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Analysis of Heat Propagation on Difference Size of Malignant Tumor

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ABSTRACT

Cancer is one of the leading causes of death in Malaysia as reported by the Malaysia National Cancer. Statistical data showed that breast cancer has the highest percentage over the other cancers in Malaysia Treatment such as hyperthermia therapy is introduced as an alternative treatment to increase the efficiency of radiotherapy and chemotherapy. This procedure exposes the malignant tissue to a high temperature between 40 to 44 degrees Celsius This study focuses on how different heat sources affect the heat propagation of malignant breast tumours. The malignant breast tumour of different sizes also will be considered in this study. The heat propagation was simulated using the computational fluid dynamic (CFD) method. Infrared sources are imposed in this study. The transient Pennes Heat equation is also applied to solve the heat generation Velocity and pressure in the blood vessel have no significant changes for all models. In summary, this study will predict the hyperthermic heat propagation efficiency onto the malignant tissue as well as predict the optimum heat generation on the malignant tumour.

Keywords:
Malignant Tumor, Heat Propagation,
CFD

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1. Introduction

According to the Malaysia National Cancer registry report, cancer is the biggest cause of death in the world and Malaysia. From 2018 to 2020, it accounted for the second-largest number of deaths in Malaysia. Most breast cancer tumours grow for several years before being discovered. The cell will mutate that spread in the body and not be damaged hence spreading to the adjacent cells by Azian Azamimi Abdullah [1]. Breast cancer is a malignant tumour that starts in the breast tissues. There are two types of tumours which are benign and malignant by Odetallah [2]. At the first stage, it is not cancerous as it still can be controlled. However, as the tumour grows and spreads all over the part of the body, it will be cancerous. The cancer treatment is necessary to kill the cell tumour before it is spreading wide Slamet Wahyudi [3].

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Therefore, Medical research is given significant emphasis under the government's goals in healthcare reform, as defined in the 12th Malaysia Plan to improve awareness of health in Malaysia, particularly in cancer rehabilitation. Treatment such as hyperthermia therapy is introduced as an alternative treatment to increase the efficiency of radiotherapy and chemotherapy by Sardari [4]. Hyperthermia treatment is a sort of medical treatment that involves exposing human tissue to temperatures between 40°C and 45°C (104°F and 113°F) to destroy and kill cancer cells while causing little or no harm to normal tissue by Nikolova [5]. This technique is one of the most effective cancer treatments because it can kill tumours at high temperatures while producing minimal or no damage to healthy tissue. It is also required to expose cancer cells to high temperatures to damage them and relieve symptoms. However, this procedure is highly risky if the body is exposed to a temperature of more than 44˚C as this temperature will introduce non-cancerous cell damage by Foulkes [6]. This is due to inconsistent heat propagation on the body. Suitable heat sources are important to obtain optimised heat propagation and penetration into the tumour tissue without damaging the normal tissue.

The main objective of this study is to determine the temperature distribution for the difference in the size of the malignant tumour in the human body and to investigate the heat propagation of the infrared sources. Infrared (IR) is one approach for focusing heat on the tumour, in which the heat source is exposed directly to the area of concern by Foulkes [6]. Besides, the side effects are still acceptable as it less dangerous compared to the other treatment. The temperature inside the breast was measured invasively using infrared at the needle's end. Infrared also known as infrared light, is a type of electromagnetic radiation (EMR) that has wavelengths that are longer than visible light.

This study also will be focused on the different sizes of malignant tumours that be modelled based on the patient-specific geometry. Next, five variations of the temperature will be considered. Only used infrared as the source and use the Computational Fluid Dynamic (CFD) software to analyse the heat propagation of breast tumour staging for different temperatures by Lana Burgess [7]. Computational fluid dynamics has become one of the primary methods used by bioengineers in simulating the flow properties of the desired object by Lana Burgess [7]. Computer modelling makes a substantial contribution and serves as a useful tool for researching the different sizes of tumours. In this study, detailed statistical data distribution is encouraged to identify the physical changes and heat distribution on the different tumour sizes and allow for analysis of the impact of infrared on malignant tumours to be generated.

2. Methodology

2.1 Discretization Technique

The discretization technique is the steps from using meshing to using the numerical method to solve a certain problem. The discretization of the computational domain is a critical step in CFD. It has an impact on the model under consideration's numerical stability as well as the consistency of the results with actual data by Jha [8]. Therefore, it depends on the governing equation use, type of mesh and type of flux. There were three types of discretization techniques which are finite difference, finite element, and finite volume by Gonzalez Hernandez [9]. For this research, the finite volume method will be applied. Since heat flux will be the type of flux study, the heat penetration formula, heat radiation equation, and Pennes bioheat equation are suitable to be the governing equation.

2.2 Governing Equation

The heat penetration equation is usually used to calculate the heat penetration factor for liquid and solid food products by Gonzalez Hernandez [9]. Since the tumour tissue is in a state of solid, it is not a problem to look at this theory. The heat penetration factor, fh formula for solid is:

$$fh = \frac{2.3 \times C_p \times \rho}{k \times S^{*2}} \quad (1)$$

where Cp is the specific heat capacity, ρ is the density and k is the thermal conductivity by Gonzalez-Hernandez [9].

There are three types of heat transfers which are heat conduction, heat convection and heat radiation by Li [10]. Since electromagnetic is one kind of radiation, heat radiation is valid in this study to calculate the rate of heat transfer in the tumour tissue. The general formula for heat radiation by following the Stefan-Boltzmann law is:

$$\frac{\mathrm{Q}}{\mathrm{t}} = \sigma \mathrm{eAT}^4 \quad (2)$$

where σ = 5.67 × 10−8 J/sm2K^4 is the Stefan-Boltzmann constant, A is the surface area of the object, T is its absolute temperature in kelvin, and e is the emissivity.

Pennes bioheat equation is the most suitable mathematical model in this study. It has been used in a previous study by Tang [11]. used this equation to model heat transfer in the breast tissue. The Pennes bioheat equation is given by:

$$\rho_n C_n \frac{\partial T}{\partial t} = k_n \nabla^2 T + \rho_b C_b \omega_b (T_b - T_n) + Q_n \quad (3)$$

where ρ_b, c_b, T_b and ω_b represent density, specific heat of blood, arterial temperature, and blood perfusion rate respectively. Meanwhile, the tissue density, specific heat, temperature, thermal conductivity, and metabolic heat generation are given by ρ, c, T, k and Q.

The heat flux and temperature continuity by Becker [12], is described by the equation:

$$\mathrm{k_n} \frac{\partial \mathrm{T_n}}{\partial_\mathrm{n}} = \mathrm{k_{n+1}} \frac{\partial \mathrm{T_{n+1}}}{\partial_\mathrm{n}} \quad (4)$$

$$\mathrm{T_n} = \mathrm{T_{n+1}} \quad (5)$$

where η is the direction perpendicular to the surface. The assumption for the core body temperature is 37 °C by Wan Mohd Zawawi [13] The symmetry boundary condition and skin surface convective boundary condition can be described as:

$$\frac{\partial T}{\partial r} = 0 \; at \; r = 0 \quad (6)$$

$$-k \frac{\partial T}{\partial n} = h \, (T_s - T_\infty) \quad (7)$$

respectively where k= 0.235 Wm^{-1}K^{-1}, h = 10 Wm^{-2}K^{-1}, T_∞ = 21 °C. Lastly, for transient analysis cooling surface, the constant temperature boundary condition is used by Kastl [14].

$$T(t) = T_{cooling}\ 0 < t < t_{cooling} \quad (8)$$

2.3 Parameter of The Model

To create the models, Figure 2 is the dimension of the model and it is important to determine the parameter first. The value for the parameters was used as the reference to generate the model. For this research, three types of models are needed. The dimensions of the model were decided by considering the relevant value based on the previous studies. The radius of the tumours will be the manipulation variable. Table 1 shows the results of the decided value for the model's dimension.

Table 1
The parameter of the model

Parameter	Dimension (mm)
Radius of epidermis	36
Radius of tissue	32
Radius of blood	10
Radius of tumour	20,40 and 60
Length of the blood vessel	72

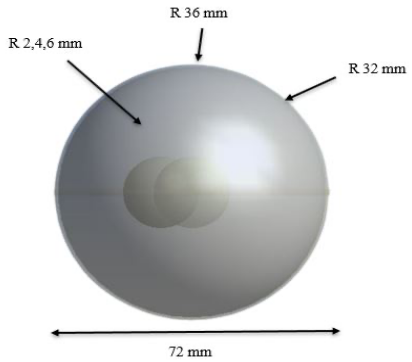


Fig. 1. The dimension of the model

2.4 Design and Geometry of Tumour

The ANSYS software's Design Modeler will be used to represent the tumour's reduced geometry. Geometry was used to calculate the influence of tumour size and location on the distribution of breast surface temperature. The three-dimensional geometry model was created for 3 different sizes of the tumour. Each model consists of four main part which is the skin layer, the fat layer at the base of the breast, the muscle chest wall and the blood vessel. The tissue was in sphere shape while the blood vessel is in cylindrical as indicated in Figure 2. Each model in this study has tumour layers with a diameter of 2mm labelled as Model A, followed by Model B for a 4mm tumour and Model C for a 6mm tumour. Table 2 is the design of simplified models.

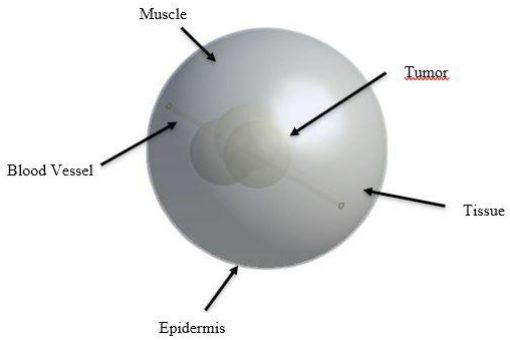
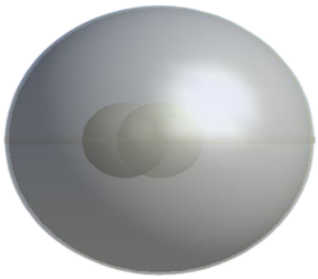
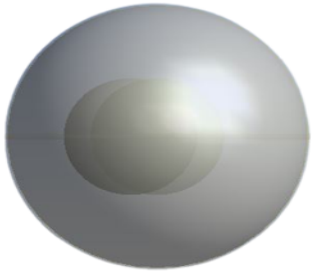
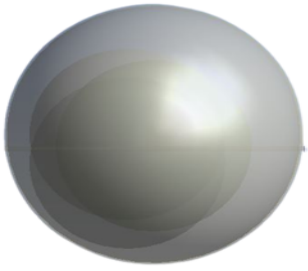


Fig. 2. The labelled model

Table 2
Design of Simplified Models

Type of simplified model	Simplified model
Model A	
Model B	
Model C	

2.5 Meshing of The Model

Mesh or grid refers to a small discrete cell or elements that are divided into a domain or model by Karthik [15]. At the centres of these tiny discrete cells or elements, all flow variables and other variables are solved. Mesh generation is the process of breaking down the physical domain into smaller cells or pieces. In general, high-quality CFD simulations start with a high-quality mesh because it allows for faster and more accurate simulation convergence. As a result, accurate and exact

geometric mesh generation is critical, as any meshing error might have a major impact on the solution by Eibner [16].

The mesh generation consists of several steps. The first step is face meshing by selecting all the surfaces of the breast cancer model. To obtain perfect meshing, this step must be done carefully on every single surface of the model. After done, volume meshing is generated by choosing the suitable type of mesh. Figure 3 shows the meshing of the model.

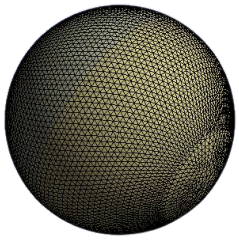


Fig. 3. The meshing of the model

2.6 Boundary Condition

The types of parameters that have been set as the boundary condition are density, thickness, and specific heat capacity. The conditions such as fluid flow velocity, inlet pressure and temperature must be set. Table 3 shows the value for the boundary condition by referring to the previous study.

Table 3
The boundary conditions of the study

No	Boundary Condition	Value	(Author)
1.	Density of epidermis	1200 (kg/m^3)	Eibner [16]
2.	Density of tumour	1040 (kg/m^3)	Eibner [16]
3.	Density of tissue	1050 (kg/m^3)	Eibner [16]
4.	Density of blood	1050 (kg/m^3)	Eibner [16]
5.	The thickness of the fat layer on the tumour	1 mm	Bhargava[17]
6.	The thickness of the epidermis on the tumour	0.5 mm	Bhargava[17]
7.	Specific heat capacity of the epidermis	3852 (J/kg. K)	Eibner [16]
8.	Specific heat capacity of tumour	3589 (J/kg. K)	Eibner [16]
9.	Specific heat capacity of tissue	3770 (j.$kg^{-1}.K^{-1}$)	Eibner [16]
10.	Specific heat capacity of the blood	3770 (j.$kg^{-1}.K^{-1}$)	Eibner [16]
11.	Blood viscosity	0.001 (kg.$m^{-1}.s^{-1}$)	Eibner [16]
12.	Thermal conductivity of epidermis	0.35	Li [18]
13.	Thermal conductivity of tumour	0.25	Li [18]
14.	Thermal conductivity of tissue	0.5 (W.$m^{-1}K^{-1}$)	Li [18]
15.	Thermal conductivity of blood	0.5 (W.$m^{-1}K^{-1}$)	Li [18]
16.	The velocity of the blood	0.008ms^{-1}	Li [18]

3. Results

3.1 Temperature Distribution

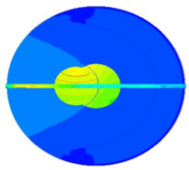
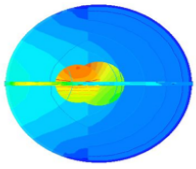
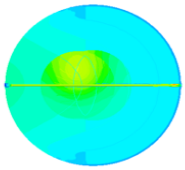
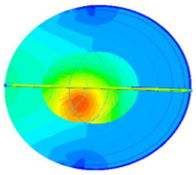
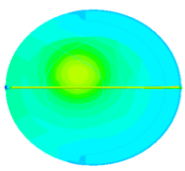
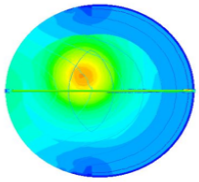
There are three different cases have been used by changing the heat temperature to the model which are 50°C, 55°C, 60°C, 65°C and 70°C. The 2mm tumour is labelled as Model A, followed by Model B for the 4mm tumour and Model C for the 6mm tumour. This will demonstrate how deeply the heat can into tumour tissue.

Based on the results in Table 4, the radiation on the model not only affected the tumour tissue but also the blood vessel. As the size of the model increase, the temperature of the tumour becomes decrease. It can be seen the table above has been covered by the higher temperature in the contour. In Model A and Model B, there are also areas with high temperatures that burn on the tumour surface. Whereas in Model C, the high temperature on the tumour surface was less burning than the others.

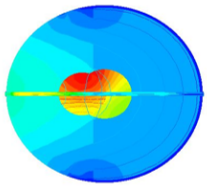
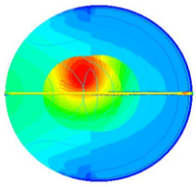
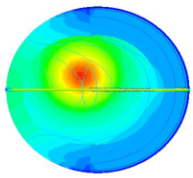
3.2 Velocity

The size of the tissue is the main reason for the difference in blood velocity. This is due to the temperature contour's indication that the quantity of heat that can reach the blood will be constrained as the tissue grows. The outcome in the outlet velocity could vary depending on the radiation temperature used in this study in each case. For all types of cases and models, the inlet velocity for this case is fixed at 0.008 m/s. To determine the velocity along the blood vessel, the simulation's results were exported. Figure 4 shows the Graph of velocity in a blood vessel for 50, 55, 60, 65, and 70˚C.

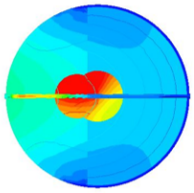
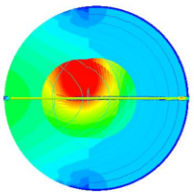
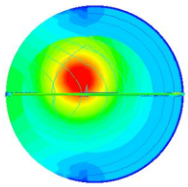
Table 4
Heat propagation in model A, model B and model C

Model	Scale	The heat propagation in the model for 50˚C	Model	Scale	The heat propagation in the model for 55˚C
A	Temperature Contour 7 323.15 322.15 321.15 320.15 319.15 318.15 317.15 316.15 315.15 314.15 313.15 [K]		A	Temperature Contour 7 328.15 308.45 288.75 269.05 249.35 229.65 209.95 190.25 170.55 150.85 131.15 [K]	
B			B		
C			C		

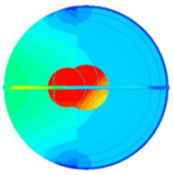
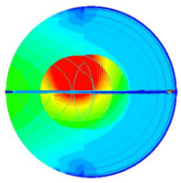
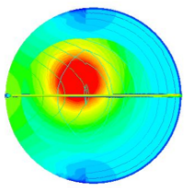
The heat propagation in the model for 60˚C

Model	Scale	Heat Propagation
A	Temperature Contour 7: 333.15, 331.15, 329.15, 327.15, 325.15, 323.15, 321.15, 319.15, 317.15, 315.15, 313.15 [K]	
B		
C		

The heat propagation in the model for 65˚C

Model	Scale	Heat Propagation
A	Temperature Contour 7: 338.15, 317.45, 296.75, 276.05, 255.35, 234.65, 213.95, 193.25, 172.55, 151.85, 131.15 [K]	
B		
C		

The heat propagation in the model for 70˚C

Model	Scale	Heat Propagation
A	Temperature Contour 7: 343.15, 321.95, 300.75, 279.55, 258.35, 237.15, 215.95, 194.75, 173.55, 152.35, 131.15 [K]	
B		
C		

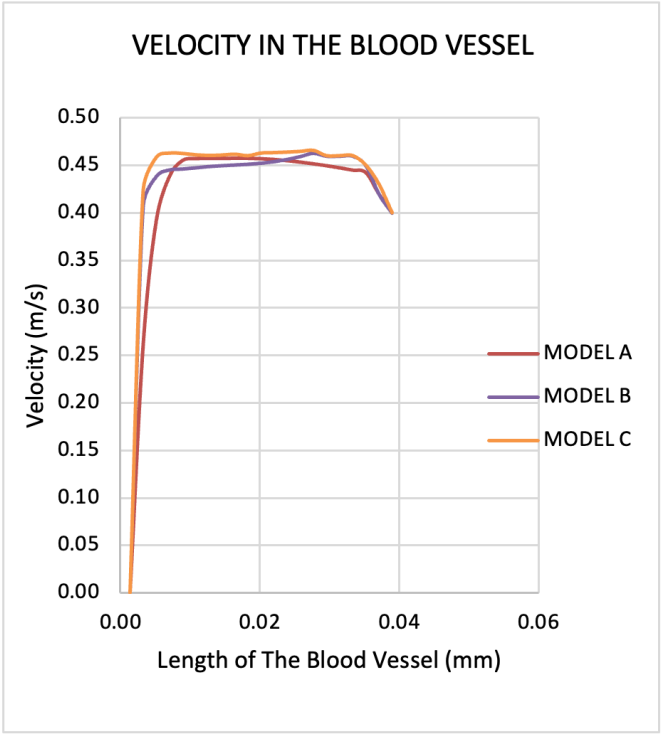


Fig. 4. Graphs of velocity in a blood vessel for 50, 55, 60, 65, 70˚C

3.3 Pressure

The pressure may not affect much on the tumour model much, but it is relevant to see how the heat propagation will have an impact on this value. Figure 5 shows the graph of pressure in a blood vessel for 50, 55, 60, 65, and 70 ˚C. For the setup, the pressure is set at 0 Pascal at the outlet heat and outlet blood vessel. Because of that, the graph has remained in the same pattern.

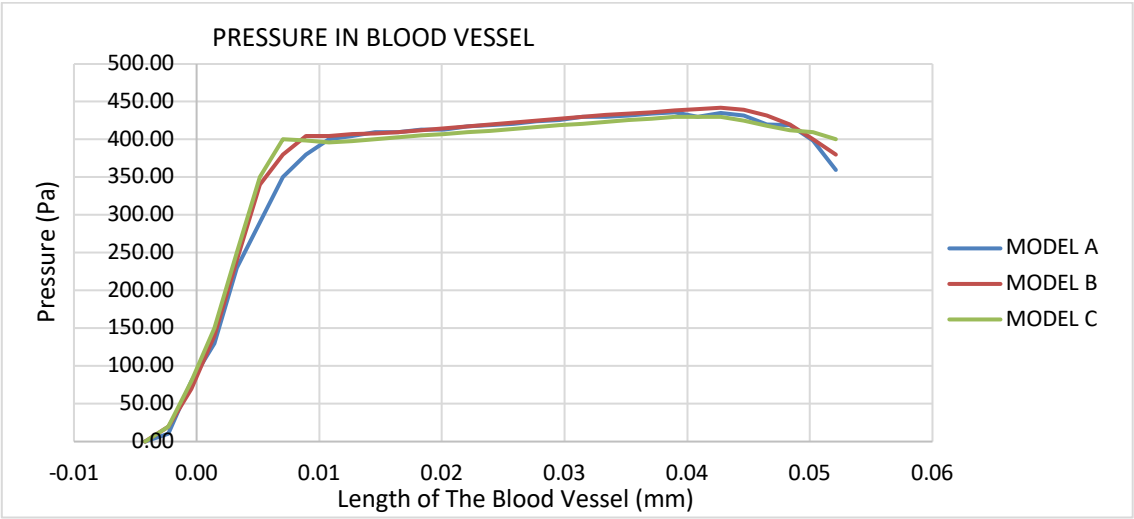


Fig. 5. Graph of pressure in a blood vessel for 50, 55, 60, 65, 70˚C

Figure 6 shows the comparison between the previous study and the simulation result. The temperature profile for breast cancer is stimulated by Morón [19]. The figure shows the temperature distribution from the result of the previous study.

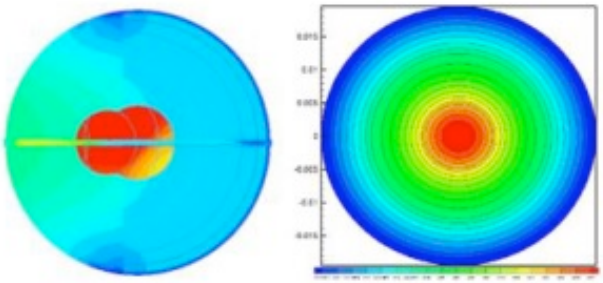


Fig. 6. Comparison between previous study and simulation result by Morón [19]

To make the result valid, a similar model to the previous study was created. The simulation was run using an identical setup to get the outcome. Figure xx below shows a comparison of the two outcomes. The result from the previous study is different. However, different temperatures have been set. It can be seen the different contours on the tumour area. This is due to the temperature that has been applied to the tumour from the previous study being more flammable than the studies that have been done by Adhikary [20]. The tumour from the previous study was more extensive than the results from the simulations.

4. Conclusions

The results illustrate that radiation can have an impact on the blood vessel. The temperature in the blood vessel shows that the temperature increases and remain constant with a little fluctuation along the blood vessel. However, the temperature slightly decreased at the end. This is because, as the tissue grows larger, the quantity of heat that can enter the blood will decrease. In addition, the surface temperature is the main factor contributing to the instability in the blood flow and temperature fields. Every case has a different contour. Model A shows operating at higher temperatures, allowing heat to reach deeper into the tumour. However, compared to other models, the high temperature that reaches the tumour is little. This may be due to radiation exposure while the tumour is still small. The larger the tumour size the less heat reaches the tumour. Meanwhile, the velocity results of each case are the same.

In conclusion, the study succeeds in determining the temperature distribution of various sizes of malignant tumours. According to the temperature contours, malignant tumours of different sizes have different temperature distributions. Finally, the study accomplishes a further objective involving heat penetration by the infrared source where the temperature data at a specific depth of malignant tumours have been obtained.

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