ABSTRACT:

We describe our new technical results dealing with microwave thermotherapy in the cancer treatment, see ref. [1 to 5]. Our research interest is to develop applicators for deep local heating and for intracavitary cancer treatment as well. Special interest is given to the case of BPH prostate treatment. Basic evaluation of clinical results is presented.

INTRODUCTION

Microwave thermotherapy (hyperthermia) is being used for cancer treatment since early 80’s in many countries around the world. Biologically it is based on the fact, that cancerous tissue due to reduced blood flow is not able to survive the temperatures above 41°C, while healthy tissue resists up to 45°C. So heating into this temperature interval cancerous cells can be selectively killed.

Our technical work is focused above all on the design, optimisation and experimental evaluation of the microwave applicators used for hyperthermia cancer treatment. This means to design a microwave structure capable of:

- to transfer electromagnetic energy into the biological tissue,
- to get the best approximation of the area to be treated by the SAR distribution.

Since 1981 we were interested in the local external applicators working at 434 MHz and 2450 MHz. These applicators were used here in Prague for the treatment of more than 300 patients with superficial or subcutaneous tumours (up to the depth of approximately 4 cm). Now, following new trends in this field, we continue our research in two important directions:

- deep local and regional applicators,
- intracavitary applicators.

DEEP LOCAL AND REGIONAL APPLICATORS

For the deep local thermotherapy treatment we develop above all waveguide type applicators based on the principle of evanescent mode waveguide, which is our specific solution and original contribution to the theory of microwave hyperthermia applicators, see ref. [3, 5]. This technology enable us:

- to design applicators with as small aperture as necessary also for the optimum frequency range for deep local and/or for regional thermotherapy treatment (the frequency band between 27 and 70 MHz).
- using our technology we need not to fill the applicator by dielectric (necessary for deep penetration into the biological tissue - i.e. up to 10 centimetres under the body surface).
- two to four of such applicators can be also used for regional treatment.

Waveguide type applicators are often used in the local external hyperthermia treatment of cancer and other modifications of microwave thermotherapy as they offer very advantageous properties, above all:

- depth of penetration of the EM energy approaching the ideal case of plane wave,
- low irradiation of the energy in the vicinity of the hyperthermia apparatus,
- very good impedance matching, i.e. perfect energy transfer to the biological tissue.

We have studied waveguide applicators heating pattern for the aperture excitation at above and at under the cut-off frequency. It has helped us to get analytical approximations of the electromagnetic field distribution in the
treated area of the biological tissue. The most important results for the effective heating depth $d$ can be characterised as follows:

- at high frequencies (above approx. 1000 MHz) the depth of effective heating $d$ is above all a function of frequency $f$ (skin effect),
- bellow approx. 100 MHz $d$ is the dominantly function of the diameter $D$ of applicator aperture ($d = 0.386D$).

Another of our research interests is to study what happens, when the frequency $f$ of hyperthermia apparatus is either very different (much higher or much lower) from the cut-off frequency $f_c$ of the used waveguide applicator or very near (even equal) to this cut-off frequency $f_c$. This can happen when either the hyperthermia apparatus is tunable in broader frequency range or the cut-off frequency $f_c$ of the applicator is changed by different dielectric parameters of various types of biological tissues near to heated locality.

Let us take into account the area of biological tissue surrounded by electric and magnetic walls. Then the hybrid waveguide mode $HE_{11}$ (i.e. the lowest possible one) can be defined and excited in the biological tissue in front of applicator aperture (it is a linear superposition of the modes $TE_{11}$ and $TM_{11}$). Higher order modes can be suppressed by the design of the applicator. Two following cases describe the change of the SAR in front of the applicator aperture as a function of working frequency $f$ of the hyperthermia apparatus with respect to the $f_c$:

- if there is enough big difference between $f$ and $f_c$, then homogeneous heating of the treated area can be expected.
- if the both frequencies are very near each to other (difference between $f$ and $f_c$ is going down), then overheating (hot-spots) out of the treated area can arise.

**INTRACAVITARY APPLICATORS**

These applicators are being used above all for prostate treatment in the case of BPH (Benign Prostate Hyperplasia). Costs and risks associated with clasical BPH treatment (TURP and open surgery) have promoted the development of minimally invasive methods. The underlying principle behind these methods is to coagulate prostatic adenomatous tissue by means of heat. Of all the available minimal invasive treatment modalities, transurethral microwave is one of the most wide spread at present. Until now more than 1000 patients has been successfully treated here in Czech Republic.

The basic type of intracavitary applicator is a monopole applicator. The construction of this applicator is very simple, but calculated and measured „Specific Absorption Rate“ („SAR“) distribution along the applicator is more complicated, than has been the first idea. „SAR“ can be measured either in water phantom or by infrared camera.

During measurements of SAR along the applicator we have found, that typically there is not only a one main „SAR“ maximum (first from the right side), but also a second and/or higher order maximas can be created, being produced by outside back wave propagating along the coaxial cable, see Fig. 1.

To eliminate this second maximum and optimise the focusing of „SAR“ in predetermined area of biological tissue needs to use the helical coil antenna structure, see Fig. 2. After coil radius and length optimisation we have obtained very good results of „SAR“ distribution. Some problems can be with the antenna self-heating, but it can be reduced by cooler at the end of applicator tip.
EFFECTIVE HEATING DEPTH

As in the previous case of external applicators, we have studied the theoretical limits of intracavitary applicator heating depth. We have found the basic relation for determination of the limit of maximum heating depth for the case of "very long" intracavitary applicator. We suppose excitation of an ideal radial wave around radiating applicator and it gives us very interesting results shown in Fig. 3. These results are in a very good agreement with experimental results obtained in water phantom or in agar phantom. Very important is that there is a radial wave, not the plane wave, and that’s why the penetration depth is smaller than penetration depth of plane wave. Some works published in this field give too optimistic results. Measurements discussed without theoretical analysis can give results influenced by thermal conductivity of mostly used agar phantom of muscle tissue. As the real heating depth is typically a few millimeters (in the best case up to ca 1 cm under the surface of the cavity), thermal conductivity of the phantom material can easily cause errors of several tenth of percents.

Fig. 3. Effective depth of heating $d$ with respect to frequency $f$ [MHz] and radius $R$ [mm].

Ideal intracavitary applicator irradiates an ideal cylindrical wave into the biological tissue surrounding the cavity. According to our experiences, Fig. 6 gives a very good approximation, i.e. the results with accuracy better than 5 % for higher frequencies ($f > 100$ MHz) and/or bigger radii ($R > 3$ mm). For lower frequencies (up to 100 MHz) combined with small radius of the cavity ($R < 2$ mm) the accuracy is ca 10 %. It is not possible to achieve a heating penetration depth (50 % decrease) higher than $R$ at any frequency and in any propagation medium. The small cavity radius plays a dominant role in the penetration depth.

Fig 4. The heating pattern obtained for different antennas: the monopole (a), the dipole (b), and the helical coil (c).
CONCLUSIONS

This category of applicators can be used for medical treatment inside various cavities of human body. We have mainly investigated two basic types of these applicators: monopole/dipole applicator and a helical coil applicator. These applicators are being used for example for prostate treatment (untill now more than 1000 patients has been successfully treated here in Czech Republic). Our intracavitary applicators are designed to work at 434 MHz and we do some experiments on 915 MHz also.

As a novel results of our work we could mention that various microwave applicators for prostate cancer or BPH treatment have been developed and evaluated. Theoretical analysis of effective heating depth and its experimental evaluation of these applicators is given.

CLINICAL RESULTS

In the case of cancer treatment the long term statistics of clinical results can be described as follows:

- Complete Response of Tumor ....53%
- Partial Response of the Tumor ....31%
- No Significant Response ..........16%

which corresponds to results obtained also by other groups around Europe.

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REFERENCES