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Modified Metamaterial Lens Structure for Non-invasive Hyperthermia Breast Cancer Procedure

Wong Vei Ling

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Modified Metamaterial Lens Structure for Non-invasive Hyperthermia Breast Cancer Procedure

Wong Vei Ling

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

Name: Wong Vei Ling

Matric No. : 19020130

Faculty of Engineering Universiti

Malaysia Sarawak

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ABSTRACT

Hyperthermia treatment procedure (HTP) is an alternative treatment for cancer, where it induces heat and forms a biological effect. The efficiency of the hyperthermia procedure depends significantly on the focusing distance position of the electromagnetic energy to elevate the temperature of the cancerous tissue until 41°C to 45°C within 60 to 360 minutes. However, the current non-invasive HTP for cancer has limitations in its penetration depth (PD) and focusing distance position (FPD) on human tissues, which may contribute to less effective treatment on the targeted cancer tissue. Thus, this research is mainly to develop a modified metamaterial-split ring resonator (MTM-SRR) lens structure for enhancing the FPD of different stages of breast cancers. To achieve the mentioned objective, five research phases are performed. First, the development of breast phantom. Second is microstrip antenna development, which follows metamaterial (MTM) lens development, then water bolus addition and the fifth, in which the final phase is the validation of the outcomes. These experiment components are developed using the SEMCAD X 14.8.4 software simulator. With SEMCAD X 14.8.4, an electromagnetic (EM) simulation is conducted to obtain the Specific Absorption Rate (SAR) distribution towards the developed breast phantom, which consists of breast fat and breast cancer tissue. From the SAR, the PD and FPD are measured. As the results, the integration of MTM has performed in a significant effect by enhancing the FPD of HTP and existed lesser unwanted hotspots area. The FPD coverage percentage of HTP execution with selected MTM-SRR designs reached 95.32%, 87.48%, 81.08% and 89.45% for early stage, stage 1, stage 2 and stage 3 of breast cancer respectively. In addition, different stages of cancers required different suitable operating frequencies and different D_0 of MTM. Then, with the addition of water bolus, the unwanted hotspots are reduced further and reshaped the SAR distribution to attain the effective field size of SAR for HTP. In summary, with a modified MTM structure applicator with the addition of water bolus, the PD and FPD on the treated cancer tissue can be enhanced and improved further. However, further work is required to perform laboratory experimentation on a real proposed HTP applicator prototype with mimicked breast cancer tissue to observe the SAR distribution of PD and FPD.

Keywords: Metamaterial, Hyperthermia, Breast Cancer, Focus Position Distance, Penetration Depth

Pengubahsuian Struktur Kanta Metamaterial untuk Prosedur Kanser Payudara Hipertermia Tidak Invasif

ABSTRAK

Prosedur rawatan hipertermia (HTP) adalah rawatan alternatif untuk kanser, di mana prosedur ini mendorong haba dan membentuk kesan biologi. Kecekapan prosedur hipertermia bergantung dengan ketara pada kedudukan jarak fokus tenaga elektromagnet untuk meningkatkan suhu tisu kanser daripada 41ºC–45ºC selama 60 hingga 360 minit. Walaubagaimanapun, HTP bukan 'invasive' yang terdapat kini, mempunyai had dalam kedalaman penembusannya dan memfokuskan kedudukan jarak kearah tisu manusia, yang mungkin menyumbang kepada rawatan yang kurang berkesan pada tisu kanser yang disasarkan. Oleh itu, penyelidikan ini dijalankan untuk meminimumkan had HTP dengan menyepadukan aplikator kanta bahan metamaterial (MTM) untuk HTP. Lima fasa penyelidikan dijalankan. Pertama, perkembangan model payudara. Kedua ialah pembangunan mikrostrip antena, seterusnya pembangunan kanta MTM, kemudian penambahan bolus air dan kelima, di mana fasa terakhir adalah pengesahan output. Komponen eksperimen ini dibangunkan menggunakan simulator perisian SEMCAD X 14.8.4. Dengan SEMCAD X 14.8.4, simulasi EM dijalankan untuk mendapatkan taburan Kadar Penyerapan Spesifik (SAR) kearah model payudara yang dibangunkan, yang terdiri daripada lemak payudara dan tisu kanser payudara. Daripada SAR, kedalaman penembusan (PD) dan jarak kedudukan fokus (FPD) diukur. Penyepaduan MTM telah menghasilkan kesan yang ketara dengan mempertingkatkan FPD HTP, dengan kawasan pemanasan yang tidak diingini yang lebih rendah, ia boleh membawa kepada kesan kesihatan yang buruk pada tisu sihat di sekelilingnya. Kajian mendapati peratus peliputan FPD kepada tahap permulaan, tahap 1, tahap 2 dan tahap 3 kanser payudara, masing-

masing mencapai 95.32%, 87.48%, 81.08% dan 89.45% .Di samping itu, peringkat kanser yang berbeza bergantung kepada frekuensi operasi yang sesuai dan D_0 *MTM yang berbeza. Oleh itu, FPD yang sesuai untuk pelbagai saiz kanser yang dirawat boleh dicapai. Kemudian, dengan penambahan bolus air, titik panas yang tidak diingini dikurangkan lagi dan membentuk semula taburan SAR untuk mencapai saiz medan SAR yang berkesan untuk HTP. Secara ringkasnya, dengan aplikator struktur MTM yang diubahsuai dengan penambahan bolus air, kedalaman penembusan (PD) dan jarak kedudukan fokus (FPD) pada tisu kanser yang dirawat boleh dipertingkatkan. Walaubagaimanapun, kerja lanjut diperlukan untuk menjalankan eksperimen di makmal untuk prototaip aplikator HTP sebenar yang dicadangkan dengan tisu kanser payudara yang dibangunkan untuk memerhatikan taburan SAR, PD dan FPD.*

Kata Kunci: *Metamaterial, Hipertermia, Kanser Payudara, Jarak Kedudukan Fokus (FPD), Kedalaman Penembusan (PD)*

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CEM	Computational Electromagnetic
CC	Cranio-Caudal
CT	Chemotherapy
DNG	Double-negative
DICOM	Digital Imaging and Communications in Medicine
DoE	Design of Experiment
EFS	Effective field size
EM	Electromagnetic
EMF	Electromagnetic Field
ENG	Epsilon-negative
FQ	Frequency
FDTD	Finite-difference time domain
FPD	Focus position distance
FM	Frequency modulation
GPS	Global-positioning System
HTP	Hyperthermia Treatment Procedure
ID	Inner Depth
MLO	Medio-Lateral Oblique

MNG	Mu-negative
MTM	Metamaterial
MTM-SRR	Metamaterial-Split Ring Resonator
MTM-ZOR	Metamaterial-zeroth order mode
MW	Microwave
NRI	Negative Refractive Index
PD	Penetration depth
RF	Radiofrequency
RT	Radiotherapy
SAR	Specific Absorption Rate
SD	Surface Depth
SRR	Split Ring Resonator
TH	Thickness
TPE	Treatment Periods Estimation
UNIMAS	Universiti Malaysia Sarawak
US	Ultrasound
WB	Water Bolus

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter consists of a research overview as well as the motivation of the research, problem statement, research objectives, contributions of research, research scopes, research gaps and thesis outlines. Details of the discussion are presented accordingly in **Sections 1.2** to **1.10.**

1.2 Research Overview

This research involves a study in developing of modified hyperthermia treatment procedure (HTP), which consists of a microstrip antenna and metamaterials (MTM) lens. This modified structure aims to improve focus position distance on the treated tissue and simultaneously reduce unwanted hot spots on the surrounding healthy tissue.

In recent years, numerous types of research on HTP applicators for non-invasive HTP applications have been carried out. This hyperthermia treatment is currently known as an alternative therapy for cancer (Vogl et al., 2018). It is often used with chemotherapy and radiotherapy, which is known as adjuvant therapy (Koo et al., 2014).

In addition, hyperthermia is a new technique to expose cancerous tissue to electromagnetic radiation in order to increase tissue temperatures around 41ºC to 45ºC for one (1) hour or more (Behrouzkia et al., 2016). Based on previous research, this hyperthermia technique is able to convert the cancerous tissue into necrotic tissue and destroy the cancerous tissue with minimal side effects (Beck et al., 2022; Lias et al., 2022).

Generally, HTP applications can be an invasive and non-invasive treatment. It is either the HTP applicator applies towards the human body internally or externally, respectively. Practically, invasive HTP can be much more effective than a non-invasive HTP, as the HTP applicator is inserted into the target region and heats the cancerous cell directly (Wang et al., 2014). However, the process of inserting this HTP applicator into the human body can be invasive and may cause several adverse health effects, such as major bleeding.

Meanwhile, as for non-invasive HTP, since it is applied outside of the human body, adverse health effects can be minimized as surgery can be avoided. In addition, this non-invasive HTP is simpler to handle if compared to invasive type HTP because it can be used as an in-situ applicator (Lias et al., 2014).

Nevertheless, both types of HTP are effective and applicable to cancer therapy. However, this research will focus on non-invasive HTP applicator development since it provides less adverse health effects and is safer than invasive HTP. This research study improves and stimulates non-invasive hyperthermia, where the HTP applicator is investigated and modified further in order to obtain the results that show the capability to perform the required depth and focus position distance on the treated tissue.

Based on the previous study, G.A. Deschamps initially introduced the idea of a microstrip antenna in the year 1953, and it was practically produced in the 1970s by Robert E. Munson and his fellow researchers using a low-loss substrate. Microstrip antenna has commonly used in many applications, such as broadcast satellite service, mobile satellite communications, a global positioning system (GPS), medical hyperthermia usage and such (Karthikeyan & Vijayalakshmi, 2014).

Meanwhile, the concept of Metamaterial (MTM) was first proposed by Veselago in the year of 1968 when he introduced the existence of materials whose permittivity and permeability were simultaneously negative (Vrba et al., 2016). Due to the negative refractive index (NRI) characteristics of MTM, Pendry introduced the perfect lens in 2000, which was known as left-handed materials (LHM). It has a great electromagnetic (EM) energy-focusing capability on the treated tissue (Pendry, 2000). However, poor wave propagation distance was found in Pendry's research. As of today, experimental results have proved that moving the microwave (MW) sources with respect to the MTM lenses based on tumour position can affect the concentration of heating within the biological tissue (Leggio et al., 2015).

When water bolus is added to the treatment procedure, it contributes to lessening the adverse health effects due to heat applied toward the treated tissue. It is mainly to provide cooling conditions during HTP execution (Juang et al., 2004).

With the integration of microstrip and MTM lens structure, it is expected the required penetration depth and focus position distance on the treated tissue can be achieved. Then, when water bolus is added to the treatment procedure, it aims to reduce unwanted hot spots on surrounding healthy tissue.

1.3 Research Motivation

There are three main factors which motivate to carry out this research.

First, the capability that was shown by the MTM lens in the previous research, where it was able to adjust the EM energy pattern (Vrba et al., 2016). Thus, when a microstrip antenna is integrated with an MTM lens to form a modified HTP applicator, it is expected that the focus position distance on the treated tissue can be improved and enhanced to cater to different sizes and locations of cancer tissue.

Second, non-invasive hyperthermia has the potential to kill cancer. However, requirements to improve penetration depth (PD) and focus position distance (FPD) on the treated tissue are significantly necessitated. This is to ensure the success rate of HTP can be increased with minimal side effects on surrounding healthy tissue (Gas & Kurgan, 2018). An overview study made by Kok et al. (2020) mentioned that current clinically used non-invasive hyperthermia treatment procedures could attain PD from 15mm to 70mm, but these are very dependent on the applied frequency and size or diameter of cancer.

Last but not least, the third factor is the increasing number of cancer incidences, especially breast cancer incidences. It is the most common cancer among women worldwide with 2.1 million new cases and caused 627 000 of cancer death in year 2018. (Wild et al., 2020).

In conjunction with this increment in cancer incidences, it is a requirement to introduce various improvement techniques to a potential alternative treatment for cancer. In this research, HTP is emphasized with MTM-Split Ring Resonator (SRR) design as it has proved able to improve the HTP efficiency (Slimi et al., 2022; Yusri & Muldarisnur, 2021).

1.4 Problem Statement

Concern for non-invasive therapy requirement has encouraged research for non-invasive HTP, as it is able to provide safer treatment procedures with minimal adverse health effects during treatment execution if compared to other conventional therapy such as