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Heat Distribution on Abdominal Aorta Having Aneurysm During Hyperthermia Therapeutic

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Abstract: Hyperthermia therapy is an induce heat treatment to the tumour temperature elevated with temperature 40˚C - 43˚C to cure the cancerous tissues. Hyperthermia therapy use an outer heat source to rise the temperature of the tumour to 40 ˚C -43°C for a certain period. On the other hand, abdominal aortic aneurysm is an enlargement area of an abdominal aorta. Over time, blood flow can cause the weak area to bulge like a balloon. An abdominal aortic aneurysm (AAA) occurs in the abdominal section of the aorta. Nowadays, the common treatment for AAA are open surgery and endovascular aortic repair (EVAR). There are two treatment for abdominal aortic aneurysm nowadays, the potential of risk is high to cause death and post procedural complications. However, an alternative way to replace the open surgery and endovascular aortic repair (EVAR) was found, it called a non-invasive method. Hyperthermia therapy with outer heat source is an alternative idea for treatment AAA. In this study, a heat source with 4 different temperature was used to rise the temperature of the AAA area and two difference physiological condition was applied in the abdominal aorta. The 4-difference temperature of heat source are 50˚C, 55˚C, 60˚C, 65°C and the two physiological condition are normal blood pressure (85mmHg) and high blood pressure (140mmHg). In this pilot study was focus on temperature distribution at the abdominal aorta wall. Computational fluid dynamic (CFD) used in this study to simulate the heat distribution on the abdominal aorta wall. CFD software used in this study is ANSYS version R19.2. In this study, the result shows that the heat source at temperature 50˚C - 60°C, the normal abdominal aorta wall and abdominal aorta having aneurysm wall temperature reach 39˚C - 44°C in NBP and HBP condition respectively.

Keywords: Hyperthermia therapy, Abdominal aortic aneurysm, Heat distribution, blood pressure, temperature

1. Introduction

Hyperthermia therapy is a technic refer to utilise a heat source via external devices to kill cancer cell with elevation the body region temperature up to 40 °C- 45 °C [1, 2]. Hyperthermia therapy treatment can operate with single modality or synthetic other cancer treatment to improve the effectiveness [3, 4]. Typically, in hyperthermia technic, electromagnetic energy with high frequency is

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applied to the tissue using either external or internal applicators depending on the tumour location. Internal applicators use a needle or probe to release the energy directly into the tumour, and external applicators radiate the tissue from outside. There are three way of thermal therapy in the clinical applications of hyperthermia which are whole-body hyperthermia, regional hyperthermia, and local hyperthermia [5]. The aorta is the largest blood vessel in the human circulatory system which carries/supplies blood to the head, arms, abdomen, legs, and pelvis. The walls of the aorta can swell or bulge out like balloon if they become weak. This phenomenon is known as abdominal aortic aneurysm (AAA) when it happens in the abdominal part of the aorta.

Bioheat transfer is define as the transport of thermal energy into the biological system. Bioheat transfer is a subfield of biomedical and bioengineering. Bioheat transfer paly an importance role in biological fields to diagnose and hyperthermia therapeutic application involving heat transfer. The transport of thermal energy in living tissue depends on temperature. Heat transfer in living tissue is a complex process and includes conduction, convection, and blood perfusion (such as delivery of the arterial blood to a capillary bed), cooling of human body by radiation, and metabolic heat generation. Metabolic heat generation results from a series of chemical reactions occurring in the living cells and blood perfusion occurs due to energy exchange between the living tissue and blood flow through small vessels in the living tissue. Of importance in bioheat transfer is the determination of the living tissue (e.g., skin, fat, muscle, bone, and blood) properties such as specific gravity, specific heat, and thermal conductivity [6]. Blood flow can significantly affect the temperature distributions during thermal treatments, particularly in large blood vessels [7]. Kolios et al. [8] demonstrated that blood flow through large blood vessels plays an important role in determining temperature profiles of heated tissues even when the treatment time is within 3– 20s.

2. Methodology

CFD software was a medium or platform to study the fluids dynamics flow and another parameter involved. It helps professionals such as engineer and scientist to understand and predict fluid flow through a simulation study. In this study, ANSYS was used to simulate the temperature distribution flow characteristic through abdominal aorta wall. The simulation was then analysed to get results.

For the present study, a Computational Fluid Dynamics (CFD) analysis was employed whereby a normal abdominal aorta and abdominal aorta having aneurysm model of 0.02m and 0.03m diameter [9] respectively with a length of 0.3m was constructed using Solid-works as shown in Figure 1 (a) model with normal aorta (b) Model with fusiform aneurysm aorta below. The geometries of both models were then imported to ANSYS Workbench R19.2 for simulation purposes under steady-state condition. The simulation was done using transition SST model which is relatively enough to capture the heat transfer of the flow.

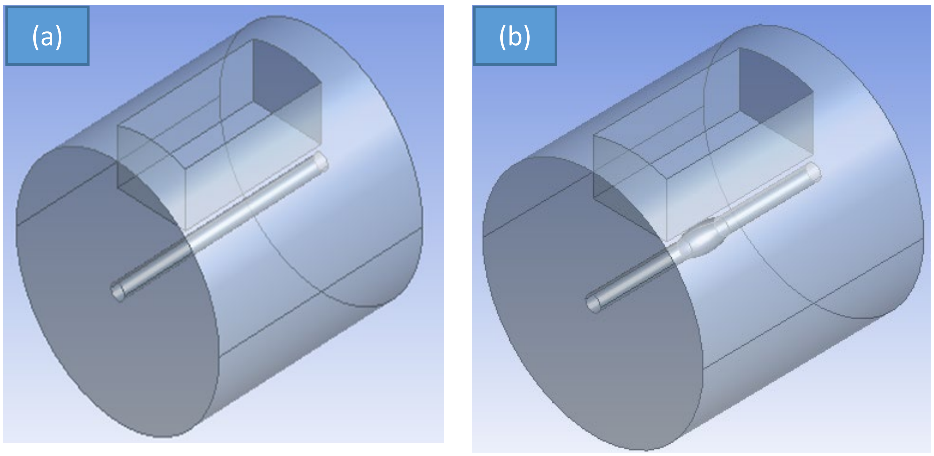


Figure 1: (a) model with normal aorta (b) Model with fusiform aneurysm aorta

2.1 Numerical modelling

The numerical model in this study was simulated with heat conduction formula as follow:

$$q = \frac{\Delta t \times \lambda}{\delta} \quad \text{Eq. 1}$$

Where q is heat flux, Δt the temperature difference so, it can obtain:

$$t_0 - t_1 = q\frac{\delta_0}{\lambda_0} \quad \text{Eq. 2}$$

$$t_0 - t_4 = q\left(\frac{\delta_0}{\lambda_0} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}\right) \quad \text{Eq. 3}$$

Solving simultaneous equation Eq. (2) and (3),

$$t_0 - t_1 = (t_0 - t_4).\frac{\frac{\delta_0}{\lambda_0}}{\left(\frac{\delta_0}{\lambda_0} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}\right)} \quad \text{Eq. 4}$$

2.2 Mesh independence study

Four sets of meshes with same simulation conditions were performed under the same boundary conditions for normal abdominal aorta model. The boundary conditions for the blood flow with velocity inlet of 0.31 m/s. The properties of the mesh along with its respective average error of temperature distribution are presented in Table 1.

Table 1: The properties of the mesh

GIT	Number of nodes	Number of elements	Max skewness	Average error of temperature distribution at aorta wall, K (%)
1	150883	872490	0.84	-
2	237469	1374594	0.85	0.69
3	328713	1895181	0.85	0.04
4	425037	2449983	0.85	0.19

Based on the results obtained, mesh 2 was picked for performing the rest of the simulations as it not only gave considerable accurate results but also a lower computational cost comparing with mesh 3 and mesh 4.

2.3 Boundary condition

In order to simulate temperature distribution on the aorta wall, the following boundary conditions were used as show in table 2.

Table 2: The simulate temperature distribution on the aorta wall

Parameter type	Parameter	Value
Blood properties	Blood Viscosity	0.0035 g/cm s
	Density	ρ=1060 kg/m3
	Specific heat capacity	3.49 kJ kg^{-1}°C^{-1} [
Boundary condition	Inflow pattern	60Hz
	Inflow velocity	31 cm/s
	Inflow rate profile	Pulsatile flow rate
	Outflow vessel blood pressure	p = 85mmHg /140mmHg

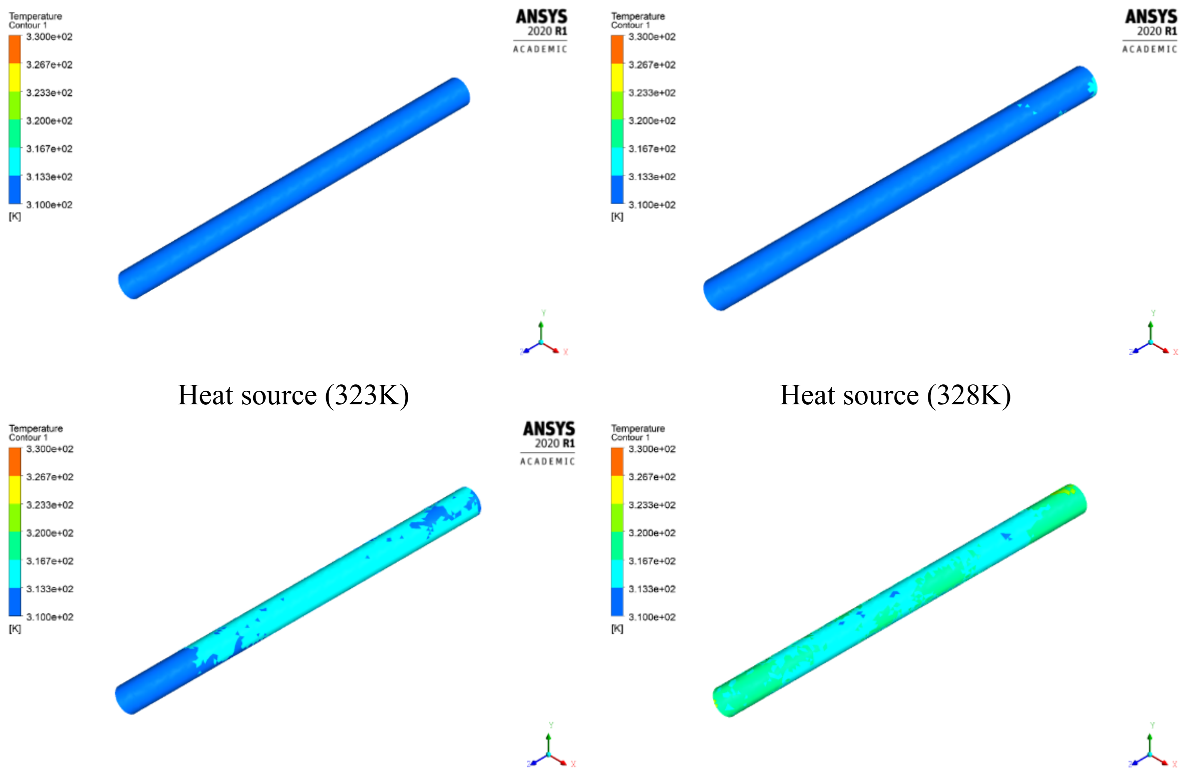
3. Results and Discussion

3.1 Normal abdominal aorta

Normal abdominal aorta is a healthy aorta with no dilation and its diameter with approximately 2 cm. Figure 2 shows the temperature distribution on the aorta wall in normal blood pressure (NBP) condition while Figure 3 shows temperature distribution on the aorta wall in high blood pressure (HBP) condition.

3.1.1 NBP for normal abdominal aorta

From the simulation result Figure 2, when the heat source temperature was set for 323K, no significant change in temperature at the aorta wall. When heat source temperature was set for 328K, a small change in temperature at the outlet. When the heat source temperature was set for 333K, temperature distribute almost cover the whole aorta wall. When the heat source temperature was set for 338K, the heat distribute fully cover the aorta wall.



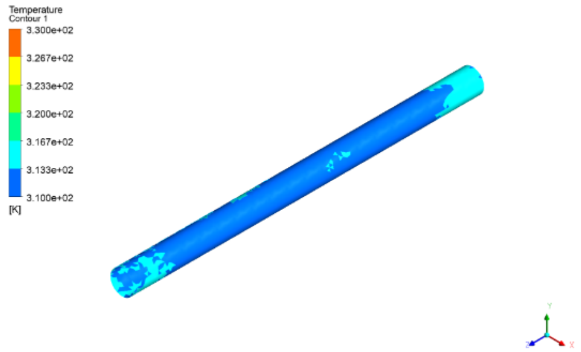
Heat source (323K) Heat source (328K)

Heat source (333K) Heat source (338K)

Figure 2: Temperature distribution on aorta wall

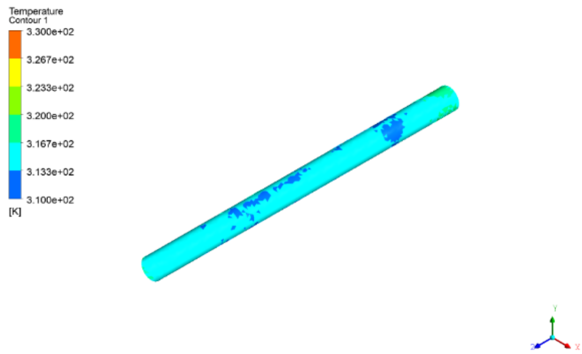
3.1.2 HBP for normal abdominal aorta

From the simulation result Figure 3, when the heat source temperature was set for 323K, temperature change at inlet and outlet. When heat source temperature was set for 328K, temperature shows significant change in outlet. When the heat source temperature was set for 333K, temperature distribute almost cover the whole aorta wall. When the heat source temperature was set for 338K, the heat distributes fully cover the aorta wall.

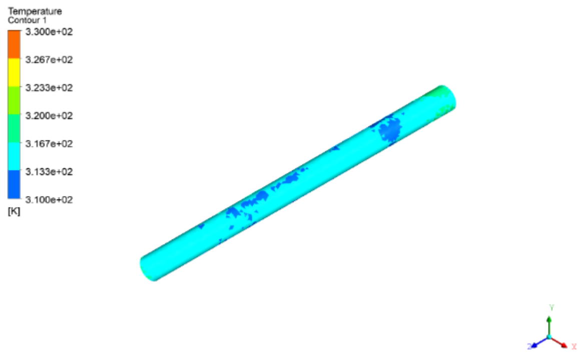


Heat source (323K)

Heat source (328K)



Heat source (333K)



Heat source (338K)

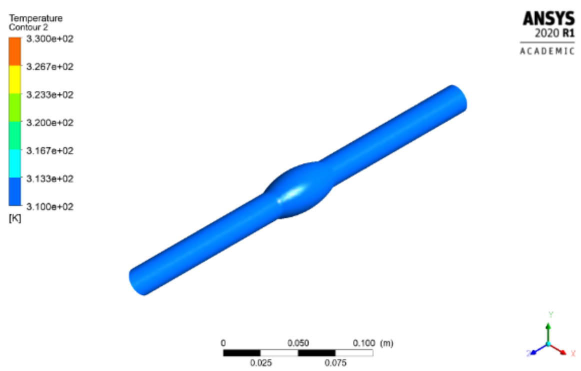
Figure 3: Temperature distribution on aorta wall

3.2 Abdominal aorta having aneurysm

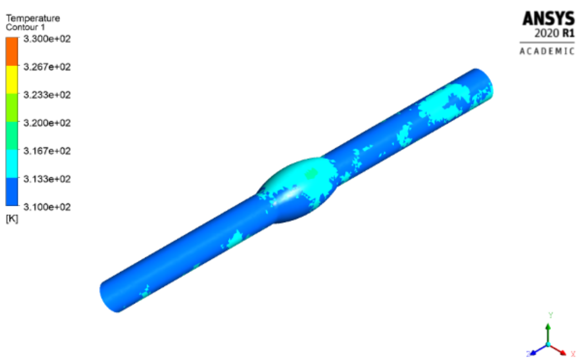
Abdominal aorta having aneurysm is knows as abdominal aortic aneurysm (AAA). The abdominal aorta with dilation at the aorta wall. The diameter of the budging area with 50% greater than the normal abdominal aorta which is 3 cm is consider AAA.

3.2.1 NBP for abdominal aorta having aneurysm

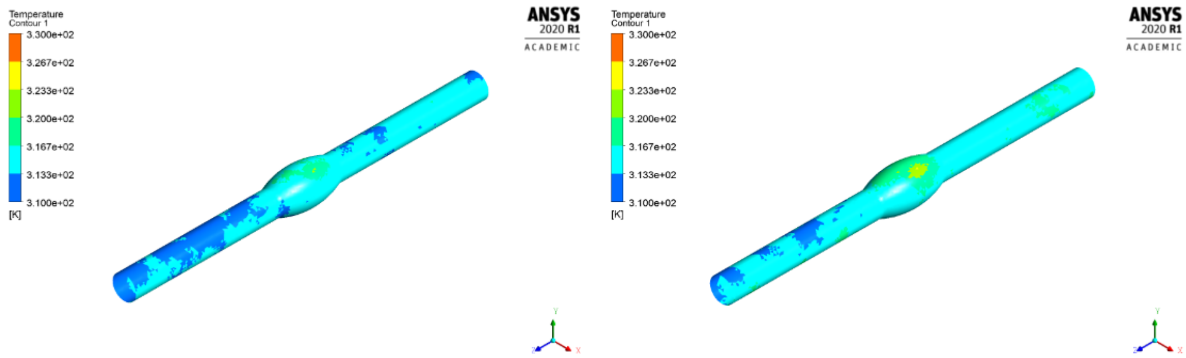
From the simulation result Figure 4, when the heat source temperature was set for 323K, no significant change in temperature at the aorta wall. When heat source temperature was set for 328K, temperature distribute isolated at aneurysm wall. When the heat source temperature was set for 333K, temperature distribute almost cover the aneurysm wall. When the heat source temperature was set for 338K, the heat distribute fully cover the aneurysm wall.



Heat source (323K)



Heat source (328K)

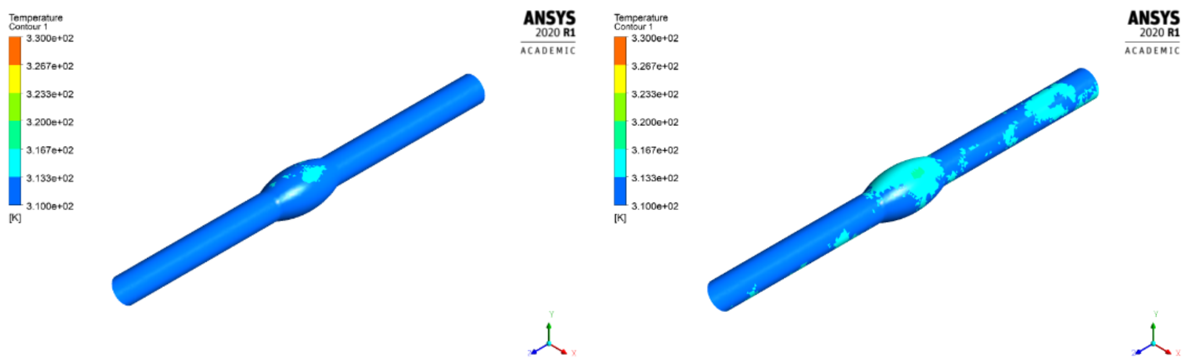


Heat source (333K) Heat source (338K)

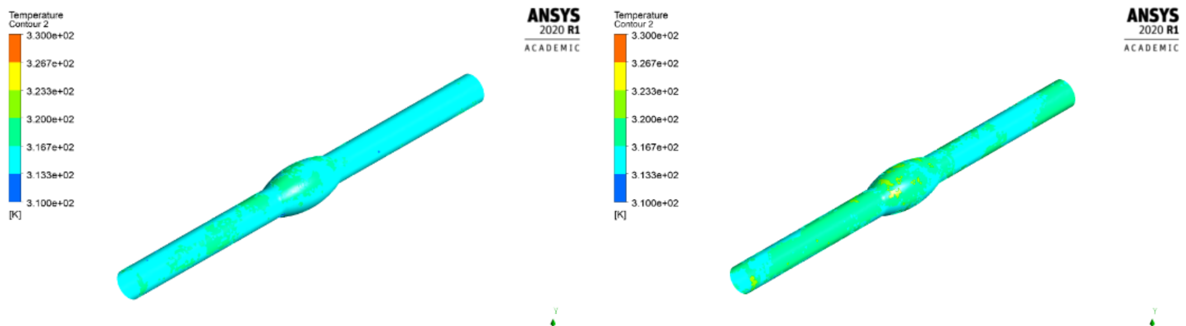
Figure 4: Temperature distribution on aorta wall

3.2.2 HBP for abdominal aorta having aneurysm

From the simulation result Figure 5, when the heat source temperature was set for 323K, no significant change in temperature at the aorta wall. When heat source temperature was set for 328K, temperature distribute isolated at aneurysm wall. When the heat source temperature was set for 333K, temperature distribute almost cover the aneurysm wall. When the heat source temperature was set for 338K, the heat distribute fully cover the aneurysm wall.



Heat source (323K) Heat source (328K)



Heat source (333K) Heat source (338K)

Figure 5: Temperature distribution on aorta wall

4. Conclusion

From the result obtained in simulation, heat source needs to rise the temperature of the aorta wall to 42°C is between 50°C to 60°C. From the result, patient with abdominal aortic aneurysm need less heat to rise the temperature to 42°C compare to the normal person with normal abdominal aorta in normal blood condition. Other than that, the result show that the temperature distribute on the patient abdominal aorta wall with high blood pressure is higher than patient with normal blood pressure. High blood pressure is cause by the slowdown of the blood pressure thus the velocity compare to the normal blood pressure is slow, the temperature distribute on the aorta wall will be higher.

Acknowledgement

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