MICROWAVE APPLICATORS FOR „BPH" THERMOTHERAPY

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Abstract: Paper deals with new results in the field of intracavitary microwave applicators used for Benign Prostatic Hyperplasia (BPH) treatment. Costs and risks associated with clasical BPH treatment (TURP and open surgery) have promoted the development of minimally invasive methods. Microwave thermotherapy, varying forms of laser treatment, transurethral needle ablation, etc. have all been developed in the 1990s. 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 [1].

Introduction

In this paper we outline new trends in microwave thermotherapy, both clinical and technical. In details we describe the field of intracavitary treatment with major applications in urology, the so called BPH treatment. New trends we can divide into two major groups:

- clinical trends,
- technical trends.

Clinical trends

The microwave thermotherapy is currently in clinics used in more scale. In present we distinguish this basic fields:

- Oncology: treatment of tumors,
- Physiotherapy: treatment of sceletal problems,
- Urology: treatment of Benign Prostate Hyperplasia (BPH)

All three modalities are practised in clinics here in the Czech Republic and altogether several thousands of patients have been successfully treated by microwave thermotherapy. Some examples of such treatment will be given during the presenation.

There are several other prospective applications of microwaves in medicine, like e.g. thermal ablation, microwave angiology, repair of retina detachments, cardiac arrhytmias, endomerial bleeding, etc.

Technical trends

Most important technical fields of microwave thermotherapy development (covered also in our activities) can be specified as:

- Applicators: development and optimisation of new applicators for more effective local, intracavitary and regional treatment,
- Treatmen planning: mathematical and experimental modelling of the effective treatment
- Noninvasive temperature measurement: research of the possibilities of new techniques (like NMR and US) for exact noninvasive measurements.

In all above mentioned key activities we need to do numerical simulations of SAR and temperature 3D distribution. Temperature distribution inside area of biological tissue heated by microwave energy can be calculated from well known formula

$$\rho_t c_t (dT/dt) = \gamma_\tau \delta T - \kappa(T - T_b) + q$$

where t is the time.
$q = q(x,y,z,t)$ is energy delivered by EM field,
$T = T(x,y,z,t)$ designates the temperature,
$T_b = T_b(x,y,z,t_o)$ is the temperature of blood,

Physical meaning and values of the here used constants for the case of high water contents tissue are:

ρ_t = 0,965 [g/cm^3] ... density of biological tissue (BT)
c_t = 3 586 [mJ/g/C] .. specific heat of BT
κ = 5,45 [mW/cm^3/C] blood flow and temperature capacity of BT
γ_t = 5,84 [mW/cm/C] spec. temp. conductivity of BT.

Possibilities of analytical solution of this equation are very limited to only a few cases - like e.g. "one dimensional" case of plane wave penetrating in homogeneous phantom. Therefore computers are to be used to solve this equation to obtain the temperature $T(x.y,z,t)$ time dependence and space distribution. For the treatment planning of microwave thermotherapy we use software product SEMCAD.

Applicators for "BPH" treatment

We have investigated basic types of microwave intracavitary applicators suitable for BPH treatment, i.e. monopole, dipole and a helical coil structures. These applicators are designed to work either at 915 or at 434 MHz. We would like to discuss it's effective heating

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depth, based on the comparison of the theoretical and experimental results. Basic mechanisms and parameters influencing (limiting) heating effective depth are described and explained in ref. [2, 3].

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.

Fig. 1. gives basic idea about SAR calculated for the case of the monopole intracavitary applicator.

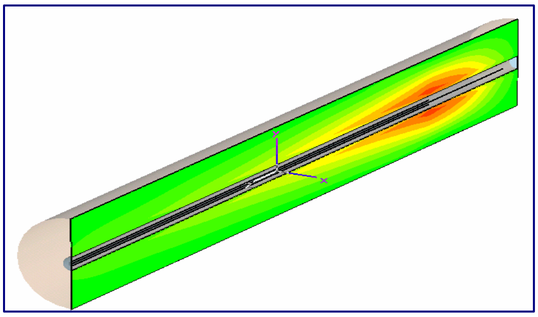

Figure 1: Calculated SAR of BPH applicator.

Evaluation of applicators for “BPH” treatment

One of our tools for experimental evaluation of microwave applicators is the apparatus, which enable us to do 3D measurements of SAR distribution. It can be used for both local external and intracavitary applicators.

The basic part of this apparatus is big salt water phantom (water with 0.3% to 0.6% NaCl) and the measurement probe with the possibility of 3D scan around the applicators. As a probes we use a Light Emitting Diodes with a fibber optic link connection to interface of the computer. The purpose of this link is to reduce influence of the metalic (i.e. conductive) components from the measured electromagnetic field. The schematics of the apparatus for 3D measurements of SAR distribution is shown in Fig. 2.

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. 3.

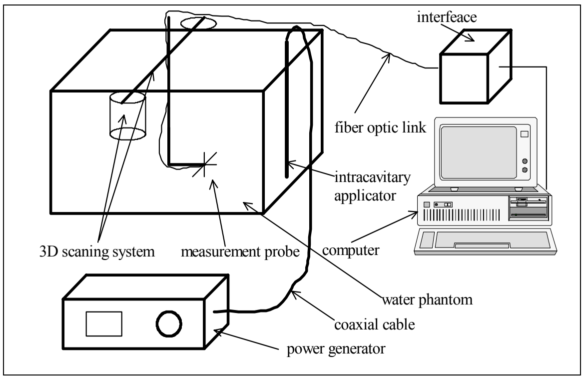

Figure 2: Apparatus for 3D SAR measurements

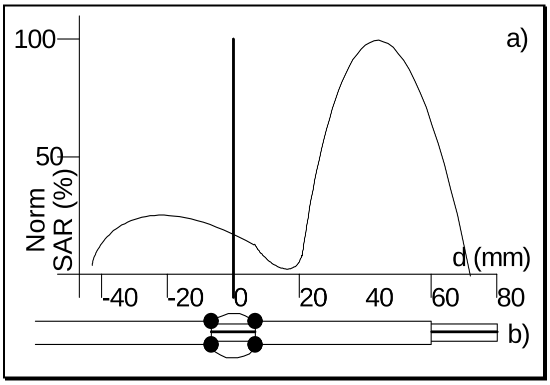

Figure 3: Monopole applicator

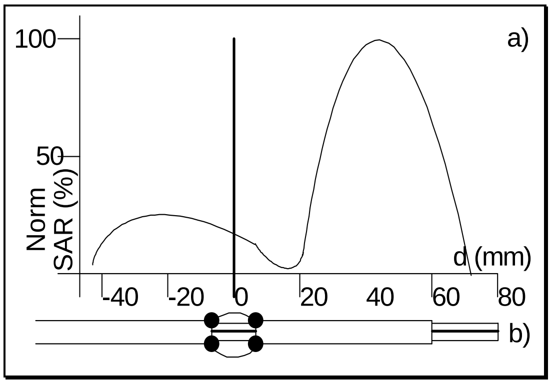

Figure 4: Dipole applicator

In Fig 4. the „SAR“ distribution improvement (i.e. reduction of second maximum) can be noticed for the case of dipole like applicator. 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.

After coil radius and length optimisation we have obtained very good results of „SAR“ distribution, see Fig. 5 and 6. Some problems can be with the antenna self-heating, but it can be reduced by cooler at the end of applicator tip.

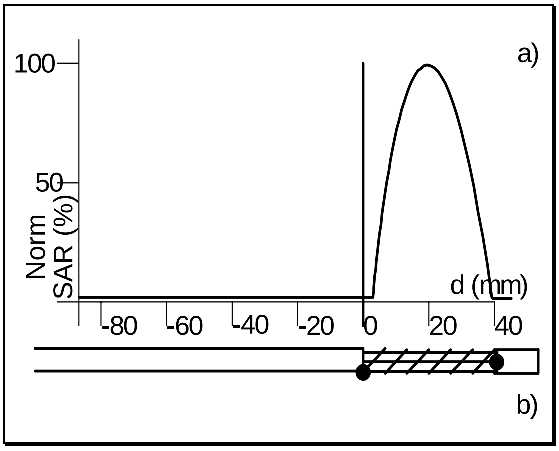

Figure 5: Helical coil applicator

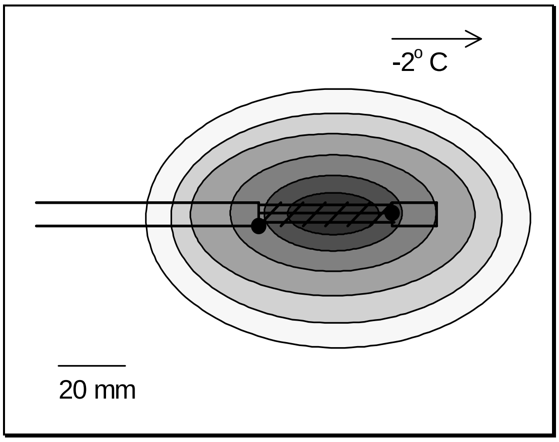

Figure 6: Temperature field around the helix

Effective treatment depth

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 arround radiating applicator.

Mentioned results can be simply interpreted by following figure, where on the horizontal axis is the working frequency of thermotherapy apparatus and on vertical axis there is effective depth of electromagnetic wave penetration. As a third parameter playing an important role there is a diameter of a discussed intracavitary applicator. More details can be found in ref. 7.

Very important is that in this case we are dealing with 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 approx. 1 cm under the surface of the cavity), thermal conductivity of the phantom material can easily cause errors of several tenth of percents.

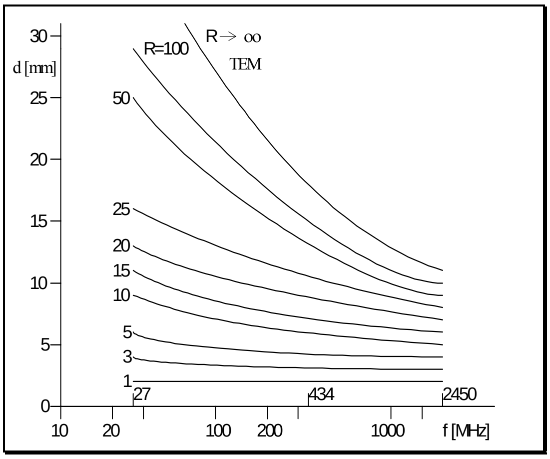

Figure:7: Effective depth of heating *d* with respect to frequency *f* [MHz] and radius *R* [mm].

Ideal intracavitary applicator irradiates an ideal cylindrical wave into the biological tissue surrouding 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 > 3mm). For lower frequencies (up to 100 MHz) combined with small radius of the cavity (R < 2 mm) the accuracy is cca 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.

"SAR" measurements by infrared camera

Infrared camera is according to our experiences a very efficient tool for "SAR" measurements of microwave intracavitary applicators.

In Fig. 8 there is the typical measured heating pattern of monopole (a), dipole (b), and helical coil antennas (c). This pattern can be obtained by heating suitable phantoms of biological tissue – mimicring the dielectric and thermal properties of the prostate tissue. Such phantoms can be made on the basis of agar or so called superstuff material.

The pattern is color-coded according to a linearly decreasing scale of white-yellow-red, where white is the maximum temperature. A diagrammatic catheter is inserted in each figure; the orientation of the bladder neck in a patient is indicated by a dashed line.

Note the long back heating tails with a monopole antenna (Fig 8a) which is caused by microwave currents that flow backwards along the cable and cause the feeding cable to radiate. The radiation pattern from a dipole antenna (Fig 8b) is generally well confined without any excessive backheating. The dipole antenna is suitable for prostates with axial length > 40 mm. The helical coil antenna (Fig 8c) has the shortest and most focussed heating and would be the choice for small prostates, 25 – 40 mm in length.

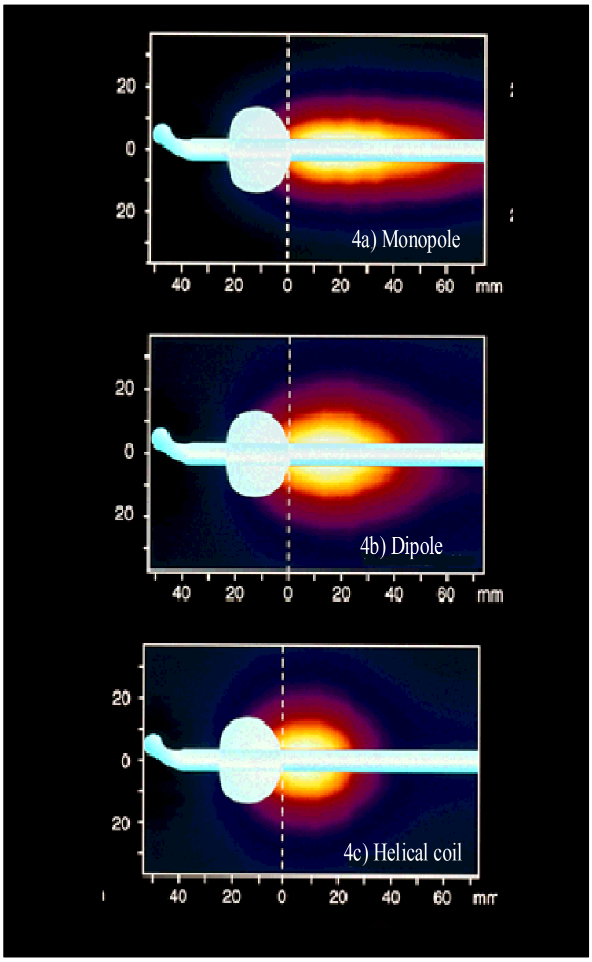

Figure 8: The heating pattern for different antennas:
- the monopole (a),
- the dipole (b),
- the helical coil (c).

The pattern is colour-coded according to a linearly decreasing scale of white-yellow-red (white-shadow-dark), where white is the maximum temperature. A diagrammatic catheter is inserted in each figure; the orientation of the bladder neck in a patient is indicated by a dashed line.

More over, by using infra-red camera we can follow a lot of other properties resp. behaviour of intracavitary applicators itself, like e.g. standing waves along feeding coaxial cable (i.e. the risk of existence of unwanted SAR and/or temperature maximas), possible overheating of some specific parts of tested applicator itself etc.

Conclusions

Microwave thermotherapy is successfully applied in many clinics around the world including the Czech Republic. Technical support for clinics is very important, e.g. from the side of technical universities. Our goal for the next technical development is:

- improve the theory of the local and intracavitary applicator design and optimisation,
- innovate the system for the applicator evaluation (mathematical modelling and measurements),
- develop of the system for regional treatment,
- to support new clinical groups to learn and to begin to practice the microwave thermotherapy.

Here discussed category of applicators for "BPH" treatment can be in general used for medical treatment inside various cavities of human body. We have mainly investigated two basic types of these applicators: monopole/dipole applicator and then a helical coil applicator. These applicators are being used for example for prostate treatment (untill now more than 2000 patients has been successfully treated in the 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.

Acknowledgements

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