Figure 1 shows the 2450-MHz Bureau of Radiological Health (BRH) prototype applicator[2] used to induce heating in a planar fat-muscle phantom with a 2 cm fat layer. This applicator meets the heating and radiation leakage requirements of the proposed diathermy standard.[1] The experimental setup for measuring heating patterns described in detail in previously published papers[2,3] is shown in Figure 2. Briefly, for internal heating, the applicator is placed symmetrically on top of the planar phantom. After the phantom has been heated with a net power of 130 W for ten seconds, one half-section of the phantom is quickly removed (to minimize thermal diffusion) so that a thermographic camera can immediately view the internal cross-sectional heating pattern.

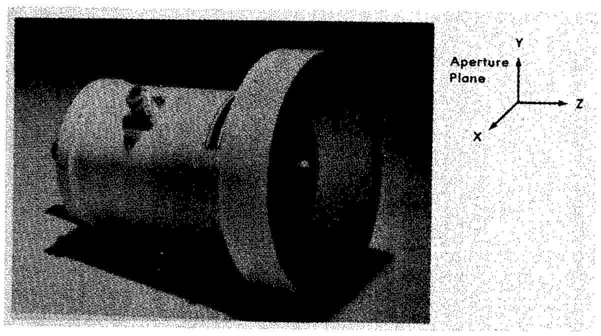
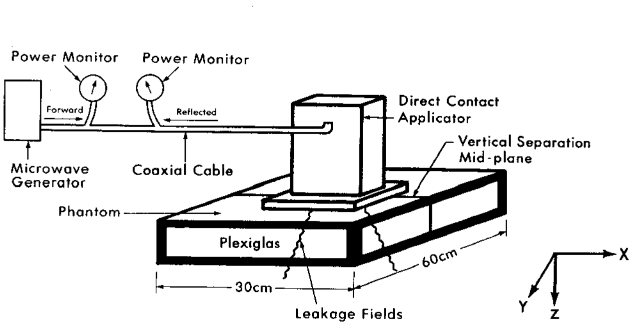


Figure 1. 2450-MHz Circularly Polarized Applicator



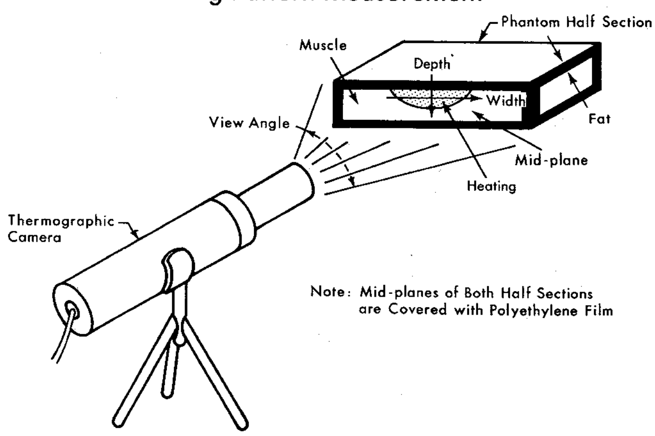


Figure 2. Thermographic Experimental Setup

b. Minimally Perturbing Temperature Probe

The same experimental setup was used, except that the planar fat-muscle phantom did not have to be separated to obtain real-time temperature measurements. To accomodate a commercially available 1-mm diameter thermometer probe, a small hole was bored out of the Plexiglas side of the phantom (Figure 3). The probe uses high-resistance leads, and its sensor is a small bead thermistor.[4,5] Table I gives additional specifications of this thermometer. The thermistor bead was placed at the various vertical (y-z) midplane locations in the half-section of the phantom and the surface of the half-section was then covered with a 0.05 mm polyethylene film. The real-time temperature response of the thermometer to microwave heating was plotted on a chart recorder; from this plot, the temperature rise vs. heating time was determined for a constant applied microwave power level.

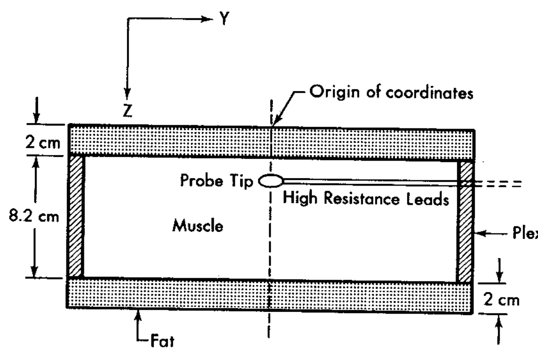


Figure 3. Half-Section of Phantom with Thermometer Inserted

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Table I. VITEK MD 101 Electrothermia Monitor specifications.

A. Probe tip diameter: 1 mm.

B. Probe exponential response time, τ, including electronics: 0.74 ± 0.1 secs*.

C. Measured thermal lag in muscle tissue when heated at 1 °C/min: approximately -0.01 °C**. A linear relationship with heating rate is assumed.

D. Noise on output signal: less than 0.01 °C.

E. Probe calibration at T = 25 °C, 35 °C and 45 °C: calibration uncertainty in T(ΔT) = ±0.01 °C**.

F. Nonlinearity: +0.012 °C per °C from 25 °C down to 22 °C and -0.012 °C per °C from 25 °C up to 26 °C.

G. For probe and leads aligned with the electric field vector in the "near field," microwave heating of the high-resistance leads showed +0.12 °C heating for a 1 °C/min heating rise in water at 2.0 GHz**, while for a 1 °C/min heating rise in simulated muscle tissue at 2.0 GHZ, it was 0.01 °C***.

*Measured at the Bureau of Radiological Health.
**Measured by the manufacturer.
***Telephone conversation with the manufacturer.

III. Measurements

a. Thermographic Data

Figure 4 shows midplane heating patterns (white areas are the hottest), the upper thermogram under ambient conditions, and the lower thermogram after microwave heating. The selected temperature profiles corresponding to the white scan lines of Figure 4 are shown in Figure 5. Each vertical division in Figure 5 corresponds to 0.63 °C. Analysis of the thermographic data gives a depth of penetration d of 1.2 cm (defined[3] as the distance between the fat-muscle interface and the depth at which there is a fifty-percent fall off from the maximum temperature rise in the simulated muscle). From the SAR calculations[6] of these data, it follows that a net power of 35.2 W is needed to deliver a SAR of 235 W/kg to the simulated muscle tissue of the phantom.

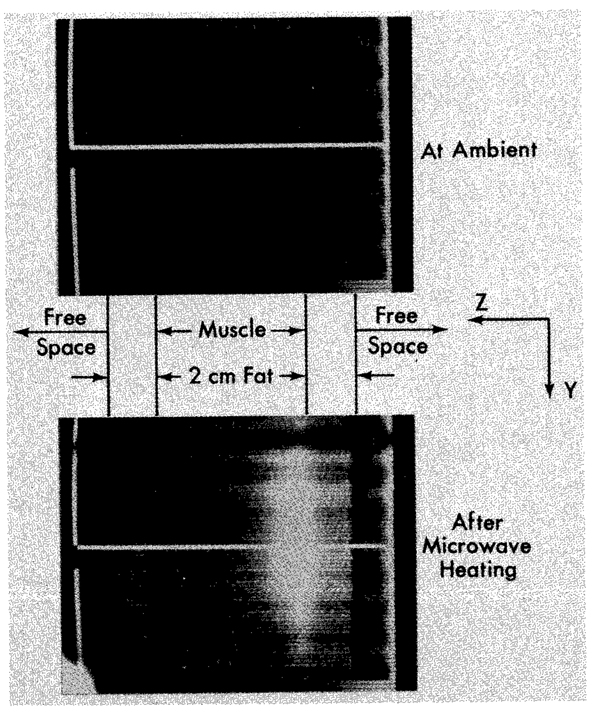

Figure 4. Thermographic Heating Patterns

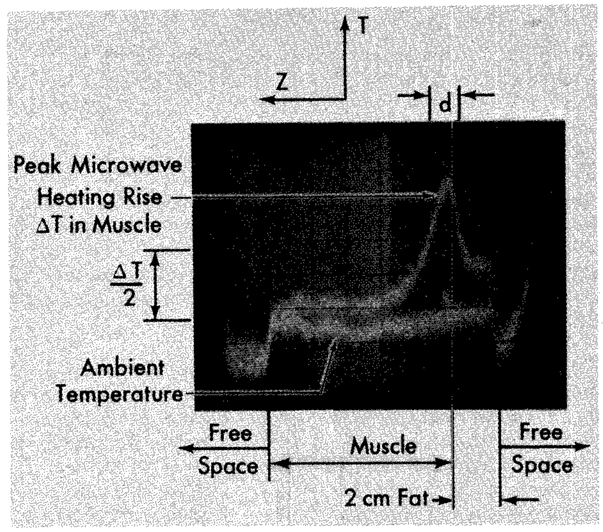

Figure 5. Thermographic Temperature Depth Profile

b. Thermometer Probe Data

The temperature rise versus time was measured in the phantom, with both halves together, at a discrete set of points along the z-axis (Figure 3). The temperature rise, measured at the time the microwave field was turned off, was used to calculate the normalized SAR (W/kg per 1 W net power). This probe has been shown to have a small amount (see Table I) of radio-frequency (RF) resistance-line heating, a finite probe response time and a small nonlinearity in the temperature response.[5,7] (These small errors were not included in the analysis). Normalized SAR along the z-axis (see Figure 3) is plotted in Figure 6. An analysis of the curve in this Figure gives a depth of penetration d of 0.8 cm; also from this Figure, it was determined that a net power of 29 W is needed to deliver a SAR of 235 W/kg to the simulated muscle tissue of the planar phantom.

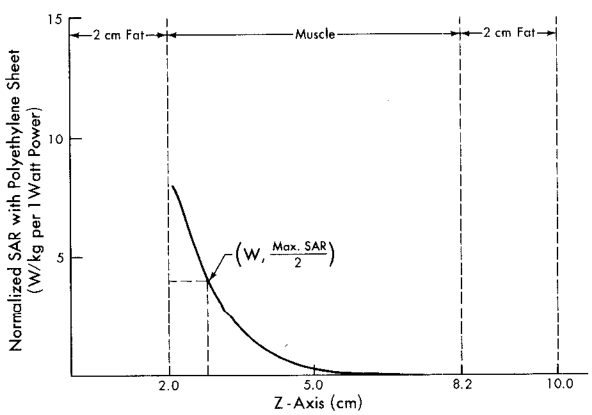

Figure 6. Thermometer SAR Depth Profile

IV. Conclusion

From the measurement section III, one can see that there is an apparent discrepancy, between the data taken with the thermographic camera and the thermometer, for the depth of penetration d and the net power of the applicator needed to deliver a SAR of 235 W/kg. The thermographic data show the depth of penetration to be about fifty percent larger than that measured with the temperature probe. The net power to deliver 235 W/kg to the muscle material is 20 percent larger for the thermographic camera than that measured with the temperature probe. The temperature probe data for the depth of penetration are very close to the theoretical value of 0.9 cm for a rectangular waveguide applicator.[9]

Explanations of these apparent discrepancies between the thermographic camera and temperature probe data are related to heat transport resulting from the time delay in separating the two phantom halfs. Under the best operating conditions, we were only able to view the open phantom 20 seconds after the microwave field was turned off. There are three heat transport phenomena that need to be considered to account for the discrepancy of the thermographic data: heat radiation and convection after the opening of the phantom, and thermal diffusion both during and after microwave heating.[4,5,8] Since these phenomena are time-and space-dependent, they cause changes in the measured temperature rise; an increase in this microwave-induced temperature rise in turn means larger heat transport effects.

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