Physics in Medicine & Biology

TECHNICAL NOTE

Hyperthermia dough: a fat and bone equivalent phantom to test microwave/radiofrequency hyperthermia heating systems

To cite this article: J J W Lagendijk and P Nilsson 1985 *Phys. Med. Biol.* **30** 709

Phys. Med. Biol., 1985, Vol. 30, No. 7, 709-712. Printed in Great Britain

Technical note

Hyperthermia dough: a fat and bone equivalent phantom to test microwave/radiofrequency hyperthermia heating systems

J J W Lagendijk† and P Nilsson‡

† Department of Radiotherapy, University Hospital, Utrecht, The Netherlands
‡ Department of Radiation Physics, University Hospital, Lund, Sweden

Received 10 January 1985, in final form 25 February 1985

1. Introduction

For the development and evaluation of adequate hyperthermia techniques it is absolutely essential to have the use of a real temperature-distribution treatment planning system. Hyperthermia treatment planning systems based on a combination of (i) the calculation of the absorbed-power distribution in tissue and (ii) a thermal model to calculate the resulting temperature distribution, are under development in several institutes (Hand *et al* 1982, van den Berg *et al* 1983, Langendijk and Mooibroek 1948, Langendijk *et al* 1984).

Knowledge about the absorbed-power distribution inside tissue is a first necessity for these planning systems. For microwave and radiofrequencies greater than 30 MHz the absorbed-power distribution inside structured tissues can only be calculated at present using a two-dimensional approximation (Iskander *et al* 1982, van den Berg *et al* 1983). A computer program for two-dimensional absorbed-power calculations is already available for a large memory IBM PC computer (van den Berg 1984). Three-dimensional computations are limited by the capabilities of the present-day computer systems. Because of the parallel E field orientation related to the tissue interfaces in the two-dimensional models, severe overheating of fat and bone structures caused by normal E field orientation can be missed (Lagendijk and de Leeuw 1984). For the determination of absorbed-power distributions in real three-dimensional structures and for the tests of the computer models, easy to handle phantoms are necessary to simulate at least muscle, fat, bone and tumorous tissues.

The highly frequency-dependent dielectric properties of human tissues are not well known (Stuchly and Stuchly 1980). According to Johnson and Guy (1972), dielectric data are given in figure 1 for tissues roughly divided into two groups: (i) high-water-content tissues, e.g. muscle, skin, internal organs; and (ii) low-water-content tissues, e.g. fat and bone.

The polyethylene based 'super stuff muscle' phantom as developed by Guy (1971) (see also Chou *et al* 1984) is successfully used by almost all the hyperthermia research workers. This muscle phantom is easy to use, inexpensive to prepare and, most importantly, easy to model. When the polyethylene filling is replaced by sugar (composition: 60% saline solution (2% NaCl per l): 22.5% sugar: 17.5% super stuff (TX-150)), the phantom material can be conserved for very long periods without any special difficulties (Nilsson 1984). By small changes in water content and salt content, every high-water-content tissue, e.g. tumour, can be simulated (Nilsson 1984).

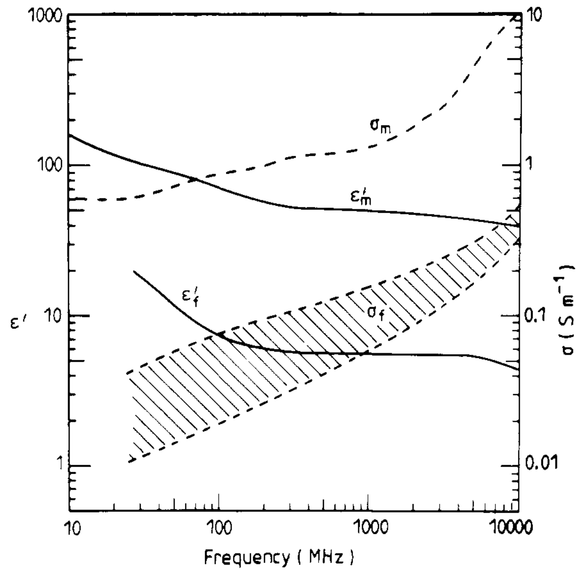

Figure 1. Dielectric constant ε' and conductivity σ as a function of frequency for muscle-like (m) and fatty (f) tissues (Johnson and Guy 1972).

Because of the difficulties in both making the phantom and modelling the phantom material, the 'fat' phantom Guy (1971) developed on the basis of a laminac polyester resin, never achieved the wide application that the super stuff muscle phantom did. Our attempts to lower the dielectric constant of the super stuff phantom by adding more polyethylene or even hollow plastic spheres did not give a useful fat phantom.

The Utrecht Department of Radiotherapy and the Lund Department of Radiation Physics developed and tested an easy to prepare, easy to model fat phantom to simulate low-water-content tissues at radio freqencies and microwave frequencies. With this new, alterable low-water-content, fat phantom and the alterable high-water-content super stuff muscle phantom, most structures of the human body can be modelled.

2. Recipe

The main problem in designing a fat-bone phantom is the difficulty in binding a low percentage of water to obtain a low ε', low-loss material without making the phantom too dry to handle. Normal flour has the property of binding both water and oil (fat). With flour, a dough can be prepared with any low percentage of water just by adding enough oil to make the dough manageable. The low dielectric constant of oil ($\varepsilon' \sim 2$) does not influence the low dielectric constant necessary.

The complex dielectric constant of this flour-oil-saline mixture has been measured using a cylindrical TM_{010} cavity (Hamnerius *et al* 1978) with a resonance frequency of 451.37 MHz, i.e. close to the ISM frequency of 434 MHz which is most frequently used for hyperthermia research in Europe. Tests at other frequencies used in hyperthermia research have to be done. The measurements were performed at room temperature (21 °C). The accuracy was estimated to ±5% for ε' and ±0.5 units for ε''.

Figure 2 gives the dependence of the permittivity on the percentage of saline solution (0.9% NaCl per l). The flour-oil weight ratio is 500:225. By changing the water content, the dielectric constant ε' can be altered over a wide range. With high water

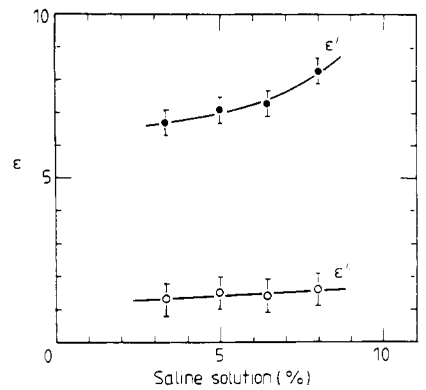

Figure 2. Permittivity measured at 451 MHz as a function of the percentage of 0.9% saline solution for the fat phantom with a fixed flour–oil weight ratio of 500 : 225.

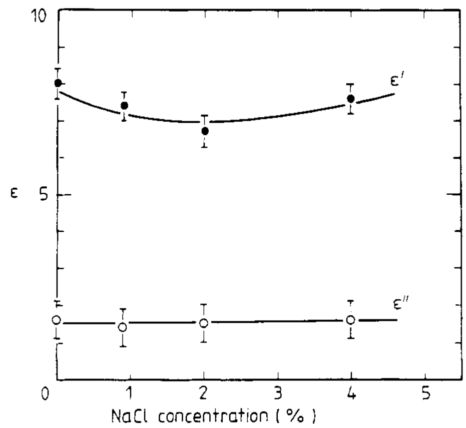

Figure 3. Permittivity measured at 451 MHz as a function of the NaCl concentration of the saline solution for the fat phantom with a flour–oil–saline weight ratio of 500 : 225 : 50.

percentages of over 8%, the oil content must be lowered to keep the phantom manageable. The loss factor ε'' is almost independent of water content with these low percentages. Increasing the NaCl concentration of the saline solution used did not significantly affect the dielectric properties of the phantom (figure 3). So far, only low NaCl concentrations have been tested. While the concentration of NaCl of the total phantom is very low with this type of phantom, higher concentrations of NaCl have to be tested.

A good recipe for a fat–bone phantom proved to be a flour–oil–saline (0.9% NaCl per l) phantom with the weight ratio 500 : 225 : 25. This results in a complex dielectric constant of $\varepsilon^* = 7.3 - j1.5$ at 451 MHz, which results in a conductivity σ of 0.038 S m^{-1} and a plane-wave half-power penetration depth of 13.3 cm.

To use the phantom for the determination of absorbed-power distributions with the thermal (short power burst) method, the density and the specific heat of the phantom have to be known. The specific heat has been measured using an adiabatic calorimeter (Schaake *et al* 1979). The results are given in figure 4 for the temperature range of 22–52 °C. At room temperature the specific heat is 1.90 J g^{-1} K^{-1}. The density found is 1.17 g cm^{-3}.

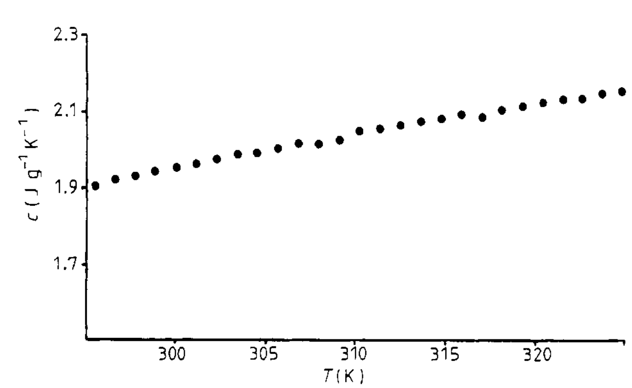

Figure 4. Specific heat c as a function of temperature for the fat phantom with flour–oil–saline (0.9% NaCl per l) weight ratio of 500 : 225 : 50.

3. Discussion and conclusions

The recipe described gives an easy to prepare, easy to handle and inexpensive fat phantom for the determination of absorbed-power distributions of microwave/radio-frequency radiation. If the phantom is used together with the high-water-content phantom (Guy 1971) the absorbed-power distributions can be determined in structured tissues. The phantom has been used in Utrecht to test the e-m boundary conditions at 434 MHz on interfaces between fat and muscle structures (Lagendijk and de Leeuw 1984) with experimental results in full agreement with theory.

The low specific heat of the phantom is slightly compensated by the high density. However, to analyse absorbed-power distributions in structured phantoms from measured-temperature distributions, these values must be taken into account.

Acknowledgments

We wish to thank Dr Yngve Hamnerius, Chalmers University of Technology, Gothenburg, for help with the permittivity measurements.

References

van den Berg P M 1984 personal communication

van den Berg P M, de Hoop A T, Segal A and Praagman N 1983 *IEEE Trans. Biomed. Eng.* **BME-30** 797-805

Chou C K, Chen G W, Guy A W and Luk K H 1984 *Bioelectromagnetics* **5** 435-41

Guy A W 1971 *IEEE Trans. Microwave Theor. Tech.* **MTT-19** 205-14

Hamnerius Y, Lundström I, Paulsson L E, Fontell K and Wennerström H 1978 *Chem. Phys. Lipids* **22** 135-40

Hand J W, Ledda J L and Evant N T S 1982 *Phys. Med. Biol.* **27** 1-16

Iskander M F, Turner P F, DuBow J B and Kao J 1982 *J. Microwave Power* **17** 175-85

Johnson C C and Guy A W 1972 *Proc. IEEE* **60** 692-718

Lagendijk J J W and de Leeuw A A C 1984 *Proc. Workshop on Loco-regional High Frequency Hyperthermia and Temperature Measurement (Freiburg) 1984* in *Recent Results in Cancer Research* in press

Lagendijk J J W and Mooibroek J 1984 *Proc. Workshop on Loco-regional High Frequency Hyperthermia and Temperature Measurement (Freiburg) 1984* in *Recent Results in Cancer Research* in press

Lagendijk J J W, Schellekens M, Schipper J and van der Linden P M 1984 *Phys. Med. Biol.* **29** 495-507

Nilsson P 1984 *PhD Thesis* Lund University, Sweden

Schaake R C F, Offringa J C A, van der Berg G J K and van Miltenburg J C 1979 *Recueil R. Neth. Chem. Soc.* **98** 408-12

Stuchly M A and Stuchly S S 1980 *J. Microwave Power* **15** 19-26