Microwave Hyperthermia System Development Based on Non Invasive Temperature Monitoring

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Abstract

Hyperthermia is heat treatment for cancer. The temperature of tumor tissue is elevated artificially in the range of 40 to 45°C with the aim of receiving therapeutic benefits. The objective of this research is to develop a microwave non-invasive infrared temperature monitoring hyperthermia system with computer based control. The temperature monitoring is implemented using infrared thermometer and infrared camera.

To achieve this research objective, the research is carried out in three steps. First, numerical model of energy transfer of microwave generator on artificial tissue is studied. Second, a system prototype which consists of microwave generator, non-contact temperature monitoring, and computer based control are built. Third, in vitro and in vivo clinical test for the system is carried out. The results show that the system is feasible for patients treatment.

Keywords: microwave, hyperthermia, cancer, therapy, infrared,

1. Introduction

There are several modes of treatment to the cancer patient: surgery, chemotherapy, radiation therapy, and combination of two or all three of these. Surgery is the oldest and most widely used method for the treatment of malignant diseases. In surgery, we excise the local lesion, plus a generous margin of normal tissue, along with the regional lymph nodes. Chemotherapy seeks to control systemic spread of cancer by the use of drugs. The anti cancer drugs interfere with the growth and spread of malignant cells. Radiation therapy employs the use of ionizing radiation, such as x radiation, to completely eradicate cancerous tissue (1),(6),(7).

In a separate area of research, heat is being used to treat tumors. There is some clinical evidence today that malignancies respond to heat treatment as either a stand alone therapy or in conjunction with radiation or chemotherapy. This respond appears to be predicated on the higher thermal sensitivity of neoplastic cells compared with normal cells. To achieve this selective destruction, the treatment temperature must be closely controlled to range of 42-43°C. This method of treatment is hyperthermia. Methods for inducing local hyperthermia include microwaves, radio frequency radiation, and ultrasound (2),(8),(9).

In general, the characteristic of cancer cell tissue has pH < 7.4, lower than normal one (pH>7.4). In consequence, oxygen and nutrition supply are low. Therefore, the temperature of cancer tissue is easier to increase than the normal one (3),(10),(11). The relation between pH, heat energy exposed time and cell lethality influence (called as surviving factor) is shown in Figure 1.

The treatment of hyperthermia on normal tissue causes the increase of 3 to 20 times than the normal blood flow. On the contrary, the same treatment to the cancer tissue only less than 2 times of the normal blood flow. It means that heat dissipation by blood flow on normal tissue is higher than the normal one (4),(12),(13). Destruction mechanism of cancer tissue because of heat energy is caused by the change of macromolecular level, cytoplasm, membrane and tumoral vascularization. The cell respond to temperature increase which is called as cell surviving curve is shown in Figure 2.

Figure 1. Relation between pH and Surviving factor.
The curve shows that if the temperature is increased, the cell surviving fraction is decreased for the same hyperthermia duration. The hyperthermia dose is depend on the temperature and the treatment duration.

2. Numerical Model

The tissue considered is muscle, skin and tissue with high water content with the thickness of 9 cm (Figure 3).

The thermal equilibrium in the biomedical tissue is the result of conduction, convection and heat transfer phenomenon from external heat generator and metabolism in the tissue. The general heat equation assuming no heat convection by ambient air cooling, blood flow, and metabolism is (5),(14).

\[
C_v \rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left[ k \frac{\partial T}{\partial x} \right] + G \tag{1}
\]

where \( C_v \): specific heat of the tissue (J kg\(^{-1}\)°C\(^{-1}\))

\( \rho \): mass density of the tissue (kg m\(^{-3}\))

\( k \): thermal conductivity (Wm\(^{-1}\)°C\(^{-1}\))

\( T \): tissue temperature (°C)

\( G \): heat generated in the tissue by metabolism and external heat generator (W m\(^{-3}\)).

The equation (1) can be solved using finite difference method and the result is shown in Figure 4.

Figure 4 shows that the peak temperature in the tissue is at the distance of about 1 cm from the surface of the body. This is caused by the fact that the ambient temperature is lower than the one of the tissue. By increasing the exposed time, the peak temperature increases accordingly. Using the power density of 1100 Wm\(^{-2}\) the peak temperature of about 43°C is obtained by heating the tissue for three minutes (180 s).

3. Hyperthermia System

The realized system is shown in Figure 5. The system consists of microwave generator, waveguide and applicator and infrared thermometer and infrared camera.

The infrared thermometer has 0.01 °C accuracy because the surviving factor change rapidly in certain narrow band of temperature. The thermometer also have fast response (about 100 ms time respond) to fulfill the control specification of the tissue temperature. This thermometer also be designed to be non invasive for patient comfort. Heating profile monitoring using infrared camera is being developed to control the extent of heating.

The treatment dosage could be controlled trough the temperature and duration variables (treatment protocol). Because of the tissue characteristic is inherently nonlinear, and time varying of its parameter, it is apparent that an intelligent controller is needed to control such system. In this research we use fuzzy logic controller to control the tissue temperature. Figure 6 shows the evolution of the temperature during the treatment.
4. Clinical Test

The prototype hyperthermia apparatus exposed to tail of 8 mice. Every 2 mice were exposed to heat of microwave all for duration of 45 minute, every 2 mice with several degree of heat: 40°, 43°, 45° and 50°Celsius in her tail (Fig.7). Then all mice were killed with Chloroform, and the exposed tail fixed in alcohol 76%, and send to Laboratory of Pathology Faculty of Medicine, Gadjah Mada University, to make parafin block and cut with microtome in order to makes coupes to see the histopathological changes (Fig. 8).

Fig. 6 Temperature evolution

The results show that the temperature appropriate to microwave hyperthermia is 43° C. 40° C give no changes, and 45 to 50 °C the destruction is very severe tend to necrotic, and bulla.

5. Conclusion

The realized hyperthermia system is in general feasible for patient treatment

The temperature control must be improved to assure the safety during the treatment by optimizing fuzzy logic control and increasing the accuracy of the thermometer.

Acknowledgment

The author would like to thank Prof. Dr. dr. Maesadji Tjokronagoro, Sp.Rad(K). Onk., for clinical test results analysis support and Fadli Ama for assisting in vivo clinical test.

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