

# 3D Heart Modeling

## Perioperative Applications

2020.09.28

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The Lynn & Arnold Irwin  
**APIL** Advanced  
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Imaging Lab

 **UHN** Peter Munk  
Cardiac  
Centre



# Competing Interests

No financial conflicts of interest.

Research & educational work supported by  
the Peter Munk Cardiac Center  
Foundation, UHN/SHS Academic Medical  
Organization, NSERC

# Objectives

At the completion of this session participants will be able to

Define **basic concepts** related to patient-specific 3D models

Describe commonly used **presentation formats for 3D models**

Describe the **process for creation** of 3D models from medical imaging data

Describe **current & emerging perioperative applications** of such models

Describe the **limitations** of current modeling techniques

# Outline

- What are patient-specific 3D models?
- How can you see them?
- How are they made?
- What can they do?
- What can't they do?
- What does the (near) future hold?

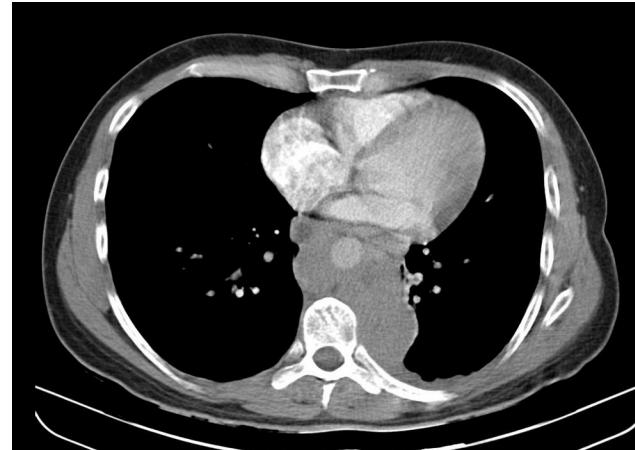
# What are patient-specific 3D models?

**Digital 3D models** created from 3-dimensional medical imaging data (**CT, MRI, 3D Ultrasound**)

Models can be **dynamic** or **static** depending on the source data

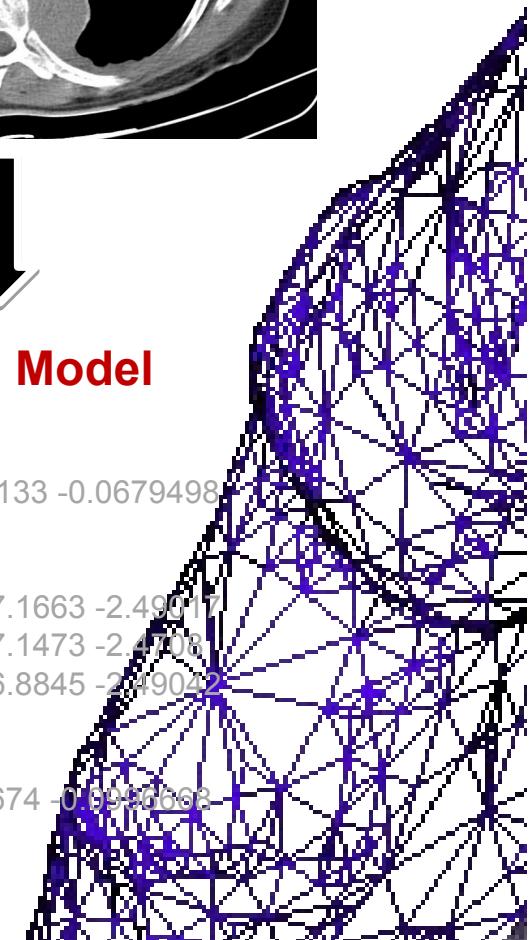
Multiple file formats (**STL, OBJ** etc.)

Digitally represented as a **mesh** (vertices & edges)



**Digital 3D Model**

```
solid ascii
facet normal 0.0927133 -0.0679498
0.993372
outer loop
vertex -54.8458 67.1663 -2.49917
vertex -55.0673 67.1473 -2.49908
vertex -55.0497 66.8845 -2.49042
endloop
endfacet
facet normal -0.665674 -0.6926568
0.739557
```



## Digital 3D Model

```
solid ascii  
facet normal 0.0927133 -0.0679498  
0.993372  
outer loop  
vertex -54.8458 67.1663 -2.49017  
vertex -55.0673 67.1473 -2.4708  
vertex -55.0497 66.8845 -2.49042  
endloop  
endfacet  
facet normal -0.665674 -0.0996668  
0.739557
```

...

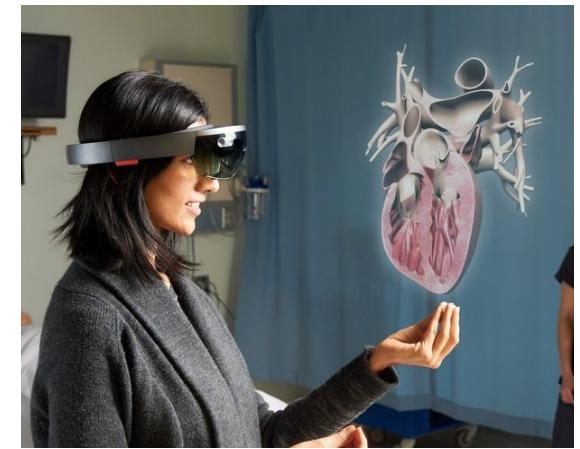
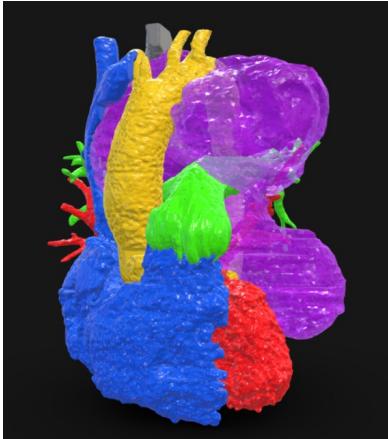
# How can you see them?

3D rendering (on 2D screen)

Stereoscopic & holographic displays

3D print

Virtual/augmented Reality



# How are they made?

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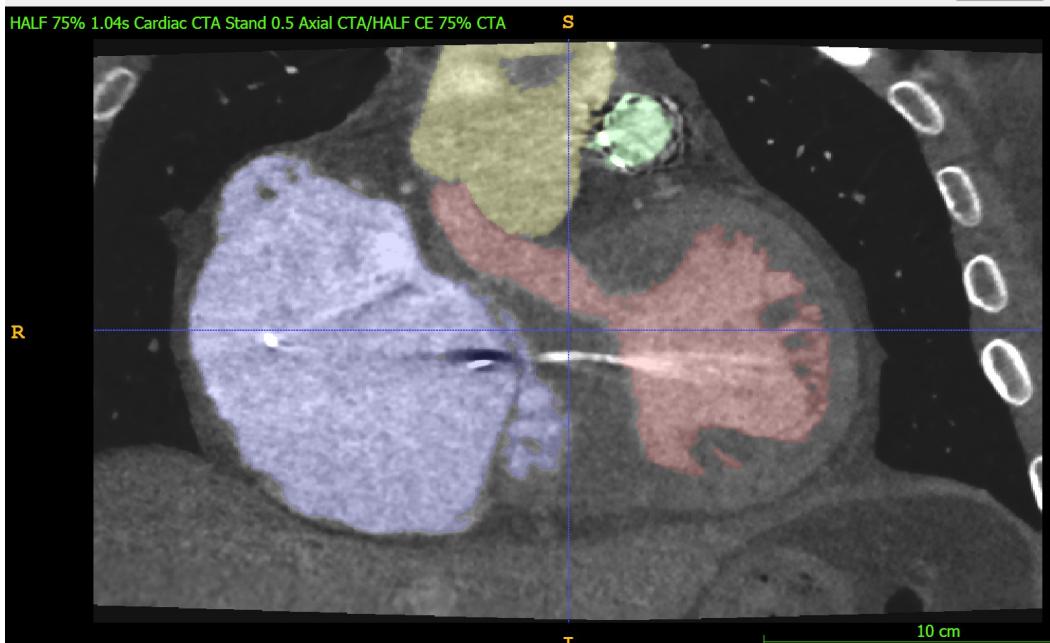
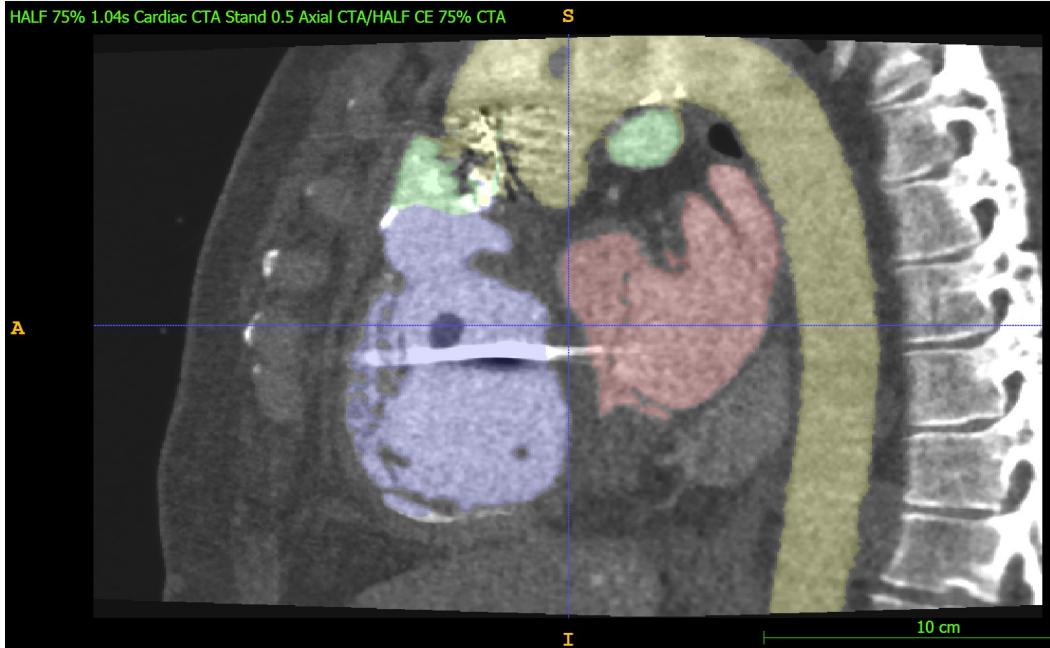
1. Imaging

2. Resampling to isotropic resolution

3. Segmentation of medical image  
to create voxel model

manual ..... automatic

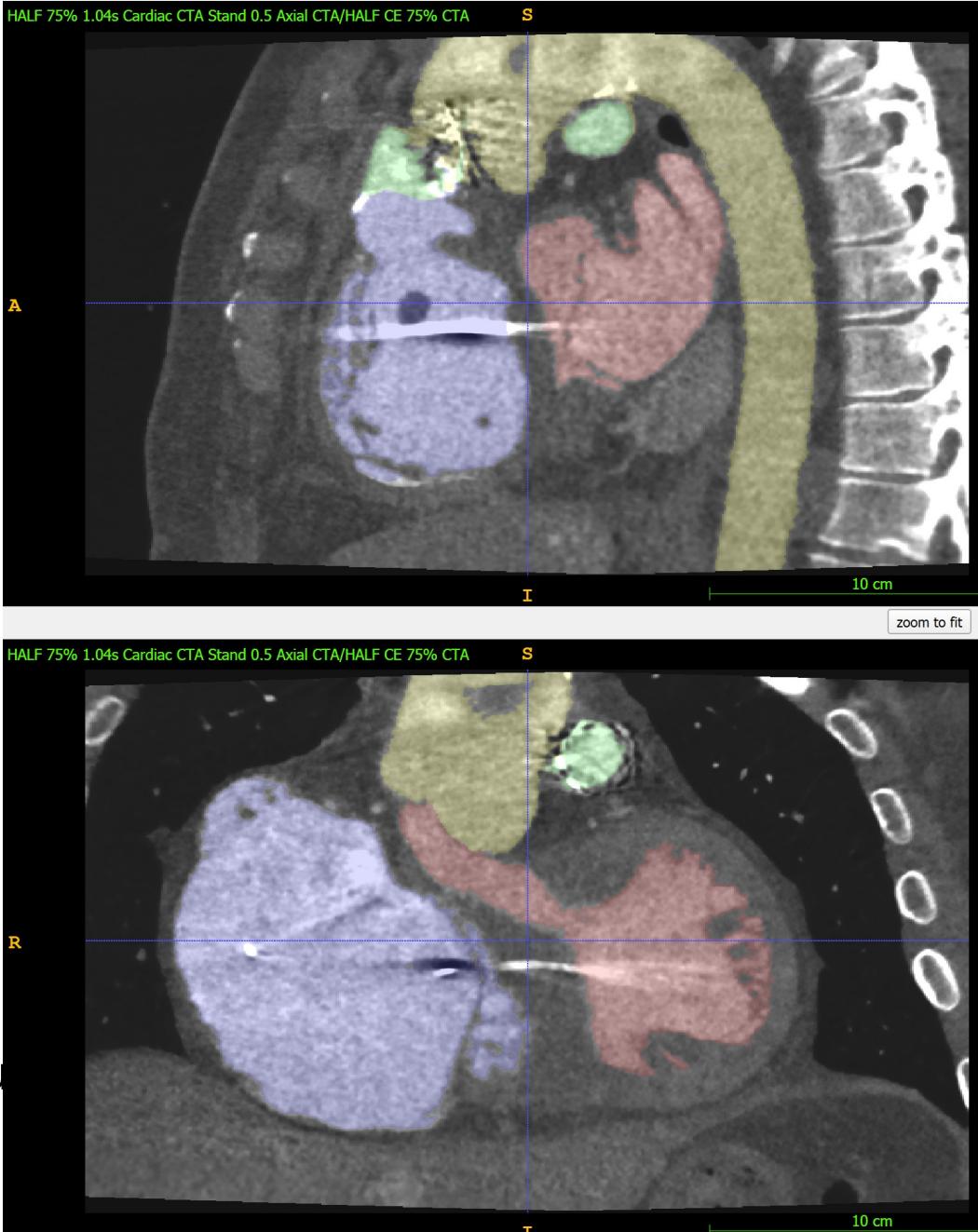
4. Modeling/Mesh generation from  
voxel model



# Source Imaging: CT

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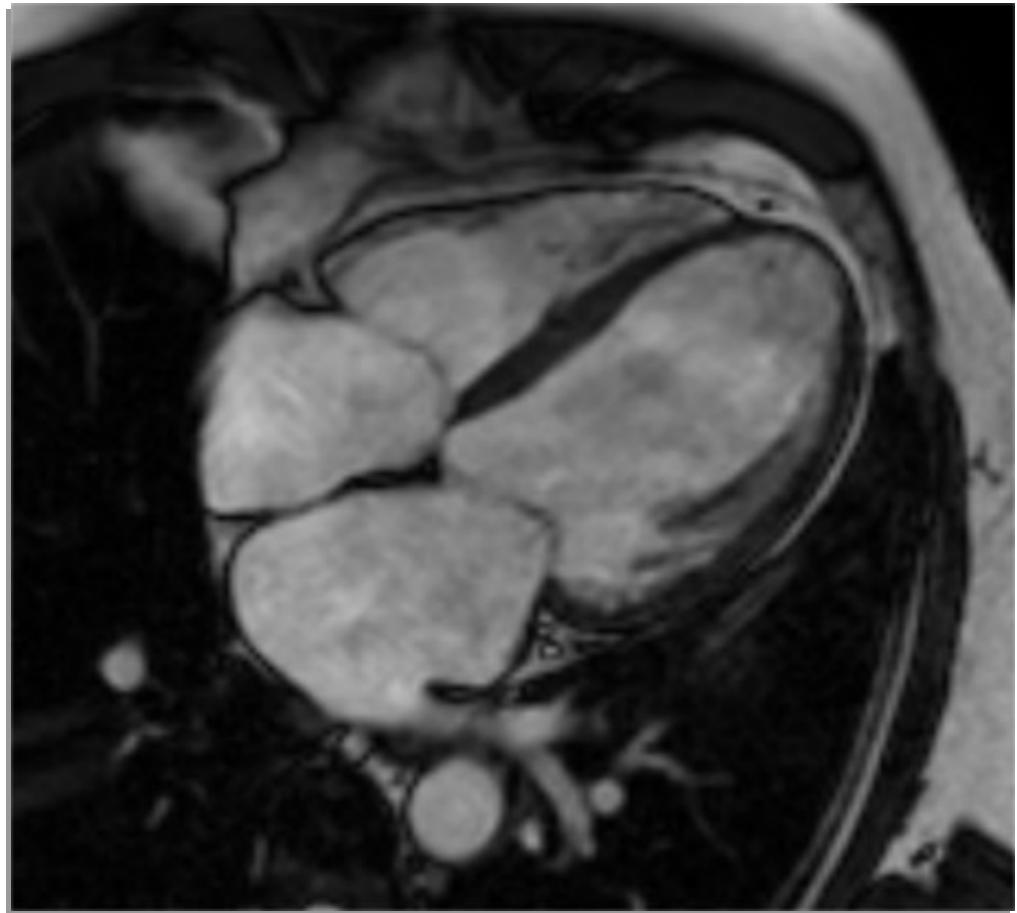
- Most common, ~ 0.5 mm resolution
- Ideally **cardiac-gated** to reduce motion artifact, with **contrast**
- **Soft-tissue boundaries** can be challenging to model accurately
- **Dual-energy CT (DECT)** can improve soft tissue distinctions but not widely available yet



# Source Imaging: MR

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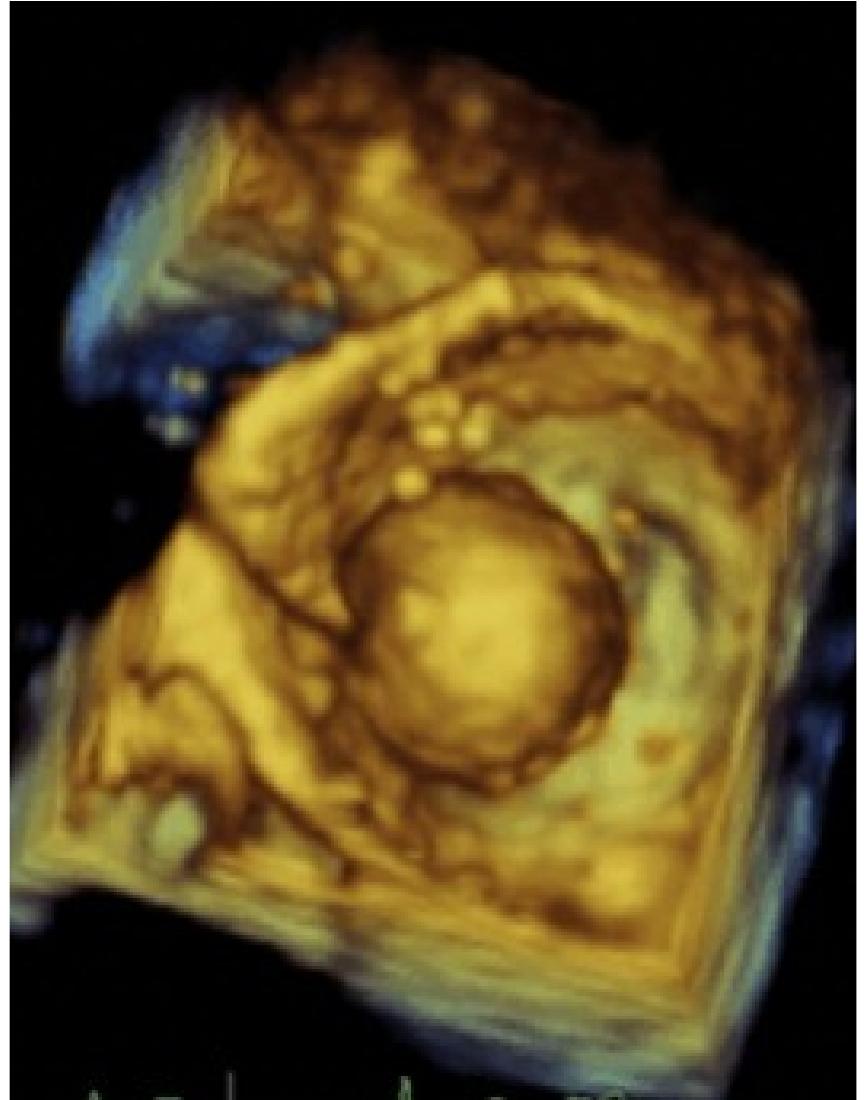
- Best **soft tissue contrast**
- **Anisotropic resolution** (with 5-8 mm slices) - limited by time & storage space, patient tolerance
- Most common in **pediatric** cases



# Source Imaging: 3D TEE

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- Best **temporal resolution**: Ideal for valves and highly mobile masses.
- **Limited spatial scope**
- **Frustum anisotropic voxel** geometry requires resampling; resolution decreases with dept
- **Non-standard DICOM format** requires vendor-specific software



# Voxel Geometry & Resolution: CT vs MRI vs Echo

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**Isotropic:** Same resolution in all 3 axis

**Anisotropic:** Varies with orientation

**CT:** Cubic or near-cubic voxels >> No or minimal resampling required (low distortion risk). Typical 0.5x0.5x0.5 mm

**MRI:** Rectangular prism  $0.5 \times 0.5 \times 5-8$  mm

**Echo:** Spherical segment voxels which grow with distance from probe



CT

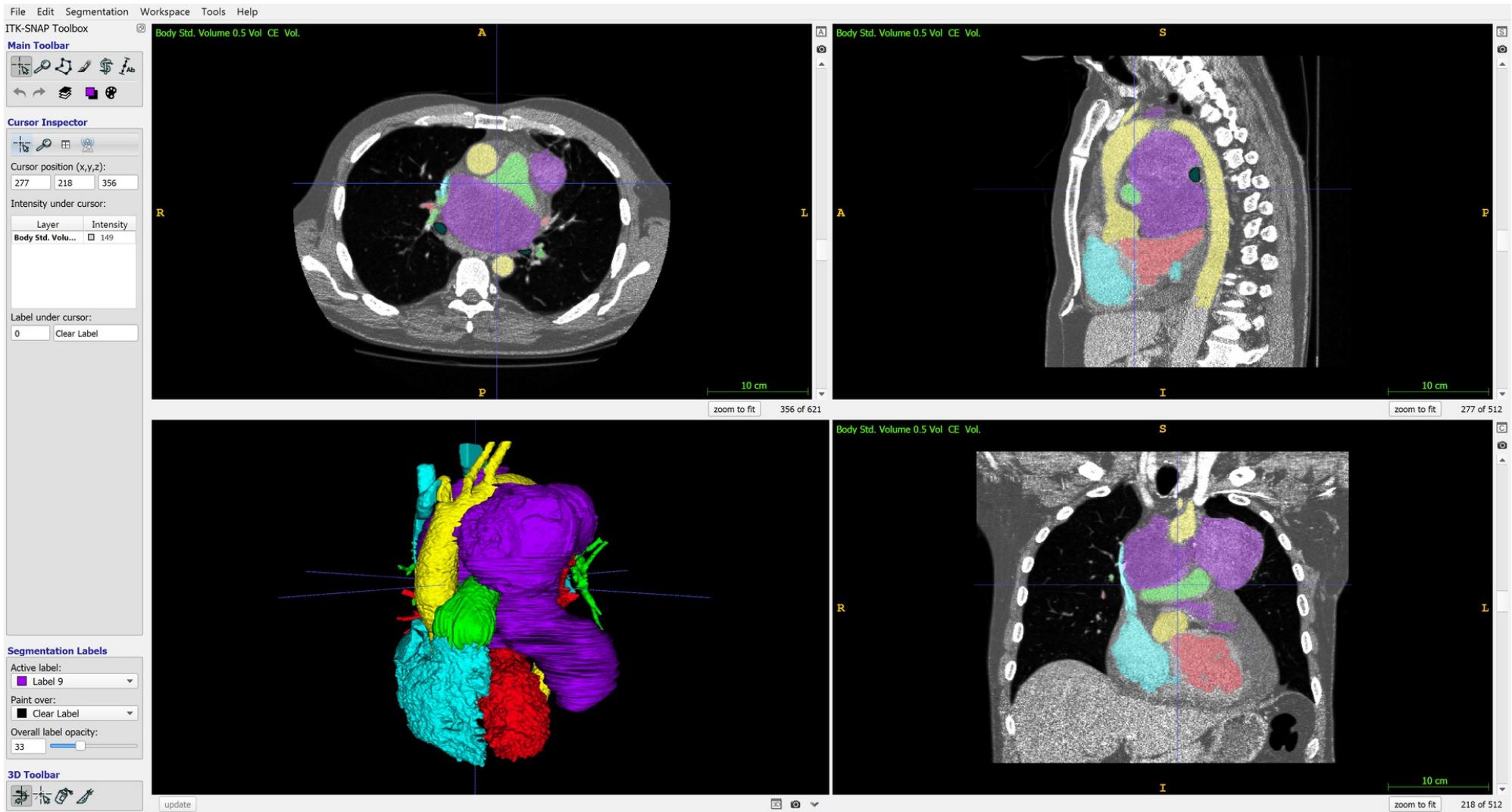


MRI

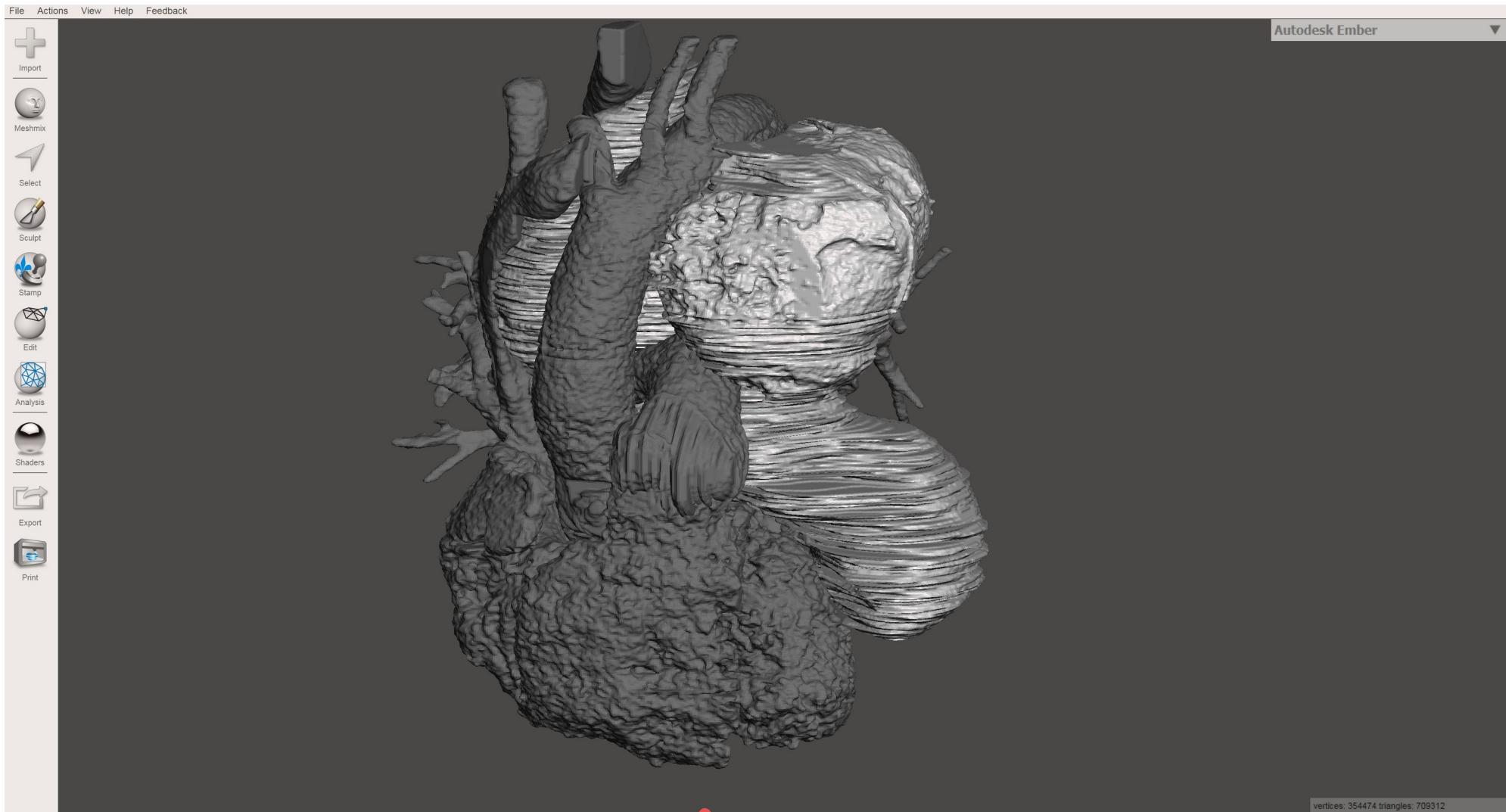


Echo

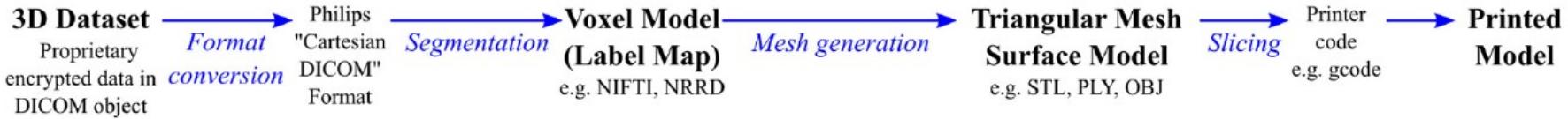
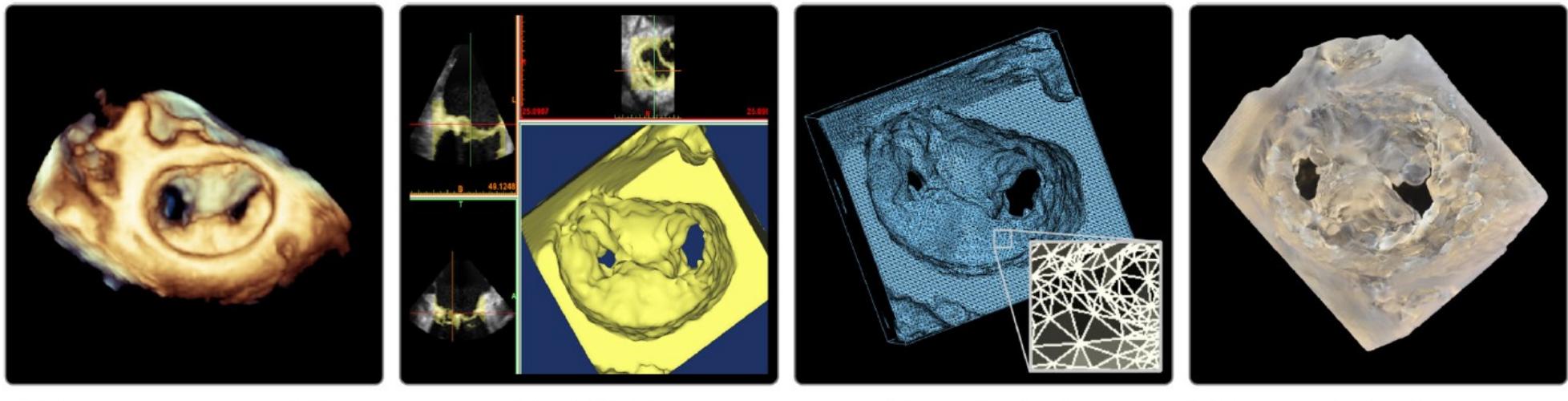
# Segmentation



# Modeling / Mesh generation / Editing

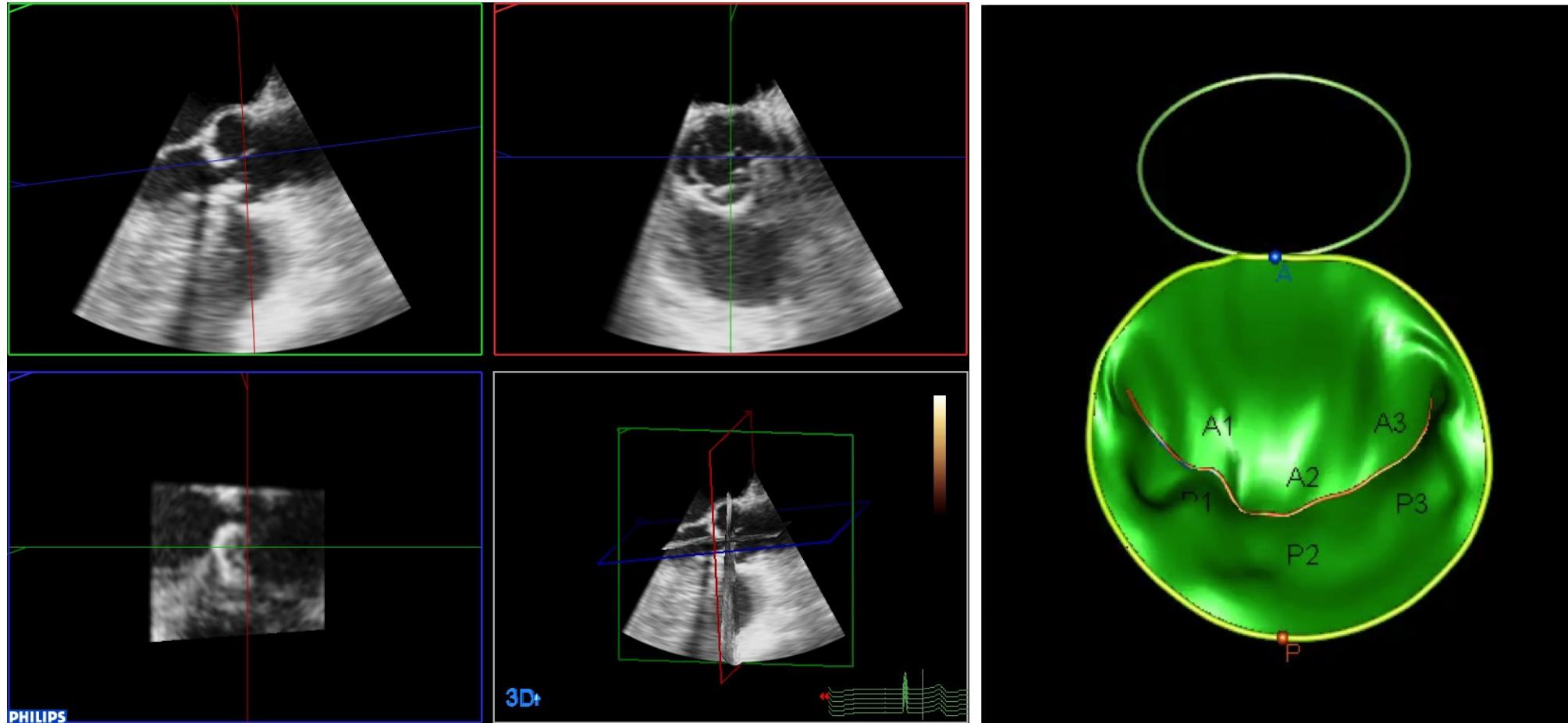


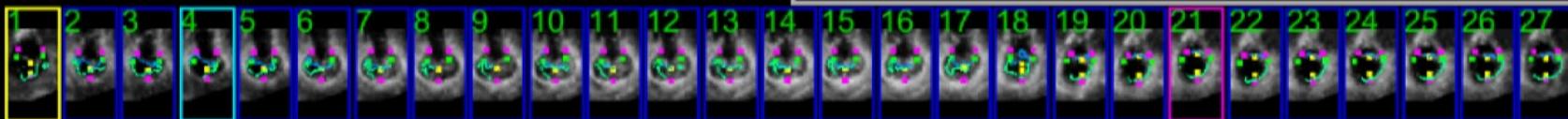
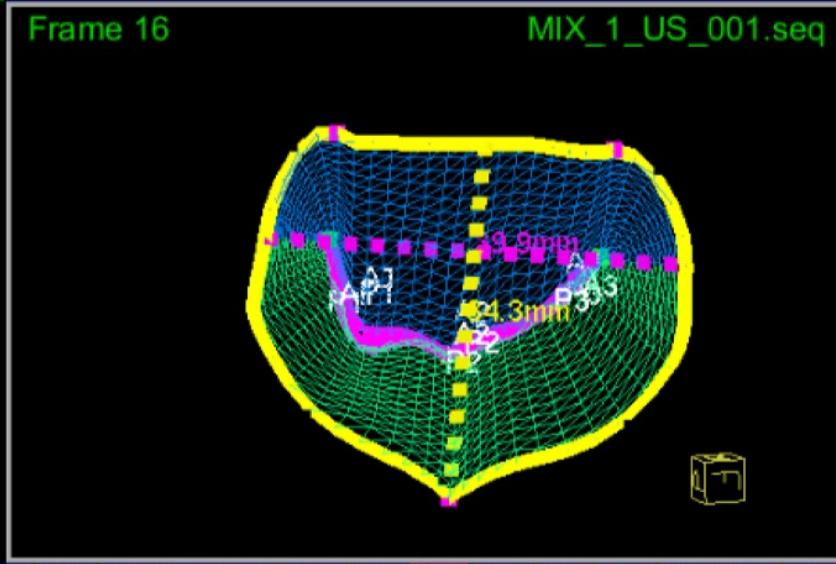
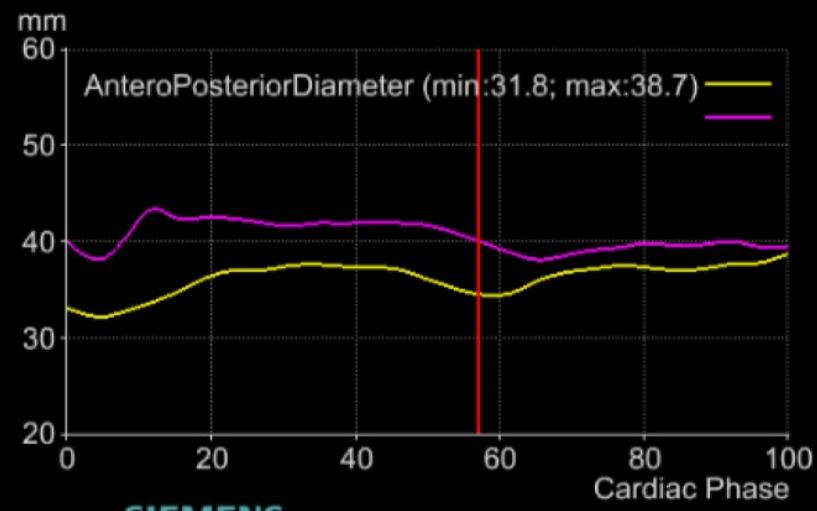
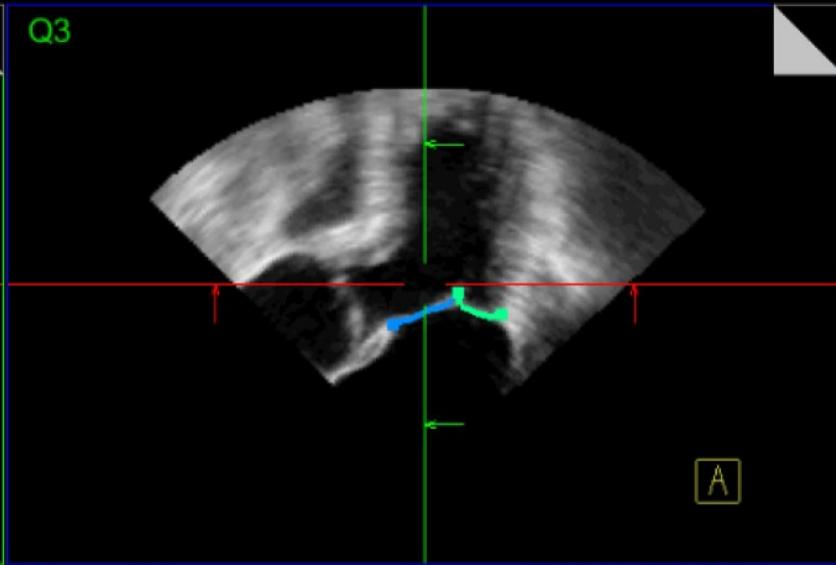
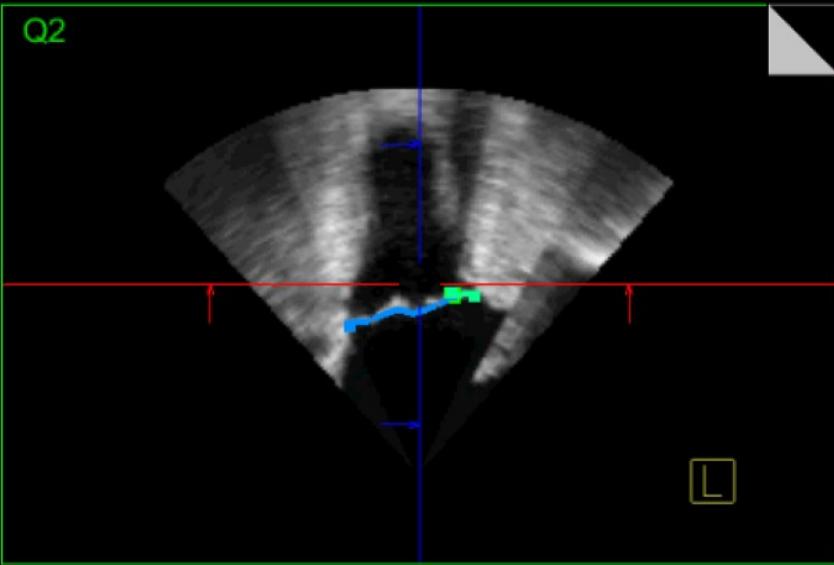




**Figure 1**

Summarized workflow for 3D printing of a 3D TEE data set of a mitral valve after a MitraClip procedure. Examples of file formats used are included where applicable. From left to right: After export from the ultrasound system, the data set is converted to the Philips Cartesian DICOM format (first panel). Using segmentation software the voxels in the region of interest are labeled, creating a 'solid' voxel model (second panel). A triangular surface mesh model is generated based on the voxel model (third panel). The mesh model is processed by the slicing software, generating a printer code, which directs the printing of the final model (fourth panel). (File formats: NIFTI, Neuroimaging Informatics Technology Initiative; NRRD, Nearly Raw Raster Data; STL, Stereolithography; PLY, Polygon; OBJ, Wavefront Object.)

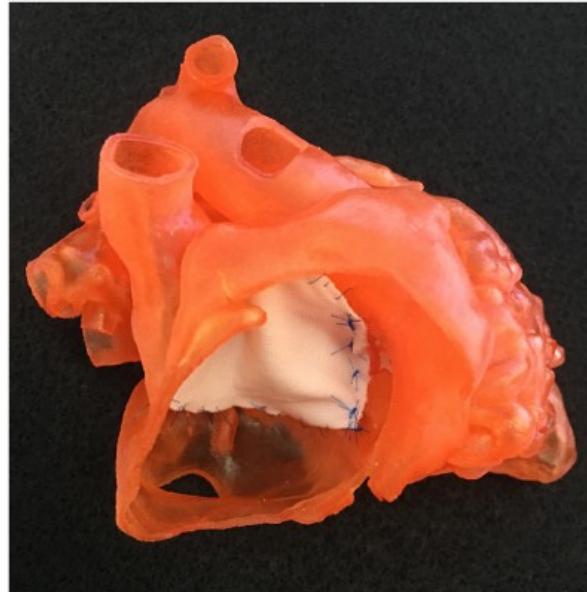
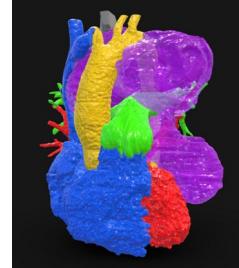




# What can you do with them?

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1. Visualization  
(education or clinical planning)
2. Procedural Simulation & Guidance



# Applications: Visualization

3D rendering (on screen)

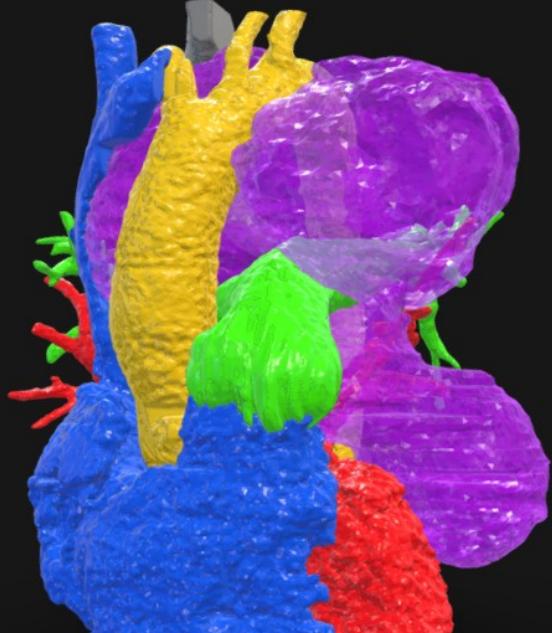
3D print

Virtual/augmented Reality

Stereoscopic & holographic  
displays

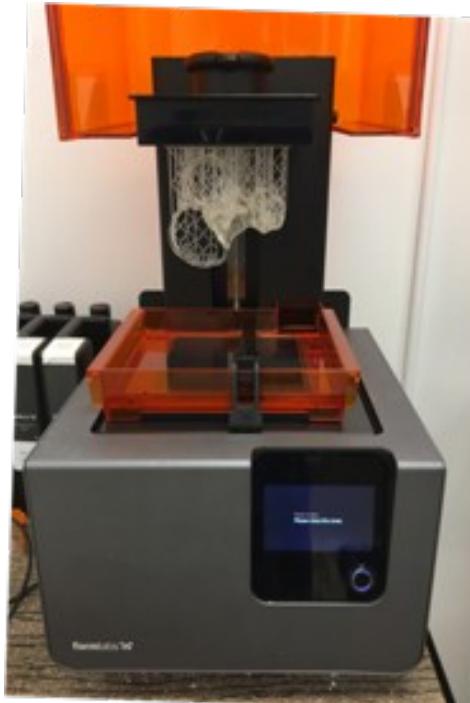
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outer loop
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vertex -55.0673 67.1473 -2.4708
vertex -55.0497 66.8845 -2.49042
endloop...
```



# Rendering

<https://apilnextcloud.ams3.digitaloceanspaces.com/201803-02/201803VIEWER.html>

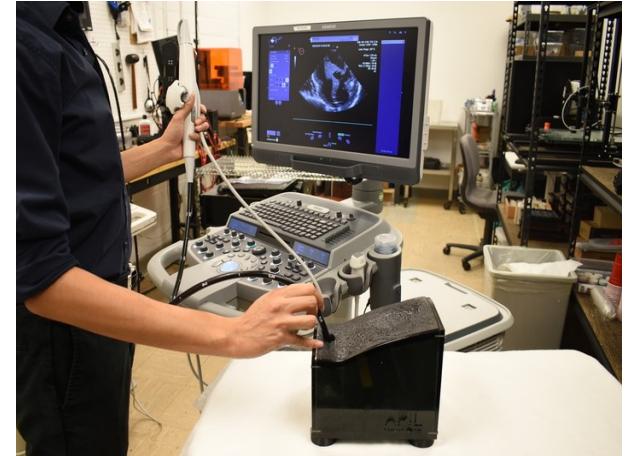
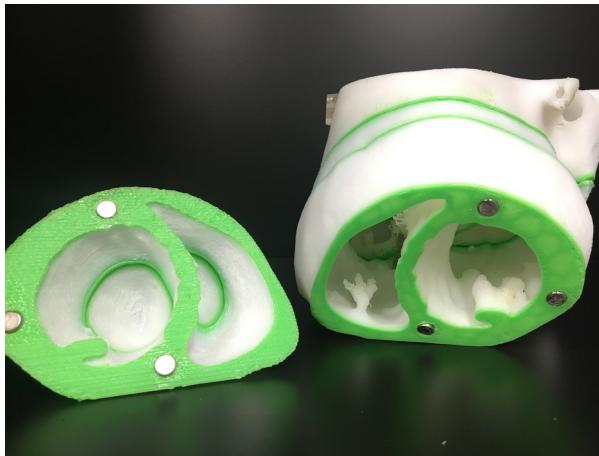
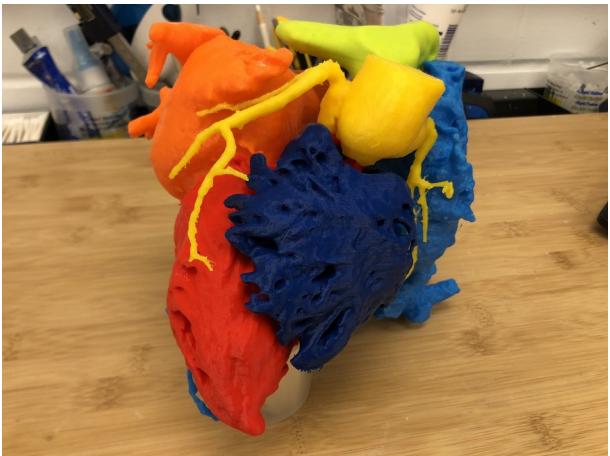
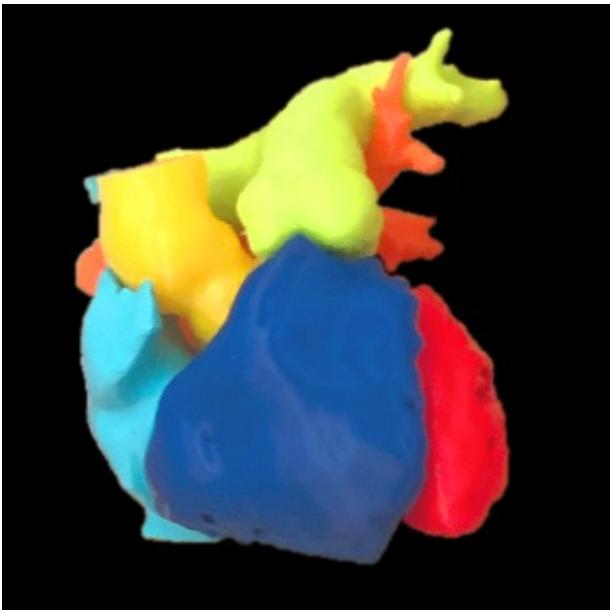


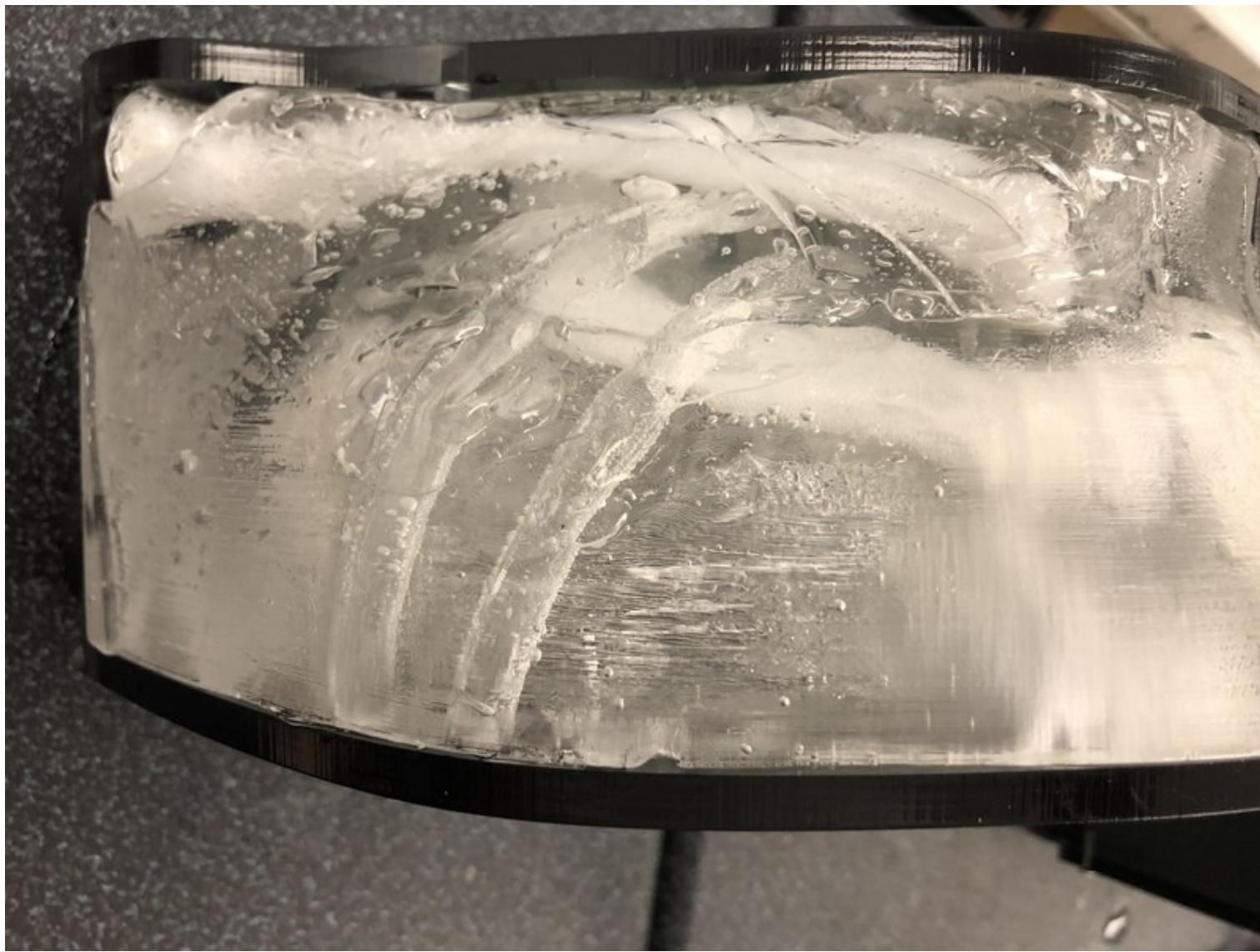
## 3D Printing

Most accessible in terms of use and interaction  
Least accessible in terms of resources / cost  
Wide range of materials, including biocompatible and tissue  
Growing rapidly, cost decreasing

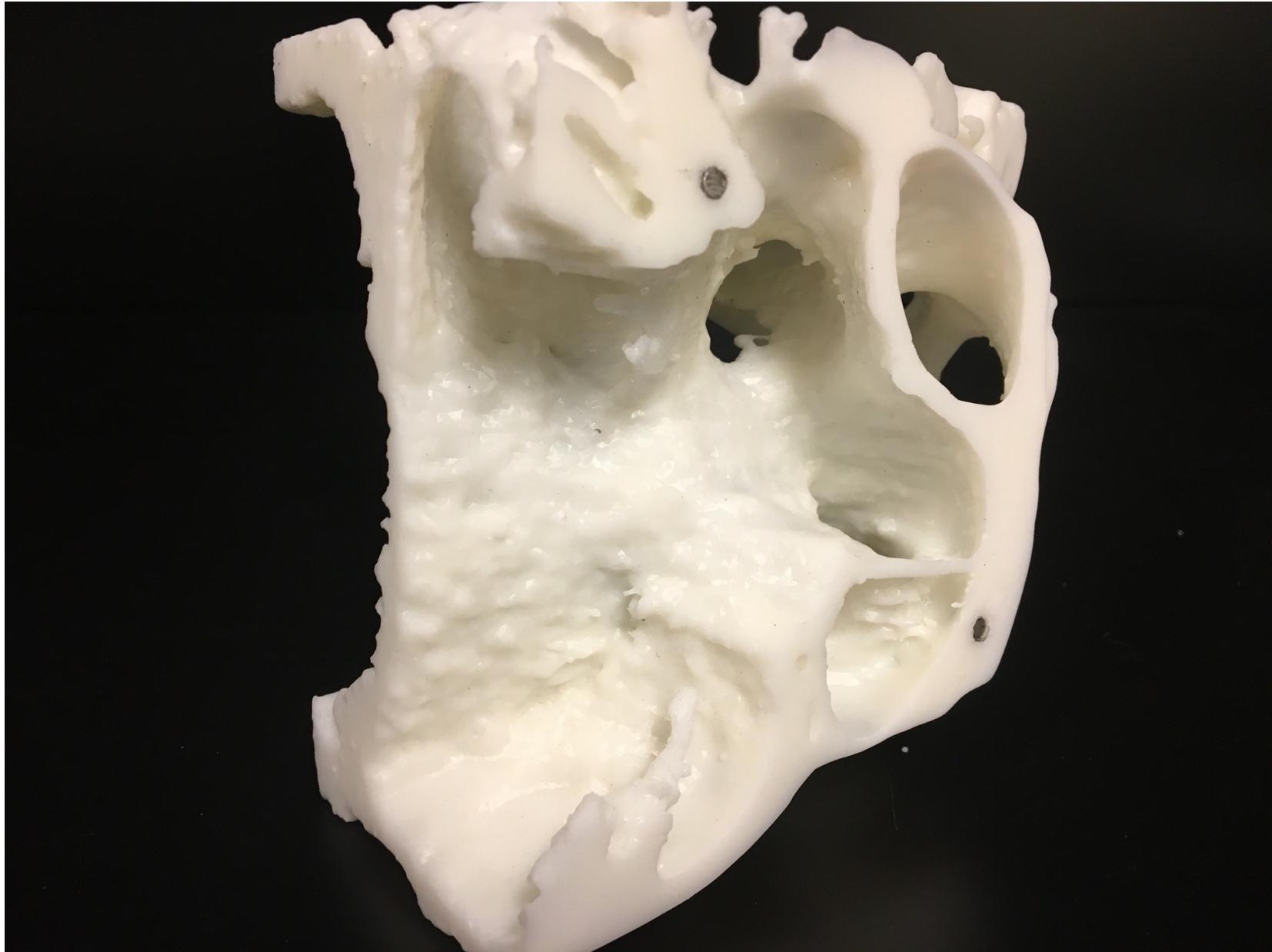
Limited interaction: scaling, material properties



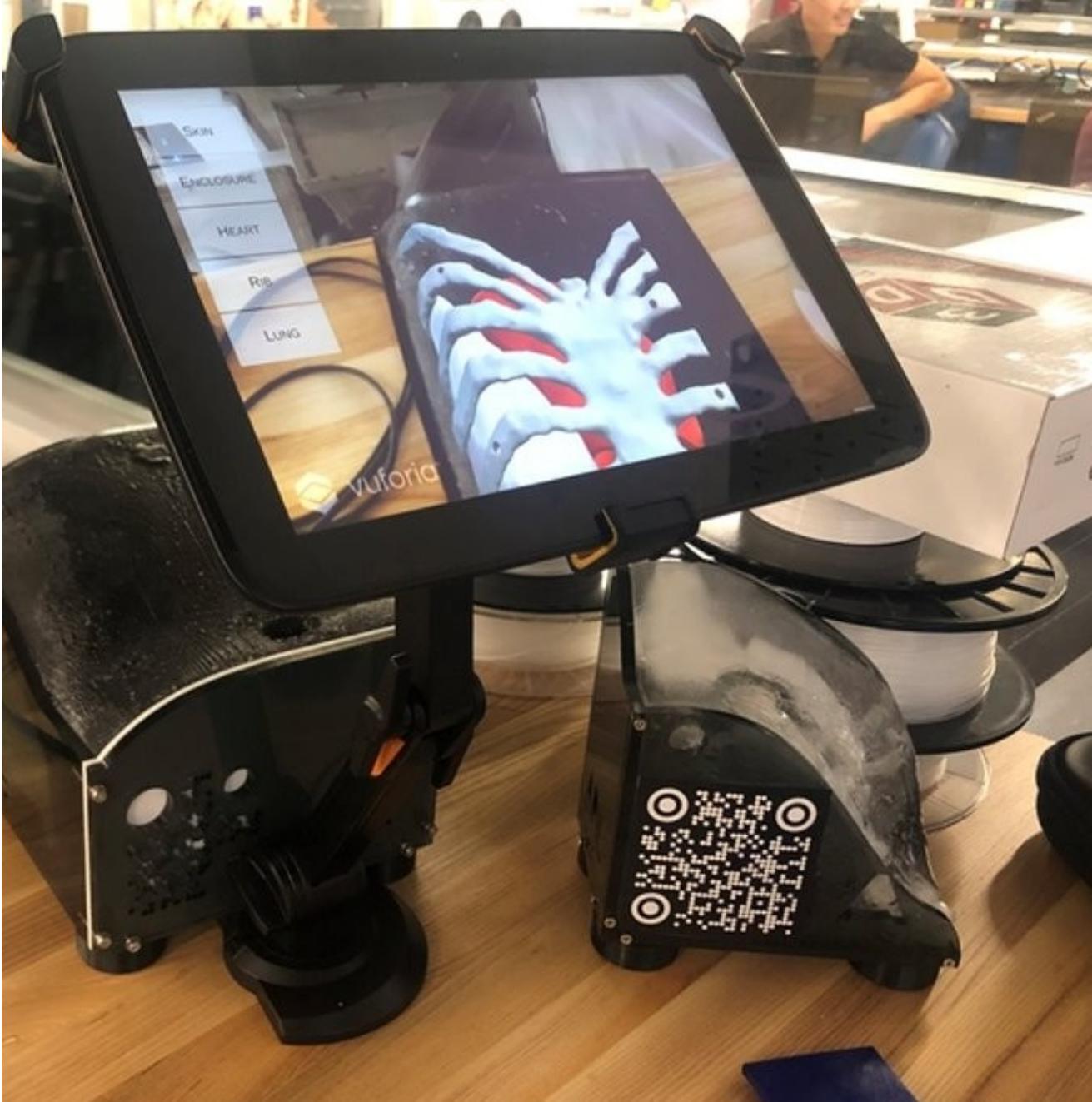




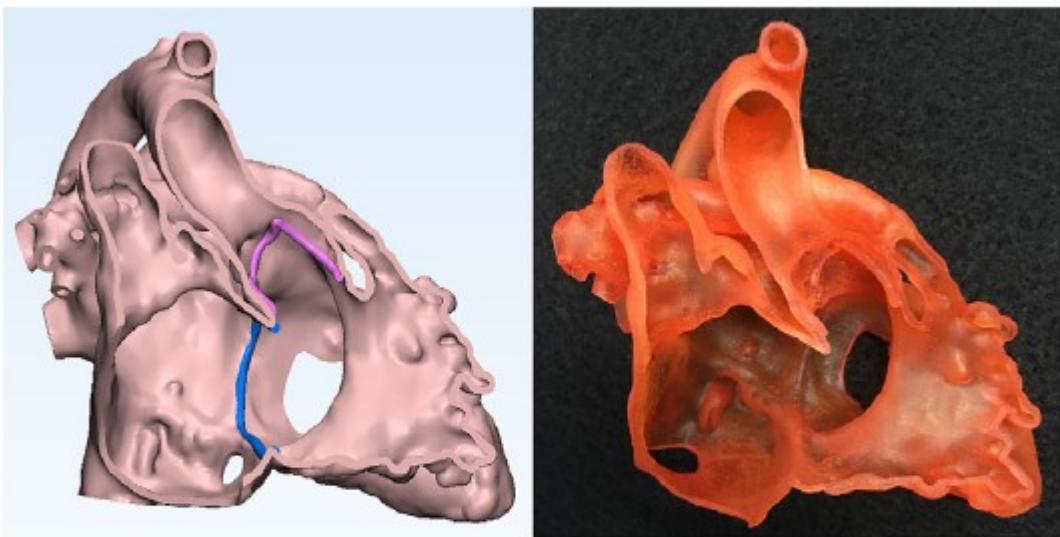




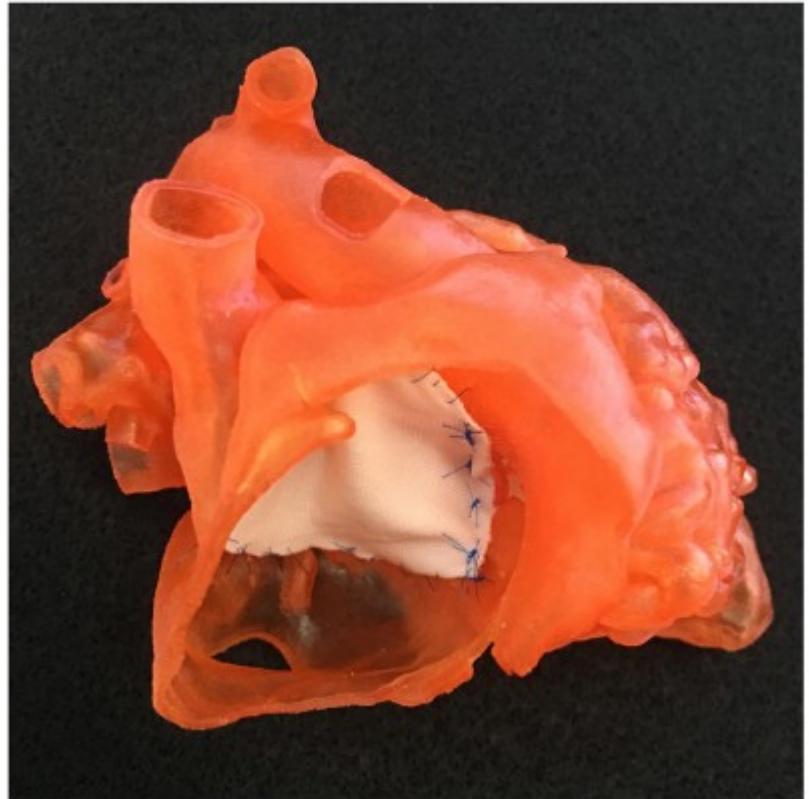
# Augmented / Mixed Reality



# Procedural Simulation (physical)



**FIGURE 3** | Graphic representation and photograph of the endocardial surface anatomy model made of soft material (TangoPlus, Stratasys Ltd., MN, USA) of the right ventricle of the case shown in **Figure 1**.



## 3D Printing in Surgical Management of Double Outlet Right Ventricle

Shi-Joon Yoo<sup>1,2\*</sup> and Glen S. van Arsdell<sup>3</sup>

*Front. Pediatr.* 5:289.  
doi: 10.3389/fped.2017.00289

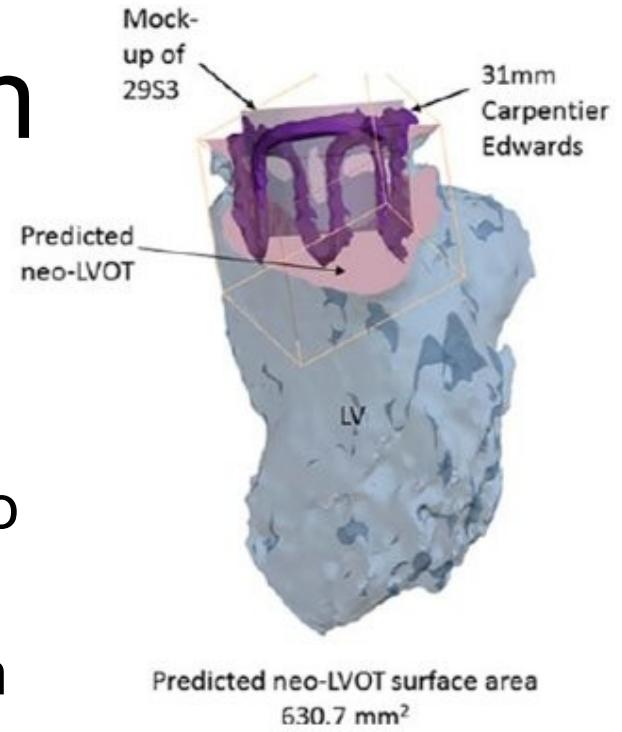
# Virtual/Mixed Simulation

## Simulation of procedure in virtual environment (VR, AR)

- Limited haptic feedback
- Mechanical properties of tissue difficult to capture

## Computational Simulation +/- visualization

- Prosthesis sizing (TAVI)
- Prediction of complications
- Complex measurements
- Optimal geometric solutions (theoretical)



*Catheter Cardiovasc Interv.* 2018;92:379–387

Validating a prediction modeling tool for left ventricular outflow tract (LVOT) obstruction after transcatheter mitral valve replacement (TMVR)

Dee Dee Wang, MD<sup>1</sup> | Marvin H. Eng, MD<sup>1</sup> | Adam B. Greenbaum, MD<sup>1</sup>

# ... evidence

Three-dimensional printing of models for surgical planning in patients with primary cardiac tumors

Daniel Schmauss, MD,<sup>a</sup> Nicolas Gerber, MSc,<sup>b</sup> and Ralf Sodian, MD<sup>a</sup>

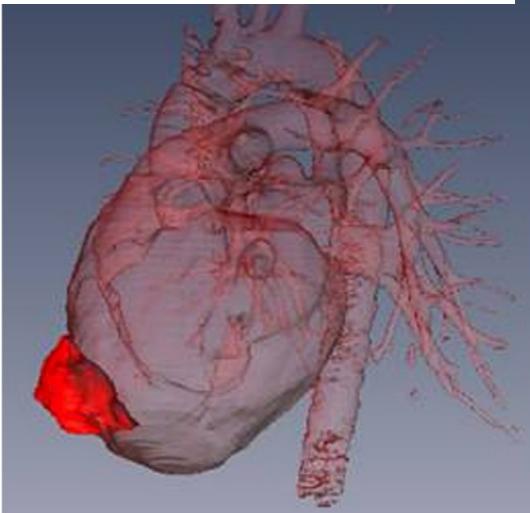
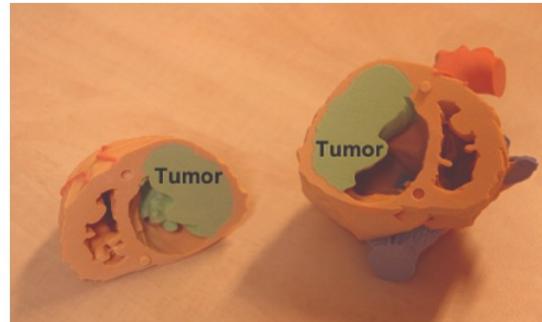


FIGURE 2. A 3-dimensional reconstruction of the heart with the tumor on the right ventricle.



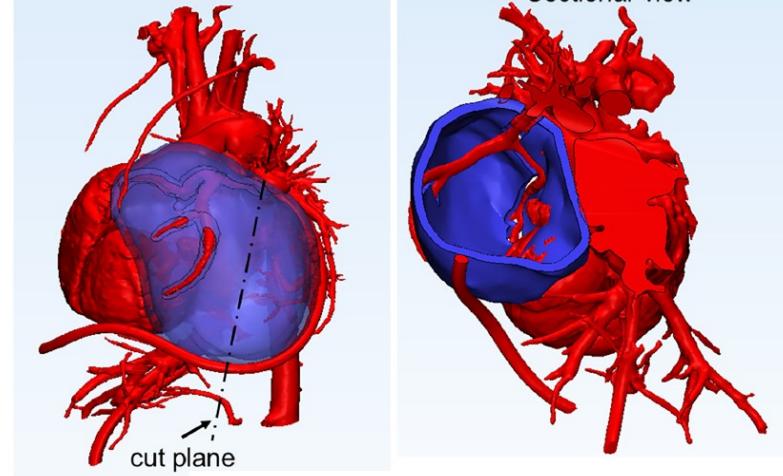
Jacobs et al. *Interact Cardiovasc Thorac Surg.* 2008;7: 6–9.

DOI 10.1111/jocs.12812

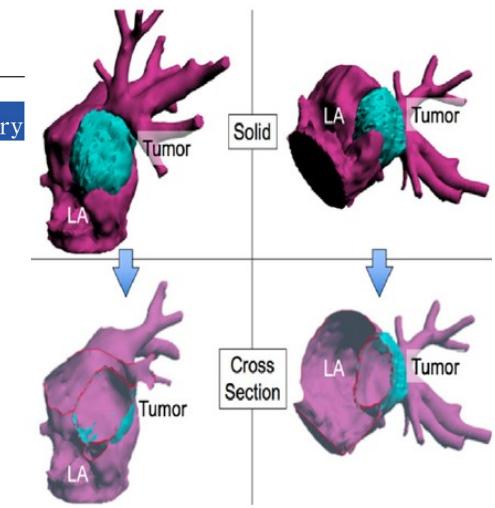
## NEW TECHNOLOGIES

### Use of three-dimensional models to assist in the resection of malignant cardiac tumors

Odeaa Al Jabbari, M.D.<sup>1\*</sup> | Walid K. Abu Saleh, M.D.<sup>2</sup> | Avni P. Patel, M.E.<sup>1</sup> |  
Stephen R. Igo, B.S.<sup>1</sup> | Michael J. Reardon, M.D.<sup>1</sup>



Riggs et al. *Transl Pediatr.* 2018;7: 196–202.



## Surgical Planning by 3D Printing for Primary Cardiac Schwannoma Resection

Kuk Hui Son<sup>1\*</sup>, Kun-Woo Kim<sup>1\*</sup>, Chi Bum Ahn<sup>2</sup>, Chang Hu Choi<sup>1</sup>, Kook Yang Park<sup>1</sup>,  
Chul Hyun Park<sup>1</sup>, Jae-Ik Lee<sup>1</sup>, and Yang Bin Jeon<sup>1</sup>

# Three-dimensional printed models for surgical planning of complex congenital heart defects: an international multicentre study

Israel Valverde<sup>a,b,c,d,\*</sup>, Gorka Gomez-Ciriza<sup>a</sup>, Tarique Hussain<sup>c,e</sup>, Cristina Suarez-Mejias<sup>a</sup>,

**METHODS:** A prospective case-crossover study involving 10 international centres and 40 patients with complex CHD (median age 3 years, range 1 month–34 years) was conducted. Magnetic resonance imaging and computed tomography were used to acquire and segment the 3D cardiovascular anatomy. Models were fabricated by fused deposition modelling of polyurethane filament, and dimensions were compared with medical images. Decisions after the evaluation of routine clinical images were compared with those after inspection of the 3D model and intraoperative findings. Subjective satisfaction questionnaire was provided.

**RESULTS:** 3D models accurately replicate anatomy with a mean bias of  $-0.27 \pm 0.73$  mm. Ninety-six percent of the surgeons agree or strongly agree that 3D models provided better understanding of CHD morphology and improved surgical planning. 3D models changed the surgical decision in 19 of the 40 cases. Consideration of a 3D model refined the planned biventricular repair, achieving an improved surgical correction in 8 cases. In 4 cases initially considered for conservative management or univentricular palliation, inspection of the 3D model enabled successful biventricular repair.

**CONCLUSIONS:** 3D models are accurate replicas of the cardiovascular anatomy and improve the understanding of complex CHD. 3D models did not change the surgical decision in most of the cases (21 of 40 cases, 52.5% cases). However, in 19 of the 40 selected complex cases, 3D model helped redefining the surgical approach.

RESEARCH

Open Access



# Radiological Society of North America (RSNA) 3D printing Special Interest Group (SIG): guidelines for medical 3D printing and appropriateness for clinical scenarios

Leonid Chepelev<sup>1†</sup>, Nicole Wake<sup>2,3†</sup>, Justin Ryan<sup>4†</sup>, Waleed Althobaity<sup>1†</sup>, Ashish Gupta<sup>1†</sup>, Elsa Arribas<sup>5†</sup>, Lumarie Santiago<sup>5†</sup>, David H Ballard<sup>6</sup>, Kenneth C Wang<sup>7</sup>, William Weadock<sup>8</sup>, Ciprian N Ionita<sup>9</sup>, Dimitrios Mitsouras<sup>1</sup>, Jonathan Morris<sup>10</sup>, Jane Matsumoto<sup>10</sup>, Andy Christensen<sup>1</sup>, Peter Liacouras<sup>11</sup>, Frank J Rybicki<sup>1\*</sup>, Adnan Sheikh<sup>1</sup> and RSNA Special Interest Group for 3D Printing

# Limitations & Challenges

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Only (at best) **as accurate as source** imaging

**Illusion of certainty:** Margins of error and uncertainty in image interpretation difficult to capture (esp 3D Print)

Multi-step process = **multiple sources of error:** verification of critical details against source or other imaging is crucial

**Mechanical properties** poorly captured

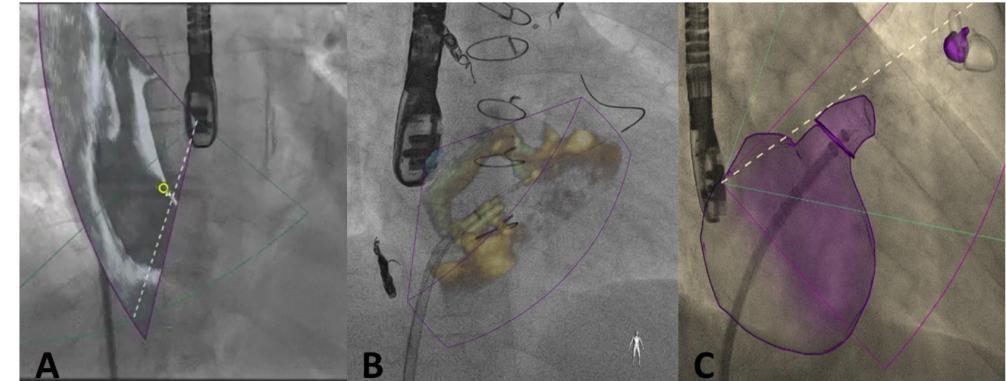
**Limited access**, frequently on experimental basis

**Limited evidence base.** Lack of **guidelines / appropriate use criteria\***.

**Infrastructure** needs to be developed for integration into regular clinical workflows: Organizational model of modeling services; PACS/EMR integration; cost recovery

# The Near Future

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**Figure 2** Different echocardiography imaging, such as 2D echocardiography with a yellow marker placed at the transseptal puncture site (A), 3D echocardiography (B), and 3D display of automatically rendered structures (C), can be overlaid onto the fluoroscopic screen to guide different procedural tasks. The tip of the catheter is in the LAA.

**Multimodal image fusion to combine benefits of different modalities**

Modeling of **mechanical properties** of tissue for better physical & virtual simulation

**Dynamic modeling** to capture mobility of structures

**Increased automation** of process to increase speed and reduce cost

Procedural guidance: Fusion of model with intra-operative imaging; **projection onto surgical field**

Improved **infrastructure**: evidence base, guidelines, PACS support; remuneration

## Acknowledgements

Joshua Qua Hiansen  
Massimiliano Meineri,  
Patricia Murphy  
Department of Anesthesia & Pain  
Management; and Division of Cardiac  
Surgery, TGH  
Toronto General and Western Hospital  
Foundation

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# Thank You!

