3D Modeling of Cardiac Tumors

Toronto Cardiac Tumor Symposium

2020.01.23

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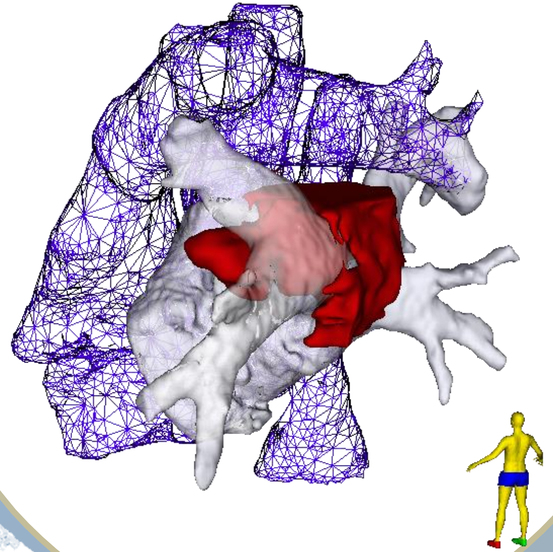
Toronto General Hospital



The Lynn & Arnold Irwin APIL Advanced Perioperative 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.

Objectives

At the completion of this session participants will be able to

1. Define **basic concepts** related to patient-specific 3D models of cardiac tumors
2. Describe commonly used **presentation formats for 3D models**
3. Describe the **process for creation** of 3D models from medical imaging data
4. Describe the **appropriate uses** of such models
5. 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?

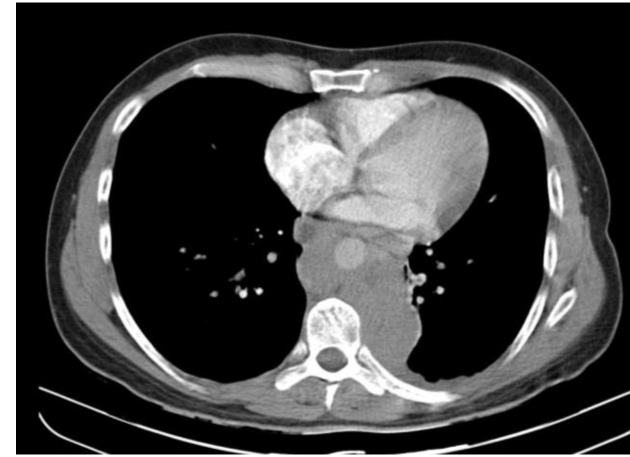
What are patient-specific 3D models?

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

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

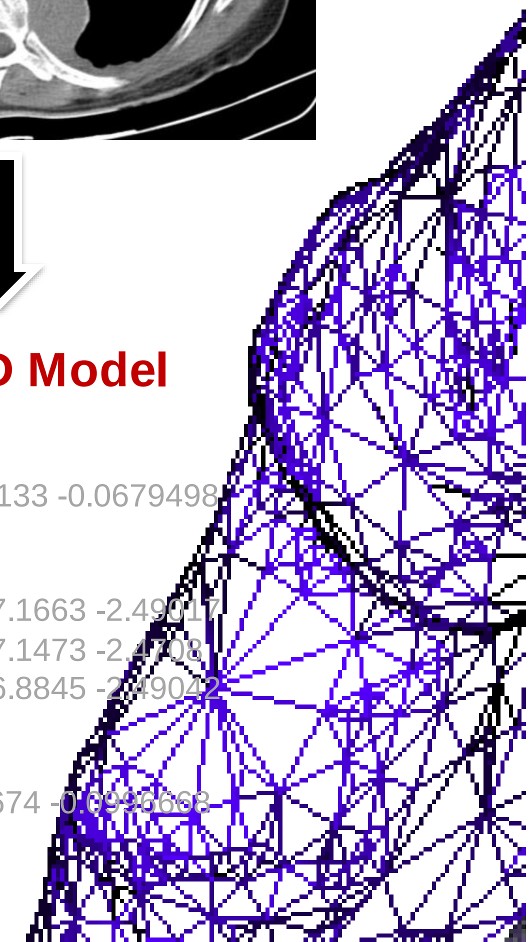
Multiple file formats (STL, OBJ etc.)

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



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
```



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0.739557
...
```

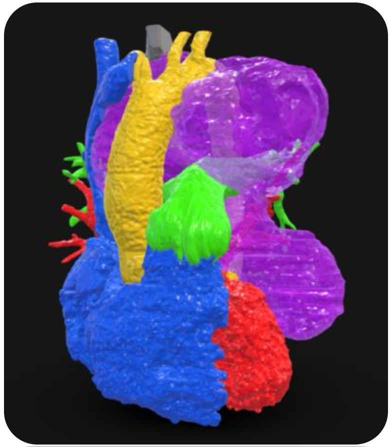
How can you see them?

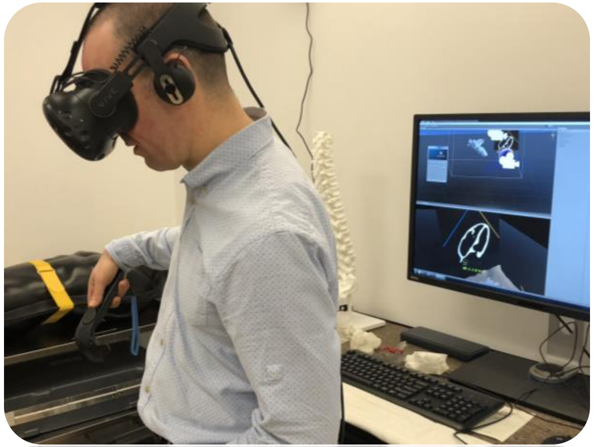
3D rendering (on 2D screen)

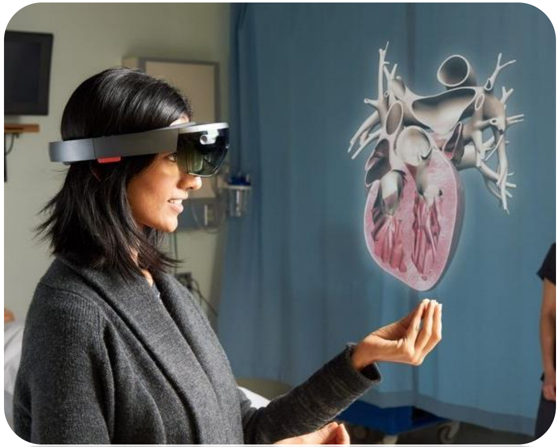
Stereoscopic & holographic displays

3D print

Virtual/augmented Reality







How are they made?

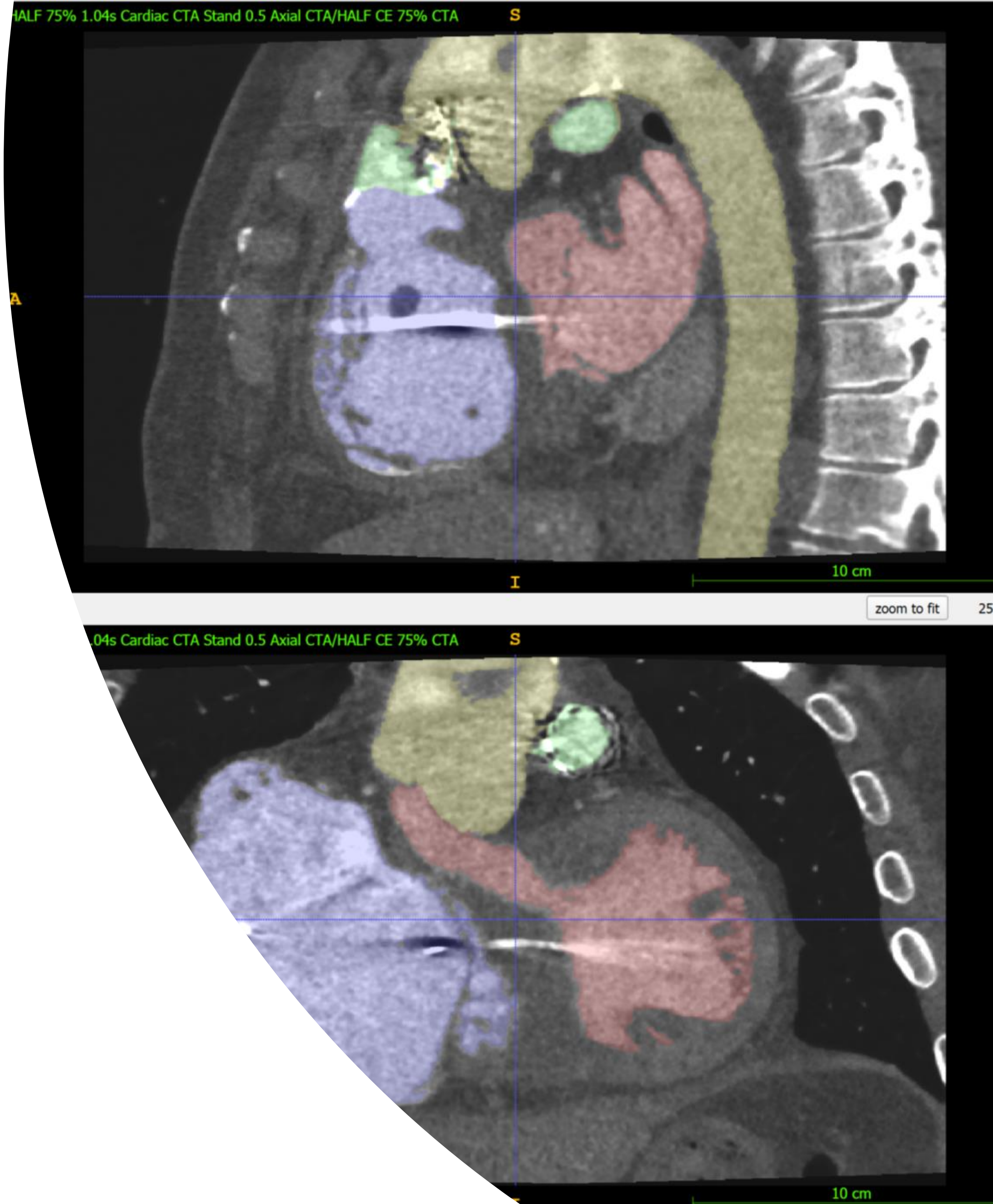
1. Imaging

2. Resampling to isotropic resolution

3. Segmentation of medical image to create voxel model

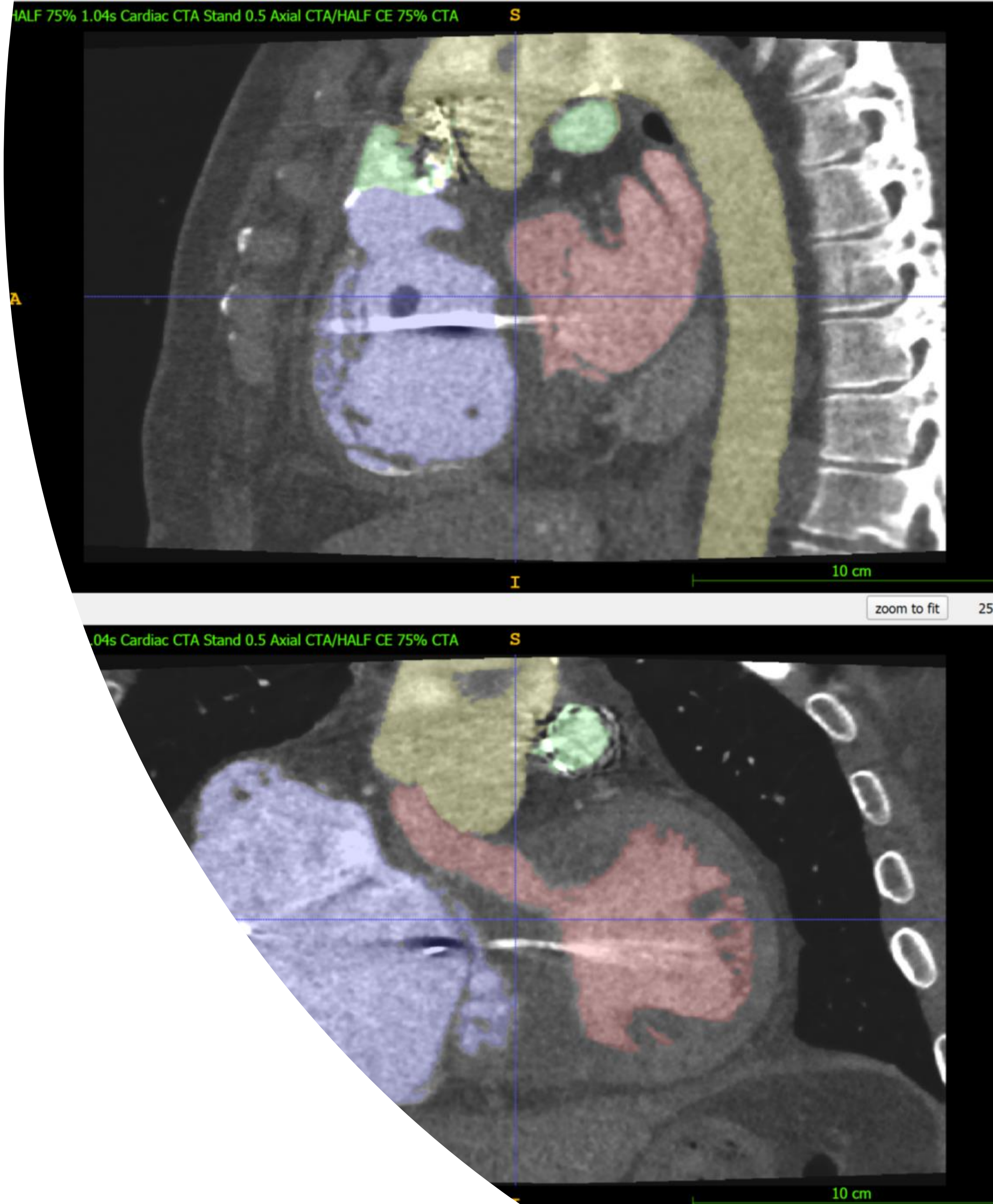
manual ………………… automatic

4. Modeling/Mesh generation from voxel model



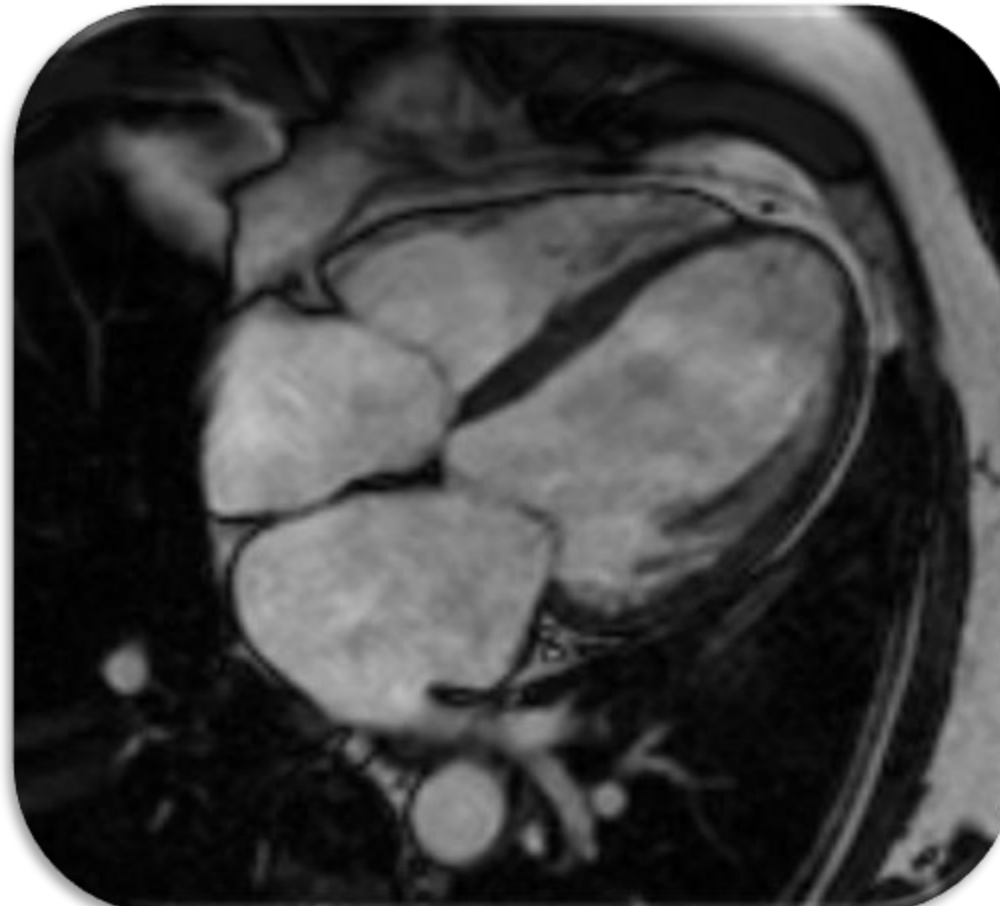
Source Imaging: CT

- 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



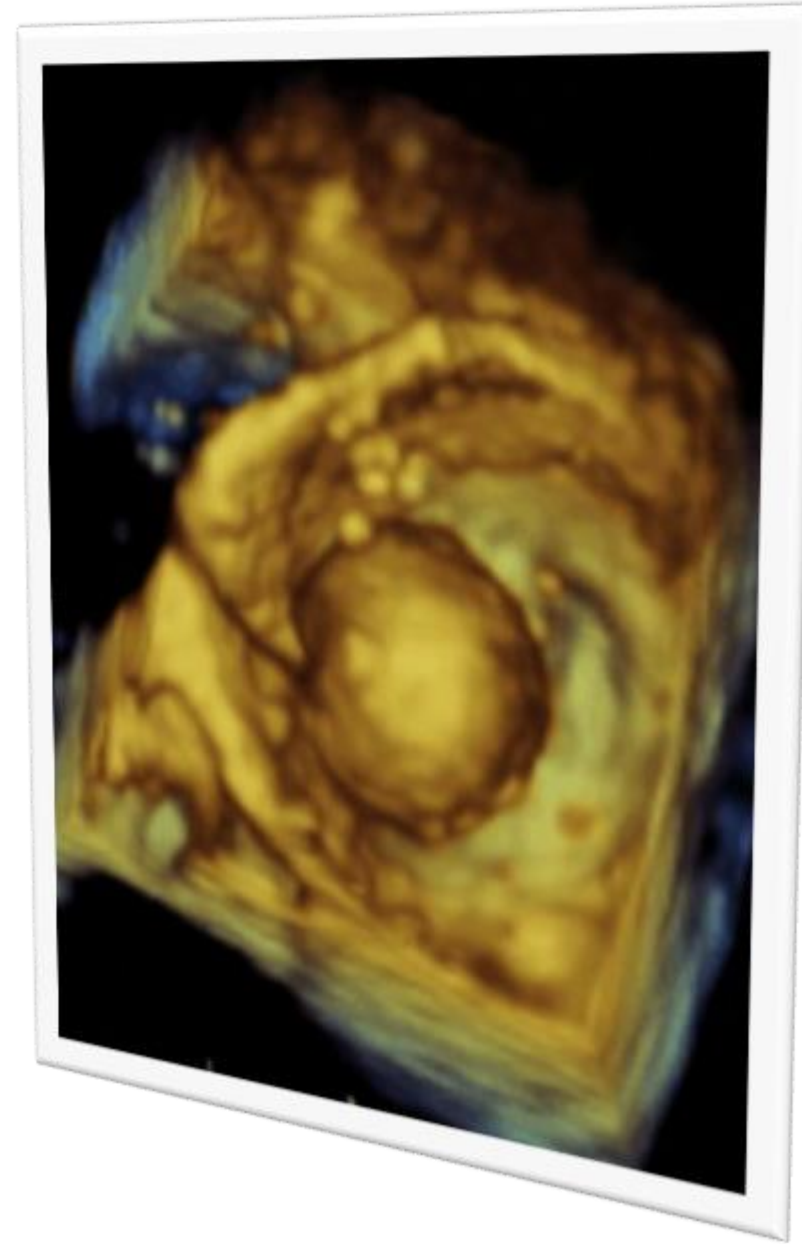
Source Imaging: MR

- 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

- 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

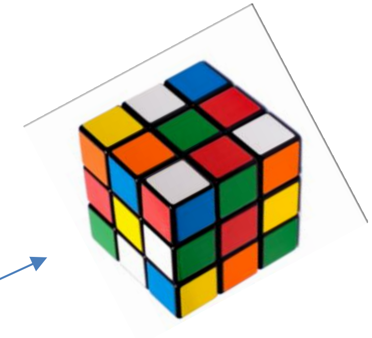
Isotropic: Same resolution in all 3 axis

Anisotropic: Varies with orientation

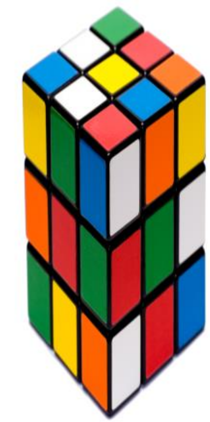
CT: Cubic or near-cubic voxels >> No or minimal resampling required (low distortion risk). Typical 0.5x0.5x0.5 mm

MRI: Rectangular prism 0.5 x 0.5 x **5-8** mm

Echo: Spherical segment voxels which grow with distance from probe



CT

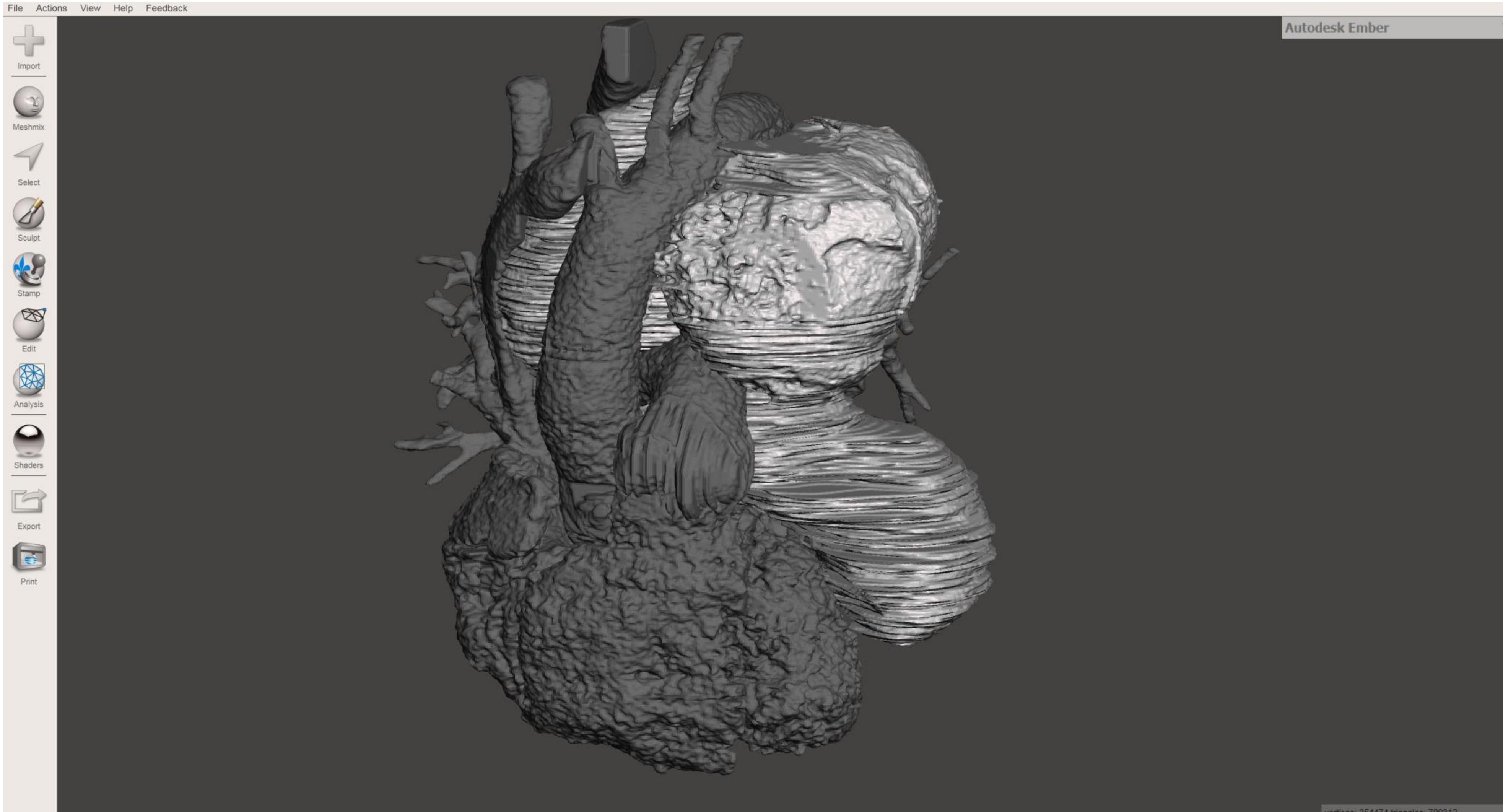


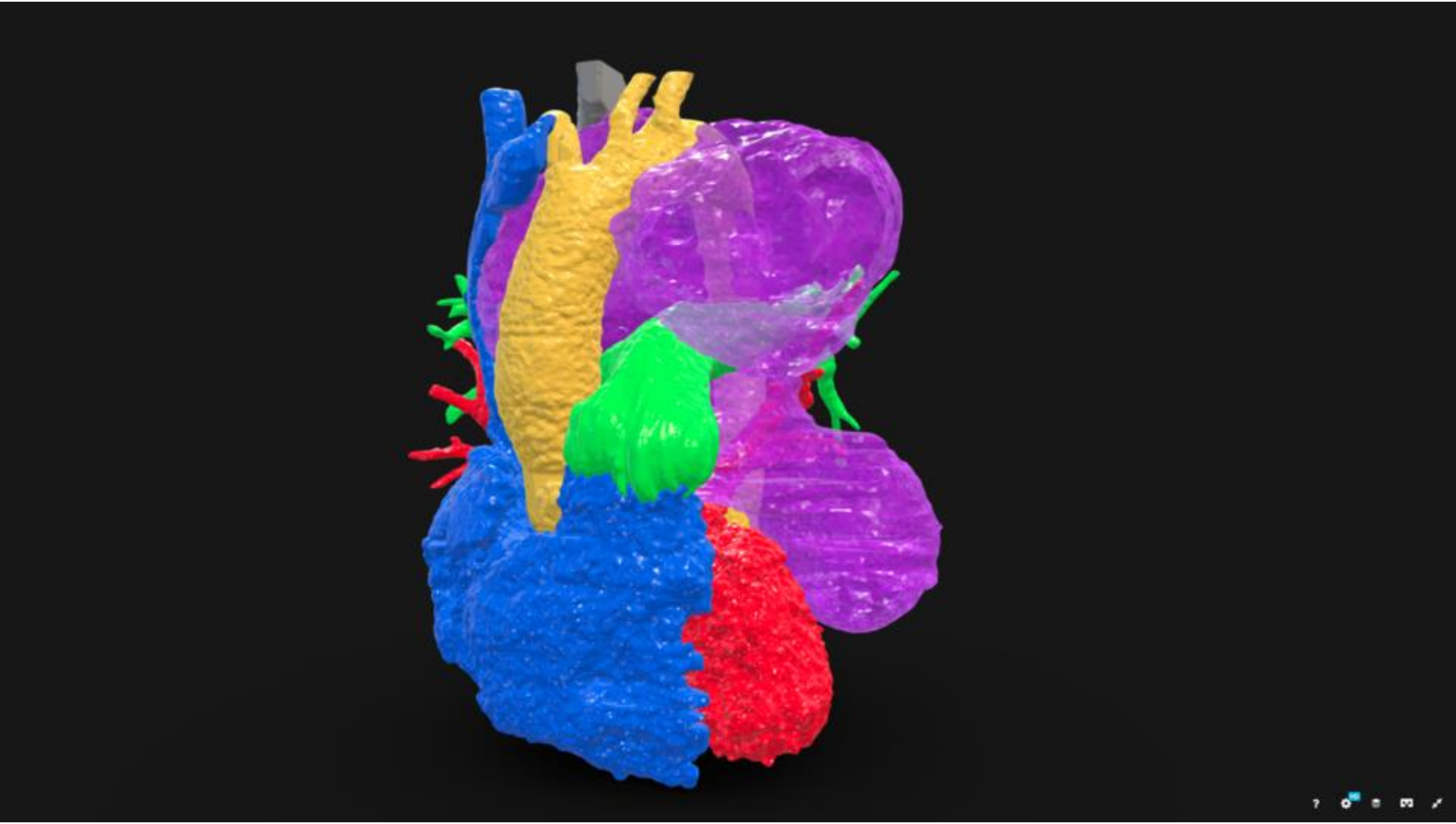
MRI

Echo

Segmentation

Modeling / Mesh generation / Editing





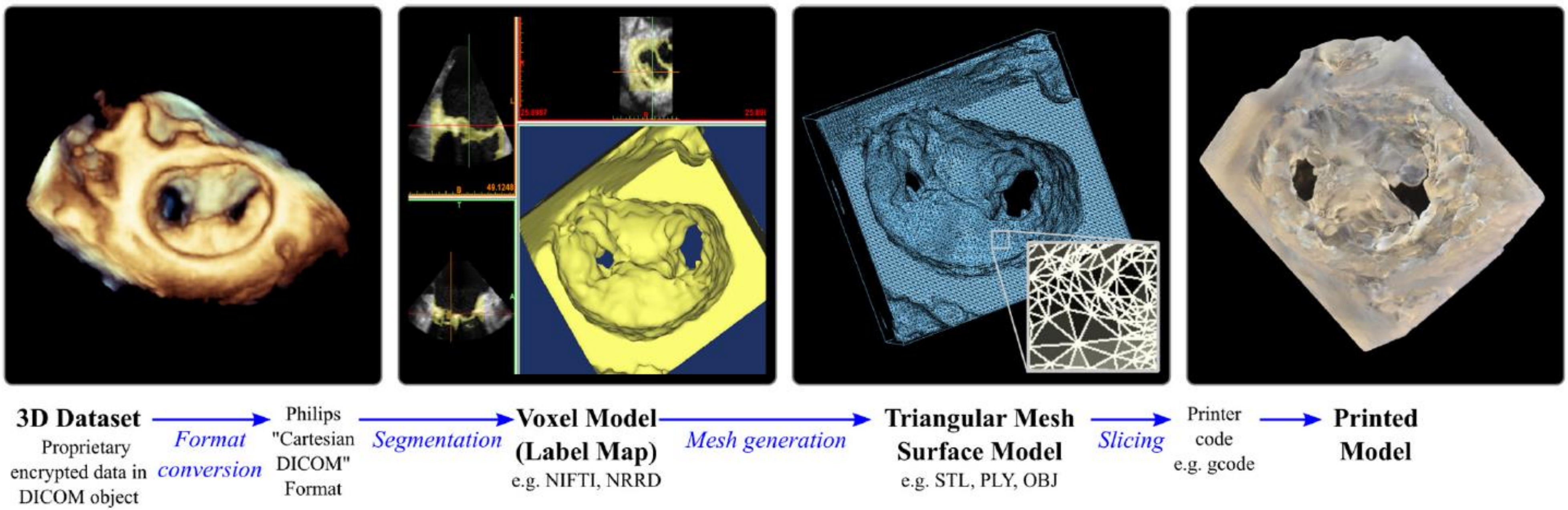


Figure 1

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.)

Applications: **Visualization**

- 3D rendering (on screen)
- 3D print
- Virtual/augmented Reality
- Stereoscopic & holographic displays

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  endloop...
```
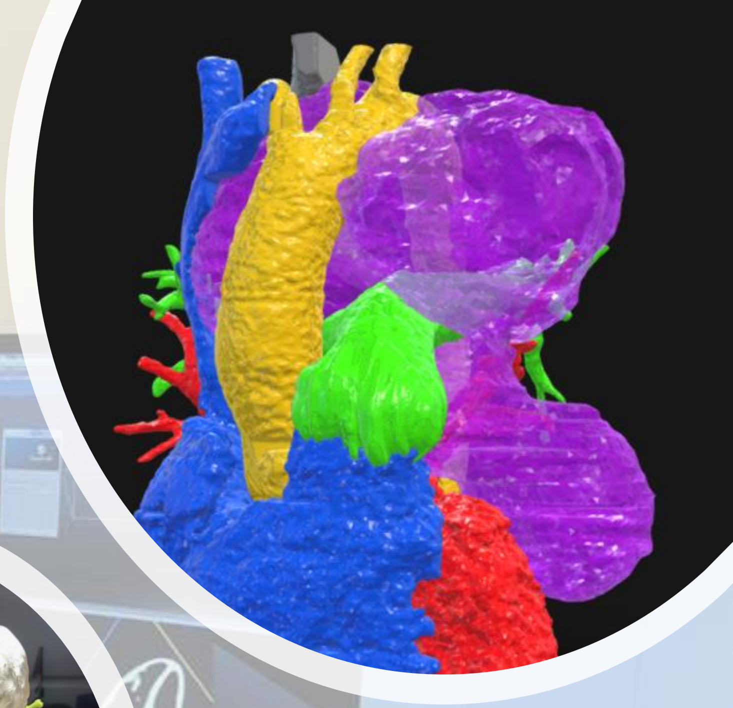
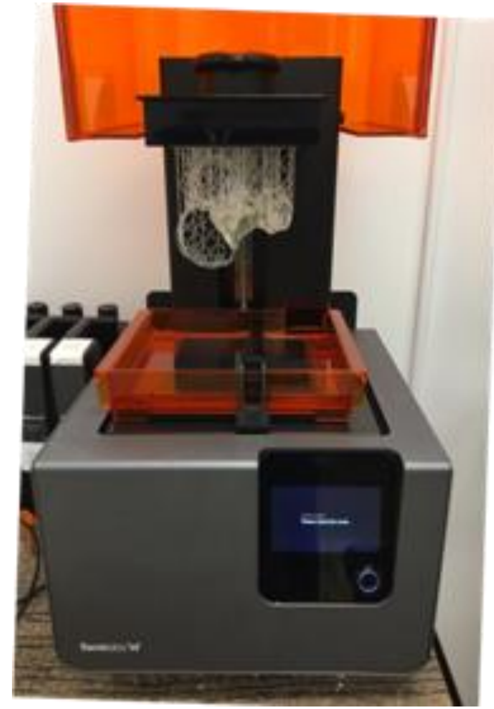



Rendering

https://apilnextcloud.ams3.digitaloceanspaces.com/2018003-02/2018003VIEWER.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

Virtual Reality

Augmented / Mixed Reality

Procedural Simulation (physical)

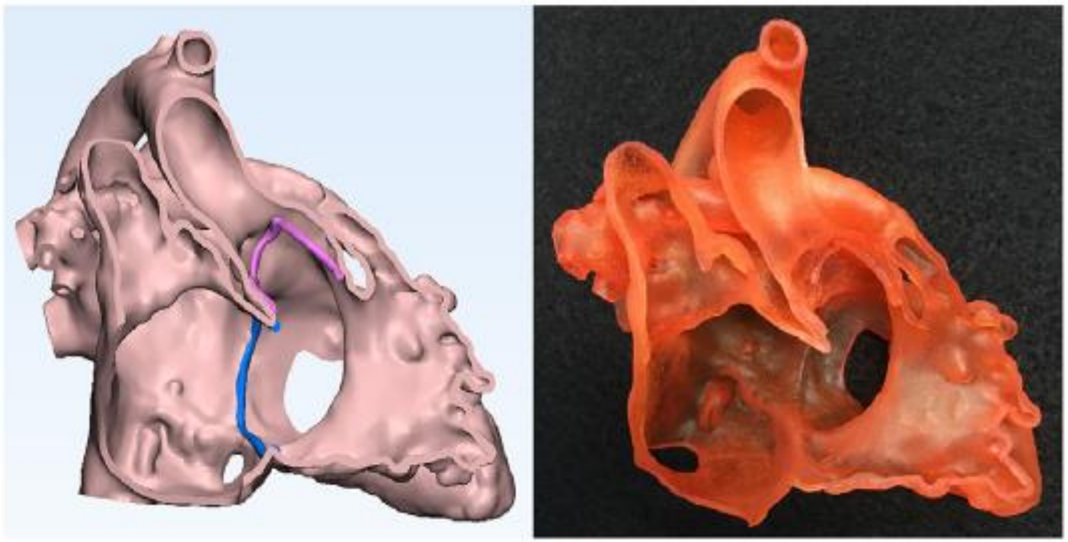
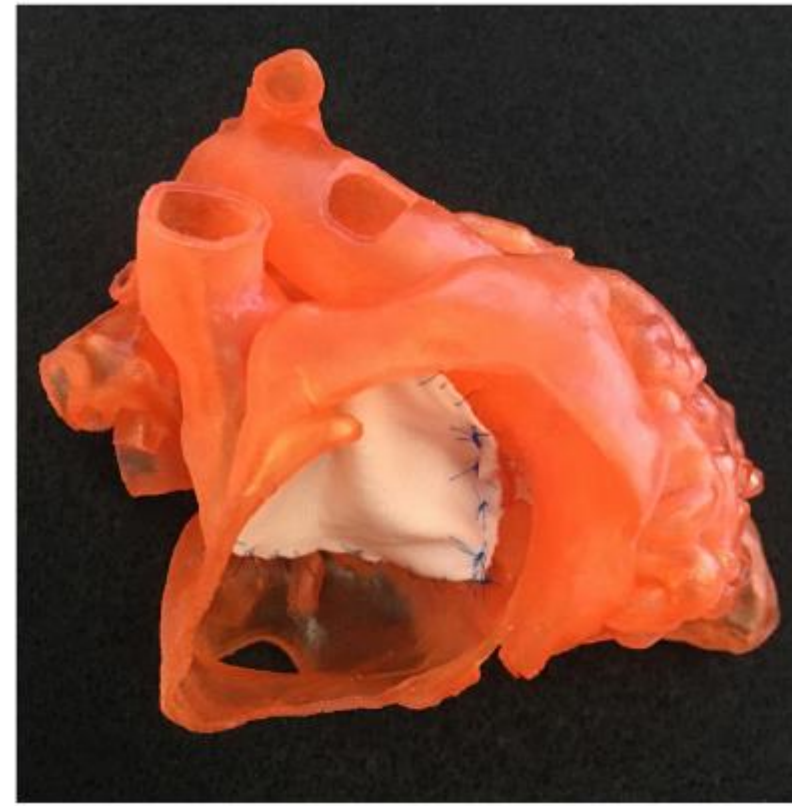


FIGURE 3 | Graphic representation and photograph of the endocardial surface anatomy model made of soft material (TangoPlus, Stratasys Ltd., MN, USA) of the right ventricle of the case shown in **Figure 1**.



3D Printing in Surgical Management of Double Outlet Right Ventricle

Shi-Joon Yoo[1,2] and Glen S. van Arsdell[3]*

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

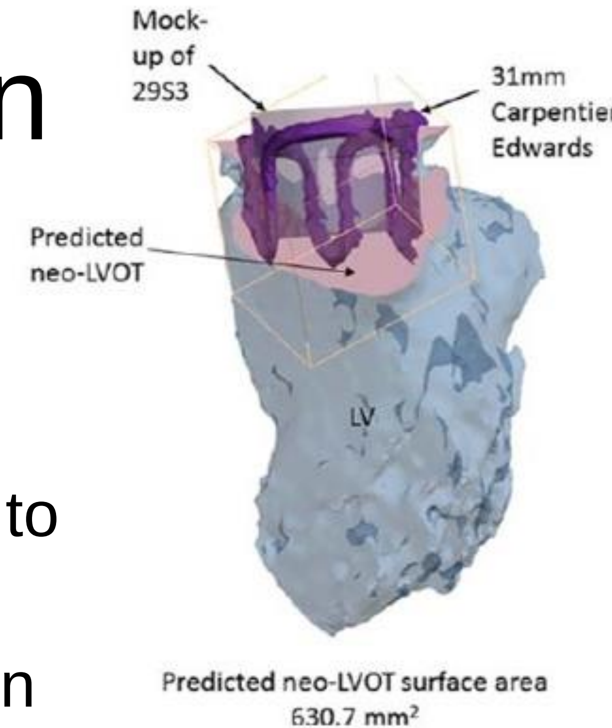
Virtual/Mixed Simulation

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[1] | Marvin H. Eng, MD[1] | Adam B. Greenbaum, MD[1] |

… evidence

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

Daniel Schmauss, MD,[a] Nicolas Gerber, MSc,[b] and Ralf Sodian, MD[a]

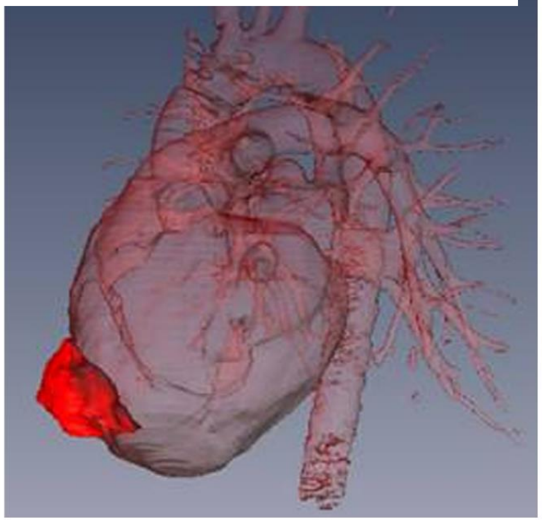
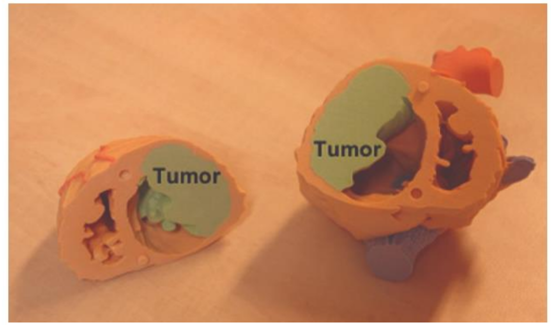
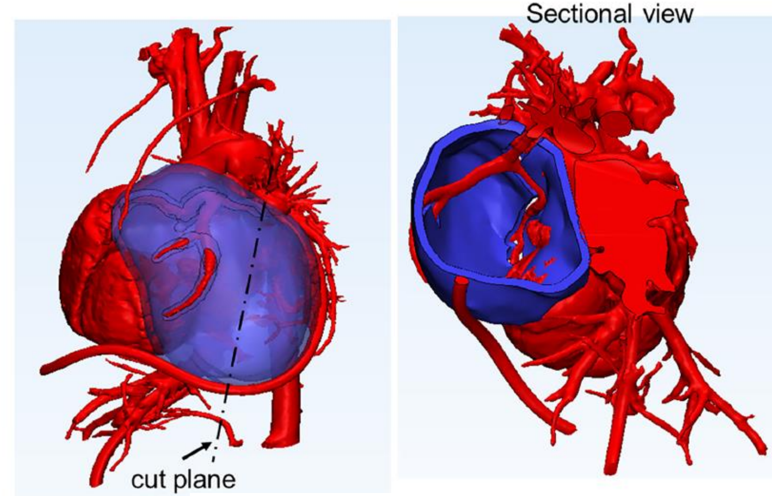


FIGURE 2. A 3-dimensional reconstruction of the heart with the tumor on the right ventricle.



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



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

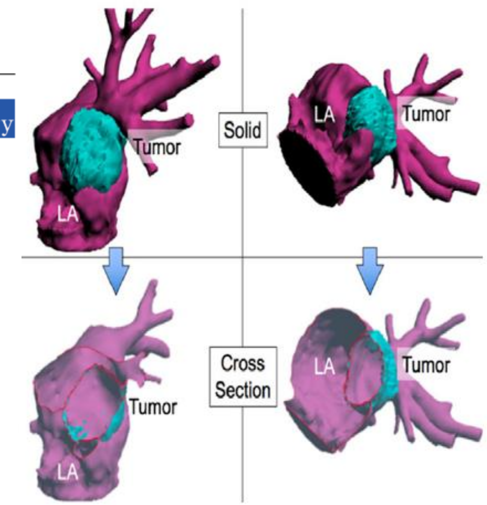
DOI 10.1111/jocs.12812

NEW TECHNOLOGIES

WILEY Journal of Cardiac Surgery

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

Odeaa Al Jabbari, M.D.[1*] | Walid K. Abu Saleh, M.D.[2] | Avni P. Patel, M.E.[1] | Stephen R. Igo, B.S.[1] | Michael J. Reardon, M.D.[1]



Surgical Planning by 3D Printing for Primary Cardiac Schwannoma Resection

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

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

Israel Valverde[a,b,c,d,*], Gorka Gomez-Ciriza[a], Tarique Hussain[c,e], Cristina Suarez-Mejias[a],

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 ± 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.

Eur J Cardiothorac Surg. 2017;52: 1139–1148.

Chepelev *et al. 3D Printing in Medicine* (2018) 4:11
https://doi.org/10.1186/s41205-018-0030-y

3D Printing in Medicine

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

Cardiac Arrhythmias		
Cardiac Arrhythmia/atrial fibrillation	6	99,100
Cardiac Pacing	6	101,102
Cardiac Neoplasm		
Cardiac Tumors	7	103-110
Cardiac Transplant and Mechanical Circulatory Support		
Cardiac transplant	7	111
Left Ventricular Assist device	7	112-114
Total Artificial Heart	3	-
Heart Failure		
Heart Failure	2	-

1–3, rarely appropriate: There is a lack of a clear benefit or experience that shows an advantage over usual practice.

4–6, maybe appropriate: There may be times when there is an advantage, but the data is lacking, or the benefits have not been fully defined.

7–9, usually appropriate: Data and experience shows an advantage to 3D printing as a method to represent and/or extend the value of data contained in the medical imaging examination.

Limitations & Challenges

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***.

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

The Near Future

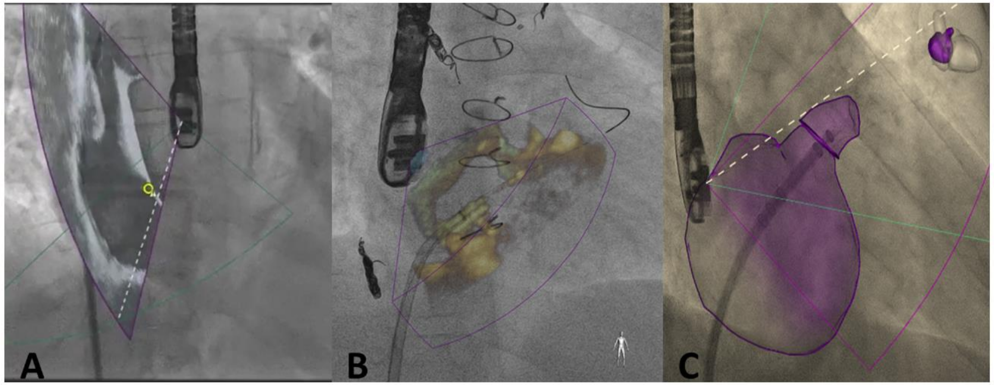


Figure 2 Different echocardiography imaging, such as 2D echocardiography with a *yellow marker* placed at the transseptal puncture site **(A)**, 3D echocardiography **(B)**, and 3D display of automatically rendered structures **(C),** can be overlaid onto the fluoroscopic screen to guide different procedural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

Peter Munk Cardiac Center Foundation

References

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2. Jone et al. Congenital and Structural Heart Disease Interventions Using Echocardiography-Fluoroscopy Fusion Imaging. Journal of the American Society of Echocardiography. 2019;32: 1495–1504. doi:10.1016/j.echo.2019.07.023
3. Son et al. Surgical Planning by 3D Printing for Primary Cardiac Schwannoma Resection. Yonsei Med J. 2015;56: 1735–1737. doi:10.3349/ymj.2015.56.6.1735
4. Schmauss et al. Three-dimensional printing of models for surgical planning in patients with primary cardiac tumors. J Thorac Cardiovasc Surg. 2013;145: 1407–1408. doi:10.1016/j.jtcvs.2012.12.0306.
5. Riggs et al. 3D-printed models optimize preoperative planning for pediatric cardiac tumor debulking. Transl Pediatr. 2018;7: 196–202. doi:10.21037/tp.2018.06.01
6. Liddy et al. The Assessment of Cardiac Masses by Cardiac CT and CMR Including Pre-op 3D Reconstruction and Planning. Curr Cardiol Rep. 2019;21: 103. doi:10.1007/s11886-019-1196-7
7. Jacobs et al. 3D-Imaging of cardiac structures using 3D heart models for planning in heart surgery: a preliminary study. Interact Cardiovasc Thorac Surg. 2008;7: 6–9. doi:10.1510/icvts.2007.156588
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Thank You!