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Muscle Equivalent Agar Phantom for 13.56MHz RF-Induced Hyperthermia

(hyperthermia/radiowave/dosimetry)

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We developed an agar phantom as a muscle equivalent phantom which is applicable to 13.56MHz RF-induced hyperthermia. The phantom is composed of 2.0 w/w % agar, 0.43 w/w % NaCl, and 97.57 w/w % water. The electric conductivity is 0.83 ℧/m at 22°C. The specific dielectric constant is 109 at the same temperature. Reference is made to the electric conductivity and the specific dielectric constant of the muscle at 37°C which are 0.83 ℧/m and 112, respectively.

Since D'Arsonval in 1893 reported the human body could be successfully heated by radiofrequency (RF) (1), RF have been utilized as diathermy for the deep heating. Pflomm (2) reported RF could inhibit the growth of malignancy, and RF irradiation had also been used for treatment of cancer. On the other hand, there was a report (3) which denied the effect of RF irradiation on cancer. Thus, the effect of RF for cancer was not confirmed up to the 1940's. Part of the difficulty was the lack of dosimetry of RF (4).

Recently, cancer cells have been again proved to be vulnerable to heat as compared with normal cells, and the action of heat on cancer has been re-evaluated both *in vitro* and *in vivo* (5, 6). Researches on hyperthermia therapy in combination with ionizing radiation is now being extensively carried out. The possibility that the hyperthermia therapy, either alone or in combination with radiation will become a useful means of treating cancer is dependent not only on the establishment of the method of deep heating, but also on a better comprehension of the temperature control and absorption energy distribution. We developed a muscle equivalent agar phantom applicable to 13.56MHz RF-induced hyperthermia in order to determine the distribution of RF absorption energy, under different conditions.

MATERIALS AND METHODS

Materials

Agar phantoms were prepared by the following method: Agar powder (Ishizu Pharmaceutical Co., Ltd.) was mixed with NaCl and aqua dist. The mixture was heated, boiled, and placed to cool naturally in a cylinder. The cow thigh was used as the muscle for application of the studies.

Methods

There are various methods of determining the electric conductivity and the dielectric constant of a substance at high frequencies (7—9). Fig. 1 shows the circuit used in determining phantoms in the present study. The part No. 1 in Fig. 1 indicates a function generator, Wavetex Model 143 which generates 13.56MHz. Part No. 2 is the 250pF variable capacitor, Tama Denyo, part No. 3 is the 30 mmϕ platinized platinum electrode, part No. 4 the sample of the agar or muscle which is compressed into a vinyl chloride cylinder 29mm in inside diameter and 20mm in length. Part No. 5 is a trimer type of variable resistor and part No. 6 the switch. Part No. 7 is an oscilloscope, Sony/Tektronix 475 which is used to determine the voltage of the variable capacitor.

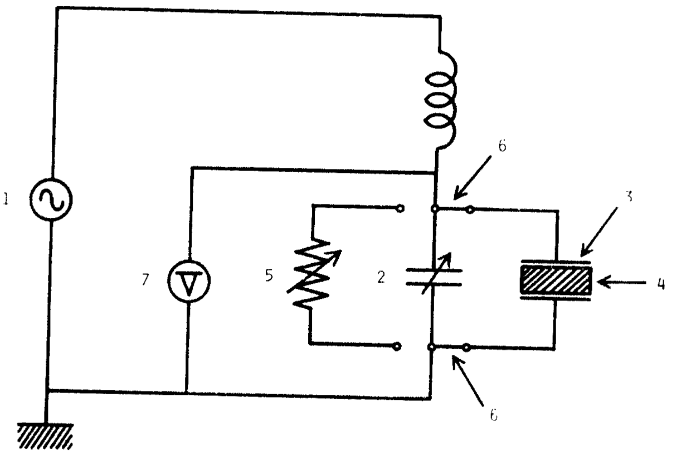

Fig. 1. Circuit for determination of electric conductivity and dielectric constant. 1 : Oscillator, 2 : Variable capacitor, 3 : Platinized platinum electrode, 4 : Sample, 5 : Variable resistor, 6 : Switch, 7 : Oscilloscope

The determination method is applied as follows : (1) The part No. 6 (Fig. 1) is connected with the sample and the part No. 2 is adjusted to get resonance. The value of the part No. 2 at this time is referred to as C_1 (F). At this adjusted point, the part No. 7 indicates the maximum value ; (2) Secondly, the part No. 6 is connected with the part No. 5 and the part No. 2 is re-adjusted to get resonance. The value of the part No. 2 at this time is referred to as C_2 (F). Thirdly, the part No. 5 is adjusted so that the voltage of the part No. 7 may be equal to the preceding voltage at the time when the switch was connected with the sample. The value at this time is referred to as R (Ω).

The above-mentioned procedure leads to the equality of (1) to (2) in terms of the circuit. Thus, capacity Cx (F) and resistance Rx (Ω) of the sample are expressed in the following equations :

$$Cx = C_2 - C_1$$

$$Rx = R$$

When a fringing effect is neglected, the specific dielectric constant ε and the electric conductivity σ are expressed in the following equations :

$$\varepsilon = \frac{Cx\,\ell}{S\,\varepsilon_0}$$

$$\sigma = \frac{\ell}{Rx\ S}$$

Where ℓ (m) is the thickness of the sample ; S (m^2) is the area of the sample ; ε_0 is the dielectric constant of a vacuum, $10^{-9}/36\pi$ (F/m).

RESULTS AND DISCUSSION

Fig. 2 shows the electric conductivity of an agar phantom of 2.0 w/w % agar at 22°C in 13.56MHz. The abscissa indicates NaCl concentration (weight %). The arrows on the ordinate indicate the electric conductivities of the muscle at 37°C and 22°C. The electric conductivity of an agar phantom increased linearly on a linear scale with NaCl concentration. Fig. 3 shows the electric conductivity of an agar phantom including 0.5 w/w NaCl at 22°C in 13.56MHz. The abscissa indicates agar concentration (w/w %). The electric conductivity of an agar conductivity decreases a little with an

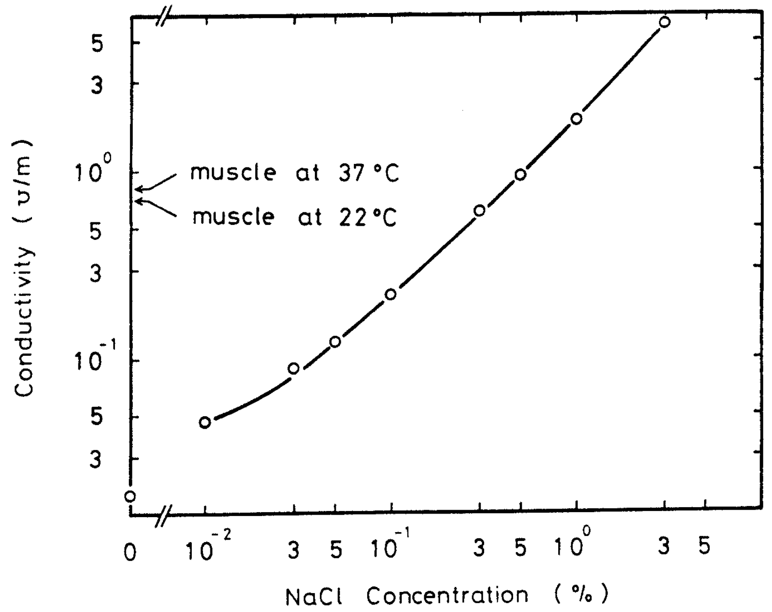

Fig. 2. NaCl concentration dependence of the conductivity of 2.0 w/w % agar phantom. The upper and lower arrows on the ordinate indicate the conductivities of the thigh muscle at 37°C and 22°C, respectively.

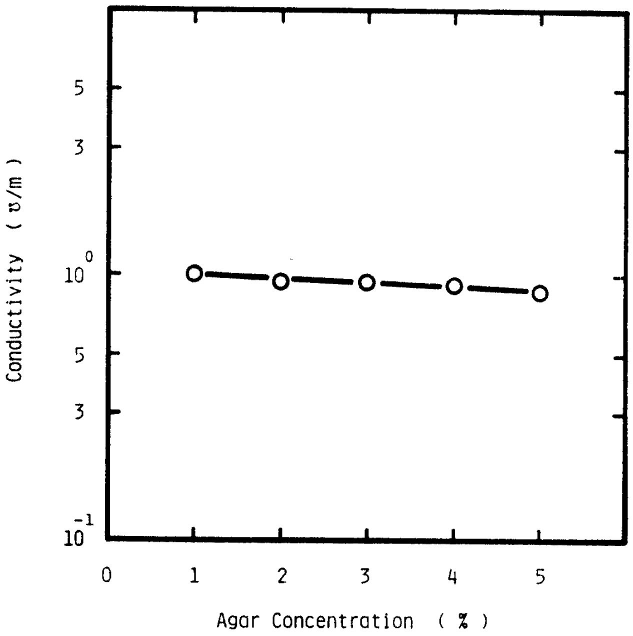

Fig. 3. Agar concentration dependence of the conductivity of 0.5 w/w % NaCl phantom.

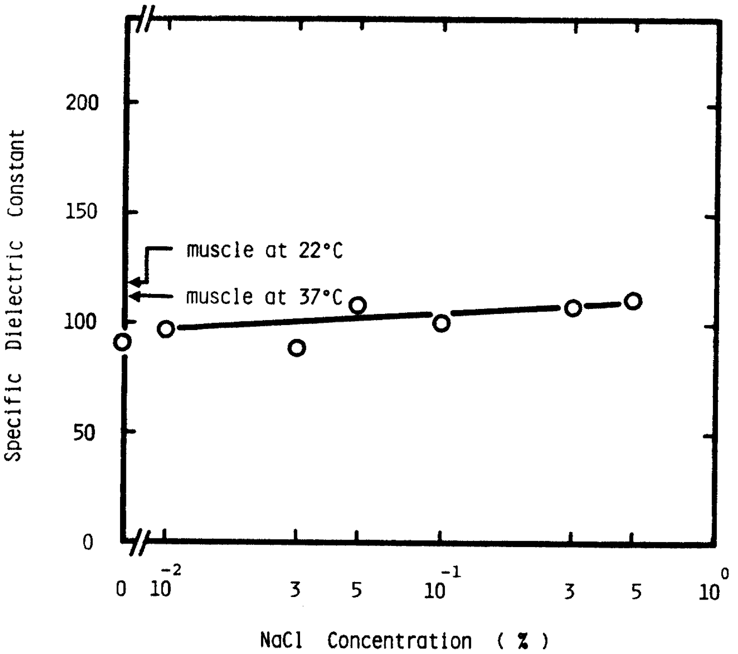

Fig. 4. NaCl concentration of the dielectric constant of 2.0 w/w % agar phantom. The upper and lower arrows on the ordinate indicate the dielectric constant of the thigh muscle at 22°C and 37°C, respectively.

increase in agar concentration. Fig. 4 shows the specific dielectric constant of 2.0 w/w % agar phantom. The abscissa indicates NaCl concentration (w/w %). The arrows on the ordinate indicate the specific dielectric constant of the muscle at 37°C and 22°C. The dielectric constant of an agar

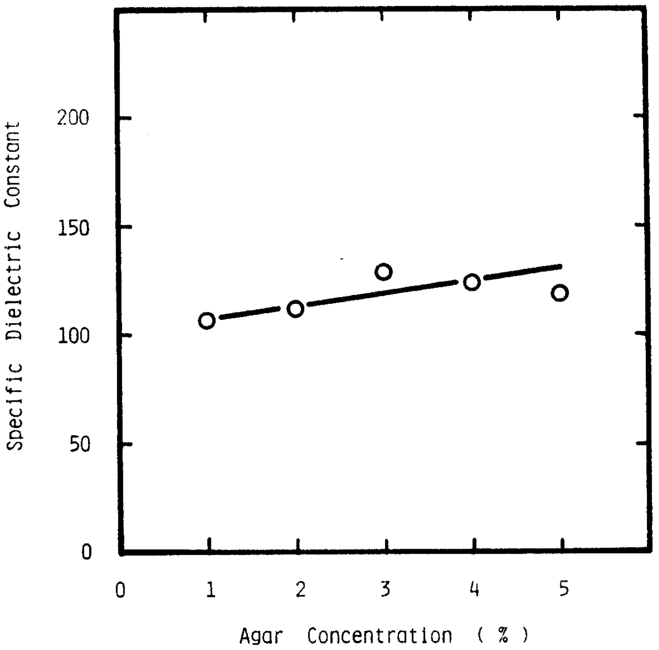

Fig. 5. Agar concentration dependence of the dielectric constant of 0.5 w/w % NaCl phantom.

phantom changes little with NaCl concentration. Fig. 5 shows the specific dielectric constant of an agar phantom including 0.5 w/w % NaCl. The abscissa indicates agar concentration (w/w %). The dielectric constant of an agar phantom increases a little with increases in agar concentration. As a result of the above experiments, we can choose a muscle equivalent phantom which is composed of 2.0 w/w % agar, 0.43 w/w % NaCl and 97.57 w/w % water. The electric conductivity and the specific dielectric constant of this phantom were 0.83 ℧/m and 109 at 22°C in 13.56MHz, respectively. These values were equivalent to the values (σ =0.83, ε=112) of the muscle at 37°C in 13.56MHz.

Liquid phantoms such as a water-, ethanol-, and NaCl-phantom (10), and Ringer's solution (11) have been reported to be usable as a tissue equivalent phantom. A solid phantom, in which jelly is used, has also been reported (12). However, it is impossible to determine the distribution of the temperatures raised by RF, because some give rise to the rapid transition of heat owing to the liquidity. Further, some are unsuitable as a phantom for 13.56MHz in the light of the use of microwave. We have already shown that the distribution of the temperature in a phantom can be determined consecutively by scanning agar phantoms with a string-attached thermocouple (13). The difference in temperature distributions before and after RF heating is made equivalent to the distribution of absorbed power by this phantom under the following conditions :

1) The time taken until the determination after heating should be within four min or less.

2) The temperature gradient in a phantom should be 3.2°C/cm or less.

3) The difference in the temperature in a phantom should be 3.0°C or less.

We showed that the influence of heat-diffusion or the influence of the electric conductivity which change according to the temperature change can be neglected under the above mentioned conditions. The agar concentration can be selected optionally in terms of the electric conductivity and the dielectric constant, and 2.0 w/w % agar is most suitable as a phantom in terms of the solidity. An agar phantom is rigid in shape, as distinct from a gelatin phantom. Accordingly, the phantom of ca. 25 litre can be readily prepared. According to Von Oßwald's report (14) on the electric properties of the different tissues, the electric properties in the high water content tissues in the case of 25MHz are expressed as follows :

$$\sigma = 0.28 \text{ to } 1.7\ \mho/\mathrm{m}$$

$$\varepsilon = 76 \text{ to } 214$$

It is possible to make σ of an agar phantom equivalent to that of the tissue, but it is impossible to make ε of some agar phantoms equivalent to that of the tissue. However, in such a case of $\sigma \gg \omega\varepsilon$ as shown by Kumagaya (15), the tissue phantom can be regarded as an electric conductor and the dielectric constant can be neglected. Thus, one has only to place emphasis on electric conductivity, when the phantom in the high water content tissue is prepared.

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