SAR distribution of non-invasive hyperthermia with microstrip applicators on different breast cancer stages

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Article Info

ABSTRACT

This paper presents the microstrip antenna with different applied frequencies used as a non-invasive hyperthermia applicator. This non-invasive hyperthermia applicator is introduced to clarify the sufficient heat distribution on the treated tissue for different breast cancer stages. 57 mammogram breast cancer images from early-stage to stage- 3 are analyzed to obtain the required penetration depth and focus position distance. Then, the simulation-based experiment is carried out to observe the heating distribution on different stages of cancer with two different operating frequencies; 915MHz and 2450MHz. Also included in this paper is the prediction on the period for hyperthermia treatment planning execution. Based on the results, various penetration depths are obtained when different operating frequencies are applied. 915MHz antenna showed better results when compared to 2450MHz, where microstrip applicator with 915MHz is able to heat cancer at stage-1, stage-2, and stage-3 with good penetration depth and focus position distance, while 2450MHz only performed well in early-stage cancer. Meanwhile, different stages require various periods of time. From the results, the shortest period for hyperthermia execution simulated in the early-stage and then followed by stage-3, stage-2, and the longest period is in stage-1.

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1. INTRODUCTION

Hyperthermia is a cancer treatment procedure by inducing heat to form a biological effect on the treated tissue [1]. Hyperthermia uses high temperature with a range of 41°C to 45°C at certain periods in order to denature cancerous tissue into necrotic tissue. This hyperthermia treatment procedure (HTP) is often used with chemotherapy and radiotherapy, which is known as adjuvant therapy [2, 3]. In recent years, the successful number of hyperthermia treatments as the adjuvant procedure has been increased [4]. It showed that hyperthermia treatment has a high potential to be used as an alternative treatment for cancer. Currently, various researches of non-invasive HTP applications were presented. Based on previous research, this hyperthermia technique was able to destroy the cancerous tissue with minimal side effects [2, 5, 6]. This is because the non-invasive method is safer as no minor surgery is involved to avoid bleeding, and other adheres effects [4, 7, 8]. However, several limitations such as poor penetration depth, difficulty to control

focus position distance, and massive skin burn problems need to be improved, especially when non-invasive hyperthermia is concerned [9, 10]. Therefore, various researches such as [2, 3, 11-13] are carried out to improve the HTP performance.

Hyperthermia treatment can be applied either with ultrasound or electromagnetic (EM) techniques. If compared to both methods, the electromagnetic technique is safer than ultrasound [14]. Hence, a microstrip antenna is used and modeled with SEMCAD X 14.8.4 to further investigate its effect on hyperthermia treatment of different breast cancer stages in this research.

In addition, most previous HTP researches such as [2, 5, 11, 15-21] are only using specific size and location of cancer data, while practically, size and location of cancer incidences will be different [22, 23]. A specific concern whereby an improvement and enhancement of HTP applicator that able to cater to different sizes and locations are significantly required to be further investigated. Therefore, this research aims to investigate the most efficient applied frequency and estimate the treatment period for different breast cancer stages. SEMCAD X 14.8.4 software simulator is used to conduct the simulation-based experiment to attain the SAR distribution, representing the focus position distance on treated tissue.

2. RESEARCH METHODOLOGY

A research methodology is discussed in three Sections: 2.1 microstrip antenna development, 2.2 average breast cancer size analysis, and 2.3 treatment period estimation. The design of simulations is presented in Figure 1. Details on the research methodologies are discussed in Section 2.1 to 2.3 and followed by results and discussion in Section 3.
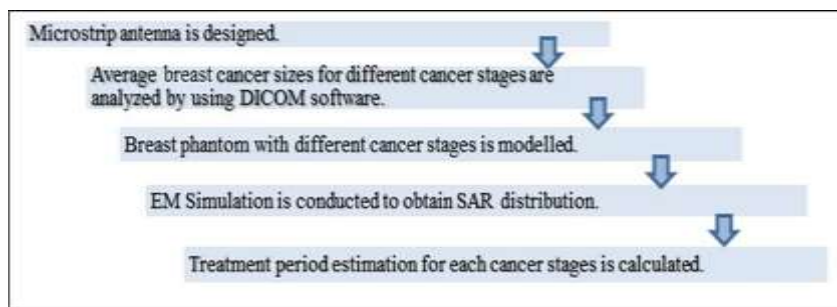

Figure 1. Flow chart for design of simulations

2.1. Microstrip antenna development

Microstrip antenna is selected to be used as its thickness and size can be manipulated through various frequencies, miniaturization factor, and array types enhancement [14]. Microstrip antenna can be designed and developed with various shapes. However, in this research, rectangular shape is emphasized as it has the widest beamwidth if compared to other shapes. Furthermore, this rectangular shape is easier to be modified when different operating frequencies are utilized [24]. In addition, the size of the microstrip patch is associated significantly with the operating frequency [25, 26]. This can also be observed from (1) to (7) for rectangular microstrip development [24].

As mentioned in [24], rectangular microstrip antenna width, W is obtained through (1), where C_o, f_o, and ε_r represent the speed of light, fundamental frequency applied, and permittivity of the substrate, respectively. The substrate chosen in this research is RO 4350 with permittivity value, $\varepsilon_r = 3.48$, referred to Gabriel Database built-in SEMCAD X.

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

The effective permittivity can be calculated with value of width, W and the thickness of the substrate used, h as in (2).

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

The microstrip antenna effective length, L_{eff} is calculated as in (3). It needed to determine the actual length of the antenna, L as shown in (5) with identified fringing effect, $\varDelta$,. Because of the EM wave are radiated outside of the strip, L and ε_r are different with L_{eff} and ε_{eff}.

$$L_{eff} = \frac{Co}{2f_o\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$\Delta L = 0.412 \frac{(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.268)}{(\varepsilon_{eff}-0.258)(\frac{w}{h}+0.8)} \tag{3}$$

$$L = L_{eff} - 2\Delta L \tag{4}$$

The ground plate length, L_g and width, W_g of the rectangular antenna are obtained as in (6) and (7), respectively.

$$Lg = 6h + L \tag{5}$$

$$Wg = 6h + W \tag{6}$$

Table 1 presents the rectangular microstrip antenna sizes with operating frequencies of 915MHz and 2450MHz. Meanwhile, in Figure 2 (a) and (b), it shows modeling of the antenna with breast phantom under 915MHz and 2450MHz, respectively.

Table 1. Designs of rectangular microstrip antenna under frequency 915 MHz and 2450 MHz

Frequency, MHz	h, mm	W, mm	ε_{eff}, mm	L_{eff}, mm	ΔL, mm	L, mm	L_g, mm	W_g, mm
915	1	109.46	3.42	88.62	0.48	87.66	93.66	115.46
2450	1	40.88	3.33	33.53	0.48	32.57	38.57	46.88

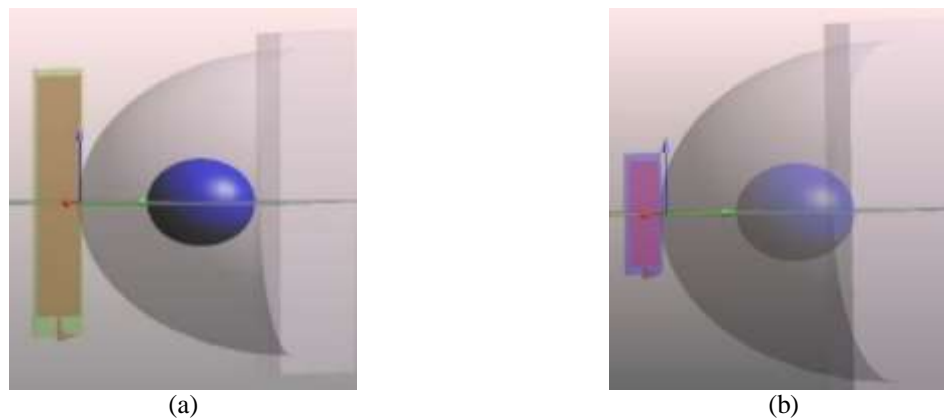(a)   (b)

Figure 2. Modelling of microstrip antenna with breast phantom under (a) 915MHz and (b) 2450MHz

2.2. Average breast cancer size analysis

Mammogram is an imaging methods for screening breast cancer [27]. 57 mammogram breast cancer images are gathered from one of the General Hospital in Malaysia. As the details of hospital and raw data are confidential under ethical approval, only the analyzed results are presented in this section. The images included breast cancer from early-stage until stage-3. Stage-4 breast cancer mammogram images are not discussed because it will be directly referred for surgical procedure.

Data analysis is proceed with digital imaging and communications in medicine (DICOM) software. The depth and size of the cancer tissue are determined and analyzed with the mentioned software. The surface depth and inner depth of breast cancer in each stage are measured as showed in Figure 3. While the average surface depth and inner are calculated according to the number of samples obtained.

Figure 4 shows the average surface depth and inner depth for each cancer stage that attain from the quantitative images analysis approach. The depths are basically to identify the required focus position distance and penetration depth of each cancer that necessitates being heated for hyperthermia execution. Breast phantoms consisting of breast fat with 4 inches (10.16cm) and breast cancer with the analyzed size from mammograms images analysis for each stage are modeled as Figure 2. The data showed in Figure 4 are agreed with the result by Wang *et al.* [28] in 2014 with the almost similar cancer depth and sizes.
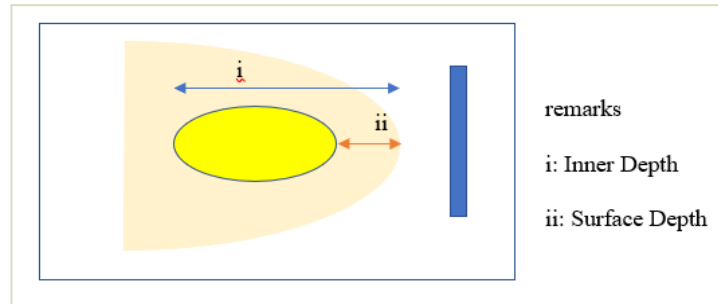
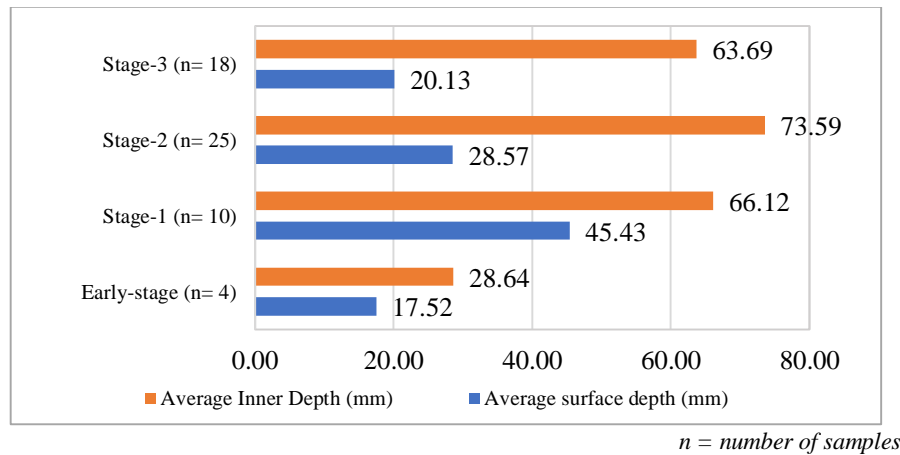

Figure 3. Surface depth and inner depth measurements

n = number of samples

Figure 4. Surface and inner depth for each cancer stage

2.3. Treatment period estimation

In order to estimate for the hyperthermia treatment period, a specific absorption rate (SAR) equation is referred. SAR is a measurement of energy absorption rate per unit mass of biological tissues during radio-frequency (RF) or microwave (MW) types of EM waves radiation. Generally, SAR parameters are presented in units of watts per kilogram or milli-watts per gram (W/kg or mW/g) [15, 29].

Referring to the international electrotechnical commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE), IEC/IEEE 62704-1 standard, SAR can be determined as in (8) and when the electric field is considered, (9) is used [30].

$$SAR = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho \delta V}\right) \tag{8}$$

$$SAR = \frac{\sigma E^2}{2\rho} \tag{9}$$

Moreover, the SAR also can be written as (10), when temperature and period are considered.

$$SAR = \left.\frac{c\Delta T}{\Delta t}\right|_{t=0} \tag{10}$$

W, t, V, E, ρ, T, σ and *c* are represented energy absorbed (Watt), time duration (second), tissue volume (m³), peak electric field vector (V/m), tissue density (kg/m³), tissue temperature (°C), tissue conductivity (S/m) and tissue specific heat capacity (J/kg°C), respectively. Therefore, after SAR distribution obtained from EM-simulation is recorded, the time taken for the hyperthermia treatment can be calculated as (10). The specific heat capacity of breast cancer tissue and required increasing temperature until 41 to 45 °C are 3510 J/kg°C and 4 to 8 °C, respectively [16].

3.   RESULTS AND DISCUSSION

The microstrip antenna with 915 and 2450MHz and breast phantom of different breast cancer stages are modeled with SEMCAD X 14.8.4. In order to obtain SAR distribution, EM-simulation is carried out. A few parameters are required to be set in the SEMCAD X before the simulation is run. Table 2 shows permittivity (*ε*), electrical conductivity (EC, S/m) and specific heat capacity (c, J/kg°C) of 915MHz and 2450MHz that are obtained from Gabriel Database build-in SEMCAD X, finding by Hussien *et al.* [9] and typical heat properties, which is used in the bio-heat transfer from [16].

Table 2. Electrical and thermal properties of elements used

Elements	915 MHz	2450 MHz
Substrate (RO4350)		
Permittivity, *ε*	3.48	3.48
Electrical conductivity, S/m	0.00077	0.00077
Specific heat capacity, J/kg°C	1×10^{-12}	1×10^{-12}
Patch (Copper)		
Permittivity, *ε*	1	1
Electrical conductivity, S/m	5.813×10^{7}	5.813×10^{7}
Specific heat capacity, J/kg°C	1×10^{-12}	1×10^{-12}
Breast Tissue		
Permittivity, *ε*	3.11433	3.24886
Electrical conductivity, S/m	0.88985	0.80329
Specific heat capacity, J/kg°C	3550	3550
Cancer Tissue		
Permittivity, *ε*	74.45	72.81
Electrical conductivity, S/m	1.88	2.72
Specific heat capacity, J/kg°C	3510	3510

The operating power and mass of SAR average over cube controlled at 1 W and 1 g during the simulation. The distance between antenna and breast phantom is fixed with 0 mm, which means it is directly in contact with the skin. Figures 5-8 show SAR distribution results with different applied frequencies in each cancer stage, and Table 3 presents the focus position and SAR, respectively.

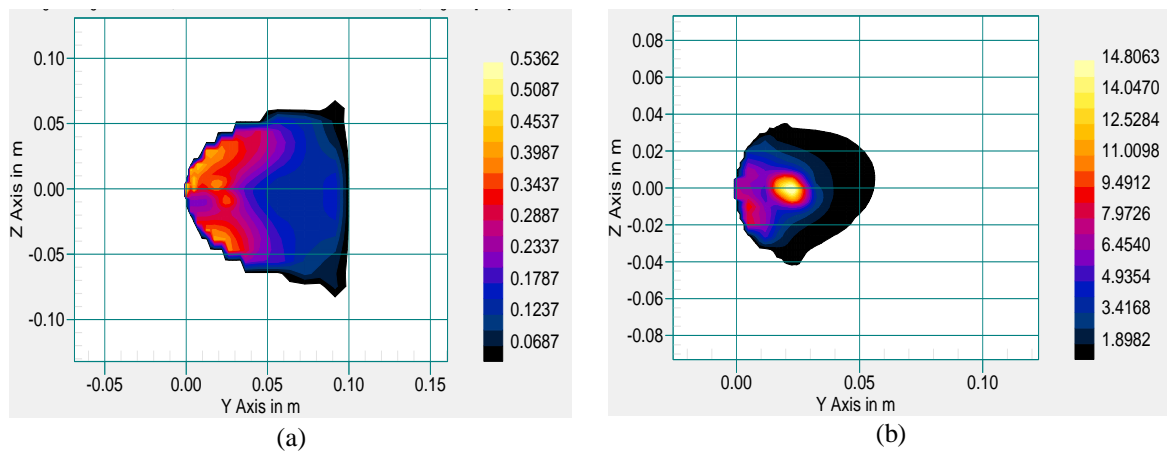(a)   (b)

Figure 5. Early stage cancer SAR distribution results in (a) 915 MHz and (b) 2450 MHz
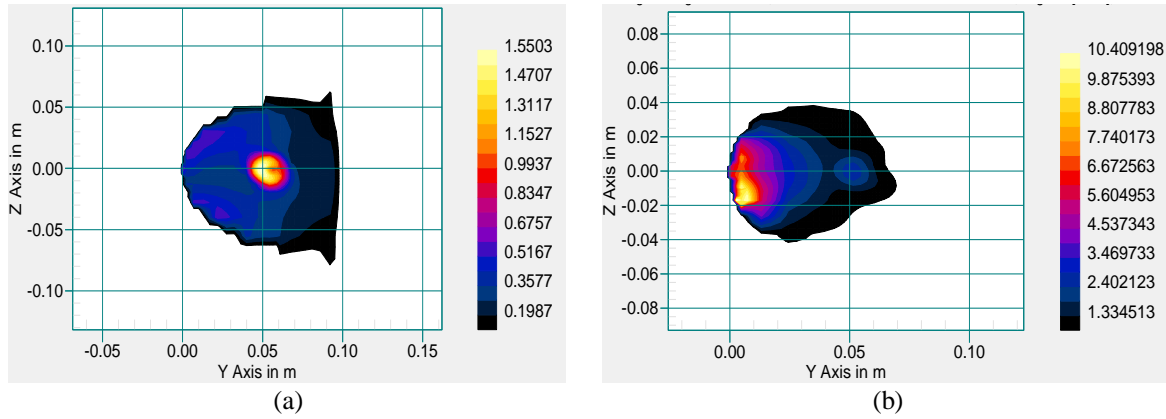
Figure 6. Stage 1 cancer SAR distribution results in (a) 915 MHz and (b) 2450 MHz
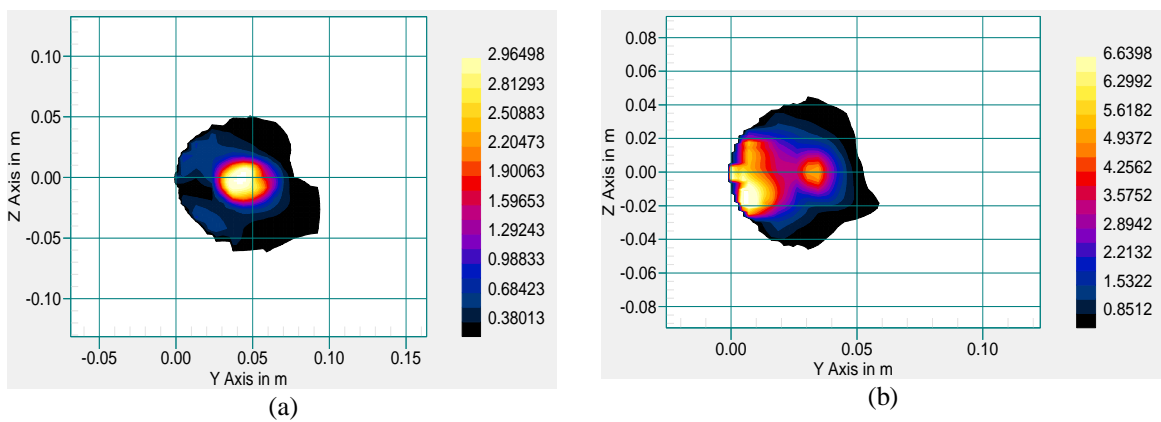

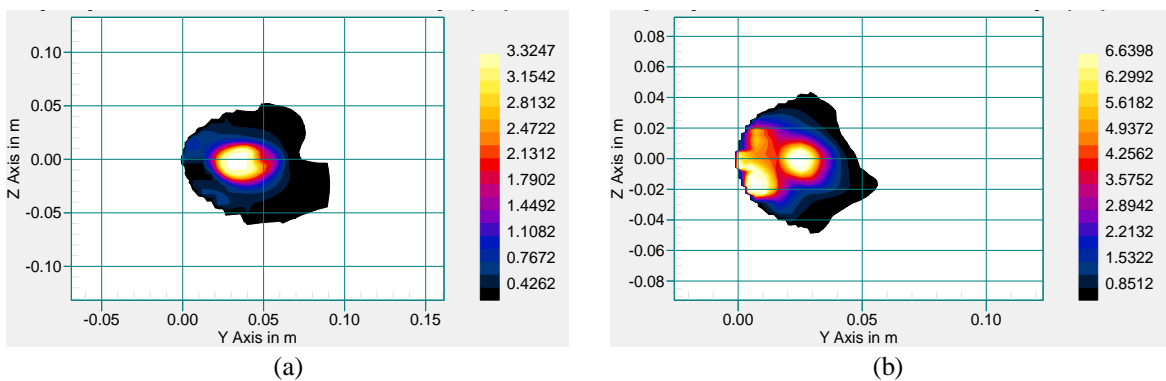Figure 7. Stage 2 cancer SAR distribution results in (a) 915 MHz and (b) 2450 MHz

Figure 8. Stage 3 cancer SAR distribution results in (a) 915 MHz and (b) 2450 MHz

Table 3. Focus position distance (FPD) and peak-spatial-average SAR results with 915 and 2450 MHz microstrip antenna

Results / Frequency	Early Stage		Stage 1		Stage 2		Stage 3	
	FPD (mm)	SAR (mW/g)	FPD (mm)	SAR (mW/g)	FPD (mm)	SAR (mW/g)	FPD (mm)	SAR (mW/g)
915 MHz	0-24	0.60	43-63	1.21	29-61	3.01	20-51	3.38
2450 MHz	15-27	15.2	EM-wave not covered into cancer region	N/A	0-16 & 27-36	6.81	0-34	6.81

As shown in Figures 5-8, and Table 3, 2450 MHz is the most suitable for early-stage cancer, where the heat from the microstrip antenna has heated cancer with good focus position distance and penetration depth. Furthermore, the location of cancer for the early-stage is near to the skin. According to the Universal Wave Equation, $= \frac{f}{\lambda}$, and wavelength is directly proportional to the penetration depth of the wave. Thus, a 2450 MHz antenna with higher gain but low penetration depth is suitable for early-stage cancer. Meanwhile, a 915 MHz antenna with higher wavelength and penetration depth is performed better than the 2450 MHz antenna for Stage-1, -2, and -3 breast cancer, where cancer locations are located in the deeper region. These research results can be validated with findings by [31], whereas temperature or SAR distribution with 2450MHz antenna decreased rapidly when propagation distance increased.

Furthermore, with the resulted Peak-Spatial-Average SAR, the estimation of treatment periods can be calculated through (10) with specific capacity of breast cancer tissue 3510 J/kg°C and required temperature increment from 4 to 8 °C as follows:

a) Early Stage:

$$dt_1 = \frac{3510(4)}{15.2} = 923.68 \; seconds$$

$$dt_2 = \frac{3510(8)}{15.2} = 1847.37 \; seconds$$

Thus, the early cancer stage required 15.39 minutes until 30.78 minutes for the treatment with a 2450 MHz antenna. With similar calculation steps, the treatment period estimation for Stage-1, -2 and -3 are:

b) Stage-1: 193.39 minutes until 386.77 minutes with 915 MHz antenna.
c) Stage-2: 77.74 minutes until 155.48 minutes with 915 MHz antenna.
d) Stage-3: 69.23 minutes until 138.46 minutes with 915 MHz antenna.

The treatment period estimation is important in further research as it can validate the efficiency of prototype fabricated. The animal studies mentioned in [32] also stated that 60 to 360 minutes are required to reach 42°C by using HTP. While [31] also proved that the increase of temperature and treatment periods could be affected by applied frequency, electrical properties of tissue and required penetration depth.

4. CONCLUSION

Hyperthermia SAR simulation in different frequencies is essential for future research as the most suitable frequency can be identified when targeted to various sizes, stages, or locations of breast cancer. Thus, microstrip antenna with 915MHz and 2450MHz are modeled with SEMCAD X software simulator to obtain the SAR distribution on different breast cancer stages. Based on the results, it is observed that 915MHz is good to be applied for breast cancer stage-1 to stage-3, while 2450MHz is performed well for early-stage cancer. In addition, different stages of cancers have different estimation of the hyperthermia execution treatment period. This period is significant to ensure hyperthermia is executed well with the required temperature range. Overall, from the results, 915MHz operating frequency is the most suitable frequency that able to perform better for most of the cancer stages. Beside clarifying the most suitable applied frequency for different breast cancer stages, in our further research, the SAR distribution or SAR coverage will be further improved by integrating various antenna designs, enhancing the lens structure as well as metamaterial structures in order to enhance the performance of HTP with less unwanted hot spots area and minimize the adverse health effects, simultaneously.

REFERENCES

[1] Y. Yagawa, K. Tanigawa, Y. Kobayashi, and M. Yamamoto, "Cancer immunity and therapy using hyperthermia with immunotherapy, radiotherapy, chemotherapy, and surgery," *J. Cancer Metastasis Treat.*, vol. 3, no. 10, p. 218, Oct. 2017.
[2] K. Lias, M. Z. A. Narihan, and N. Buniyamin, "An antenna with an embedded ebg structure for non invasive hyperthermia cancer treatment," in *IECBES 2014, Conference Proceedings-2014 IEEE Conference on Biomedical Engineering and Sciences: "Miri, Where Engineering in Medicine and Biology and Humanity Meet,"* 2014, no. December 2014, pp. 618-621, doi: 10.1109/IECBES.2014.7047577

[3]   Y. S. Koo, R. Kazemi, Q. Liu, J. C. Phillips, and A. E. Fathy, "Development of a high SAR conformal antenna for hyperthermia tumors treatment," *IEEE Trans. Antennas Propag.*, vol. 62, no. 11, pp. 5830-5840, 2014, doi: 10.1109/TAP.2014.2357419.

[4]   S. Jha, P. K. Sharma, and R. Malviya, "Hyperthermia: role and risk ractor for cancer treatment," *Achiev. Life Sci.*, vol. 10, no. 2, pp. 161-167, 2016, doi: 10.1016/j.als.2016.11.004.

[5]   E. Korkmaz, O. Isik, and S. Kara, "Electromagnetic modeling of a female breast hyperthermia applicator," in *IEEE Antennas and Propagation Society, AP-S International Symposium (Digest)*, 2013, pp. 2048-2049, doi: 10.1109/APS.2013.6711682.

[6]   N. Sharma, B. Jain, P. Singla, and R. R. Prasad, "Rectangular patch microstrip antenna: a survey," *Int. Adv. Res. J. Sci. Eng. Technol.*, vol. 1, no. 3, pp. 144-147, 2014.

[7]   P. Chalasani, A. Agarwal, and A. Patel, "Targeted therapies in hematological malignancies," in *Current Cancer Treatment - Novel Beyond Conventional Approaches*, InTech, 2011, pp. 455-474, doi: 10.5772/22170.

[8]   K. P. Tamarov *et al.*, "Radio frequency radiation-induced hyperthermia using Si nanoparticle-based sensitizers for mild cancer therapy," *Sci. Rep.*, vol. 4, 2014, doi: 10.1038/srep07034.

[9]   M. Hussein, F. Awwad, D. Jithin, H. El Hasasna, K. Athamneh, and R. Iratni, "Breast cancer cells exhibits specific dielectric signature in vitro using the open-ended coaxial probe technique from 200 MHz to 13.6 GHz," *Sci. Rep.*, vol. 9, no. 1, pp. 1-8, 2019, doi: 10.1038/s41598-019-41124-1.

[10] S. Park, J. Hwang, Y. Kwon, and C. Cheon, "A new antenna system for microwave non-invasive hyperthermia lipolysis," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, vol. 2, pp. 5683-5686, 2012, doi: 10.1109/EMBC.2012.6347285.

[11] W. C. Choi, S. Lim, and Y. J. Yoon, "Evaluation of transmit-array lens antenna for deep-seated hyperthermia tumor treatment," *IEEE Antennas Wirel. Propag. Lett.*, vol. 19, no. 5, pp. 1-1, 2020, doi: 10.1109/LAWP.2020.2982676.

[12] D. Vrba, D. B. Rodrigues, J. Vrba (Jr.), and P. R. Stauffer, "Metamaterial antenna arrays for improved uniformity of microwave hyperthermia treatments," *Prog. Electromagn. Res.*, vol. 156, no. April, pp. 1-12, 2016, doi: 10.2528/PIER16012702.

[13] Y. Tao and G. Wang, "Influence of source offset on breast tumor hyperthermia with Γ-shaped LHM lens applicator," in *2010 Int. Conf. Microw. Millim. Wave Technol. ICMMT 2010*, pp. 1859-1861, 2010, doi: 10.1109/ICMMT.2010.5524876.

[14] K. Lias, N. Buniyamin, and M. Z. B. A. Narihan, "An overview of cancer thermal therapy technology based on different types of antenna exposure," in *2013 International Conference on Electrical, Electronics and System Engineering, ICEESE 2013*, 2013, pp. 96-101, doi: 10.1109/ICEESE.2013.6895050.

[15] K. Lias, N. Buniyamin, and M. Z. A. Narihan, "Simulation study of an EBG-M applicator towards non-invasive breast hyperthermia cancer procedure," *J. Teknol.*, vol. 78, no. 5-6, pp. 75-81, 2016, doi: 10.11113/jt.v78.8641.

[16] L. Leggio, O. De Varona, and E. Dadrasnia, "A comparison between different schemes of microwave cancer hyperthermia treatment by means of left-handed metamaterial lenses," *Prog. Electromagn. Res.*, vol. 150, no. October 2014, pp. 73-87, 2015, doi: 10.2528/PIER14101408.

[17] N. A. Jaffar, K. Lias, N. K. Madzhi, and N. Buniyamin, "Improving the performance of applicators for use in hyperthermia cancer treatment procedure by the introduction of LHM lens," *Int. J. Electr. Electron. Syst. Res.*, vol. 14, no. 6, 2019.

[18] S. Curto and P. Prakash, "Design of a compact antenna with flared groundplane for a wearable breast hyperthermia system," *Int. J. Hyperth.*, vol. 31, no. 7, pp. 726-736, 2015, doi: 10.3109/02656736.2015.1063170.

[19] D. A. M. Iero, L. Crocco, T. Isernia, and E. Korkmaz, "Optimal focused electromagnetic hyperthermia treatment of breast cancer," *2016 10th Eur. Conf. Antennas Propagation, EuCAP 2016*, 2016, doi: 10.1109/EuCAP.2016.7481515.

[20] P. T. Nguyen, A. M. Abbosh, and S. Crozier, "3-D focused microwave hyperthermia for breast cancer treatment with experimental validation," *IEEE Trans. Antennas Propag.*, vol. 65, no. 7, pp. 3489-3500, 2017, doi: 10.1109/TAP.2017.2700164.

[21] O. Fiser, I. Merunka, and J. Vrba, "Microwave hyperthermia system for head and neck area with noninvasive UWB temperature change detection," *Prog. Electromagn. Res. Symp.*, vol. 3, pp. 1657-1662, 2017, doi: 10.1109/PIERS.2017.8262015.

[22] A. W. Kurian *et al.*, "Recent trends in chemotherapy use and oncologists' Treatment Recommendations for Early-Stage Breast Cancer," *JNCI J. Natl. Cancer Inst.*, vol. 110, pp. 493-500, 2017, doi: 10.1093/jnci/djx239.

[23] L. Xu and X. Wang, "Focused microwave breast hyperthermia monitored by thermoacoustic imaging: a computational feasibility study applying realistic breast phantoms," *IEEE J. Electromagn. RF Microwaves Med. Biol.*, vol. 4, no. 2, pp. 81-88, 2020, doi: 10.1109/JERM.2019.2931623.

[24] S. Alam, I. Surjati, and Y. K. Ningsih, "Patch modification and slot arrangement of microstrip antenna for improving the axial ratio," in *2017 International Conference on Broadband Communication, Wireless Sensors and Powering, BCWSP 2017*, 2018, vol. 2018-Janua, pp. 1-5, doi: 10.1109/BCWSP.2017.8272553.

[25] A. Banwari, N. Acharya, M. Kumar Sharma, and S. Saxena, "Low loss semicircular slotted microstrip patch antenna for ISM band application," in *2017 6th International Symposium on Next Generation Electronics, ISNE 2017*, 2017, pp. 4-7, doi: 10.1109/ISNE.2017.7968718.

[26] M. Sethi and G. Nijhawan, "Design of microwave antenna for hyperthermia system," *Int. J. Wirel. Microw. Technol.*, vol. 6, no. 4, pp. 39-47, 2016, doi: 10.5815/ijwmt.2016.04.04.

[27] M. Salimian, A. Rezai, S. Hamidpour, and F. Khajeh-khalili, "Effective features in thermal images for breast cancer detection," in *2nd National Conference on New Technologies in Electrical and Computer Engineering*, 2019, pp. 1-7.

[28] Z. Wang *et al.*, "Tumor size of breast invasive ductal cancer measured with contrast-enhanced ultrasound predicts

regional lymph node metastasis and N stage," *Int. J. Clin. Exp. Pathol.*, vol. 7, no. 10, pp. 6985-6991, 2014.

[29] G. Chakaravarthi and K. Arunachalam, "A compact microwave patch applicator for hyperthermia treatment of cancer," in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC 2014*, 2014, pp. 5320-5322, doi: 10.1109/EMBC.2014.6944827.

[30] *IEC/IEEE 62704-1*, 1/2017 ed. Geneva: IEC (International Electrotechnical Comission) and IEEE (Institute of Electrical and Electronics Engineers), 2017.

[31] P. Gas, "Tissue temperature distributions for different frequencies derived from interstitial microwave hyperthermia," *Prz. Elektrotechniczny*, vol. 88, no. 12 B, pp. 131-134, 2012.

[32] Z. Behrouzkia, Z. Joveini, B. Keshavarzi, N. Eyvazzadeh, and R. Z. Aghdam, "Hyperthermia: how can it be used?," *Oman Med. J.*, vol. 31, no. 2, pp. 89-97, 2016, doi: 10.5001/omj.2016.19.

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