Abstract: Brain cancer can be treated by several therapies. One of the methods available is the elimination of cancer cells in the tumor targeted volume through the influence of heat. In the case of this technique, it is necessary to know the location and distribution of the tumor volume in the surrounding tissue. Correct and precise tumor localization is one of the crucial parts of the brain tumor local hyperthermia, which is necessary for the corresponding adjustment of the local hyperthermia system. This method of cancer treatment requires the observance of temperature distribution in the treated tissue. In this article, the authors focus on local hyperthermia for local increase of the tumor tissue temperature and on the minimization of the treatment influence on the healthy tissue. The paper includes simulations of the tumor tissue heating method based on the utilization of the complex permeability and complex permittivity of the heated tissue. The authors also discuss the adjustment of the local hyperthermia system, mainly the time of exposition needed to achieve the required temperature distribution in the tumor volume.

Keywords: Nuclear magnetic resonance, tumor, head, numerical modeling, hyperthermia, treatment, tissue, exposition.

1 Introduction

This article analyzes the possibilities of use of local hyperthermia as a method of cancer treatment. Local hyperthermia is used together with other methods of cancer treatment. This technique is based on the effect of temperatures up to 42°C, which cause elimination of the cells in the targeted volume Wust P, Hildebrandt B, et al., 2002. Effect of the heat is also shown in radiation therapy and chemotherapeutic drugs Bull JMC., 1984, Urano M, Kuroda M, Nishimura Y., 1999.

Systems for local hyperthermia of non-surface tumors are based on arrays of antennas emitting microwaves or radiowaves delivering the required power density in W/kg. Commercially used antennas are designed with regard to the size of the heated area. These antennas could be designed as a whole body, regional or local, in dependence on the size of the heated area and the required therapeutic depth. All hyperthermia system also require a system for the heated area temperature monitoring.

1.1 Whole body hyperthermia

This method is used in the case of metastatic malignant tumors where the use of local or regional hyperthermia is not feasible because of a higher number of tumors in different areas of the body. The whole body hyperthermia utilizes lower temperatures (less than 42°C) to prevent any damage to the healthy tissue.

1.2 Regional hyperthermia

The method of regional hyperthermia is used for deep localized tumors or in the case of a higher number of tumors in the same area. This method requires a sophisticated system for the planning of the heating process. Three-dimensional antenna systems are used for the controlling of power distribution in the heated area.
1.3 Local hyperthermia

If the tumor is close to the body surface, it is possible to use the local hyperthermia system. In this way, the adjustment of the local hyperthermia system is crucial for achieving a high temperature only in the tumor volume.

2 MR Methods of brain cancer localization

MRI is a constantly developing field of medicine suitable for the study of soft tissues, KUBÁSEK R., BARTUŠEK K., FIALA P., 2010. The current methodologies for obtaining images weighted by relaxation times provide us not only with information about the distribution of soft tissues, but also with an image insight into the function of the tissue. The localization of brain cancer is a necessary precondition for further treatment. In the case of radiation therapy, precise localization of the tumor and the surrounding tissues constitutes a crucial element.

Many MR sequences are used for imaging the tumor and the peritumoral region area with the aim to achieve an image with a higher contrast. Figure 1 shows an example of the T1 weighted (T1W), T2 weighted (T2W), and perfusion weighted (PWI) images. The T1W and T2W images show anatomical information about the tissue in the slice volume. These images are acquired in a higher spatial resolution, such as 512x512, pixel size 0.4x0.4 mm. PWI images are used for investigation into the function of the tissue. A PWI image could be a T1 or T2 weighted. Spatial resolution is 64x64 and pixel size 3.4x3.4 mm, Figure 1. C).

![Figure 1. Imaging examples: Tumor and the peritumoral region area](http://aum.svsfem.cz)

3 Optimum Mode of the Hyperthermic Method

Optimal progress of the hyperthermic process depends on the method of heating the target material group, Wust P, Hildebrandt B, et al., 2002. In this paper, the authors describe the method of tissue heating by the help of an antenna and tissue temperature monitoring, Figure 1. According to the applied source, a patient can participate in magnetic resonance (MR) tomography diagnostics, MIKULKA J., GESCHEIDTOVÁ E., BARTUŠEK K., 2011, while the therapy is in progress. Here, the proposed method of electromagnetic heating can be affected by problems related to the stability and accuracy of an MR tomograph (MRT) as a diagnostic instrument for the monitoring of tissue heating. The frequency of an electromagnetic wave excitation ranges within 100-150 MHz. As a rule, there occurs the heating of surrounding tissue that is not being/not to be subject to therapy; in this tissue, contrariwise, non-reversible damage may be incurred MARCOŇ P., BARTUŠEK K., BURDKOVÁ M., DOKOUPILE Z., 2011. Using the MRT, we can nevertheless arrive at another progressive solution. Viewed from macroscopic description of the electromagnetic field, the tissue of carcinomes shows peculiar
characteristics, which holds true even in respect of the dependence on temperature and frequency. In the case of the described model of heating by means of an electromagnetic wave, it is possible to formulate the electromagnetic wave in this environment using the diffusion equation for function $u$ and parameters $C_{10}$, $C_{11}$, $C_{12}$, and $Fiala P., 2001, Drexler P., Jirku T., Szabo Z. et al., 2007.

$$\Delta u = C_{10} \frac{\partial^2 u}{\partial t^2} + C_{11} \frac{\partial u}{\partial t} + C_{12} u + C_{13}.$$

(1)

The electric component incident wave, according to Figure 4, is according to formula (1):

$$\mathbf{E}_t = E_0 e^{-j\kappa_0 t} \mathbf{r}.$$  

(2)

![Figure 2. Scheme of a system for local hyperthermia. The applicator position and power output may vary until a clinically satisfactory adjustment is achieved Wust P, Hildebrandt B, et al., 2002.](image1)

![Figure 3. Non-invasive measurement of temperature distribution in the hybrid hyperthermia applicator Wust P, Hildebrandt B, et al., 2002.](image2)
where \( k \) is the complex wave number
\[
k = \sqrt{j \omega \mu \cdot (\gamma + j \omega \varepsilon).}
\] (3)

Figure 4: The reflection and refraction of light [9]

where \( \gamma \) is the conductivity, \( \varepsilon \) the permittivity and \( \mu \) the permeability. Relation (1) is defining for the boundary line between the dielectrics medium. Generally, \( k_1 \) and \( k_2 \) is complex; then angle \( \theta_2 \) is complex. The propagation of the electromagnetic wave is understood as the propagation of electric field strength and magnetic field strength.

\[
E_r = E_1 e^{-jk_1u_{n1} \cdot r}, \quad E_t = E_2 e^{-jk_2u_{n2} \cdot r}.
\] (4)

where \( E_0 \) is the amplitude of electric field strength on the boundary line, \( r \) is the positional vector and \( u_{0} \) is the unit vector of the direction of propagation. For numerical modelling, there is a suitable relation in the form of

\[
E_r = \frac{\mu_2 k_1 \cos \theta_0 - \mu_1 \sqrt{k_2^2 - k_1^2 \sin^2 \theta_0}}{\mu_2 k_1 \cos \theta_0 + \mu_1 \sqrt{k_2^2 - k_1^2 \sin^2 \theta_0}} E_0 \cdot e^{-jk_1u_{n1} \cdot r},
\]

\[
E_t = \frac{2 \mu_2 k_1 \cos \theta_0}{\mu_2 k_1 \cos \theta_0 + \mu_1 \sqrt{k_2^2 - k_1^2 \sin^2 \theta_0}} E_0 \cdot e^{-jk_2u_{n2} \cdot r}.
\] (5)

In view of the given problem, it is important to remain within the model of electromagnetic wave propagation (5) respecting the complex character of magnetic permeability \( \mu \) and electric permittivity \( \varepsilon \). However, these material parameters of the environment are the functions of temperature and frequency \( \text{MARCOŇ P., BARTUŠEK K., BURDKOVÁ M., DOKOUPIL Z.,2011, MARCOŇ P., BARTUŠEK K., ČÁP M.,2011, KUBÁSEK R., BARTUŠEK K., FIALA P.,2010.} \)

\[
\varepsilon = \varepsilon(T, \dot{f}), \quad \mu = \mu(T, \dot{f}).
\] (6)

In respect of these forms of material characteristics, an optimum heating method can be proposed for a small increase in temperature as already applied in the field of hyperthermic therapy. These characteristics were respected in the emulsion microwave heating with a phase change of materials Drexler P., Jirku T., Szabo Z. et al.,2007.

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4 Heating Test in the Numerical Model

The described model (1) having the given characteristics (6) was tested in the numerical model using the finite element method. The geometrical model was simplified to a phantom according to Figure 5.

![Figure 5: A phantom of the human head- numerical model](image)

Figure 5: A phantom of the human head- numerical model

![Figure 6. A phantom of the human head – the non-homogeneity position](image)

Figure 6. A phantom of the human head – the non-homogeneity position

![Figure 7. A phantom of the human head – result, distribution of the electric intensity E module, max=6THz](image)

Figure 7. A phantom of the human head – result, distribution of the electric intensity $E$ module, max=6THz

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Figure 8. A phantom of the human head – result, distribution of the magnetic intensity $H$ module, max=6THz

Figure 9. A phantom of the human head – result, distribution of the electric intensity $E$ module, max=6THz
Figure 10. A phantom of the human head – result, distribution of the magnetic intensity $H$ module, max=6THz

Figure 11. A phantom of the human head – result, distribution of the current density $J$ module, max=6THz
Figure 12. A phantom of the human head – result, distribution of the joule heat generation $J_{\text{he}}$ module, max=6THz

The analysis of numerical modeling, results evaluation of field distribution are shown in Figures 7 -12.

5 Conclusion

Using the inversion problem method, the numerical model reconstructs such signal and electromagnetic pulse shape that will only provide for local heating of the carcinoma tissue, with the surrounding tissue not subject to heating by the source of the electromagnetic wave. This shape of the electromagnetic field can be applied, without any spurious effects resulting from hyperthermia, to specific conditions of individual tissue disorder cases.

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REFERENCES


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