Georgia Tech SURE 2021 Research: Increasing the speed and accuracy of the segmentation of the whole human heart

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INTRODUCTION

Dr. Wei Sun's Tissue Mechanics Lab is working to improve the treatment of cardiovascular disease by applying a combination of computational simulations with experimental evaluation.

Generating a 3D segmentation of the whole human heart from CT images plays an important role in many clinical applications [2]. Having a patient-specific model of the heart geometry allows for numerical simulations which aid in predicting patient outcomes and allows for the identification of better treatment strategies. Such methods have shown promising results for predicting patient outcomes in TAVR patients, using Fine Element Analysis to model the aortic valve [3].

The tissue mechanics lab proposes a deep learning method that allows for training prediction models using segmentation labels.

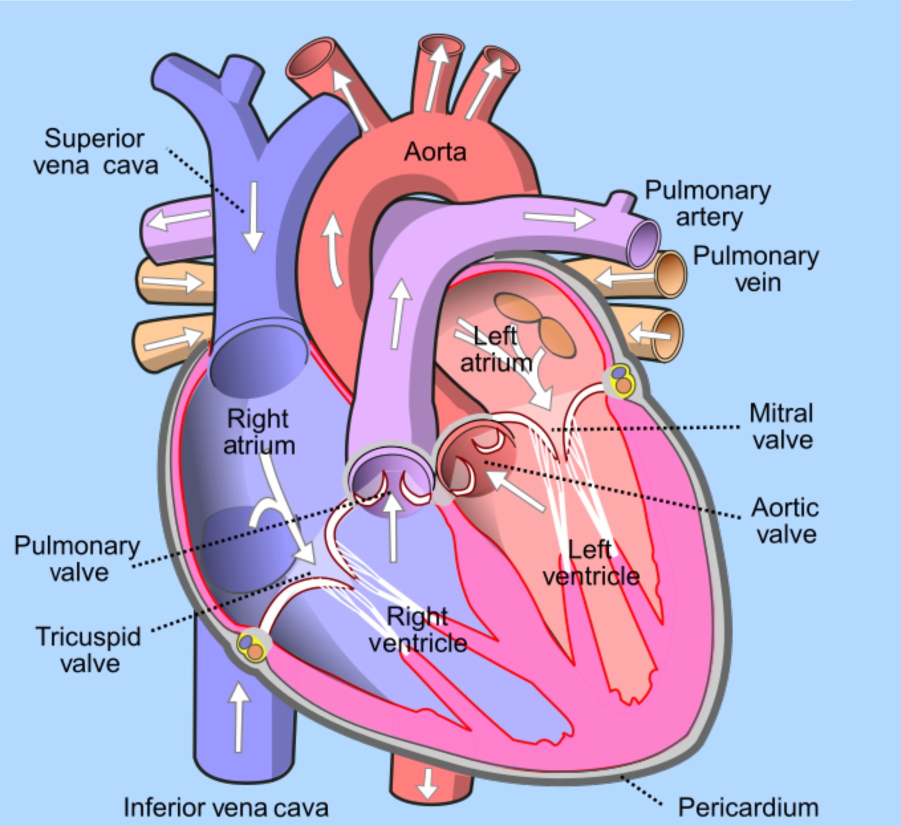

Figure 1. Diagram of human heart showing the four chambers, as well as the pulmonary artery and the aorta

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CHALLENGES

Automating the segmentation of the whole human heart remains a difficult and unsolved problem. This is due to the complex geometries of the heart segments, large structural deformation over the cardiac cycle, and difficulties differentiating individual structures from the surrounding tissue. Current automation methods often make heavy assumptions about the topology, limiting how much they can be adapted from case to case. This requires manual segmentation which takes several hours for a single heart, leading to a significant bottleneck in the generation of Fine Element Analysis (FEA) mesh generation from CT images. [3]

METHODS

The Tissue Mechanics Lab is proposing a weakly supervised deep learning-based deformation strategy for predicting fine element meshes from noisy 3D CT scans. The method proposes a novel image analysis formulation that allows for weakly supervised training of image to mesh prediction models, where the training is performed using segmentation labels instead of mesh labels. Minimal assumptions are made when defining the formulation, allowing it to easily adapt to various imaging conditions and desired output mesh topology. [3]

Before the deep learning model can be implemented, a train/test dataset must be compiled. This requires manually segmenting each heart in the dataset. As this dataset will be used to train the deep learning network, careful attention to detail is necessary to ensure that no systematic mistakes are present.

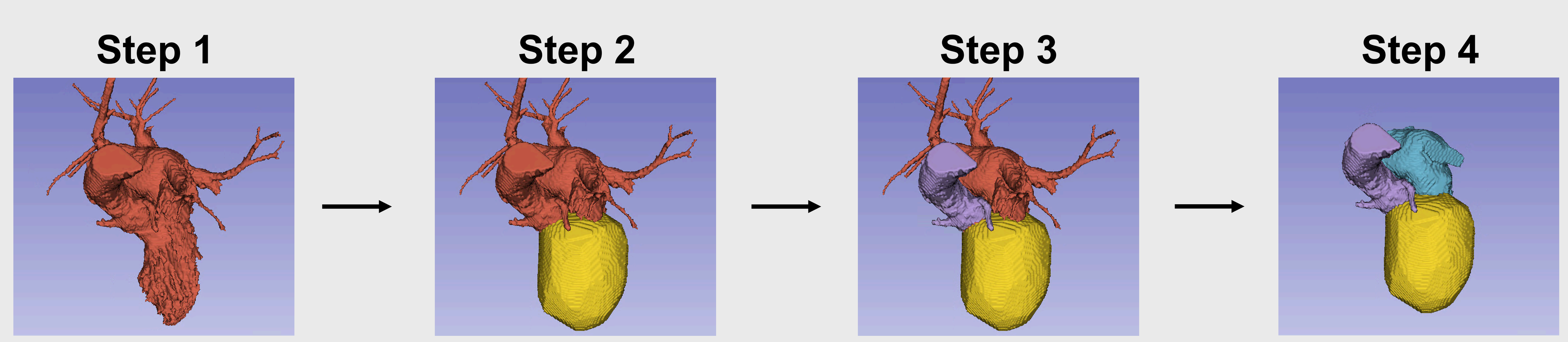

Figure 2. Left heart segmentation:
1. Rough segmentation of blood pool
2. Left ventricle segmentation using surface cut tool
3. Aorta segmentation using logical operators
4. Left Atrium segmentation using scissors and eraser

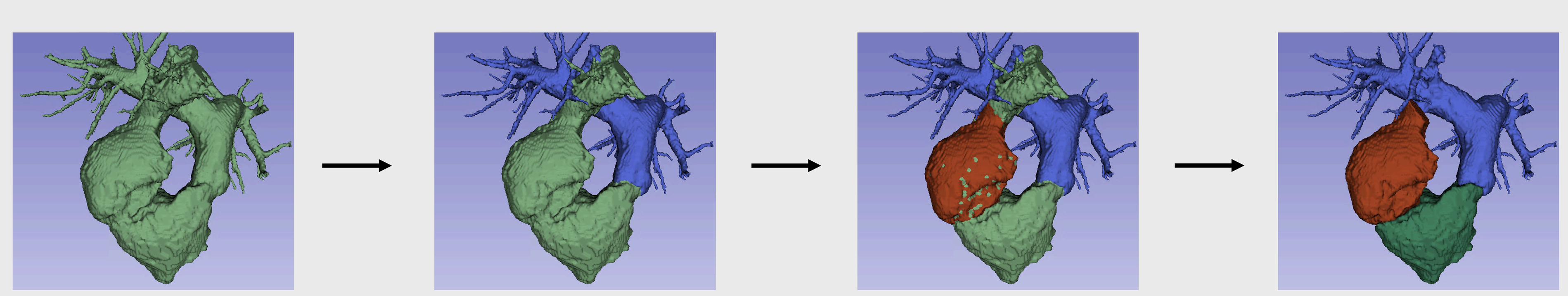

Figure 3. Right heart segmentation:
1. Rough segmentation of blood pool
2. Pulmonary artery segmentation using scissors and eraser
3. Right atrium segmentation using scissors and eraser
4. Right ventricle blood pool using logical operators, smoothing, and paint

RESULTS

Due to the number of cases in the train/test dataset, full labeling of the entire dataset was not possible, so a rigorous quantitative analysis of the labels could not be performed. Instead, to determine if the segmentation is a good fit to the CT images, careful inspection by eye is done to ensure a good qualitative match between image and segmentation. Prior efforts to automate modeling have been lenient to errors at the boundaries [3], so extra attention was paid to ensuring agreement between the image boundary and the labeled segmentation boundary.

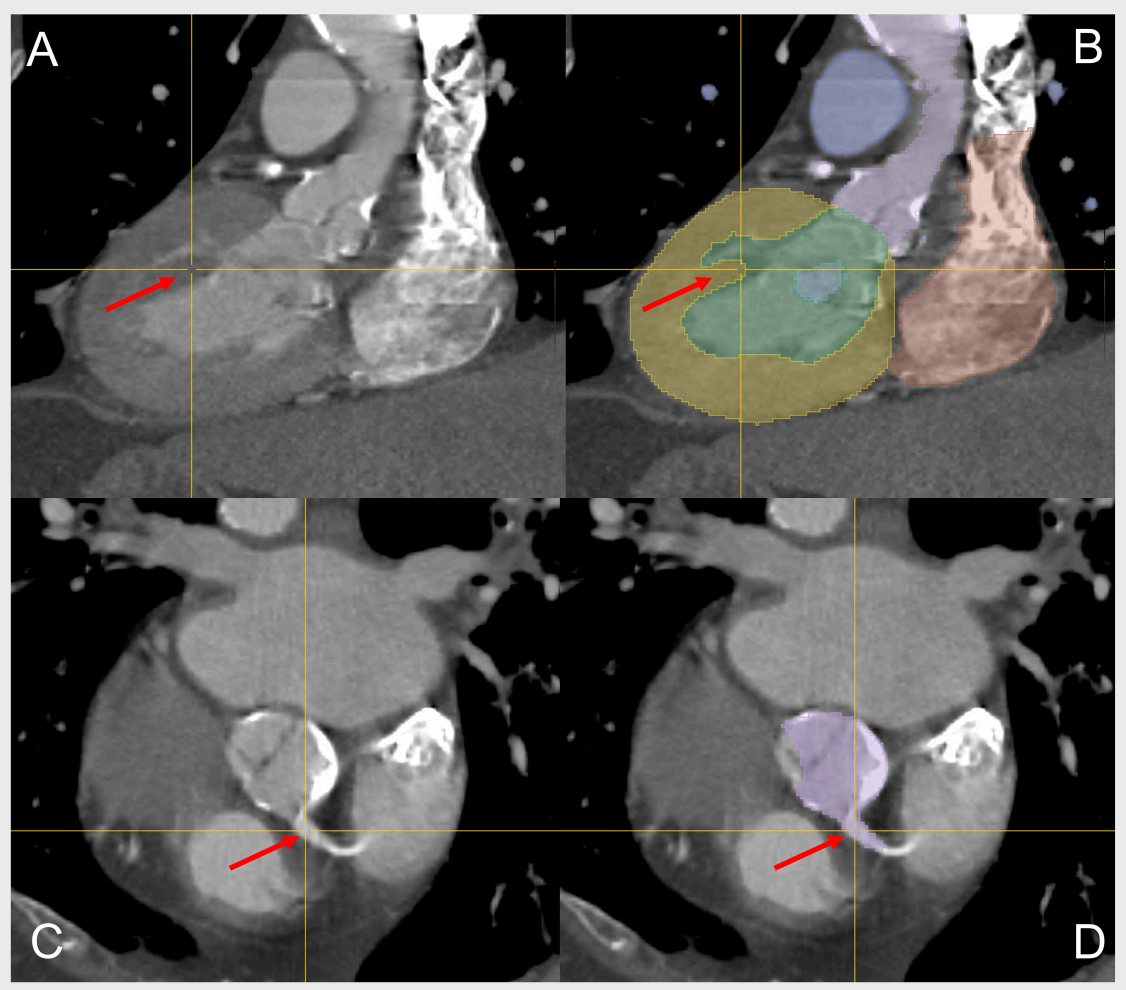

Figure 4. (**A**) Location of papillary muscle. (**B**) Papillary muscle included in left ventricle. (**C**) Location of coronary artery. (**D**) Coronary artery included in aorta

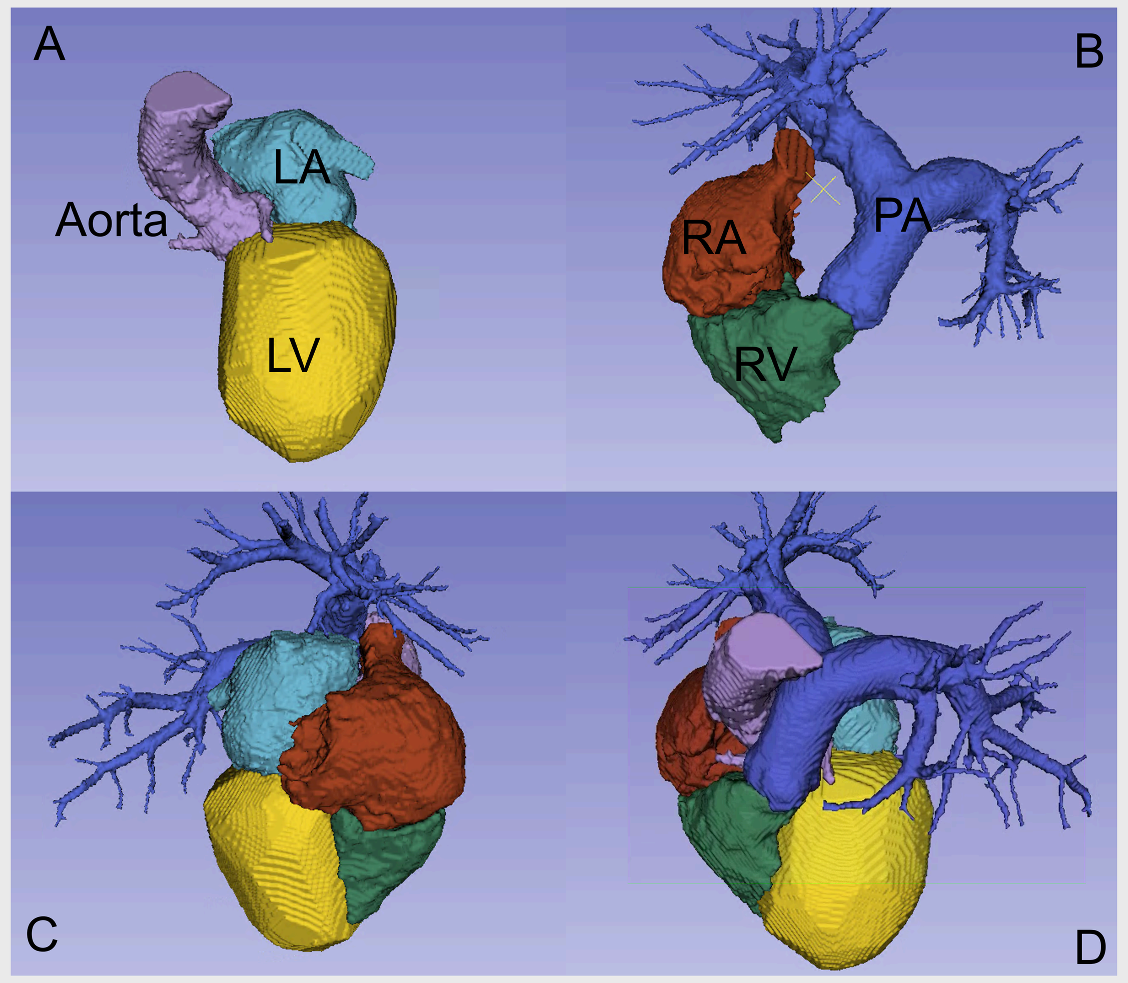

Figure 5. (**A**) Left heart segmentation. (**B**) Right heart Segmentation. (**C**) Whole heart segmentation. (**D**) Whole heart segmentation rotated 180º

DISCUSSION

Structures of interest:

- Papillary muscle, which connect to the aortic valve leaflets via the chordae tendineae (Figures 4A-B)
- Smoothed left and right ventricle blood pool
- Coronary arteries, which flow out of the aorta and deliver oxygenated blood to the heart (Figures 4C-D)
- Two distinct openings in the left ventricle myocardium to allow blood flow between is and the left atrium and the aorta

REFERENCES

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2. Kong et al, 2021: 2102.07899
3. Daniel H. Pak, Minliang Liu, Shawn S. Ahn, Andrés Caballero, John A. Onofrey, Liang Liang, Wei Sun, and James S. Duncan. Weakly supervised deep learning for aortic valve finite element mesh generation from 3d ct images. In Aasa Feragen, Stefan Sommer, Julia Schnabel, and Mads Nielsen, editors, Information Processing in Medical Imaging, pages 637–648, Cham, 2021. Springer International Publishing.

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