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Heat distribution improvement with the implementation of polyethylene-covered water bolus into breast cancer hyperthermia

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Abstract. This paper presents the implementation of polyethylene-covered water bolus into a non-invasive breast cancer hyperthermia applicator. This modified hyperthermia applicator is introduced to improve the performance of hyperthermia by reducing or removing unwanted hotspots during hyperthermia treatment. This simulation-based experiment is carried out to observe the heating distribution of hyperthermia with water bolus coated by three different thicknesses of polyethylene cover or layer, which are 0.5mm, 0.8mm and 1.0mm. The solvent used in the water bolus is distilled water. The 915MHz microstrip antenna as a hyperthermia applicator and stage 2 breast cancer with a cancer depth of 28.6 mm to 73.6 mm is selected for this study. Based on the results, with the modified HTP integrated by water bolus, the heat pattern of hyperthermia simulation becomes more concentrated into the targeted cancer region, and unwanted hotspots nearby the skin area of breast tissue are removed. The 0.5mm thick polyethylene cover showed the best results with a focusing region between 29.4mm to 69.4mm compared with the result of hyperthermia without implemented water bolus, which heated the 26.6mm to 67.3mm region.

1. Introduction

Hyperthermia is an alternative treatment for cancer treatment procedures by inducing heat to form a biological effect towards the treated tissue [1]. The hyperthermia procedure is used to elevate the temperature of the cancerous tissue to 41°C–45°C without affecting the surrounding healthy tissue [2]. Hyperthermia treatment procedure (HTP) has been proven to increase the efficacy of conventional cancer treatment. Currently, successful therapy method in a combination of HTP with radiation therapy and/or chemotherapy has increased [3], [4].

This is due to HTP complex effects on cancer, which are significantly disrupted the ability of tumour cells to divide and lead to the shrinkage of tumours. HTP is also able to prevent cancer cell repair after adjuvant therapy with chemotherapy or radiotherapy as it is able to coagulate the cancer tissue to necrotic tissue and then destroy it by the human antibody system [5], [6].

However, several limitations, such as poor penetration depth, difficulty in controlling focus position distance, and massive skin burn problems, need to be improved, especially when non-invasive hyperthermia is concerned [7], [8].

There are numerous research studies that have recently been focusing on improving the efficiency of HTP. For example, Rahpeima & Lin introduced magnetic fluid hyperthermia with an external AC magnetic field [6]. Yusri & Muldarisnur designed complementary split-ring resonator metamaterial with gaps from 0.5 to 3.5 mm to increase the heat concentration of HTP [9]. Various HTP antenna slot designs such as Y-slot, C-shaped slot, and multi-arrayed circular slot are proposed to improve the radiating path and focus position distance of HTP [10]–[12].

Besides the above research on HTP, water bolus (WB) is another element in HTP that was proven to be able to reduce skin burn issues during the treatment [13], [14]. It is often used as a cooling material with the proposed HTP applicators [15], [16]. The implementation of WB in HTP was observed to improve the effective field size (EFS) of the EMF in the targeted tissue [17].

Therefore, this research was an enhancement or further development of the research team's previous research with the implementation of polyethylene-covered WB into breast cancer HTP [10], [18]. This research was further developing the breast-shaped WB discussed in [10] with polyethylene layer as the container of WB.

The antenna design and breast phantom used in this research were proposed and introduced in another previous research of the research team published in the year 2021 [18]. Thus, the main purpose of this research is to investigate the addition of polyethylene-covered WB to improve the efficiency of a 915 MHz microstrip antenna in stage 2 breast cancer treatment through EM simulation.

2. Methodology

This section will discuss the research type, microstrip antenna and breast phantom development and WB designs in subsections 2.1, 2.2 and 2.3, respectively.

2.1. Research type

The research approach in this study is a quantitative experimental approach. According to John W. Creswell, this approach is used to determine how a specific treatment affects an outcome [19]. This approach figures out how different designs of water bolus will affect the HTP efficiency.

This research focuses on experimentation by simulation type of research. A simulation study is important as it is an initial step before further experiments are conducted. The simulation also allows concepts and ideas to be more easily verified, communicated and understood. Therefore, the performance of the HTP applicator can be measured through this simulation study, and the resulting radiation distribution can be observed via Specific Absorption Rate (SAR) measurement parameter.

The simulator software used in this experimental investigation is called SEMCAD X 14.8.4, which is produced by SPEAG. The SEMCAD X software is a highly specialised full-wave EMF solver used to design an HTP applicator, as well as to obtain the radiation distribution, which presents the EM energy penetration depth and its energy focus distance. This software is a thermal simulation platform and 3D full-wave electromagnetic simulation based on the FEM and FDTD methods.

2.2. Microstrip antenna and breast phantom development

The usage of a microstrip antenna was chosen because it can have its thickness and size altered using different frequencies, a miniaturisation factor, and an improvement in the type of array [20]. Microstrip antennas can be built and designed in a variety of ways.

In this study, the rectangular shape was highlighted because, as compared to other shapes, it has the greatest beamwidth. When using different operating frequencies, this rectangular shape is also simpler to modify [21]. Moreover, there is a strong correlation between operating frequency and microstrip patch size [22], [23]. Equations (1) to (7) showed the formula used in microstrip antenna development.

$$W = \frac{Co}{2f_o\sqrt{(\varepsilon_r+1)/2}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{(1+\frac{12h}{W}}}\right] \tag{2}$$