Two Novel Approaches to Visualizing Internal and External Anatomy of The Cardiac Cycle with A Windowed Virtual Heart Model

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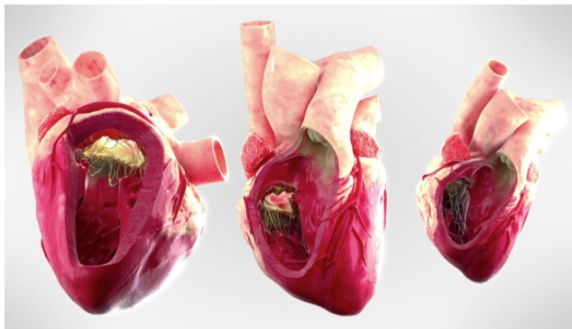

Figure 1: Rendered image of windowed heart.

ABSTRACT

Presented are two novel approaches to visualizing both internal and external anatomy of the heart through the cardiac cycle. The first uses "windows" manually cut through each chamber of a virtual heart model. The use of windows allows for internal and external views simultaneously while showing the varying thickness of the ventricular walls through the cardiac cycle. Internal structures such as both semilunar valves, both AV valves, chordae tendineae, and papillary muscles are kept intact and can be visualized in motion. The second approach is a rigging and control system that allows for independent rotation directions for the base, midpoint and apex of each ventricle both internally and externally, allowing for a more accurate wringing motion.

CCS CONCEPTS

• **Human-centered computing → Scientific visualization**; • **Computing methodologies → Modeling and simulation**; **Computer graphics**; • **Applied computing → Life and medical sciences**; **Education**;

KEYWORDS

Anatomy, cardiac, heart, medical visualization, animation, rigging, modeling

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1 OVERVIEW

The field of medical illustration and visualization has always struggled with how to present the internal anatomy of the heart. Most solutions have involved views of a dissected heart, usually bilaterally. The problem with such an approach is key anatomical features such as valves are also split bilaterally which can impact comprehension of their structure and their positions and relations to other anatomical features in situ. Another approach is to make occluding surfaces semi or completely transparent. This removes the need for dissecting the model and the problems inherent in that approach but it prevents a clear cross section view of the walls of the heart chambers. The transparency affect also has the potential for still partially occluding views and hiding anatomical features. Our approach strategically cuts windows into the model, leaving all key anatomical features intact, provides cross section views of the chamber walls, and leaves nothing hidden. Furthermore, we can seamlessly transition between the whole and windowed heart as they're animated through the cardiac cycle.

Our rigging and control system also differs from most approaches for visualizing the cardiac cycle by allowing for the external base, midpoint and apex of each ventricle to rotate about the ventricular axis independently of each other and independent of their internal counterparts. This allows for a more accurate depiction of the wringing motion of the ventricles as explained in Sengupta et al. [2008] and Nakatani [2011].

2 CONSTRUCTION

Osirix was used for extracting a polygonal base model from CT scan images of a human heart. The virtual heart model was constructed manually in The Foundry's Modo application, using the extracted base model as a guide. References for the internal structures that could not be extracted adequately from CT scans include direct dissection and observation of both human and pig hearts, Anderson et al [2013], Roberts et al [1972] and Cheung [2012]. The whole heart model was created first with surface topologies that supported the required motions and deformations for animation. The locations for the windows were then plotted out to allow maximum visibility of the internal anatomy of the heart without removing, in whole or in part, key structures such as all four valves, the papillary muscles or the chordae tendeneae. The window areas of the surface were made into "islands" (areas of a polygonal surface surrounded by at least one polygonal loop) by beveling, making use of the "preserve surface curvature" option. Islands not only make for cleaner hole cutting but prevent surface variation between a whole and windowed version of the heart model.

3 ANIMATION

Each chamber of the heart has its own skeletal rig setup in Autodesk's Maya. Due to the unique wringing motion of the ventricles, there's an internal and external rig for each, allowing for them to twist opposite of one another. Controls exist along the anterior, posterior, lateral and septal walls, inside and out, of each ventricle along its axis. These controls are grouped at the apex, midpoint, and at the AV line of each ventricle allowing for them to easily be translated or rotated as a group for wringing, filling and ejection motions. Dozens of individual controls allow for granular changes of each valve. IK chains provide automatic loosening and tightening of the chordae tendeneae as the mitral and tricuspid valves open and close, while floating "elbow" joints provide manual adjustments of the shape of each chord. Set driven keys provide simplified automation while manual overrides exist for fine tuning any motions, such as for abnormalities like atrial fibrillation or cardiac atrophy. Both the whole and windowed heart share the same control rig, ensuring seamless matching of motion between them.

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