DESIGN AND MODELING USING THE FDTD METHOD OF A NEW GENERATION OF APPLICATORS REALIZED FROM COAXIAL ANTENNAS FOR MICROWAVE HYPERTHERMIA

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ABSTRACT

An increased interest in the application of the electromagnetic techniques for intracavitary thermotherapy treatments has been observed for treatment of prostate gland. This paper describes a new generation of applicators designed for this endocavitary thermotherapy. The applicators are realized from coaxial antennas associated with a water cooling system. The electromagnetic modeling is achieved by the FDTD. This method allow to determine the tissues volume which will be heated at the therapeutic temperature level. The possibility to increase the heated volume (by using simultaneously the urethral and rectal applicators) is clearly focused by theoretical results obtained from the bioheat transfer equation solution which are presented and confirmed by experimental measurements on a polyacrylamide phantom.

INTRODUCTION

A large number of devices have been designed in order to produce therapeutic heating by microwave hyperthermia of tumors having different sizes and located in various places of the human body. Among these devices, the coaxial interstitial antennas present the advantage to deposit the power directly inside the tumor, specially in the case of deep and semi-deep tumors [1]. In this paper, we propose to present the results (theoretical studies and experimental verifications) concerning a new generation of applicators realized from coaxial antennas: the urethral and rectal applicators used for the treatment of both benign prostatic hyperplasia and cancer.

MATERIAL AND METHOD

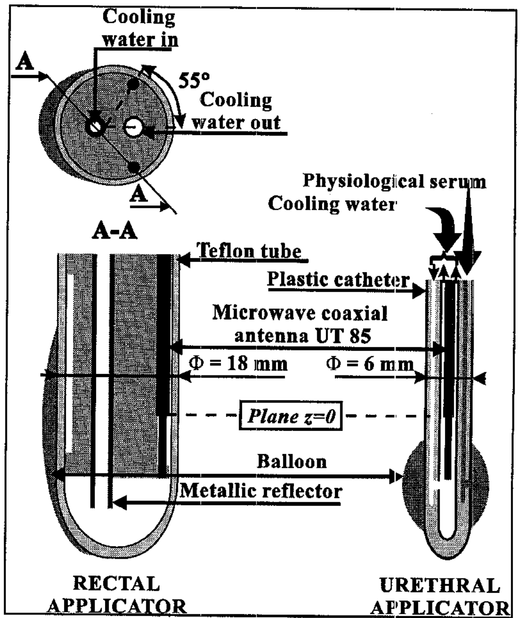

Figure 1: Description of the microwave endocavitary applicators

The interstitial antennas are realized from a standard coaxial cable of 50 Ω characteristic impedance which external diameter is depending on the use. At the end of this coaxial cable, the outer conductor is removed on a length h. From these antennas, we have made several applicators :

- the urethral applicator is built from a flexible coaxial cable (∅ = 2.2 mm) inserted in a Foley type plastic catheter which external diameter (∅ = 6 mm) allows to introduce it easily in the urethra (figure 1). The total length of this applicator is about 500 mm. To allow a good thermoregulation of both the antenna and the urethral wall, a water cooling circulation is realized in the catheter

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- the rectal applicator includes several antennas (two, four or more) made from UT85 standard semi-rigid coaxial cable (∅ = 2.2 mm) associated with a metallic reflector in order to focus microwave energy in the prostate (figure 1). Antennas and metallic reflector are inserted in a Teflon tube which includes a cooling system by water flowing. The external diameter of the applicator is about 18 mm and the length 190 mm.

A model based on the well known Finite Difference Time Domain (FDTD) method [2] has been developed. With this model, it is possible to know how the electromagnetic energy is deposited inside lossy media such as human body for every kind of interstitial antenna, array of antennas or endocavitary applicators. In fact, this method allows to take into account the exact shape of applicators and tissues. Due to the axis symmetry, theoretical bidimensionnel studies are carried out in a longitudinal plane for the urethral applicator. For the rectal applicator, this study is achieved in the cross section plane z = 0 cm perpendicular to antenna direction. In fact, modeling shows that the maximum energy occurs in this plane [3]. Moreover, the electromagnetic field is defined by one electric and two magnetic components [4]. These computation are achieved at the heating frequency and at the medium radiometric frequency: 3 GHz [5].

Then solving the bioheat transfer equation in the steady state from the Cholesky method [6], we obtain the thermal mapping. The heterogeneous character of the medium can be taken into account (particularly the blood flow term vs different in each type of tissue and also the thermal conductivity kt) [7].

In order to verify these theoretical results, experimental measurements have been carried out not only on phantom models of human tissues (saline solution at 6 g/l or polyacrylamide phantom), but also on anaesthetized animals. The first one is the measurement of the S_{11} parameter as a function of frequency using a network analyzer HP 8510 in order to obtain the level of adaptation of the applicator at the heating frequency (915 MHz in this study). Then, the energy distribution is determined with a single system for mapping the electric field pattern created in a saline solution by the microwave applicator under test [8]. The thermal performances have been also characterized : this is obtained from the temperature measurement performed on a polyacrylamide phantom after a heating session of about forty five minutes using an automatic experimental apparatus.

RESULTS AND DISCUSSION

The theoretical determination of the bare length (h) of the microwave coaxial cable, which assure a good matching at 915 MHz has been found to be equal to 36 mm for the urethral applicator and to 32 mm for the rectal one. These values were confirmed after measurement of the S_{11} parameter with a network analyzer. This result is shown on the figure 2. We can see that a correct matching obtained in a large frequency band around 3 GHz allows to use this applicator as an receiver antenna for radiometry in the 2-4 GHz bandwidth.

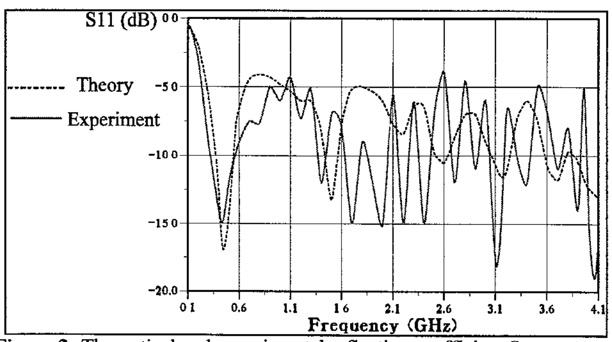

Figure 2: Theoretical and experimental reflection coefficient S_{11} versus frequency: case of the urological applicator dipped in salt water (6g/l).

A comparison between theoretical and experimental power deposition at different depth in a longitudinal plane is presented in figure 3 for the urethral applicator. The values were normalized to the maximum power value located on the applicator at the junction plane z = 0 cm. Experimental points confirms the computed results.

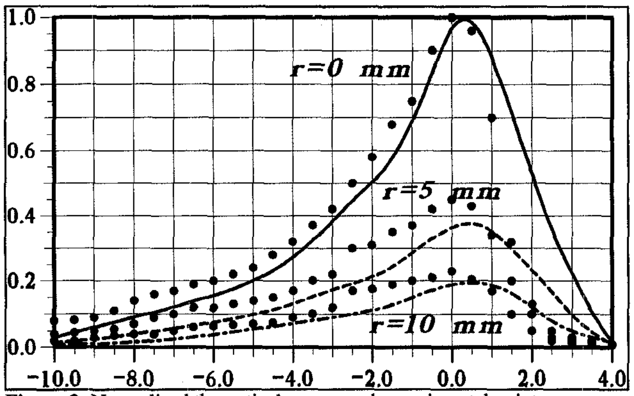

Figure 3: Normalized theoretical curves and experimental points power deposition versus the distance from the catheter in a longitudinal plane for the urethral applicator dipped in salt water (6g/l) at 915 MHz.

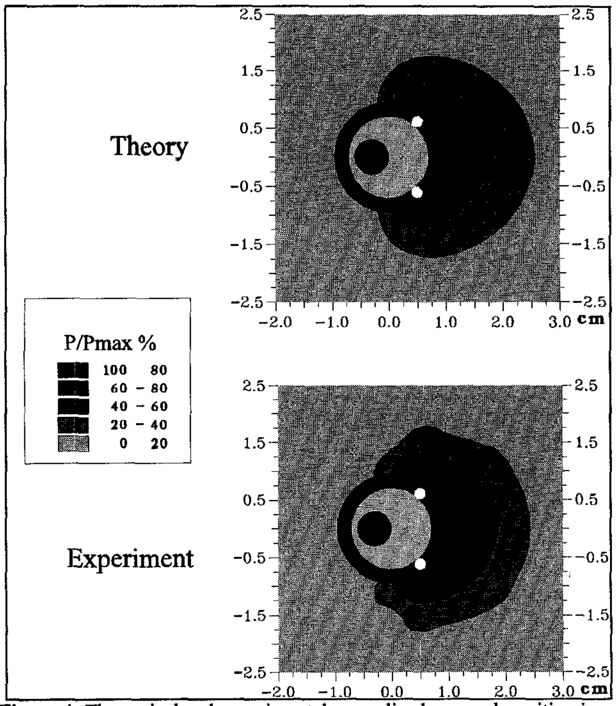

Figure 4: Theoretical and experimental normalized power deposition in the cross section plane z = 0 cm at 915 MHz for the rectal applicator dipped in salt water at 6g/.

For the rectal applicator, computation and experiment have been achieved in a cross section plane at z = 0 cm, where the deposited power is maximum. The results are presented in the figure 4. The upper part of the figure gives the FDTD calculation. Results are normalized to the maximum deposited value on the applicator. The lower part shows the experimental power deposition reconstructed from the measured values in the saline solution. The results show a good agreement between theory and experiment. The power is focused in a half plane due to the metallic reflector.

In order to obtain a larger heated zone, the urethral and rectal applicators are used together to heat the prostate gland (this technique is called "cross fire"). The applicators are distant of 20 mm. A simulation obtain with the rectal and urethral applicators is presented on the figure 5. The rectal applicator includes four antenna which allows a greater heated volume.

In that case, the antennas of the two applicators are fed in phase. Power deposition has been computed at every point of the cross section plane with the FDTD method.

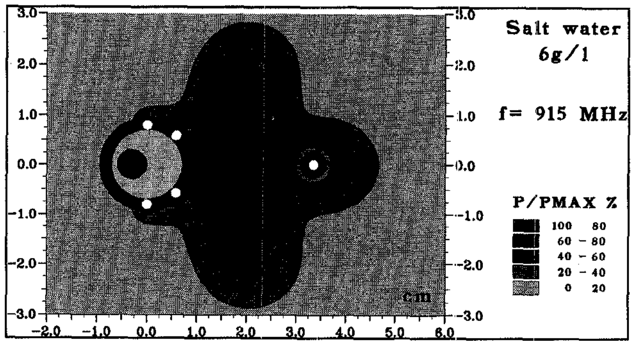

Figure 5: Normalized theoretical power deposition in the antennas junction plane for the two applicators working simultaneously. Antennas are fed in phase at 915 MHz.

After having determined the power pattern deposition, we can solve the bioheat transfer equation with the different data (incident power, water cooling temperatures, radiometric temperature, ...). A result given on figure 6 for a rectal applicator including two antennas shown that the heated zone is greater than the one previously obtained by the applicators operating alone (increase of about 200% with respect to the rectal applicator heated zone). The maximum of the normalized power deposition is now located in the middle axis of the two applicators. These very interesting results have been confirmed by experiments on animals and prove the interest of using the two applicators simultaneously.

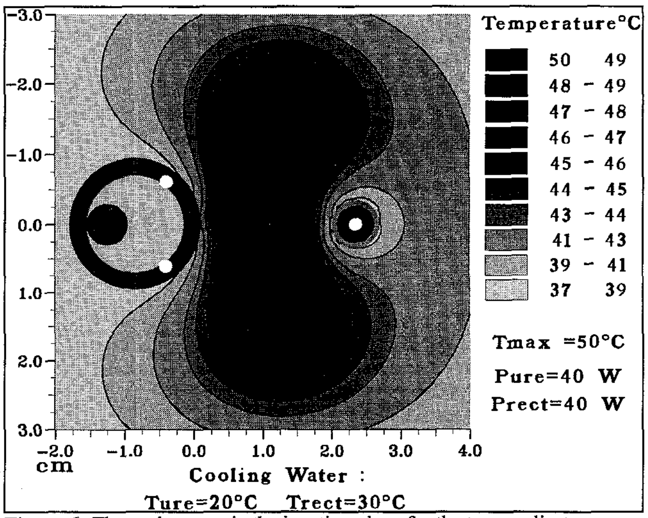

Figure 6: Thermal pattern in the junction plane for the two applicators working simultaneously. Antennas are fed in phase at 915 MHz.

CONCLUSION

We have developed a new generation of applicators realized from coaxial antennas : the urethral and rectal applicators used for the treatment of the prostate gland. The theoretical results obtained from the FDTD method are confirmed by experimental measurements. More, we have also shown that the technique called "cross fire" (the two applicators are working simultaneously) allows to increase nearly by a factor two the heated zone.

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