27 MHz WAVEGUIDE APPLICATORS FOR LOCALIZED HYPERTHERMIA TREATMENT OF CANCER

R. W. Paglione and F. Sterzer
RCA Laboratories
David Sarnoff Research Center
Princeton, NJ 08540

and

J. Mendecki, E. Friedenthal and C. Botstein
Department of Radiotherapy
Montefiore Hospital and Medical Center
Bronx, NY 10467

ABSTRACT

The design of a 27 MHz ridged-waveguide applicator for use in localized hyperthermia treatment of cancer is described. The design includes considerations for mechanical constraints and for the size and location of tumors. Results of animal and clinical experiments are given.

Introduction

The five lowest industrial, scientific and medical (ISM) frequencies allocated by the FCC are 13.56, 27.12, 40.68, 915 and 2450 MHz. Only the three lowest frequencies have depths of penetration suitable for heating deep-seated tumors to the hyperthermic range (∿42.5–43.5°C). Various types of capacitive and inductive applicators have been used at these frequencies for producing hyperthermia; however, the electric field produced by these applicators often causes excessive heating of the skin and of fat layers. Waveguide applicators operating at these frequencies produce little heating in the fat layer and therefore mostly heat the muscle layer. The design of this applicator and experimental results will be described.

Waveguide Applicator

An air-filled waveguide, operating in the TE_{10} mode, at 27.12 MHz, would have a minimum broad-wall dimension of about 7 meters. The corresponding minimum dimension at 40.68 MHz would be about 3.7 meters, and about 11 meters at 13.56 MHz. This minimum dimension can be reduced by dielectrically loading the waveguide with a low-loss material such as deionized water, ε=81. This reduces the minimum broad-wall dimension to 77 cm at 27.12 MHz, 41 cm at 40.68 MHz, and 1.23 meters at 13.56 MHz.

Further reduction of the size of the waveguide can be accomplished by using ridged guides. The introduction of a ridge into rectangular waveguide lowers the cutoff frequency of the guide and also concentrates the electric field into the region above the ridge. A single-ridged waveguide can be designed from the equations given in several references[1,2,3]. For an effective heating area of about 400 cm^2, the dimensions of a water-filled guide are: waveguide width = 58.4 cm, waveguide height = 26.3 cm, ridge width = 29.2 cm, and ridge height = 12.6 cm. The impedance of this guide is approximately 24 ohms and the guide wavelength is 2 meters.

The TE_{10} mode can be excited in this waveguide by a coaxial probe through the broad-wall of the guide above the ridge. The depth and position of the probe can be found empirically[4], or can be calculated[5]. For a probe diameter of 10.2 cm, the depth into the waveguide is 13.7 cm and the position of the probe from the shorting plane is approximately 50 cm. The overall length of the applicator is 86.4 cm.

A sketch of the ridged-waveguide applicator is shown in Figure 1. The top of the waveguide is covered with a 1/16-inch sheet of neoprene rubber. This cover contains the deionized water and also acts as a conforming cushion for the patient. The tuner shown in the figure is used to match the impedance of the applicator to the impedance of the patient. The plexiglass bulkheads are used to compartmentalize the applicator so that it could be used in a horizontal position without the water creating an excessive pressure on the neoprene cover.

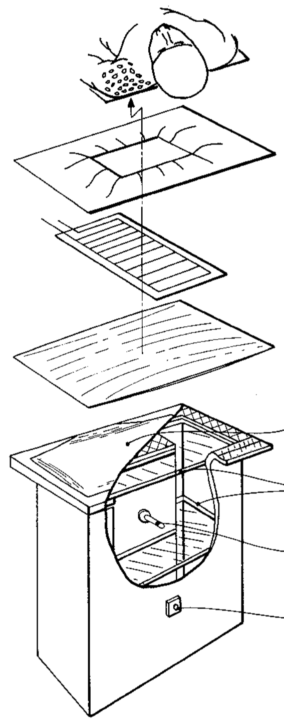

Figure 1. Ridged-waveguide applicator.

Also shown in Figure 1 are a deionized-water-filled bag, a water-cooling pad, and a saline-filled bag. This arrangement is placed between the patient and the applicator for the following purposes: (1) The deionized-water-filled bag helps to spread the high electric fields present at the metal walls of the applicator. This prevents excessive hot spots on the patient at these locations. (2) The cooling pad keeps the surface tissues at or near a predetermined temperature (usually 20°C). Higher applied power levels can be used and therefore deeper heating can be effected if the surface tissues are cooled in this manner. (3) The bag nearest the patient is filled with 0.9 normal saline, and it has a cutout to allow for the radiation of the electric fields from the region above the ridge. The saline, which is an absorber of RF energy, limits the heating area on the patient to that area directly above the ridge, and it reduces the amount of stray radiation into free space from all other areas on the face of the applicator.

Temperature Measurements

The temperature distributions produced by this applicator were measured under various conditions in several animals. Figure 2 shows the results obtained by heating the gluteal region of a 35 kg, anesthetized pig. The cooling pad in contact with the skin was maintained at 20°C. Four plastic angiocaths were introduced into the muscle mass at depths of 2, 5, 7 and 9 cm. The pig was then heated with 250 watts of 27 MHz

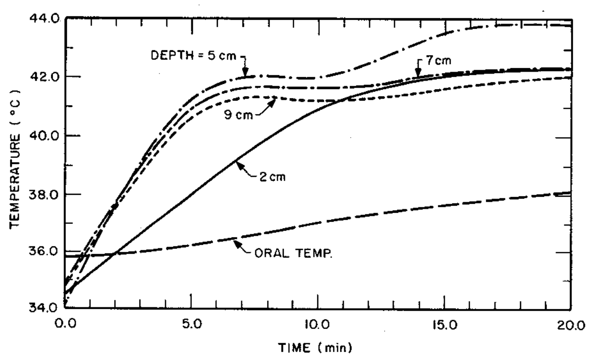

Figure 2. Results obtained by heating the gluteal region of a 35 kg, anesthetized pig.

power. The muscle temperature was monitored at five-minute intervals by inserting thermocouples into the angiocaths. During these measurements, the RF power was interrupted for 20-30 seconds. Note that after 20 minutes of heating, the temperature distribution in the muscle is reasonably uniform with the peak temperature occurring at a depth of 5 cm.

Applicator Arrangements

Using two applicators to heat a given tissue volume will often produce a deeper and more uniform heating pattern. Two arrangements are possible with the applicator of Figure 1: two applicators facing each other in a horizontal position, or one applicator in a horizontal position and one in a vertical position. Figure 3 shows how a patient can be heated simultaneously from above and below by using one applicator of the type shown in Figure 1 and a second similar applicator modified by the addition of a 90° mitered band.

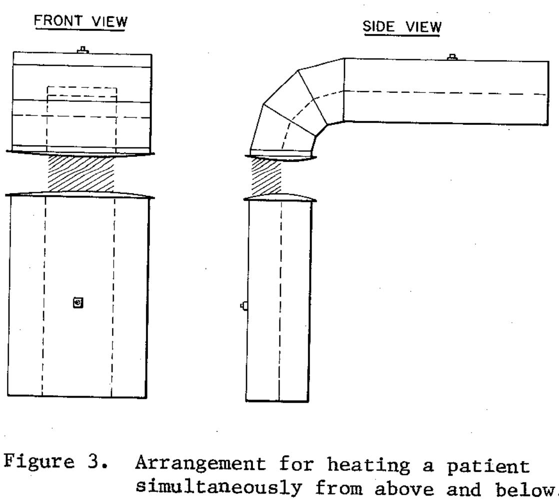

Figure 3. Arrangement for heating a patient simultaneously from above and below.

Clinical Studies

The 27 MHz water-filled ridged-waveguide applicators described above have been used for the past two years in clinical trials to treat various deep-seated malignancies, including tumors located in the lungs and in the lower intestinal cavity. In all cases, the hyperthermia treatments were accompanied by radiation therapy. Patients generally tolerated treatment well with no serious side effects, and reported varying degrees of pain relief. During the period of treatment oral temperature increased, usually to 39°C, accompanied by moderate sweating and acceleration of heart rate.

Figure 4 shows a patient with carcinoma of the prostate being treated with 27 MHz hyperthermia. The

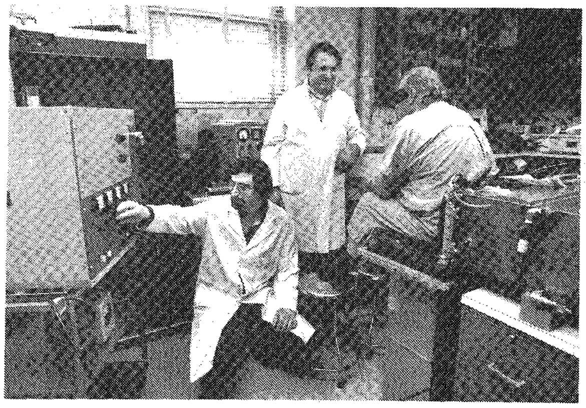

Figure 4. Patient with prostate tumor being treated with two ridged-waveguide applicators.

patient is sitting on one applicator; the other applicator, in a horizontal position, is against his lower back. The combination of 27 MHz heating and radiotherapy treatments produced a regression of the tumor in this patient that was not observed with a previous course of radiotherapy alone.

Conclusions

Ridged-waveguide applicators operating at a frequency of 27 MHz are useful for heating of deep-seated malignant tumors not accessible by applicators operating at microwave frequencies (⩾ 915 MHz). The use of a ridged-waveguide filled with deionized water keeps the 27 MHz waveguide applicators to a manageable size, while saline-filled bags and water-cooled pads serve to respectively define the treatment area and increase the depth at which heating to the hyperthermic range can be achieved.

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