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Biomechanical Analysis of Hypertrophic Cardiomyopathy Behavior of Human Heart using Dynamic Finite Element Method

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Abstract: *Hypertrophic cardiomyopathy (HCM) is the most familiar inherited cardiac disorder exhibits significantly by clinical heterogeneity and genetic. The aim of this research is to understand the effect of the wall thickness in terms of the performance of the human heart. In HCM symptoms, it is easy to understand with related to the wall thickness become thicker than normal size. In this study, a simple 3D human heart model is developed using 3D CAD software. Then, the simple 3D human heart model involved with the thicker thickness which is correlated with HCM. There are two thicknesses for HCM which are 14.0 mm and 22.0 mm and compared with the normal thickness which is 6.0 mm. After the simple 3D model of the human heart successfully developed, the simple 3D model of the human heart is exported to LS DYNA to undergo the simulation procedure. The results show the correlation between the wall thickness and the displacement of the human heart. With 14.0 mm and 22.0 mm of wall thickness, the results show 7.15 mm and 6.97 mm, respectively. Compared with 6.0 mm for normal thickness, the displacement is 7.30 mm.*

Keywords: Hypertrophic Cardiomyopathy; Human Heart; Wall Thickness; Finite Element Method

1. INTRODUCTION

Heart is the most important organ in our body. It is a very important organ to distribute blood throughout the circulatory system for surviving [1]. However, if the heart has a problem like Hypertrophic cardiomyopathy (HCM), it will give bad conditions to the patient. HCM is the symptom which increases ventricular wall thickness that is unexplained by myocyte enlargement and disarray, underlying condition, and increased myocardial fibrosis and also known as a primary disorder of the myocardium [2,3].

According to Hunter and Borg (2003) and Noble (2002), the research about heart investigation is involving integration based on computational sciences as a powerful tool [4,5]. Therefore, this study is aimed (1) to develop simple 3D model of the human heart and (2) to study the effect of different wall thickness of human heart correlate with HCM symptom.

2. METHODOLOGY

2.1 Development of simple 3D Model of Human Heart.

In this study, the simple 3D model of human heart has been done using 3D CAD application software which is known as JVision 3.6 software. Before the simple 3D model of human heart can be completely developed, it should be drawn in one layer which involved 93 number of nodes and 60 number of elements for this 3D model as shown in Fig. 1. The complete version of human heart in simple 3D model consists of 3603 number of nodes and 2400 number of element as shown in Fig. 2.

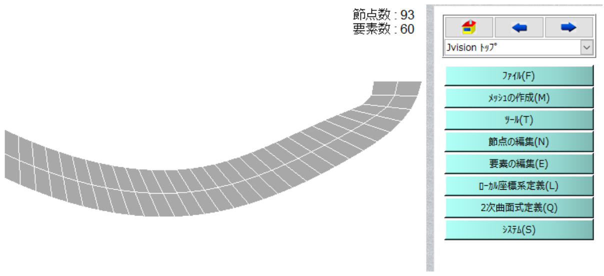

Fig. 1. One layer of 3D Model

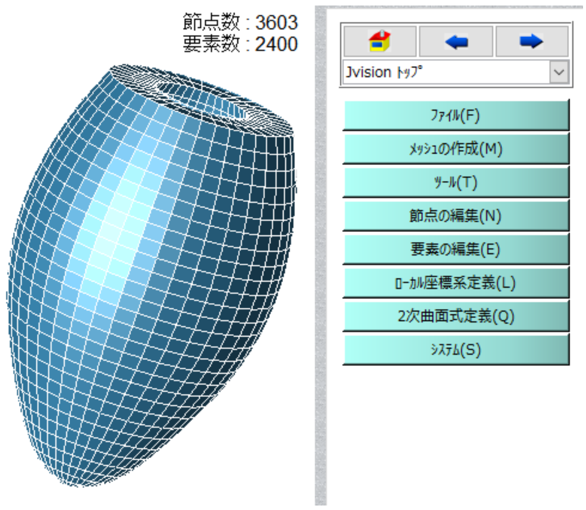

Fig. 2. Completely simple 3D Model of Human Heart

2.2 Simulation of simple 3D Model of Human Heart.

The completely simple 3D model was exported to LS DYNA (Liverware Software, Livermore, CA) software for conducting the simulation procedure as shown in Fig. 3. Post-processing was performed with LS-PREPOST.

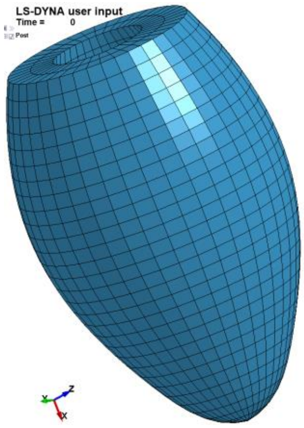

Fig. 3. 3D model in LS PREPOST software.

According to Iwamoto et al, in reality, the condition of lung, stomach, heart, intestine, and duodenum are not solid organs, but they are occupied with solid elements which are to represent air, blood, and other contents inside [6]. Therefore, in this study, it is considered as a solid element as well.

In this study, the material used is material type 128 (MAT_128) also known as MAT_HEART_TISSUE in LS DYNA material dictionary. Walker et al (2005) described in his paper this material model of a heart tissue model [7]. This current study uses the various number of wall thickness as shown in Table 1.

Table 1. Wall Thickness Involved in Simple 3D Model of Human Heart [8,9]

Wall Thickness (mm)		Authors
Normal	6.0	Kalsi et al (1999)
HCM 1	14.0	Kalsi et al (1999) Maron et al (2013)
HCM 2	22.0	Kalsi et al (1999) Maron et al (2013)

3. RESULTS AND DISCUSSION

3.1 Beating confirmation in 3D Model of Human Heart

This simple 3D of human heart model was successfully behave as systole condition as well as diastole condition as shown in Fig. 4 and Fig. 5, respectively.

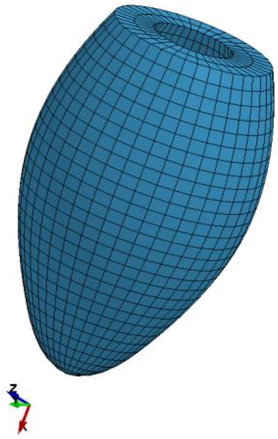

Fig. 4. 3D model in systole condition

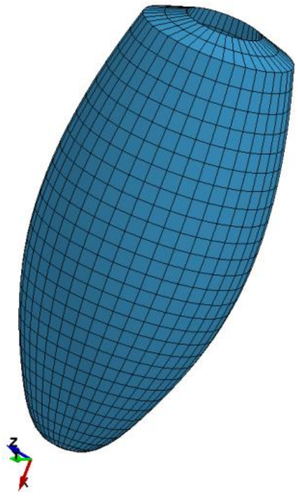

Fig. 5. 3D model in diastole condition

It is found that the total number of beating is 7 times in between 5 second as shown in Fig. 6. Therefore, in 60 seconds it will be 84 beatings. According to Bahar Gholipour (2018), the normal beating heart rate is between 60 and 100 beats per minute (bpm) for adults 18 and older [10]

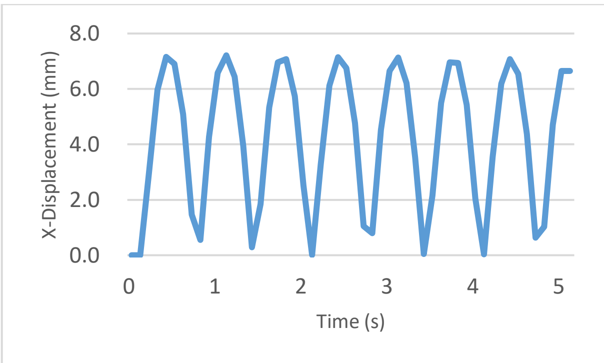

Fig. 6. Beating in the 3D model of Human Heart

3.2 Effect of wall thickness in beating behavior.

In this study, three different wall thicknesses (see Table 1) were involved in order to know the effect of the wall thickness in terms of beating behavior. The graph can also be used as tool for predicting other thicknesses. The results for three different wall thicknesses are tabulated as shown in Fig. 7.

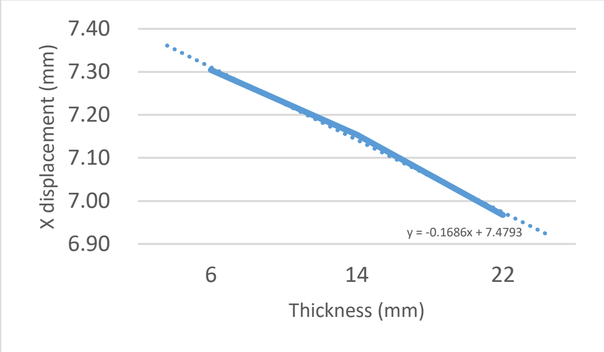

Fig. 7. The effects of wall thickness on displacement

Based on the result tabulated on the graph, it can be simplified that the thicker wall thickness will decrease the displacement of the 3D human heart model in terms of the mechanical point of view. If the displacement is smaller, the ability of the heart to pump will also be diminished.

According to Maron et al (2016), if the thickness of left ventricle (LV) equals or more than 30.0 mm, it is considered to be extreme LV wall thickness [11]. Kalsi et al (1999) mentioned that it is also known as HCM symptom if the thickness is (15.8 ± 5.5) mm [8]

In terms of medical point of view of the character human heart, the symptom of HCM will give short breath and from the results, if displacement is smaller, the heart will generally be weaker to pump the blood.

4. CONCLUSION

In conclusion, this study is important to know the effect of the wall thickness by using 3D model of human heart which involved with the finite element method. In normal thickness which is 6.0 mm, the displacement is 7.30 mm. In HCM patients, the thicknesses are 14.0 mm and 22.0 mm and the displacements are 7.15 mm and 6.97 mm, respectively. The displacement of the heart or the ability of the heart to pump blood will decrease as the wall thickness becomes thicker.

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