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Heart frontal section and hypertrophic cardiomyopathy

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Heart Frontal Section

and

Hypertrophic Cardiomyopathy

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ABSTRACT

The heart is one of the most vital and complex organs in the body. However, most of the existing heart animations focus on showing the outer surface of a beating heart, and attempt to simulate its function with its outer views. This thesis model, however, focuses on the inner structure of the heart in order to provide detailed visualizations of different parts of the heart, their functions and the related disease.

This thesis model has been created by using a real human heart provided by the Rochester Institute of Technology, as well as published material about the inside structure of the heart. The model of the frontal section of the heart was made by using the 3D computer graphic software known as Maya as well as 2D graphics using Adobe Flash.

This project includes the visual simulation of a heart disease known as Hypertrophic Cardiomyopathy. This is a heart disease that develops from abnormal growth of interventricular septum. This enlarged septum impedes blood flow. If this disease is not treated, the patient can suddenly go into cardiac arrest. This 3D model of heart frontal section is created to provide detailed visualization of the cause, process and surgical treatments of Hypertrophic Cardiomyopathy.

Part I
Heart Frontal Section

Introduction

The heart is one of our main vital organs. The heart continually pumps blood through our body to maintain blood circulation. For a healthy adult, the heart beats about 75 times per minute, and pumps about 5.25 liters of blood from one ventricle per minute at rest.

This important muscular organ is made up of four chambers. These chambers are: the right atrium, right ventricle, left atrium and left ventricle. The heart also has four valves. These valves are as follows: the tricuspid valve, Mitral valve, pulmonary valve and aortic valve. Valves are made of leaflets that prevent the back-flow of blood which ensures that the blood flows unidirectionally. The opening and closing of these valves depend on the blood pressure change in each chamber.

The right side of the heart receives deoxygenated blood from our veins. Most veins fuse to become two large veins called the superior or inferior vena cava. The deoxygenated blood passes through the superior and inferior vena cava and drains into the right atrium. Then this deoxygenated blood passes through the tricuspid valve and enters the right ventricle. The blood then passes through the pulmonary valve to reach the pulmonary artery. It then enters the lungs for gas exchange. After the blood becomes

oxygenated, it passes to the left atrium, and then drains through the mitral valve, and into left ventricle. Finally this oxygenated blood pumps into the aorta through the aortic valve, and flows back into the rest of body. This circulation plays an important role in our bodies because this blood delivers oxygen and nutrients to the rest of the body and collects carbon dioxide and waste material from the body as well. At the end of the cycle, the low oxygenated blood returns to the right side of the heart.

Despite the importance of the heart and its functions, it is usually illustrated schematically or with animations that shows only the outer surface of heart. Very few resources exist to introduce the interior of heart to the individual. In order to make the cardiac cycle clearer to the learner, the inside of the heart must be utilized as a key component. It is necessary to build a heart frontal section with a 3D computer model to explain the detailed structure of its interior, including, but not limited to the papillary muscles, chordae tendineae, trabeculae carneae, tricuspid valves, mitral valves, pulmonary valves and aortic valves.

Step 1-Modeling

The model was constructed using Maya with the use of published data from "Anatomy of The Human Body" (Henry Gray), and using reference images from "Atlas of Human Anatomy" (Frank Netter). Also, self-taken photos of the human hearts obtained from Rochester Institute of Technology's Anatomical Studies laboratory were utilized as well.

According to the book "Anatomy of The Human Body", the heart's length, height, and width are 12cm high, 8-9cm high and 6cm thick, respectively. These measurements were used to create a semi-clear purple box in Maya to regulate the proportion and dimensional accuracy of the model.
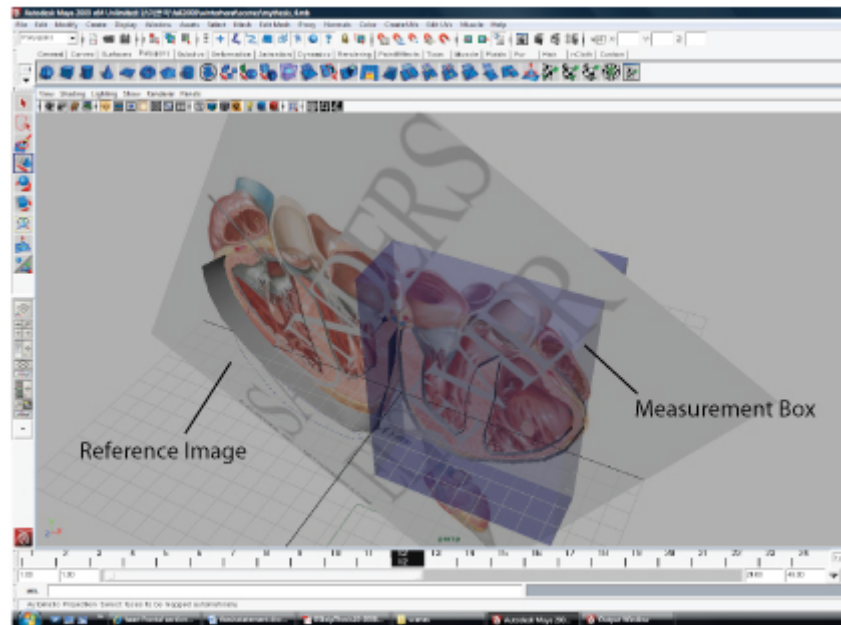
Figure 1. Reference Image and Measurement Box in Maya

Step 2-Modeling

3D heart models created in a frontal plane are very rare. When a model demonstrates heart beats, usually, it only shows one side of the ventricles instead of the two sides at the same time. when compared to the existing models, this thesis model is unique because it is designed to show the both ventricles. In addition, the pulmonary trunk is included anterior to the frontal plane of the heart.

  This design also efficiently visualizes how pulmonary valve acts as it bridges between the right ventricle and lung. By moving the pulmonary valve in Anterior to the frontal plane, this model can show the complete cardiac cycle without rotating the model. Existing 3D heart models are designed to show the outer surface of the heart first, then rotate 90° to show the cardiac cycle. This may confuse the viewer, as they may take these two models as separate models, instead of one model of the same system.
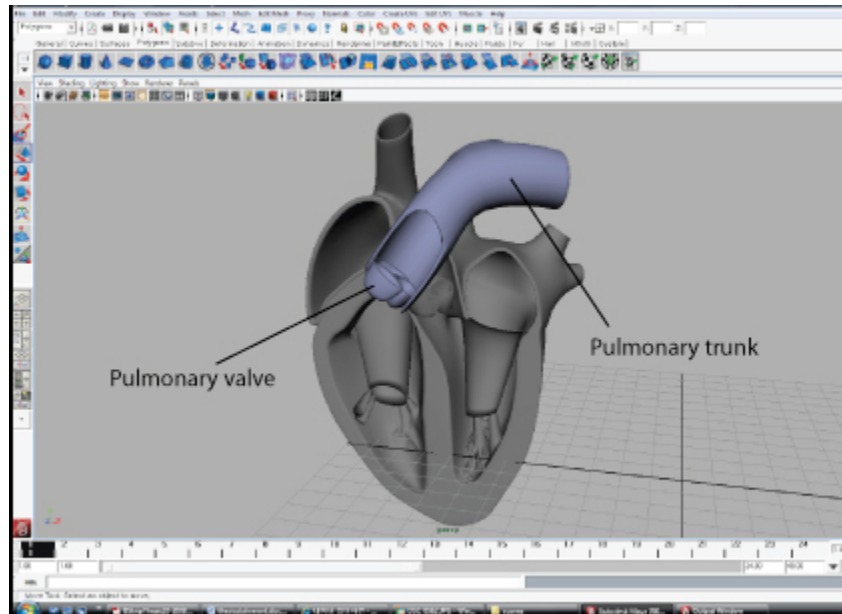
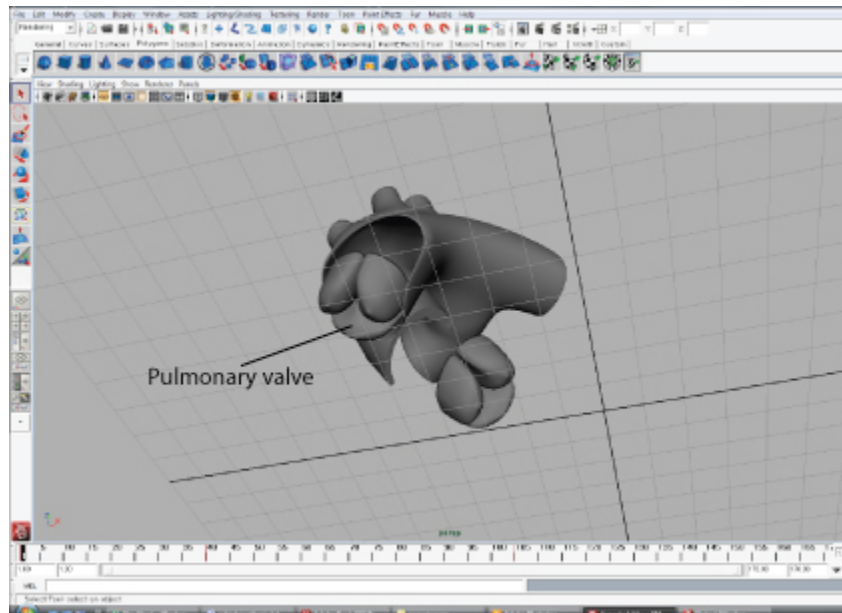Figure 2. Pulmonary valve placed in front of heart frontal section

Figure 2a. Bottom view of pulmonary valve

Step 3-Modeling

Many of the existing animations of 3D-computer generated heart models do not include the trabeculae carneae. However, this thesis model shows the detailed physical appearance of trabeculae carneae. Even though, trabeculae carneae can create technical difficulties in realistic depiction in 3D, it can provide accurate and realistic information about the interior structure of the human heart to the viewers.

Trabeculae carneae is created with three different layers of Maya plane, then, the layers of Maya planes are modified and attached to the ventricular wall. Even though this step made the model more complex and creates more polygons, it improves the model by making it more realistic and visually pleasing.
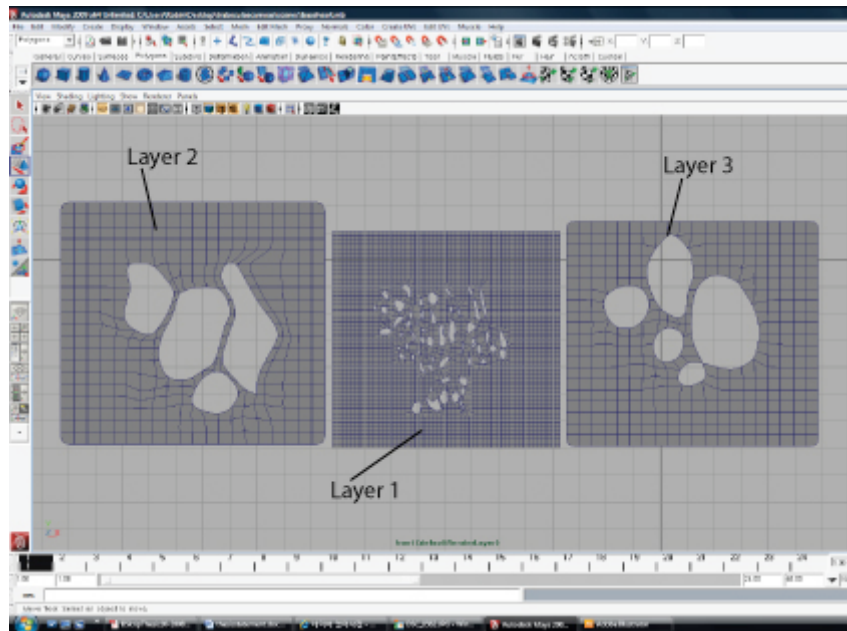
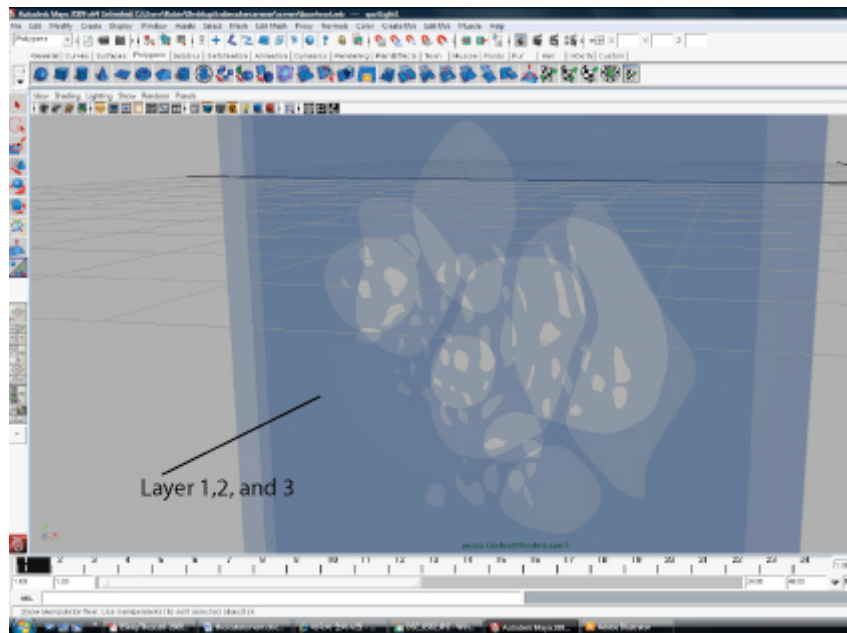Figure 3a. Three individual layers for creating trabeculae carneae
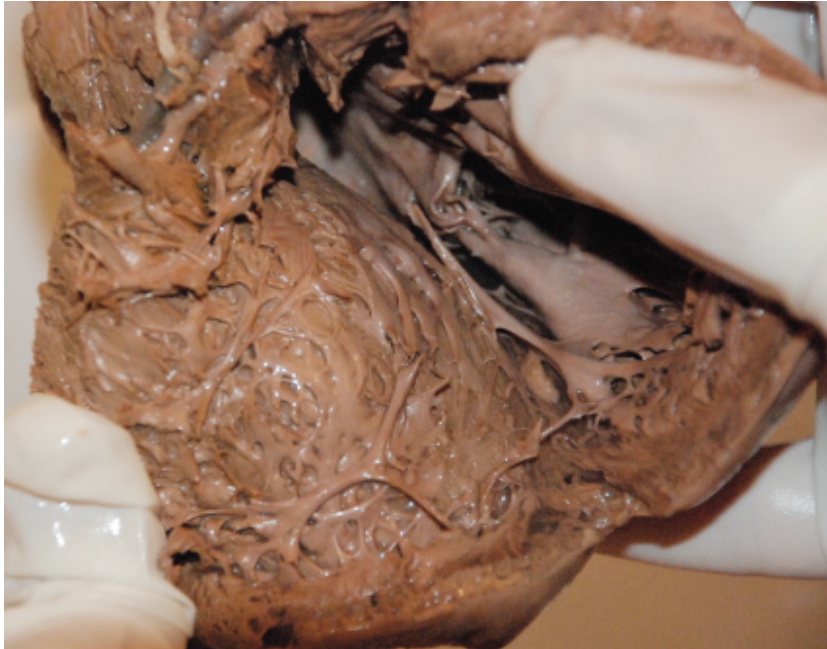

Figure 3b. Three layers overlaid top of each others
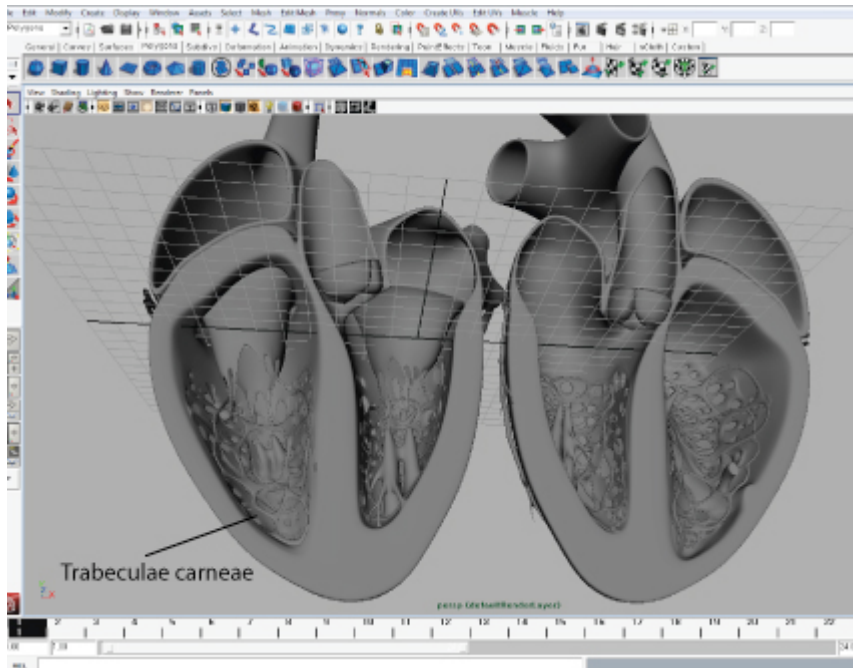
Figure 3c. Human trabeculae carneae

Trabeculae carneae

Figure 3d. Three layers applied to the model

Step 4-Texturing

The purpose of the medical illustration is to provide medical information to the viewer. For this reason, the majority of medical illustration looks less artistic compared to "normal" artwork. However, medical illustrations can use many of the mediums that are used in fine art, and it is possible to adopt the artistic principles in this field. This model explores the idea by incorporating the x-ray shader in Maya, which allows the model to have a distinctive approach to the appearance of a physical feature.

The x-ray shader is the one of the special shaders that gives the transparent and glassy texture to a model and it is used to make this model more artistic and distinctive. In order to create the proper color and texture for the glass shader, the x-ray shader requires modification. The original x-ray shader is connected with the 3D texture Cloud as an out color for ramp 1. Ramp 1 is then connected to the x-ray shader for color. Lastly, ramp2 is connected with the x-ray shader for the transparency.

This project uses a mental ray to render the images to improve the transparent and glassy texture.
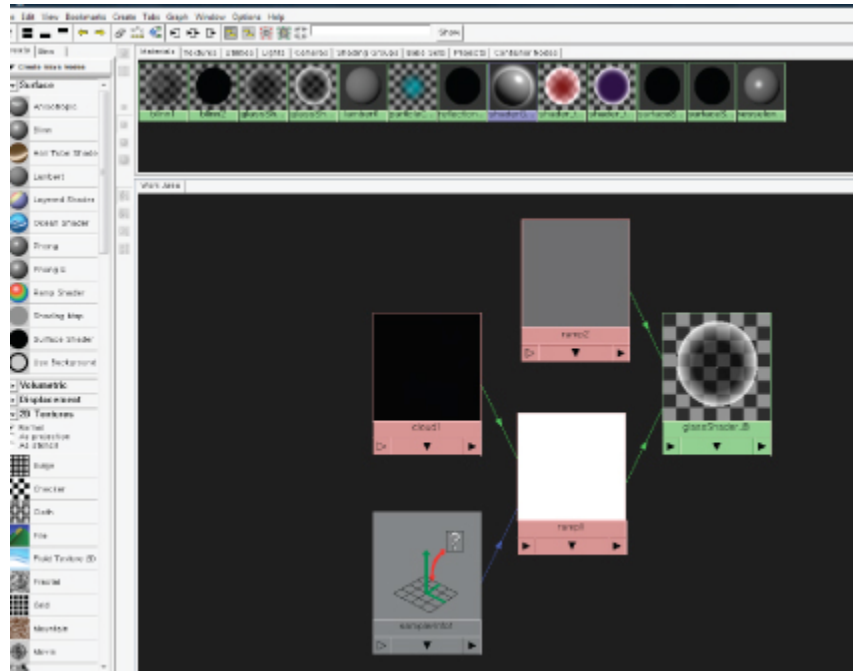
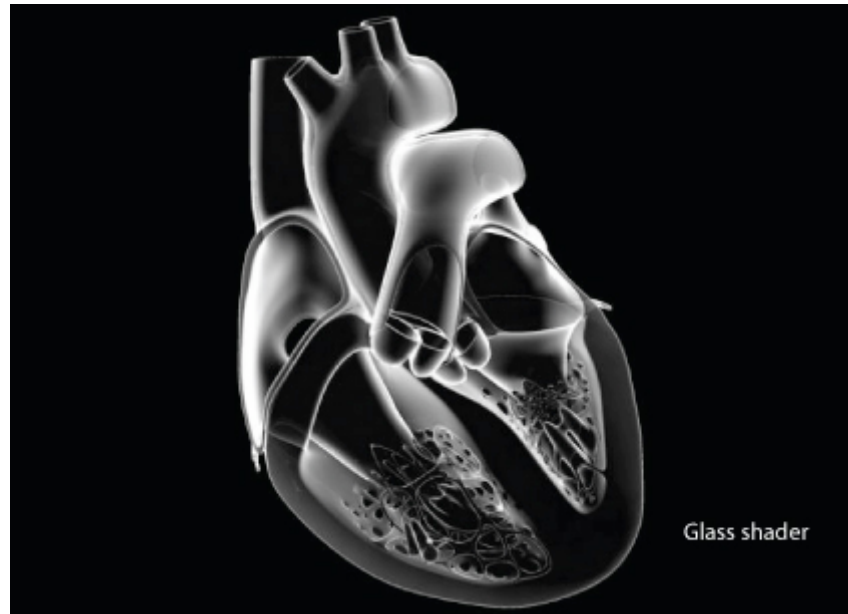Figure 4. Hypershade in Maya showing the modified the x-ray shader

Figure 4a. Glass shader applied to the model

Step 5-Animation

The cardiac cycle is the repeating pattern of heart chamber's simultaneous contraction and relaxation. Systole is the phase of contraction, and diastole is the phase of relaxation. When a ventricle contracts, the tricuspid valve and mitral valve close, and produce a sound that is known as the "lub". When the pulmonary and aortic valves close, they produce the "dub "sound. The general heart beating sound "lub-dub" is produced by closing heart valves that pull the cusps together.

This 3D computer generated model visualizes the cardiac circulation and cardiac cycle by showing each of the chambers contracting and relaxing, as well as the valves opening and closing simultaneously.   Adobe Flash was used to label the heart structures and creates 2D arrows to explain the direction of blood flow.
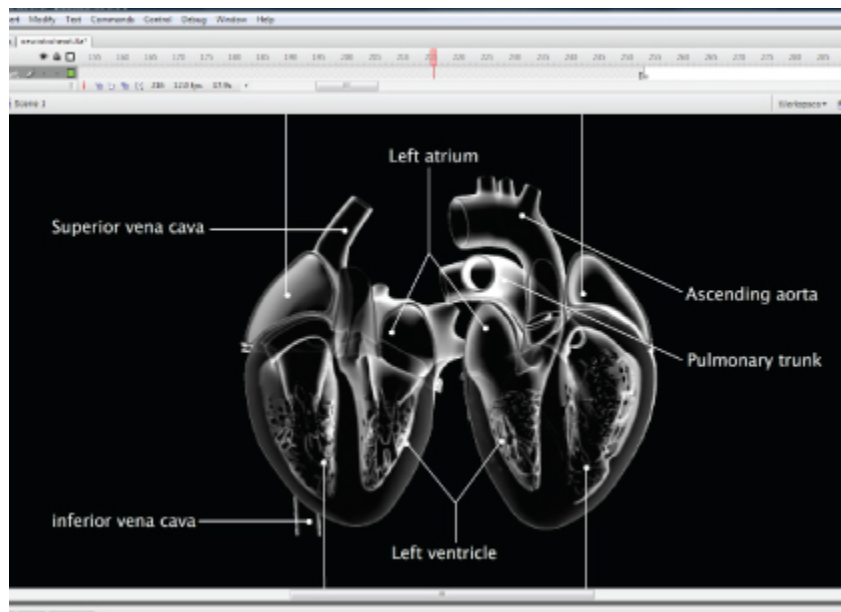
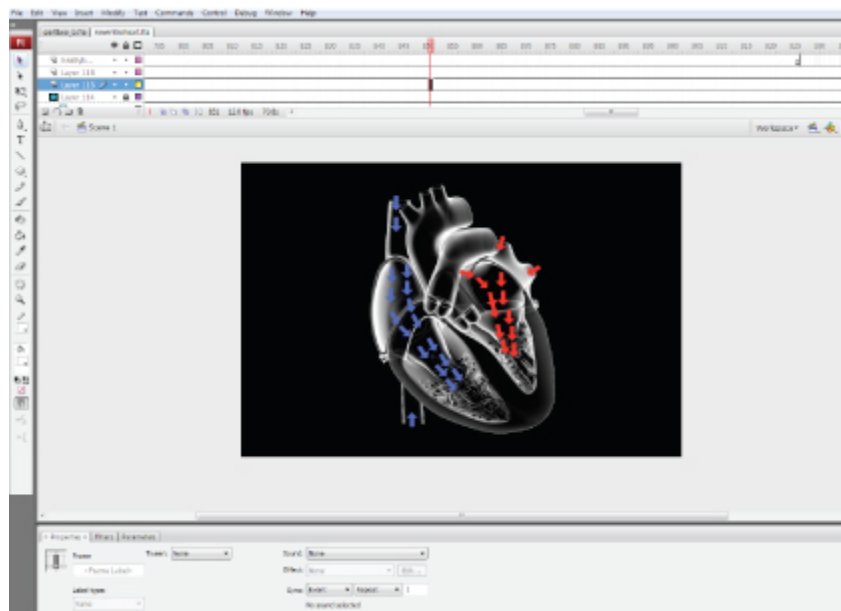Figure 5a. Each inner elements named in Adobe Flash

Figure 5b. 2D graphic arrows indicate the direction of the cardiac circulation

Part 2

Hypertrophic Cardiomyopathy

Hypertrophic cardiomyopathy is one of the known common heart muscle diseases. This disease usually occurs at the septum located close to the aortic valve. When the myocardium becomes more than 1.5cm, it is defined as hypertrophic cardiomyopathy. This abnormally thick septum impedes the blood flow to the aorta, consequently, the left ventricle pumps blood harder than it does in a healthy heart. This stenosis increases blood pressure inside of the heart, and the left ventricle cannot perform systole and diastole properly. Also, this narrowing interventicular septum causes mitral valve disorder. The function of the mitral valve is to prevent the blood backflow from the left ventricle into the left atrium. However, when blood pressure is increased, the mitral valve opens, and blood leaks into the left atrium.

One in every five-hundred people has hypertrophic cardiomypathy. This disease can affect all different age groups and equally affects men and women. This is also the most common cause of sudden cardiac arrest in the individuals under the age of 30, and is especially common among young athletes. There are many causes for the hypertrophic cardiomypathy; a genetic cardiovascular disease is one of the well known cause for hypertrophic cardiomypathy. This inherited disease can be caused by a mutation in one of the ten genes that encodes the proteins of the cardiac muscle fibers. It could also be acquired by aging or hypertension.

Most of hypertrophic cardiomyopathy patients do not have any symptoms. However, some symptomatic patients experience symptoms such as fatigue, dyspnea, chest pain, syncope, palpitations and sudden death. Most of these symptoms are associated with blood regurgitation in the mitral valve and dysfunctional diastole movement.

These symptoms can be treated with diet, exercise, medications, and surgical procedures such as septal myectomy, alcohol ablation, and heart transplantation.

Introduction

This project is a 3D computer generated heart frontal section model and it focuses on showing the detailed inside structure of the heart. This model is also designed to provide the visual aid for the understanding of the heart disease that involves heart muscle disorder.

Hypertrophic cardiomypathy has distinctive characteristics of septum enlargement. In Part 2, this animated model introduces the physical characteristics of hypertrophic cardiomypathy and its symptoms. Also introduced are the two different surgical options that treat this disease, the septal myectomy and alcohol ablation procedures.

Step 1-Disease progression Modeling

The distinctive features of the hypertrophic cardiomypathy are the septum enlargement and bulge into the left ventricle. This animation model includes the enlargement progression of septum by using the blend shape tool in Maya. Lattice is used to manipulate the original shape of heart frontal section and to increase the size of septum. It is also used to protrude the muscle of the septum in the area close to the aortic valve. The shape of the healthy heart is manipulated by applying the blend shape tool to create the shape of the heart with the hypertrophic cardiomypathy.
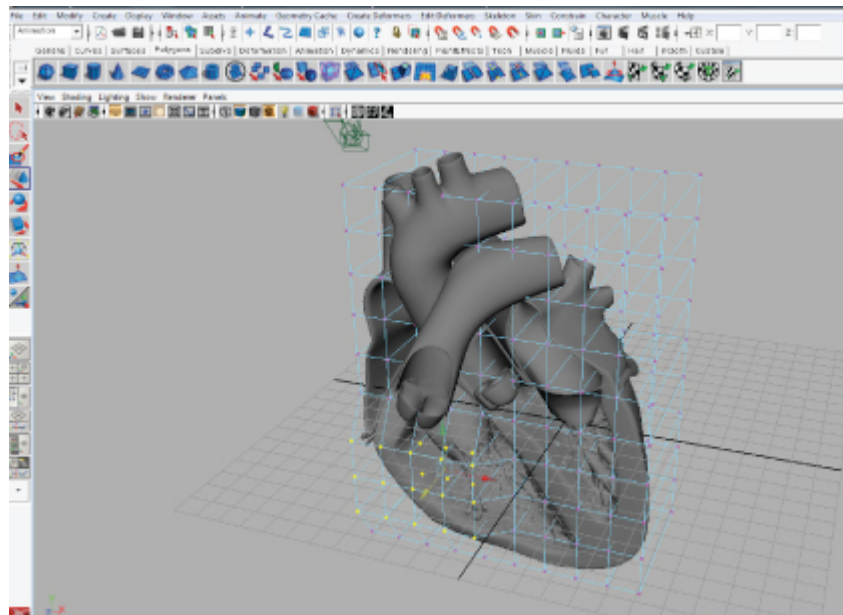

Figure 6. Using the lattice to manipulate the shape of heart

Step 2-Symptoms of Hypertrophic Cardiomyopathy

Another sign of hypertrophic cardiomyopathy is the blood back-flow into the left atrium. The thickened muscle near the aortic valve blocks the passage of blood flow to the aorta and prevents the blood to be pumped into the aorta properly. Therefore, blood regurgitation occurs in the left atrium.

In order to provide the effective visualization of the blood regurgitation, this animation model requires clear visualization of the direction of the blood flow. The direction of the blood flows have been indicated with different types of colors; the white colored arrows represent the direction of blood leaking into the left atrium while the blue and red arrows represent the deoxygenated and oxygenated blood in the cardiac circulation. The arrows are created in 2D graphics instead of 3D graphics with Adobe Flash. In the earlier version of the cardiac cycle animation, the blood flowing simulation was created using Maya particle dynamics. However, the round shape particles did not effectively show the direction of the blood flowing inside of heart chambers. In this animation, the 2D arrow graphics are employed to provide clear visual simulation of the disease and its symptoms.
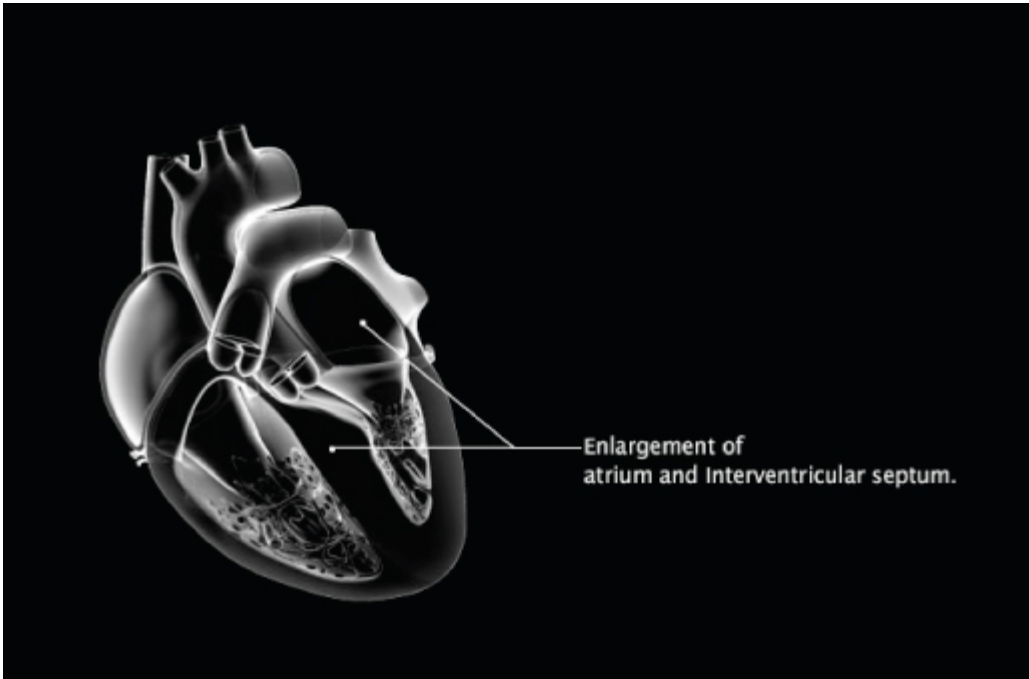
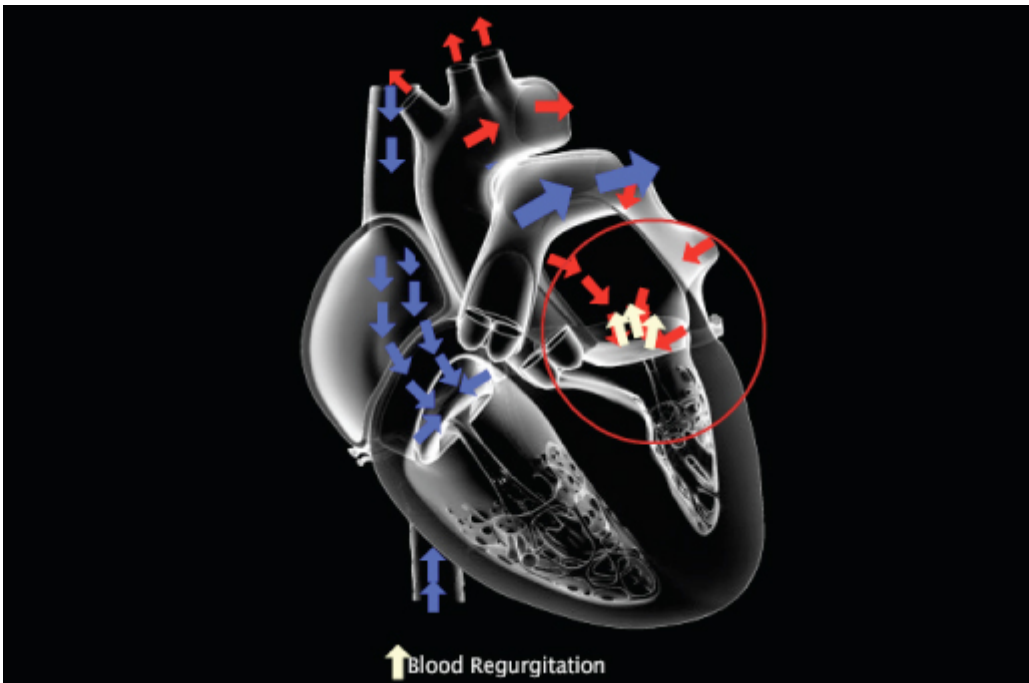Figure 7. Showing the sign of Hypertrophic cardiomyopathy

Figure 7a. The white arrows indicate the blood regurgitation

Step 3- Surgical Simulation

Septal Myectomy

Septal myectomy is the surgical procedure often used when medications have no effect in treating the patients with hypertrophic cardiomyopathy. Septal myectomy surgery involves the removal of a small amount of heart muscle from septum. This makes the outflow tract wider and results the blood to flow into the aorta properly.   The most part of the septal myectomy procedures are created in Maya except the 2D graphic arrows used in the blood flow simulations that show the affects of before and after surgery.
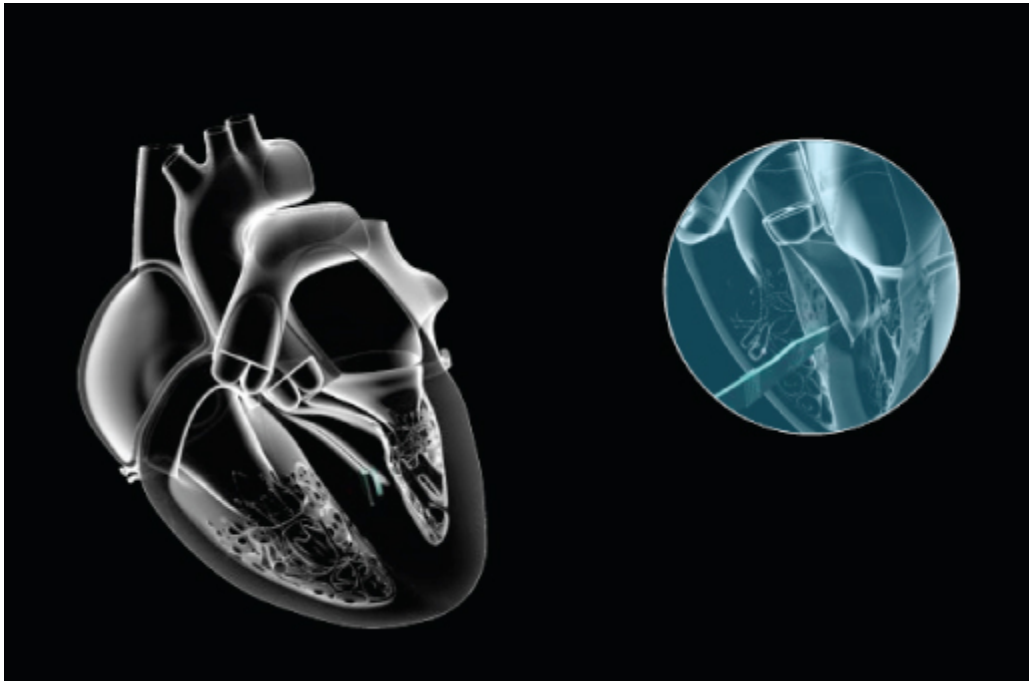

Figure 8. Septal myectomy surgery

Alcohol ablation

Alcohol ablation is another surgical option requires the insertion of a balloon catheter into the small coronary artery. This form of surgery is better in treating the septum sizes in between 1.8 and 2.5cm in thickness. A small amount of pure alcohol is then injected to the thickened septum wall through the catheter. The pure alcohol kills the muscle cells and shrinks the area that narrows the outflow tract to the aorta which result the septum to become to the normal size. This option is often performed on older or less optimal patients. These steps of operation are also created in Maya.
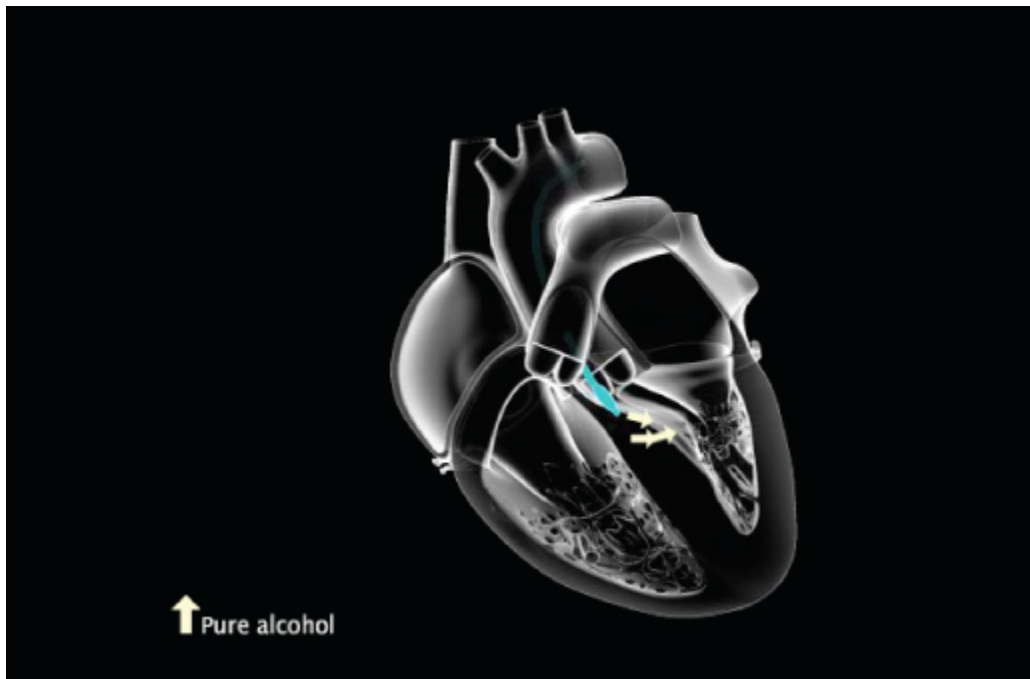

Figure 9. Alcohol ablation

Conclusion

This thesis model has been created with two important principles; simple and accurate presentation of medical information and artistic presentation of the 3D graphics and animations.

One of the reasons for choosing human heart for this thesis model is that the heart disease is one of the leading causes of death in the United States. However, learning about the heart and the heart diseases can be a difficult task for the individuals without any medical education background. Furthermore, many of the existing medical education sources such as books and visual aids tend to be too complicated or too schematic for the most people. The idea of simple and accurate presentation of the medical information has been one of the most important criteria in making decisions during the process of building this model.

One of the distinctive aspects of this thesis model is its appearance. This thesis model is designed with glassy transparent outer texture to make it more artistic and visually interesting. During the thesis show, it was quite surprising to see how many people have expressed their interest in the appearance of this thesis model, and how the visual interests lead them to the opportunity to learn about the heart.
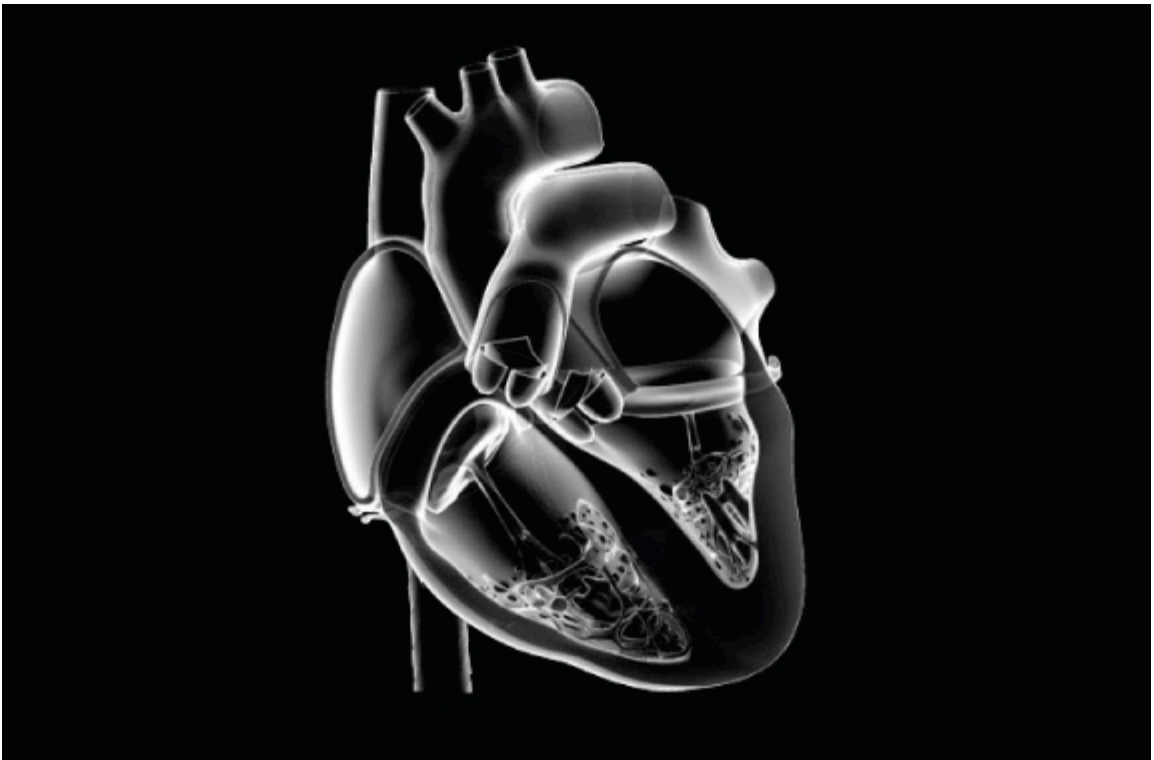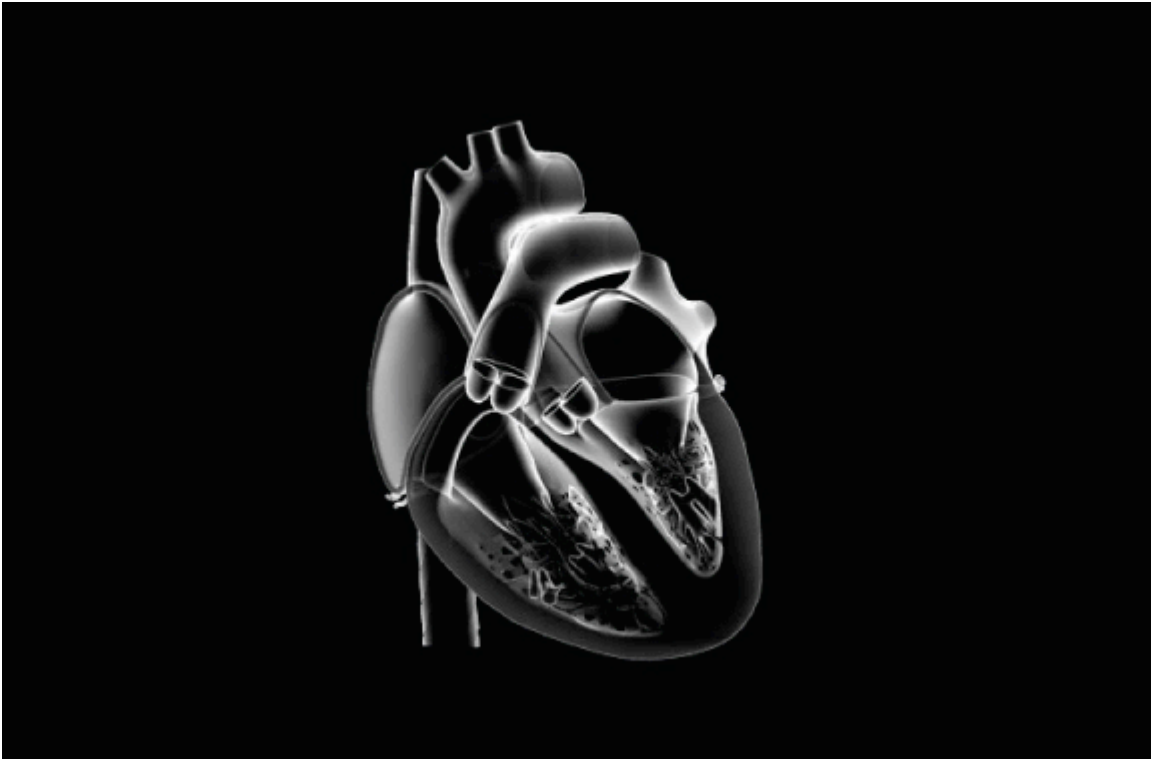
This thesis model includes the basic heart anatomy, hypertrophic cardiomyopathy and its surgical procedures. In the future, this model can
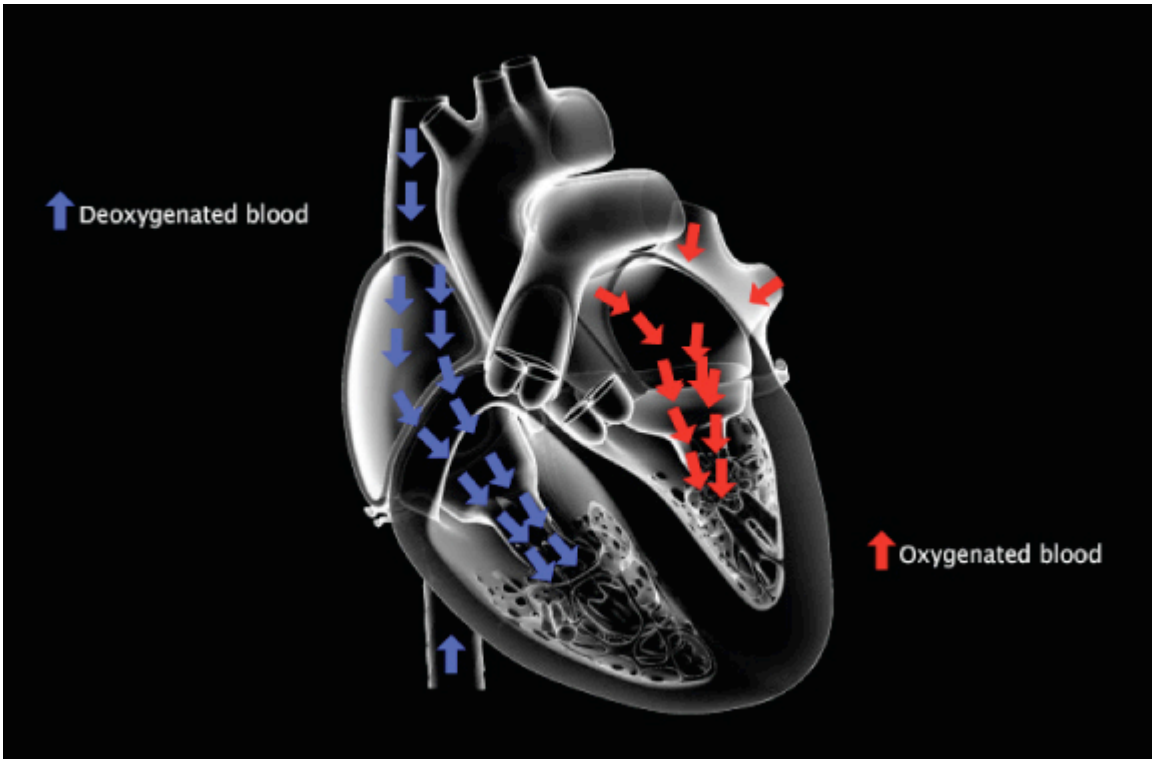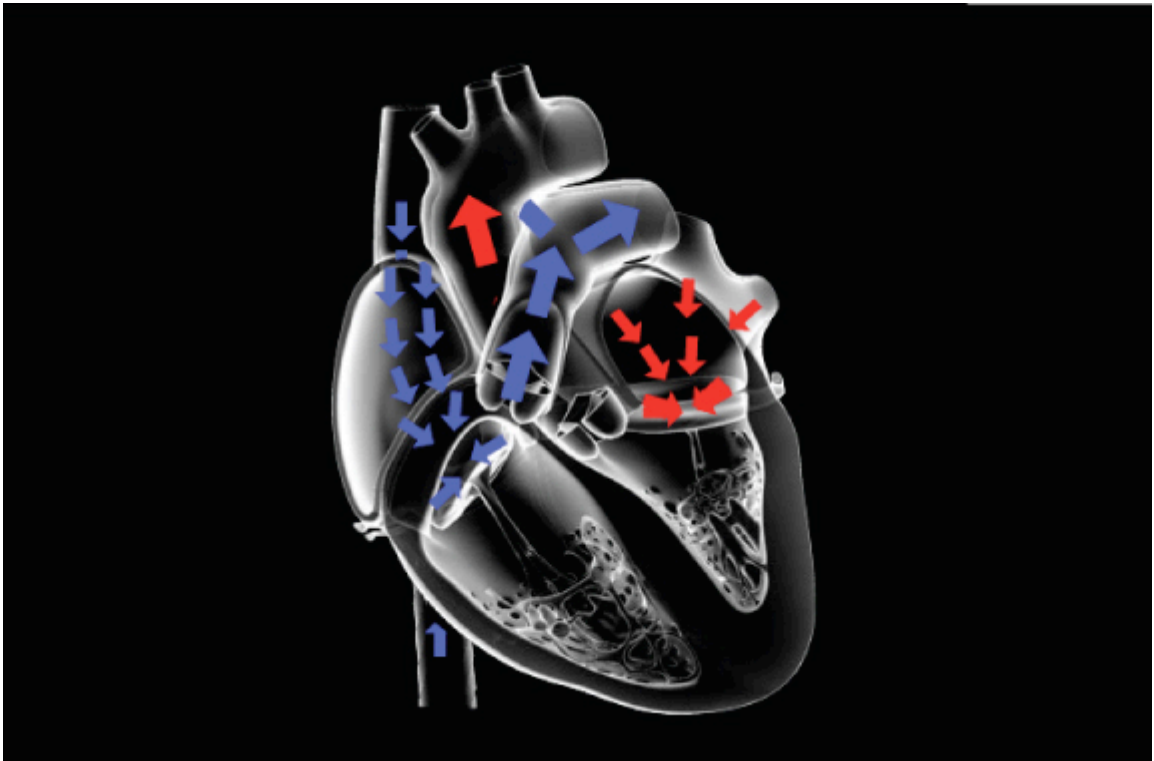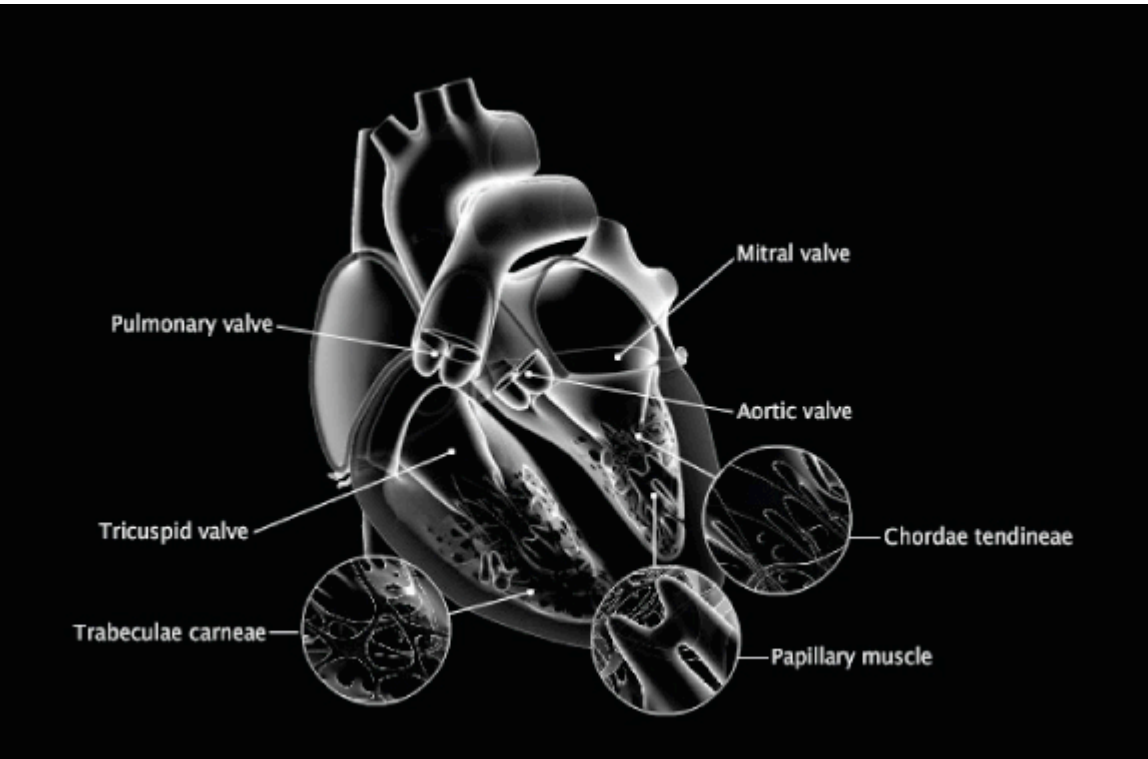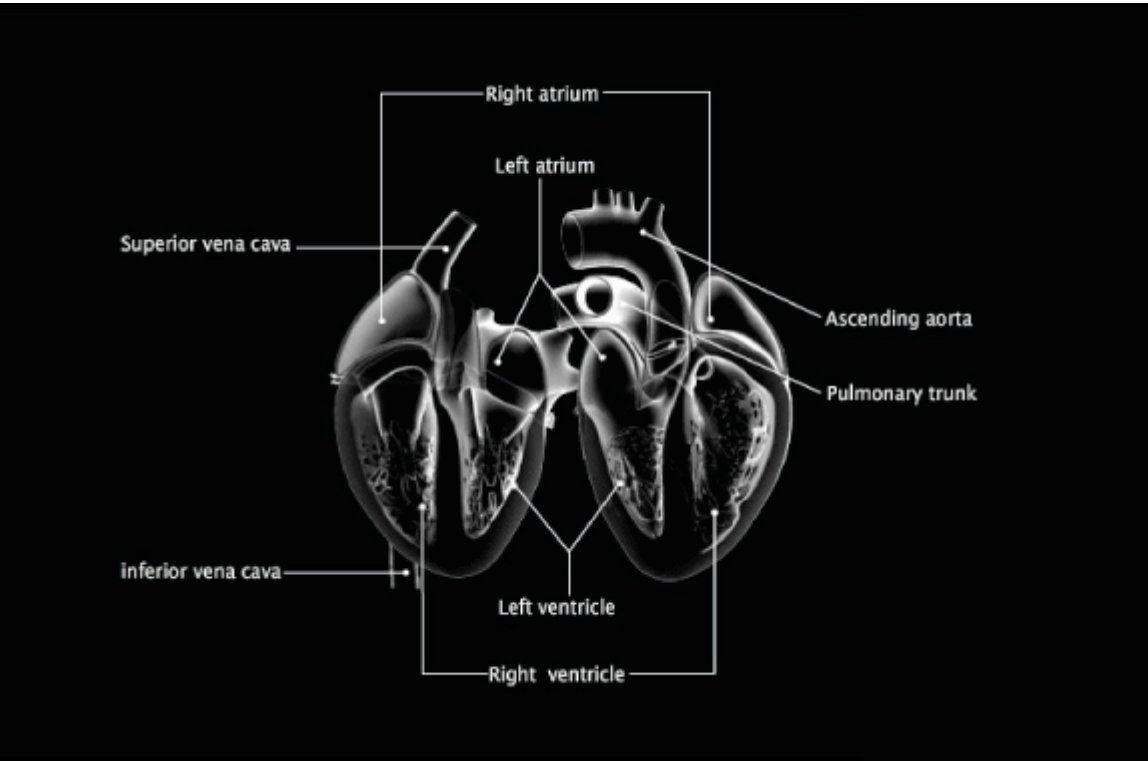
be used for more cardiac pathology and its simulations with the proper

modifications and additions. This model also can be the base model for the

interactive application for the heart anatomy and pathophysiology.   This

application can be used by the patients or introductory anatomy class.


HEART FRONTAL SECTION

Deoxygenated blood

Oxygenated blood

Right atrium

Left atrium

Superior vena cava

Ascending aorta

Pulmonary trunk

inferior vena cava

Left ventricle

Right ventricle

Mitral valve

Pulmonary valve

Aortic valve

Tricuspid valve

Chordae tendineae
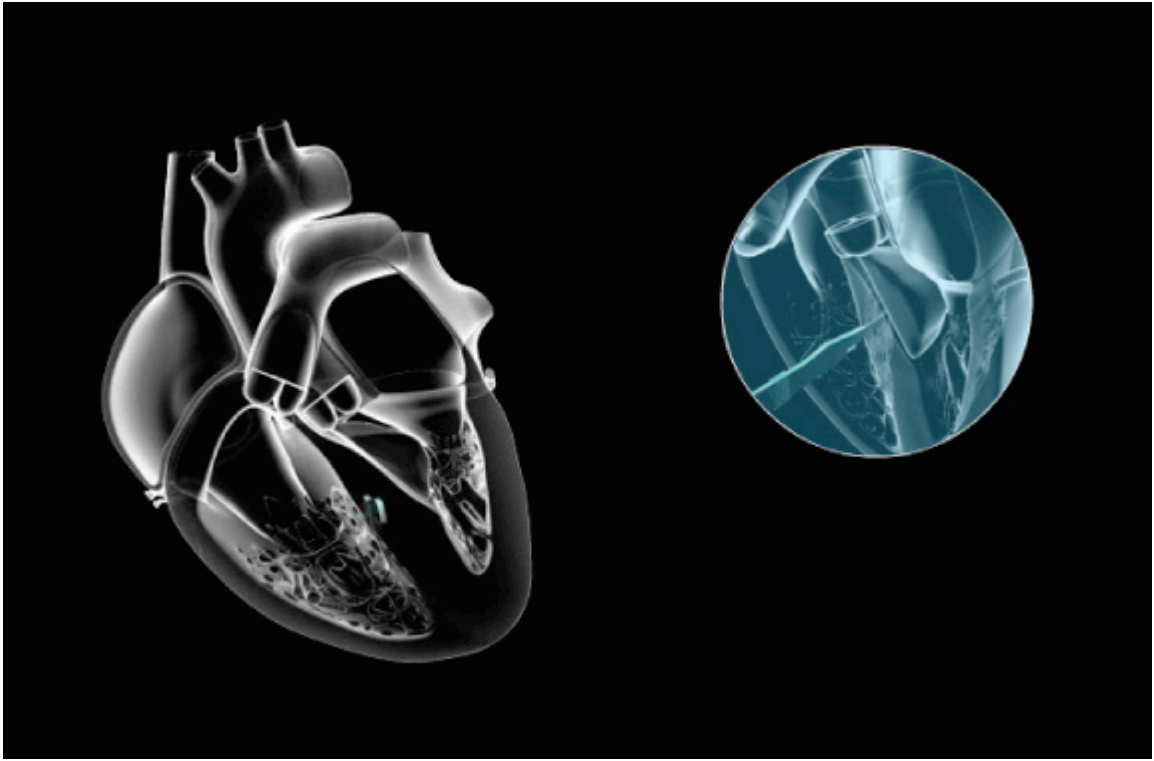
Trabeculae carneae

Papillary muscle

When the myocardium becomes more than 1.5cm, we define this as **Hypertrophic Cardiomyopathy.**

Blood Regurgitation

Pure alcohol
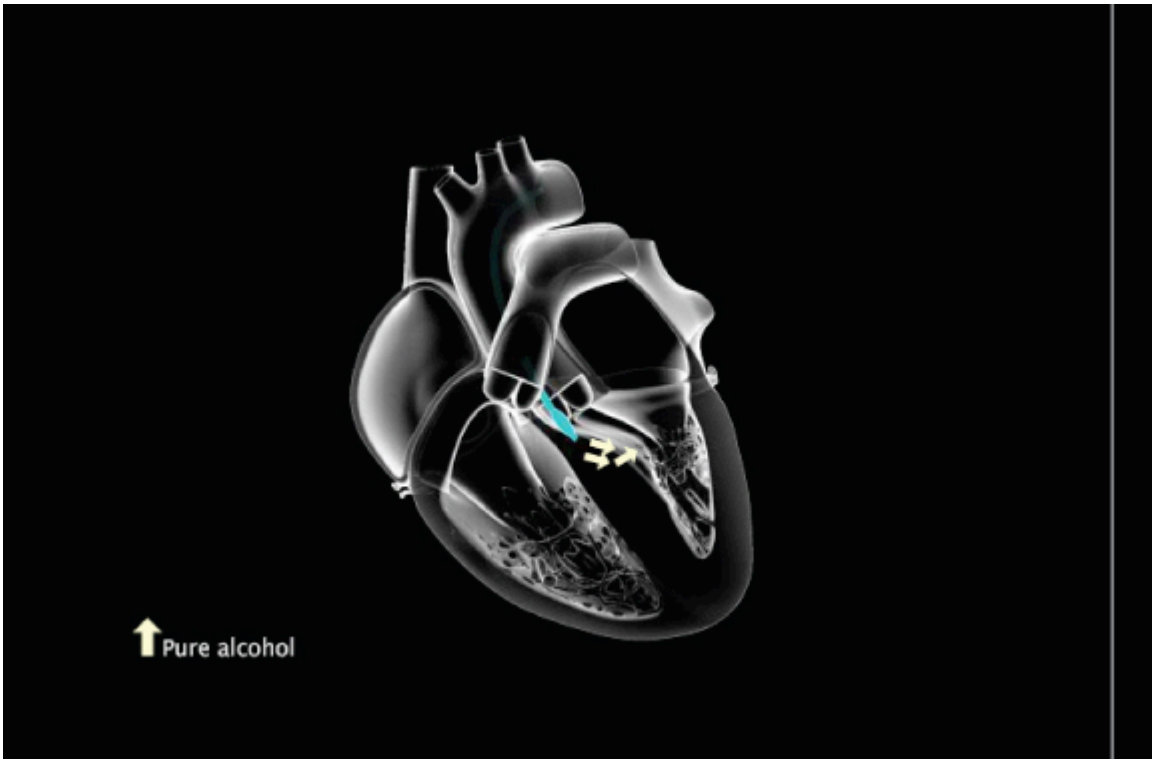
Bibliography

Frank H. Netter. <u>Atlas of Human Anatomy 4th Edition.</u>

Pennsylvania: Elsevier, 2006

Carmine D. Clemente. <u>Anatomy: A Regional Atlas of the Human Body</u>

Philadelphia: Lippincott Williams & Wilkins, 2007

Michael Mckinley and Valerie Dean O'Loughlin. <u>Human Anatomy.</u>

New York: McGraw-Hill Companies, Inc., 2006

Cohen Jules and Shah Pravin M. <u>Cardiac Hypertrophy and Cardiomyopathy</u>

New York: American Heart Association, 1974

Barry D. Fletcher and Mark D. Jacobstein.

<u>Magnetic Resonance Imaging of Congenital Heart Disease</u>

Missouri: The C.V. Mosby Company,1988

Keith L. Moore and Anne M. R. Agur. <u>Essential Clinical Anatomy 3rd Edition.</u>

Maryland and Philadelphia: Lippincott Williams & Wilkins, 2007

Carol Mattson Porth. <u>Pathophysiology Concepts of Altered Health States.</u>

Philadelphia: Lippincott Williams & Wilkins, 2005