EXPERIMENTAL DETERMINATION OF ABSORBED POWER DISTRIBUTION IN A PHANTOM IRRADIATED WITH A MICROWAVE APPLICATOR [§]

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ABSTRACT

An original method is described for automatic acquisition of SAR-patterns of applicators used in hyperthermia therapy of cancer. The SAR is determined by processing adequately the time impulse response of the temperature signal in a glass bulb scanned through a liquid phantom above the applicator. The whole process is controlled by a Macintosh PC.

INTRODUCTION.

The use of solid phantoms is quite common and classically accepted in clinical methods to assess the performance of hyperthermia applicators. However the use of a liquid electromagnetic equivalent phantom resulted in an inexpensive invasive thermometric method to determine the distribution of the Specific Absorption Rate (SAR) with easy to develop instrumentation. Advantages of the proposed method when compared to other thermometric methods are

-simple automatic positioning of the invasive thermometer, which is rather difficult in solid phantoms
-short cooling time, due to convection, of the heated material to the initial steady state after radiation exposure; in solid phantoms, especially in large phantoms, this is a longlasting process
-vertical mounting of the invasive temperature sensor to minimize the interference of the sensor leads with the electromagnetic fields, which is not always possible in solid phantoms
-small, consequently less field perturbing, isotropic radiation meter, unlike short dipole electric field probes
-good fit between any shape of applicator, included intracavitary antennas, and the phantom material, being not always the case with solid phantoms
-short heating times even with power as low as 20W.

METHOD AND MATERIALS.

With careful system design we could strongly reduce effects of heat conduction and convection on a initial temperature increase, measured by a thermocouple, during a short burst of high power microwave radiation. Then SAR results from:

$$SAR = c\frac{dT}{dt}, \text{ with}$$

c : phantom specific heat, T : sensor temperature and t : time. To eliminate convection effects in the immediate surroundings of the thermocouple junctions, these are centered in a small glass bulb filled with a polyacrylamide gel with identical electromagnetic properties as the liquid environment (figure 1). Heat conduction effects are reduced by measuring over a short time enough during microwave exposure. In this way temperature increases remain small and in addition a constant thermocouple sensitivity is assured.

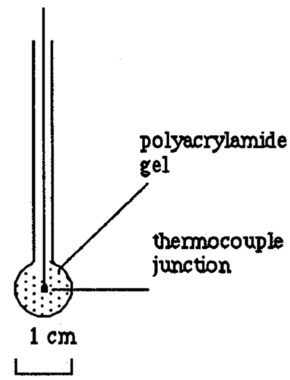

Fig. 1. Glass bulb.

For measuring only temperature changes of the exploring bulb, the cold thermocouple junction can
be positioned anywhere in the phantom bath out of the radiation field. The applicator is placed in (for intracavitary antennas) or underneath the phantom bath. A flexible bottom provides a good fit between any shape of applicator and phantom material due to hydrostatic pressure (figure 2).

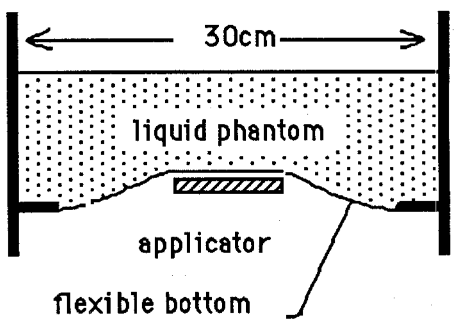

Fig. 2. Cross-section of phantom bath.

To maintain same measurement conditions throughout the liquid, a circulation pump forces the phantom temperature to be homogeneous. We use a 3-D scanning waterphantom system (Wellhöfer), used in ionizing radiation dosimetry, to position the thermocouple hot end. The complete measurement process is controlled by a Macintosh microcomputer interconnected to the measurement equipment by means of a specially for Macintosh designed MacFactory™ interface and data-acquisition unit. The rest of the equipment exists of an additional interface to drive the DC-motors of the positioning system, a measurement amplifier to raise the thermocouple voltage to a MacFactory™ digitizer level and an obstacle detection microswitch providing a self detecting ability of the system to allow for arbitrary shapes of applicators and intracavitary antennas. A schematic diagram of the total measurement system is shown in figure 3.

The system automatically scans in disrete points of different planes. In each point 1000 samples of the sensor voltage are taken during a 9.5 seconds heating pulse, linear regression is performed and corresponding SAR is calculated and saved. After the heating pulse temperature is further monitored until temperature is stationary again. From the matrix of SAR-values isoSAR curves in planes parallel to the axis are calculated by an interpolation method.

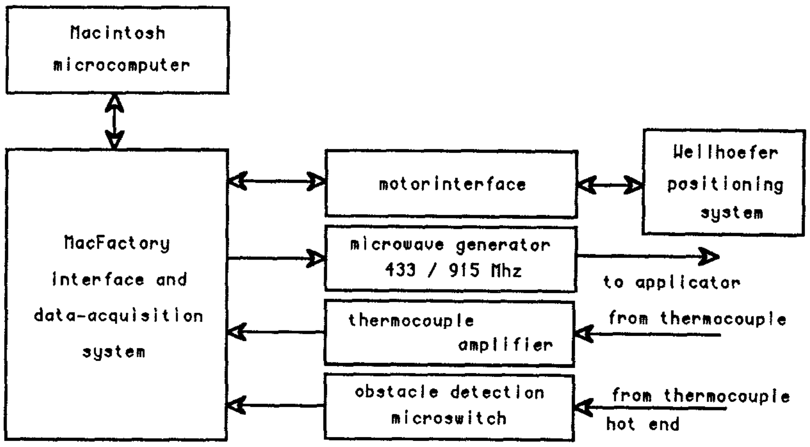

Fig. 3. Schematic diagram of measurement system.

In order to obtain representative information to determine the SAR, careful signal processing is required. Firstly high frequency electromagnetic pick-up by the sensing circuitry has been reduced by radiofrequency filtering of the sensor signal as well as by shielding and grounding of the electronic measurement system. Electromagnetic interference in the sensor accounts equally for the self-heating phenomenon of the thermocouple junction. The very fast temperature change in figure 4 is the typical effect of the self-heating of the junction in a temperature measurement and is been easily eliminated by a sampling delay of 1 second after switching on microwave power. Over a longer term the influence due to this additional heat generation in the gel is negligible, because of the very small junction mass with respect to the gel mass. A short measurement period, in our case less than 8 seconds, is required to reduce heat conduction effects between gel and liquid on sensor temperature as shown in figure 5, in which sensor responses on a high power microwave radiation step are registered with and without forced high convection on the bulb surface. However a measurement period as long as possible is needed to reduce the effect of low frequency components of the amplifier noise on the linear regression of the measured temperature. Artefacts like perturbation of the electromagnetic fields, caused by reflection or shunting of the electric field by the thermocouple, and the presence of an extra material, the glass bulb, with different electromagnetic properties are considered in the design of the measurement system and have no significant influence on the temperature measurement.

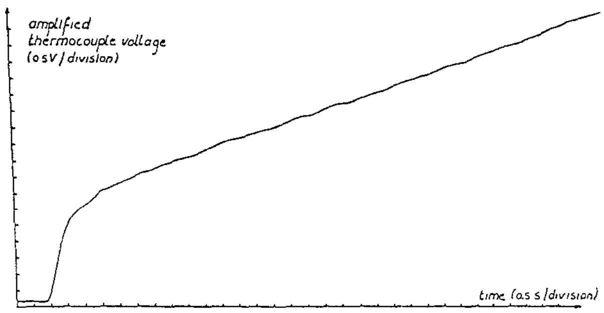

Fig. 4.Effect of self-heating of thermocouple junction on sensor temperature.

To determine absolute SAR-values an appropriate calibration of the measurement system and calometric determination of the specific heat of the solid phantom material is done.

The measurement system offers a spatial resolution of less than 5 mm, i.e. the bulb radius.

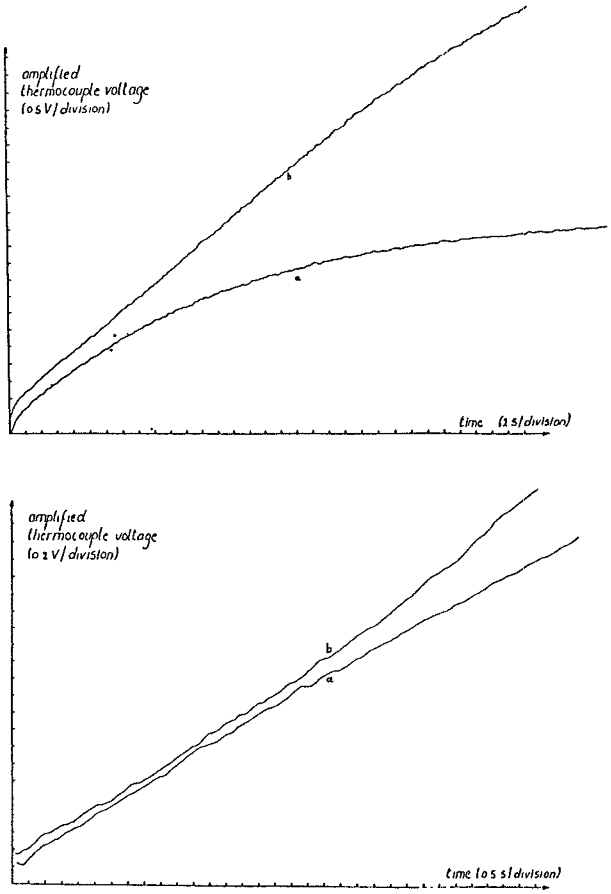

Fig. 5. Sensor response with (a) and without (b) forced high convection on bulb surface.

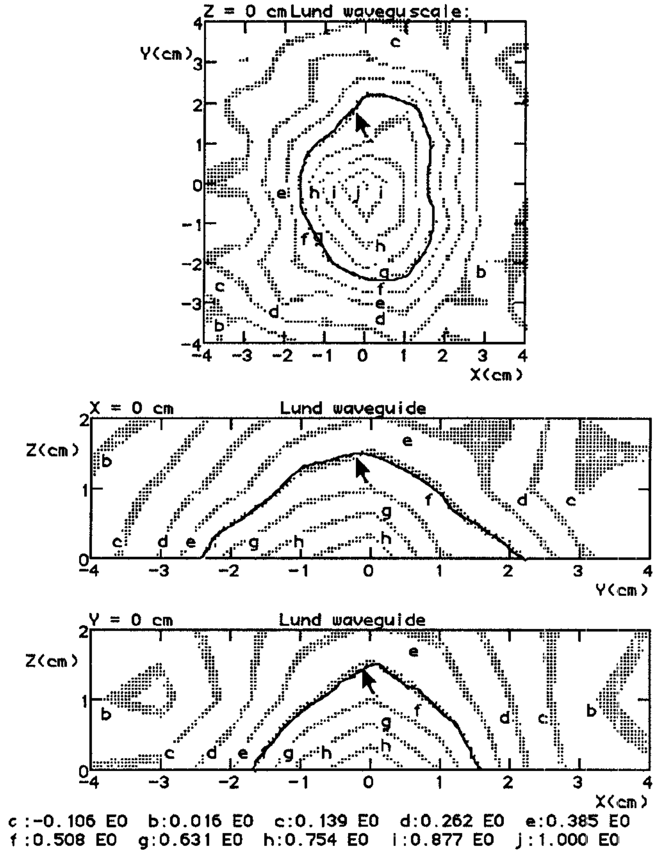

Fig. 6. IsoSAR-patterns of the 915 MHz Lund waveguide applicator. Full line is 50% isoSAR.

RESULTS.

Figures 7 to 9 show the relative isoSAR-curves of : a commercial 915 MHz Lund-Hyperthermia rectangular waveguide, a self-made flat and a folded array (figure 6) of 4 microstrip slot antennas. Several sections through the phantom and their position with respect to the applicator are shown. Positions in the phantom are expressed in rectangular coordinates X,Y,Z in cm with Z the vertical distance from the bottom of the measurement probe to the applicator (to a horizontal plane through the lowest point of the applicator in case of the folded array). Due to the finite dimensions of the glass bulb sensor, the plane Z=0 is in fact exactly 5 mm below the phantom surface: this depth is the depth recommended by the ESHO (European Society of Hyperthermic Oncology) Quality Assurance technical Committee for measuring the effective field (50% isoSAR encompassed area) of an applicator. The indices represent the relative SAR values listed below each plot. The effective field is approximately bounded by the f-isoSAR-curves (marked by an arrow) For the Lund applicator the 50% isoSAR is enhanced by a full line. In figure 8 the Z=1 and Y=0 patterns are drawn with the highest resolution, the X=0 with a faster low resolution.

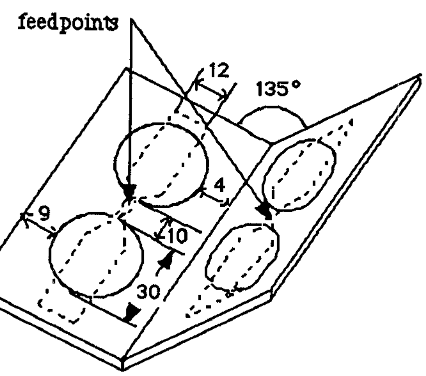

Fig 7. Microstrip slot folded array (sizes in mm).

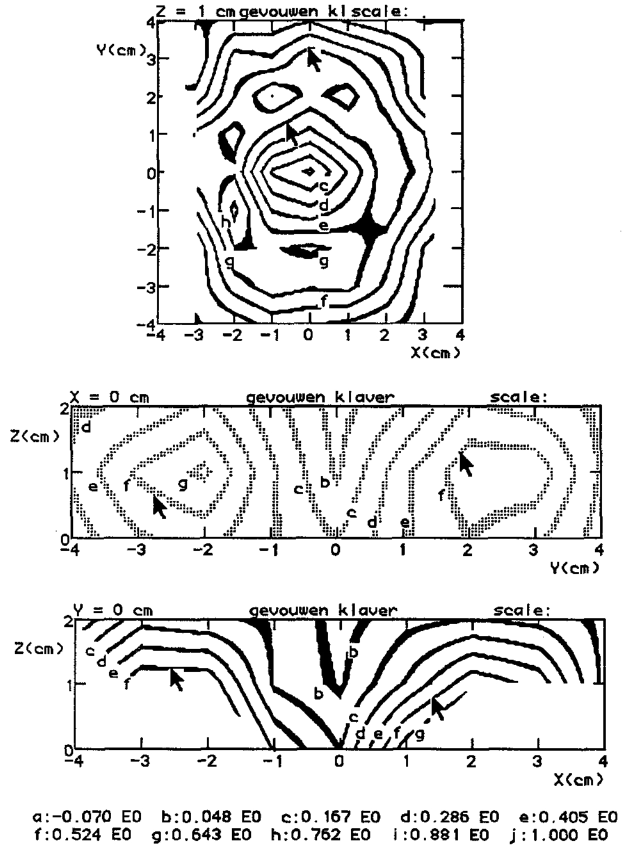

Fig. 8. IsoSAR-patterns of the 915 MHz folded (135°) microstrip slot array.

CONCLUSIONS.

We developed a fully automated system to measure the absorbed power distribution in phantoms irradiated with microwaves. The system allows acquisition of the isoSAR of single and multiple applicator configurations including tilted applicators. This is a valuable aid for the design of own developments and for the evaluation of commercial applicators before clinical treatment.

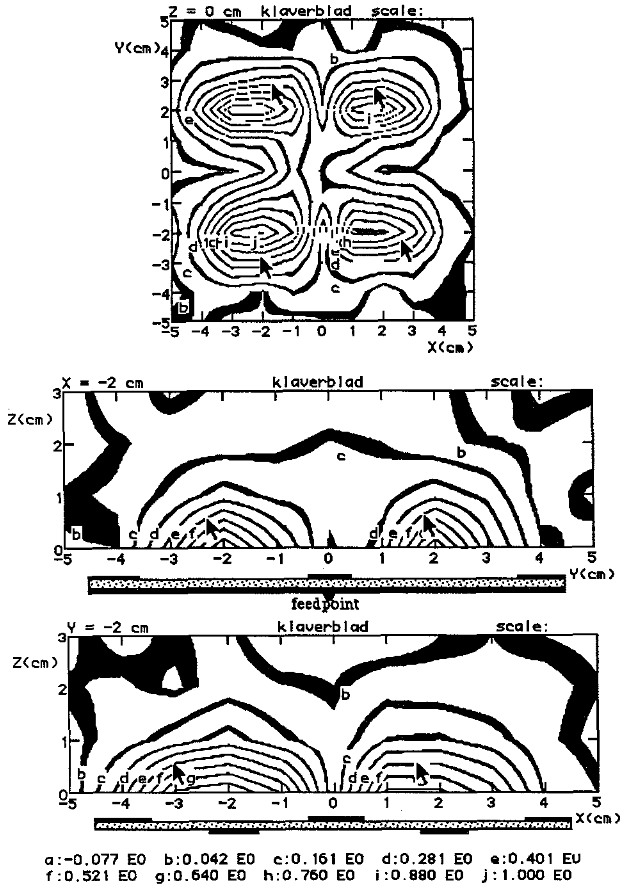

Fig. 9. IsoSAR-patterns of the 915 MHz flat microstrip slot array.

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