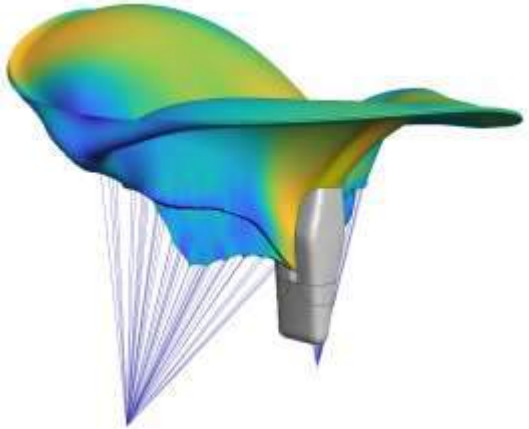
Modeling of Valves:
Can It Have a Clinical Impact?



Matthew Jolley, MD

Associate Professor

Pediatric Cardiac Anesthesia and Pediatric Cardiology (Imaging)

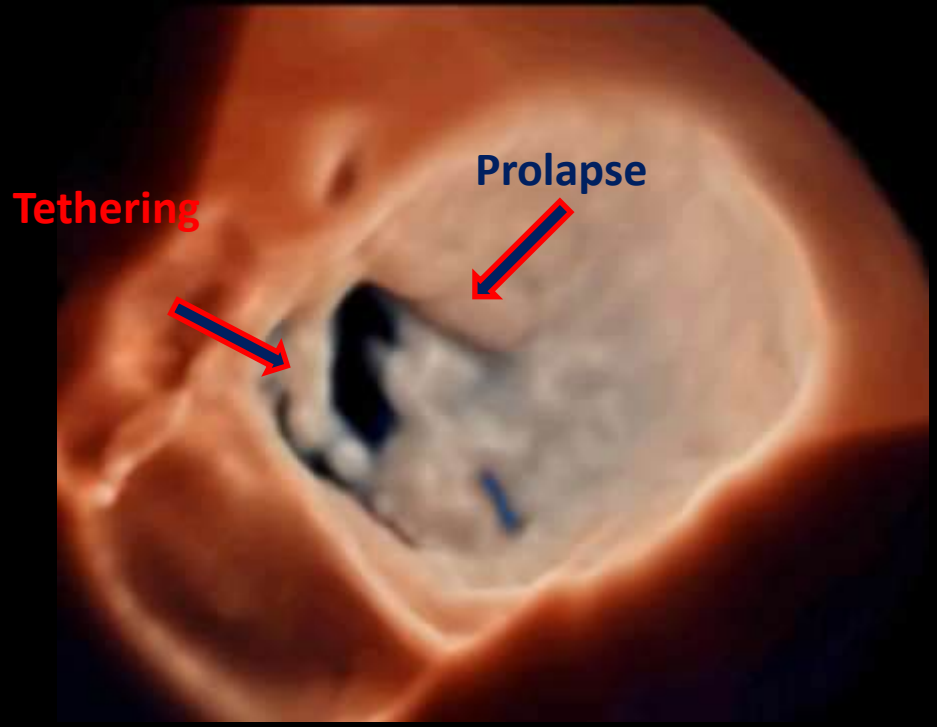
Children's Hospital of Philadelphia

University of Pennsylvania Medical School

Children's Hospital of Philadelphia
Pediatric Heart Valve Center

Perelman School of Medicine
University of Pennsylvania

NO CONFLICT OF INTEREST OR FINANCIAL DISCLOSURES

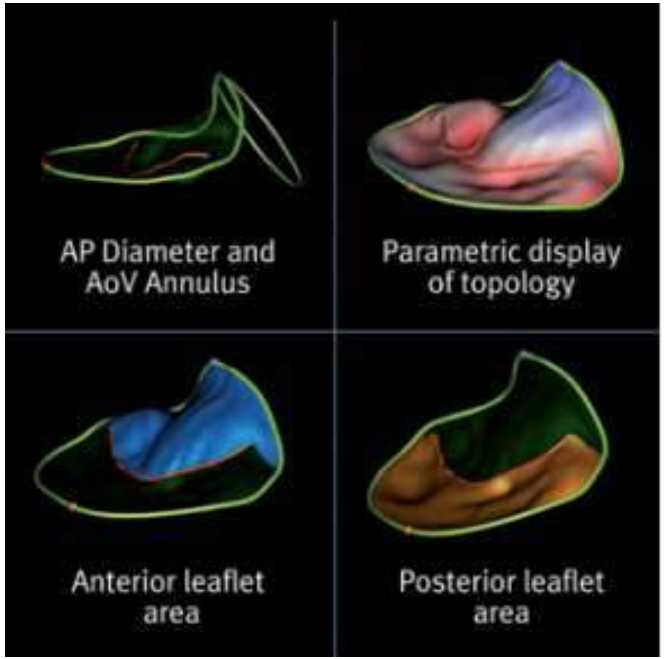


Atrial View

Atrial View

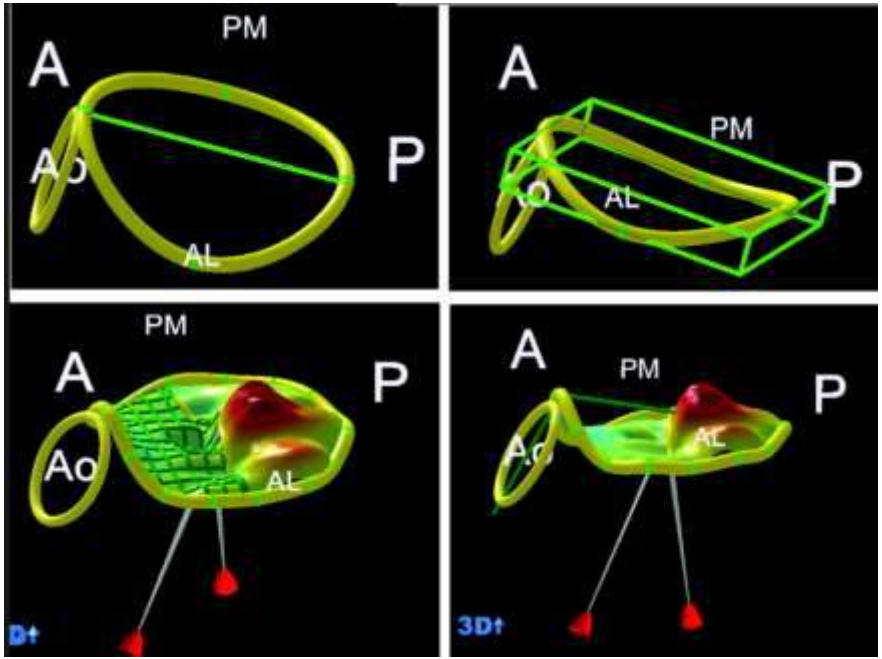
Commercial Tools

Tomtec MV Modeling



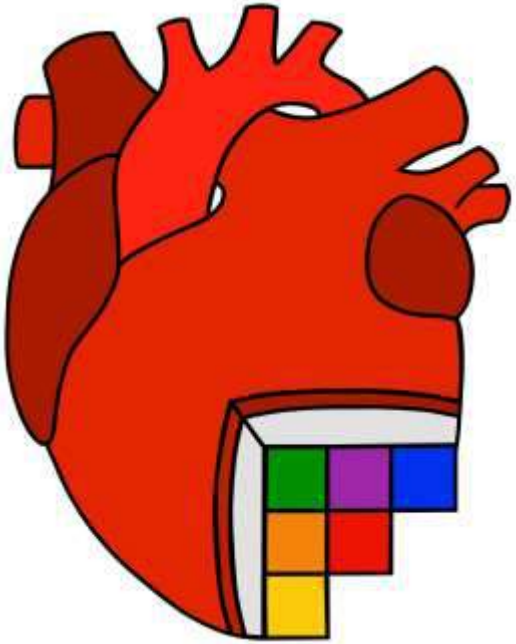
Tomtec.de

Philips MV Modeling



usa.Philips.com

SlicerHeart



www.slicerheart.org

REVIEW article

Front. Cardiovasc. Med., 06 September 2022
Sec. Pediatric Cardiology
Volume 9 - 2022 | https://doi.org/10.3389/fcvm.2022.886549

This article is part of the Research Topic
Advanced Non-Invasive Cardiac Imaging in Congenital Heart Disease
View all 8 Articles >

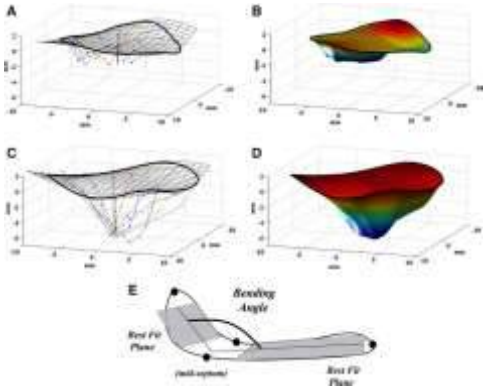
SlicerHeart: An open-source computing platform for cardiac image analysis and modeling

Andras Lasso[1], Christian Herz[2], Hannah Nam[2], Alana Ciancilli[2], Steve Pieper[3], Simon Drouin[4], Csaba Pinter[5], Samuelle St-Onge[4], Chad Vigil[2], Stephen Ching[2], Kyle Sunderland[1], Gabor Fichtinger[1], Ron Kikinis[6] and Matthew A. Jolley[2,7]*

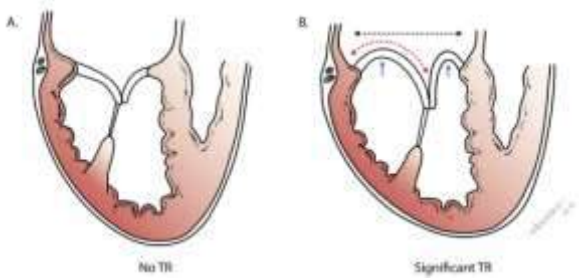
[1] Laboratory for Percutaneous Surgery, School of Computing, Queen's University, Kingston, ON, Canada
[2] Department of Anesthesiology and Critical Care Medicine, Children's Hospital of Philadelphia, Philadelphia, PA, United States
[3] Isomics, Inc., Boston, MA, United States
[4] Software and Information Technology Engineering, École de Technologie Supérieure, Montreal, QC, Canada
[5] Pixel Medical, Kingston, ON, Canada
[6] Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States
[7] Division of Cardiology, Children's Hospital of Philadelphia, Philadelphia, PA, United States

Lasso et al, Frontiers in Cardiovascular Medicine, 2022.

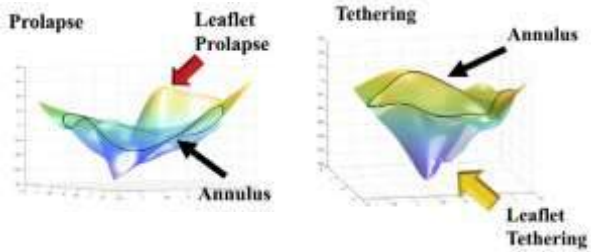
Overview of SlicerHeart Modules



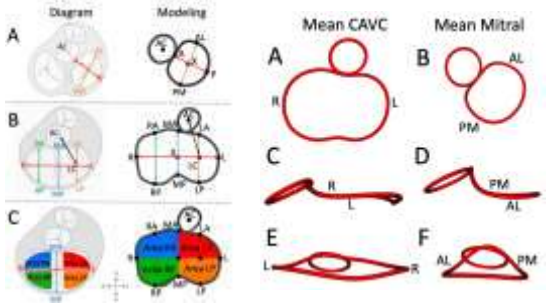
Kutty et al Circ Imaging, 2014



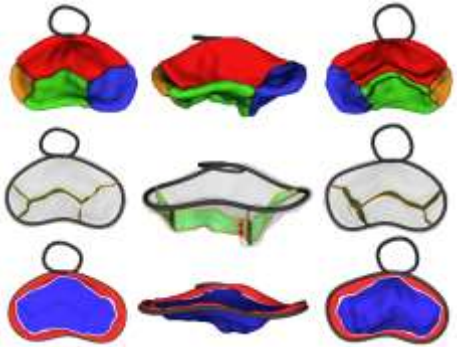
Colen et al, JASE, 2018



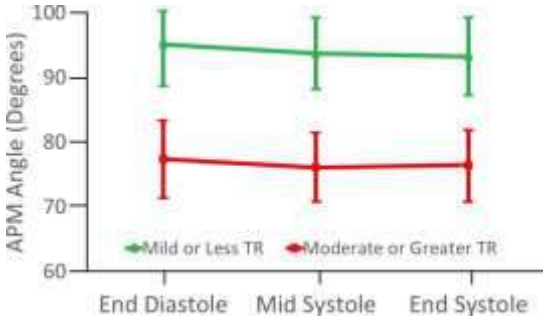
Shigemitsu et al, JASE, 2022



Nam et al, ATS, 2021.



Nam et al, JASE, 2022.



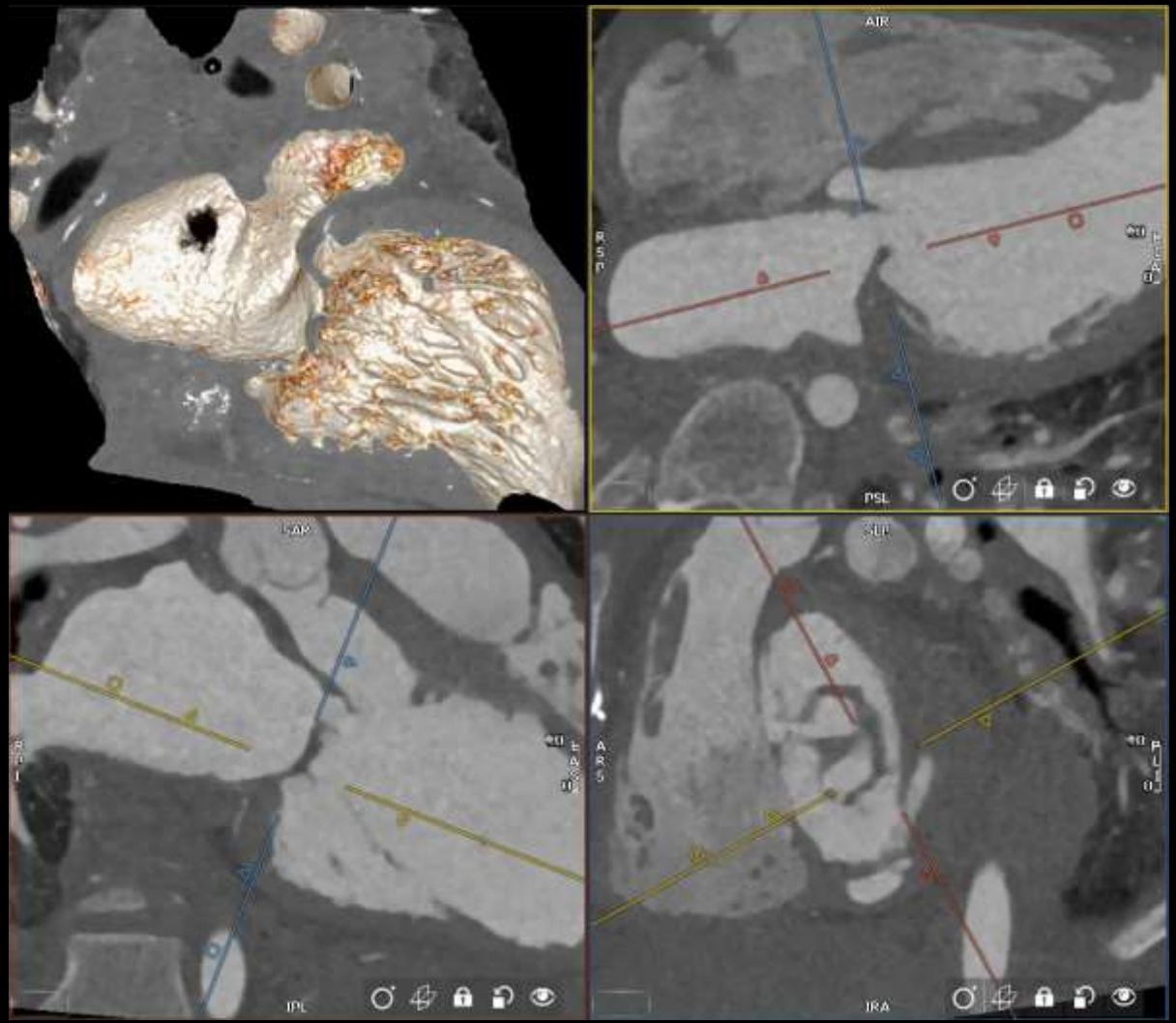
Nguyen et al, JASE, 2019

EDITORIAL

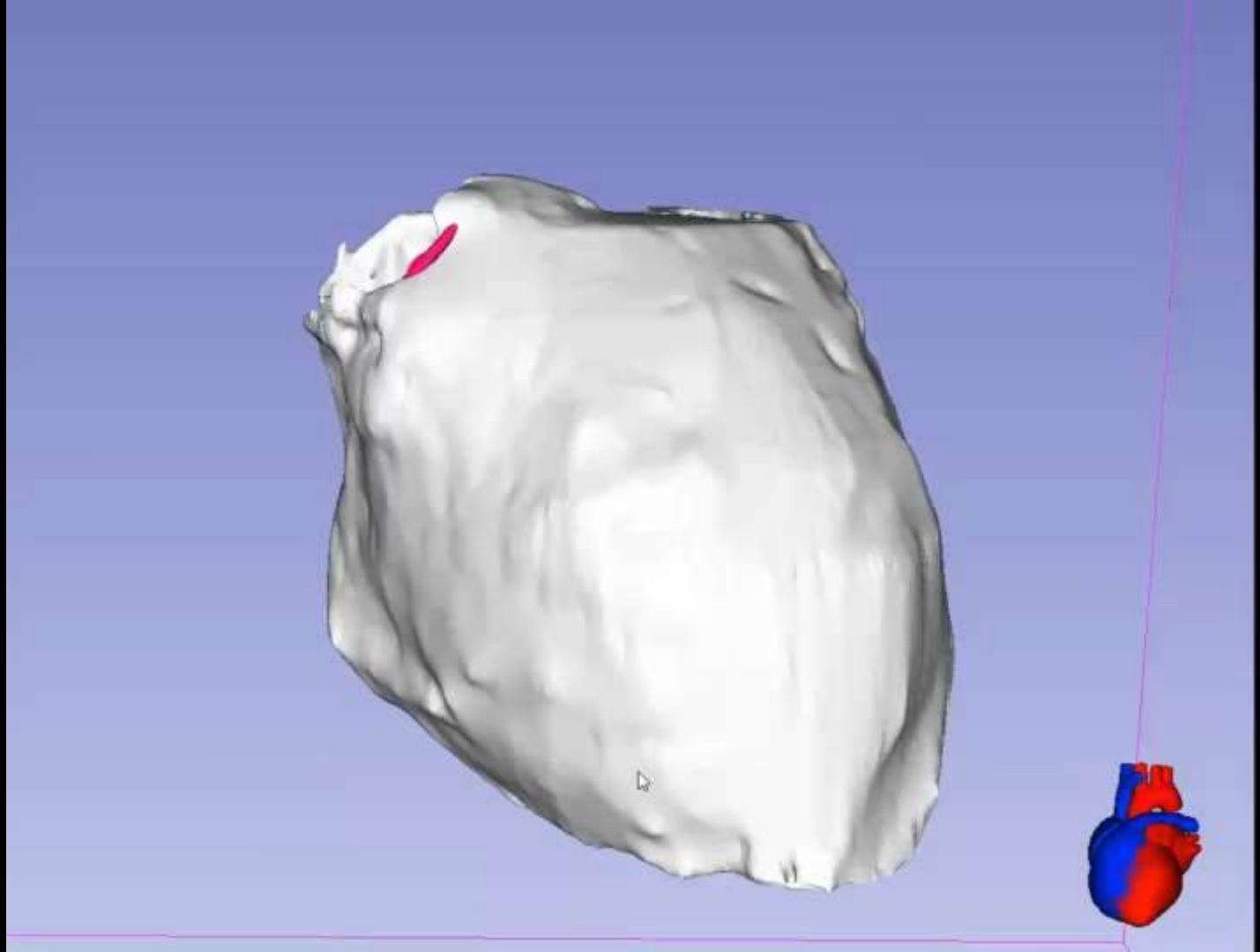
Opportunities of 3-Dimensional Modeling and Quantitative Valve Analysis to Improve Valve Interventions

David M. Hoganson, MD; Pedro J. del Nido, MD

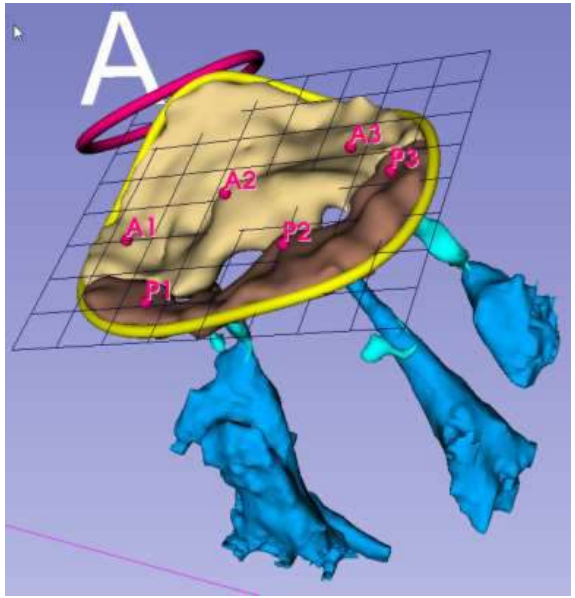
"There exists an opportunity, if not an imperative to integrate this analysis into preoperative planning to optimize what can be done surgically… and minimize long-term risks to these patients."



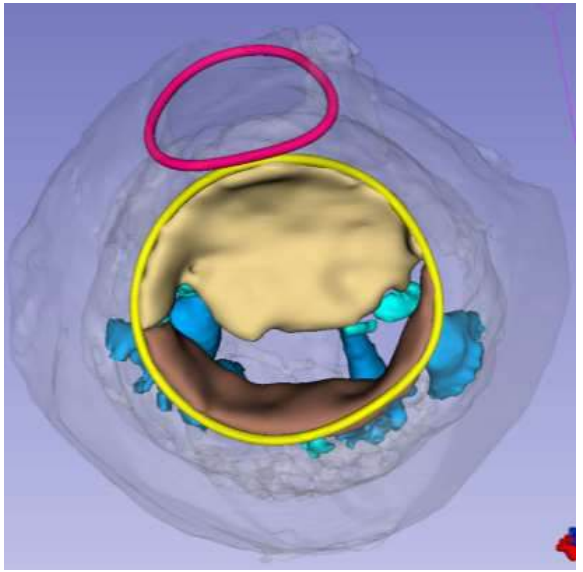
Courtesy Reena Ghosh



Quantitative Analysis

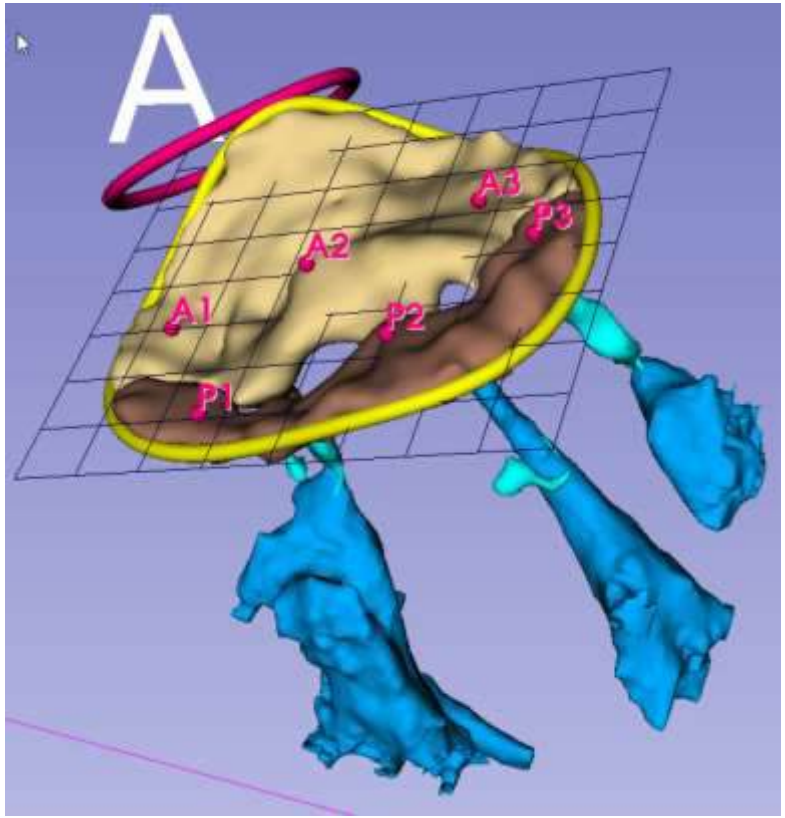


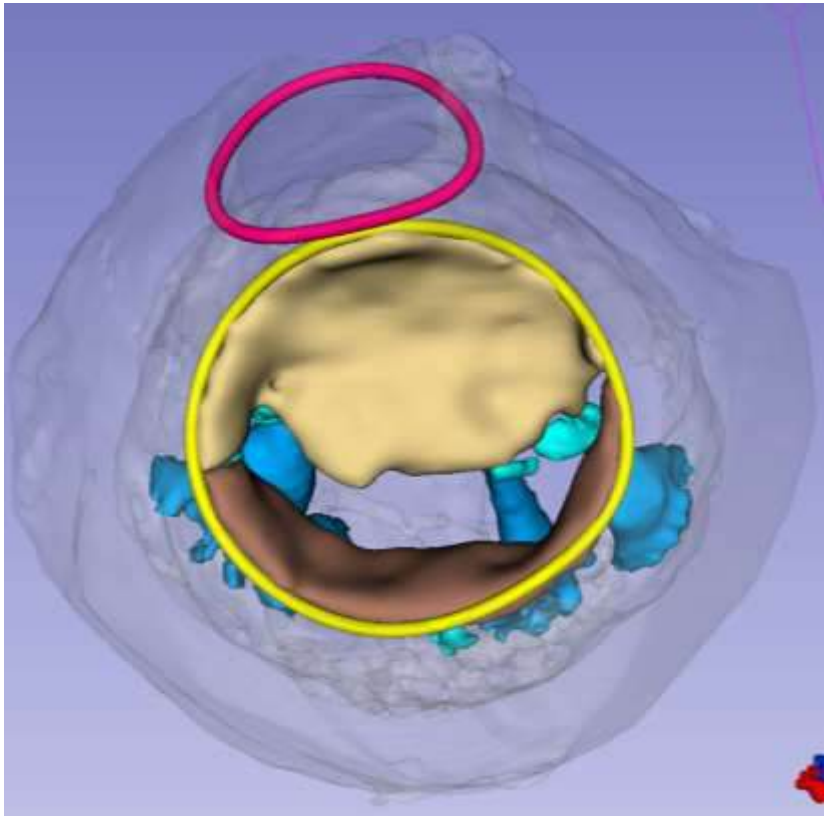
Mid Systole	Measurement	Mid Diastole
93.0	Annulus Circumference (mm)	85.7
28.0	AP distance (mm)	25.3
29.1	AL-PM distance (mm)	27.6
29.6	ALC-PMC distance (mm)	27.4
0.96	Sphericity Index (AP/AL-PM)	0.92
6.3	Annulus Height (mm)	4.8
6.2	Annulus Area (2D) (cm^2)	5.51
6.3	Annulus Area (3D) (cm^2)	5.6
	Z score; 50^{th} percentile	10; 1.7
	Inflow Orifice Area (cm^2)	1.73
150	Annulus bending angle (A-P) (degrees)	163



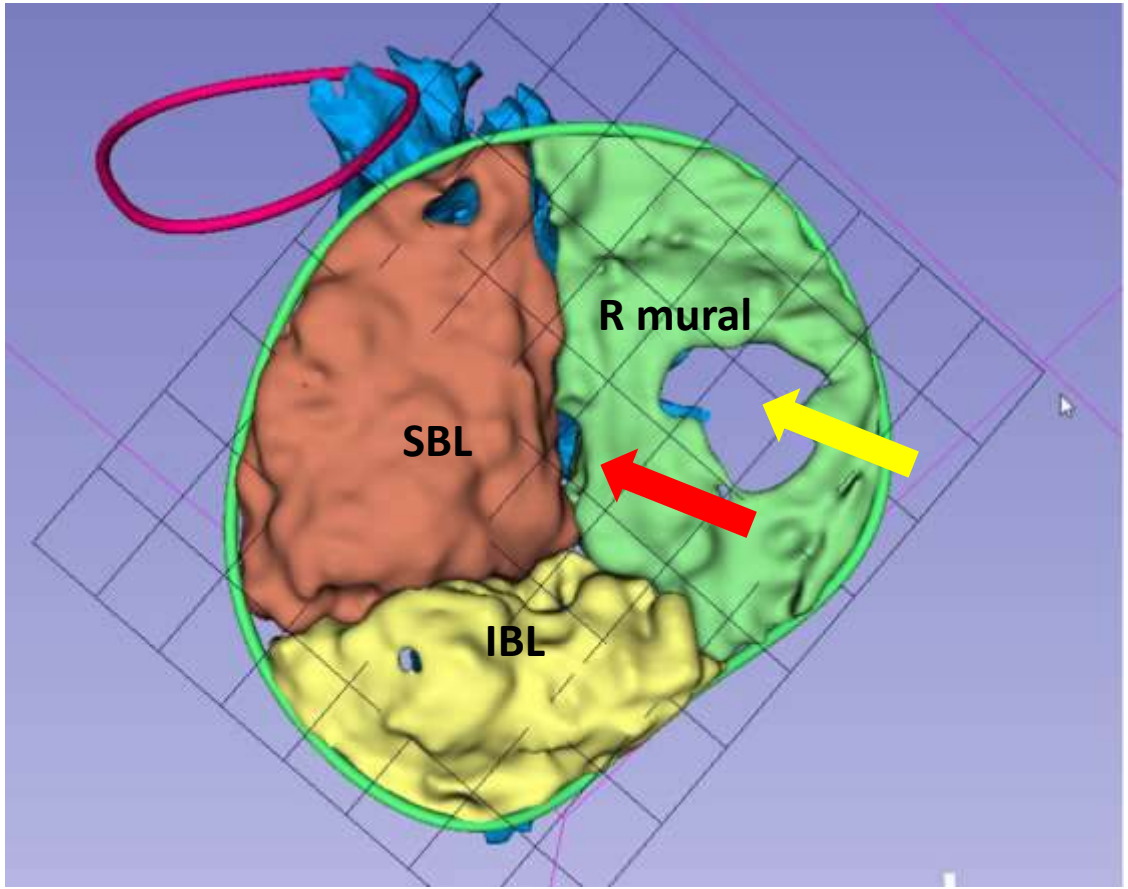
Courtesy Reena Ghosh

Interpretation

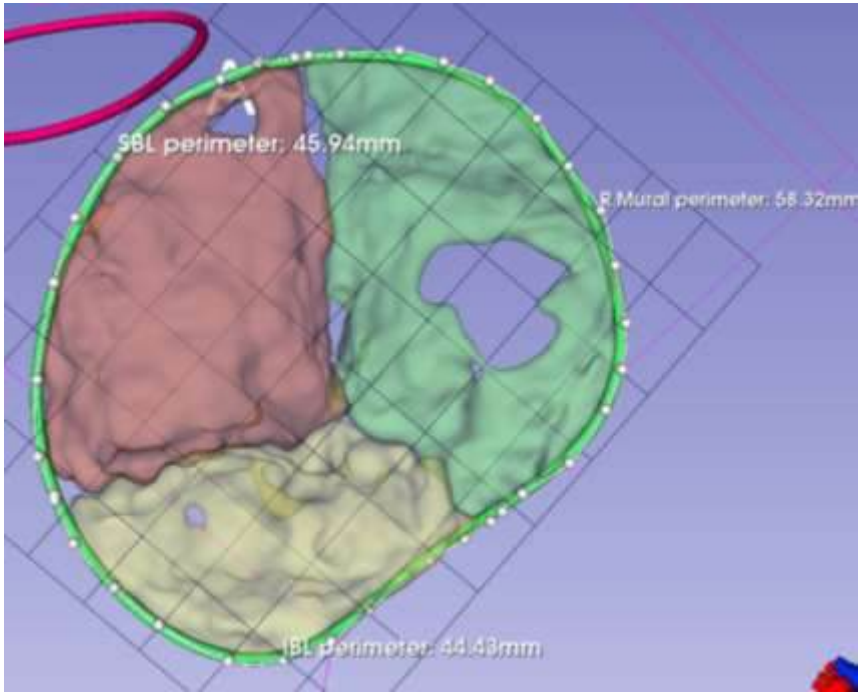




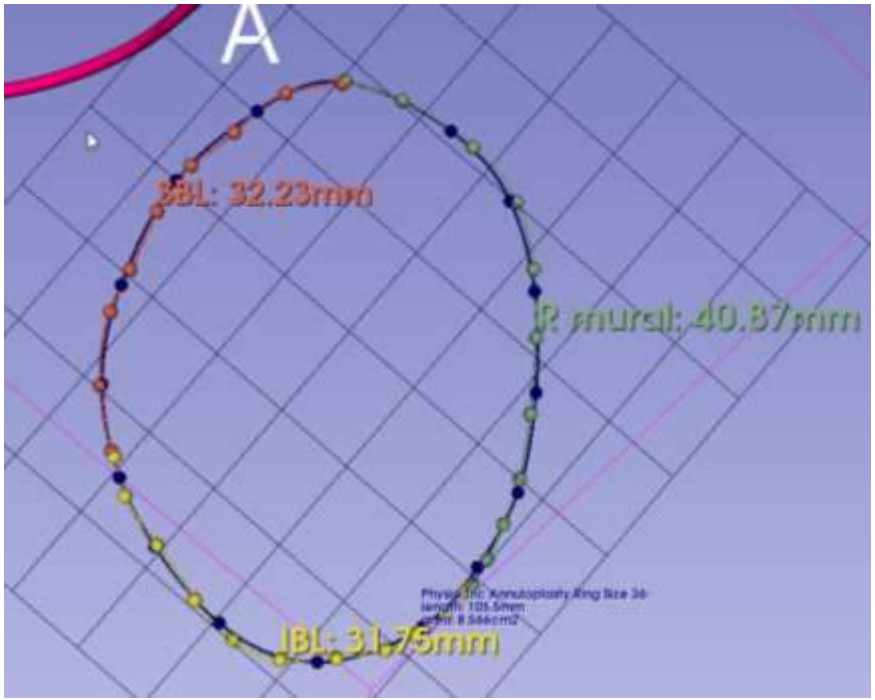
Virtual Surgery: Atrioventricular Valves



Courtesy Reena Ghosh



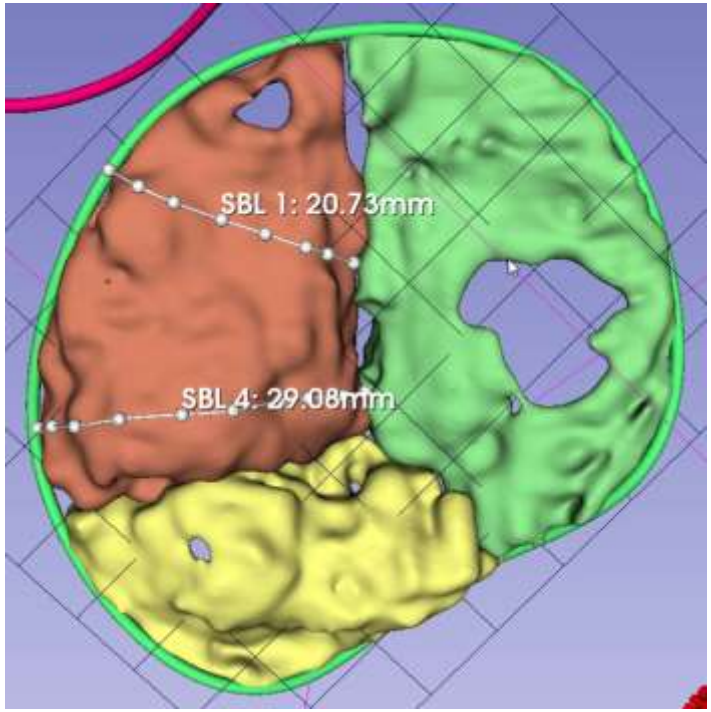
Annular perimeter of each leaflet:
SBL = 46 mm
IBL = 44 mm
R Mural = 58 mm



Decrease annulus circumference to 70%
SBL = 32 mm
IBL = 32 mm
R mural = 41 mm

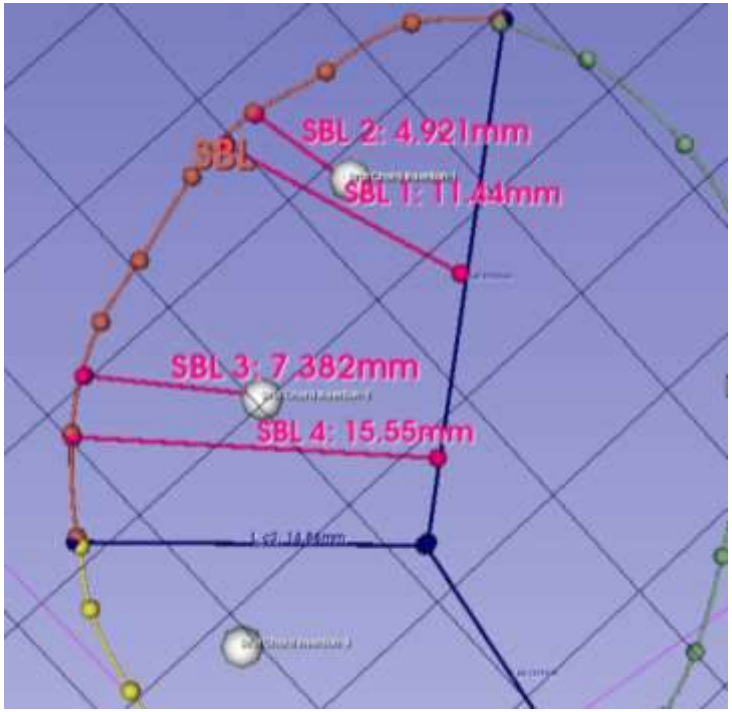
Courtesy Reena Ghosh

Native Valve



Annulus to top of coaptation zone
SBL 1 – 20.7 mm
SBL 4 – 29.1 mm

Annuloplasty with Neochords



SBL 1 - 11.4mm
SBL 2 – 4.9 mm (to strut chord)
SBL 3 – 7.4 mm (to strut chord)
SBL 4 – 15.6 mm

Courtesy Reena Ghosh

Report

3D Model Features and Assessment

Structures segmented: cardiac atria, ventricles, great vessels, myocardium, papillary muscles and chordae, valve leaflets and annuli

Model Assessment:

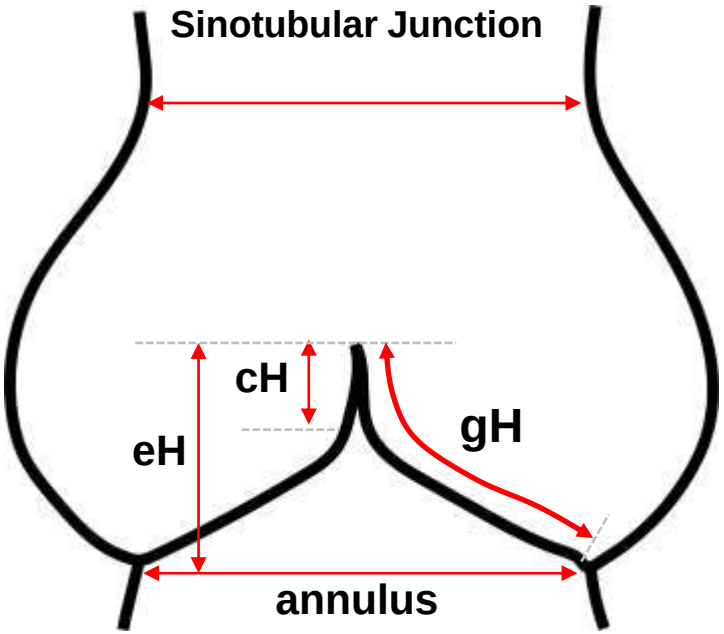
6 y/o boy with no PMH presenting with tachycardia and dyspnea, found to have congenital mixed mitral valve disease. He now presents for surgical repair of his mitral valve. A 3D model was created from the cardiac CT scan for preoperative planning and intraoperative guidance.

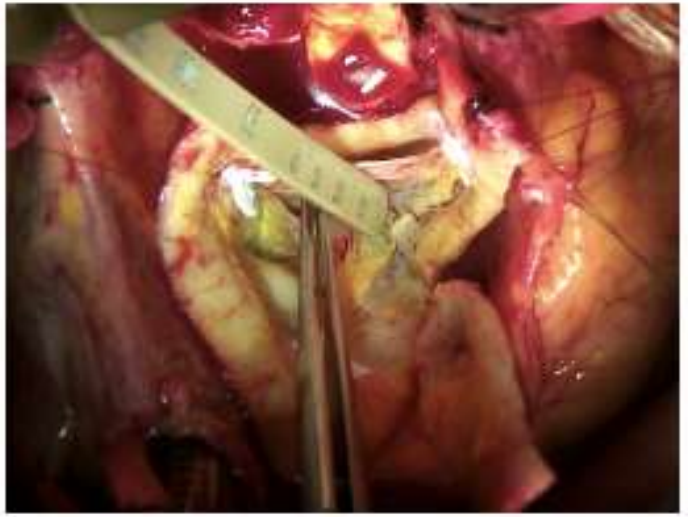
The model highlights the complex pathology of the arcade mitral valve. There are 2 hypertrophied and elongated papillary muscles (PMs) which extend basally and insert directly onto the leaflets, essentially encircling the commissures and restricting diastolic leaflet excursion – the effective inflow orifice area is 1.5cm^2. There are also matted chords that extend from the tips of the elongated PMs to the leaflets, including in the region of the P2 cleft.

There is annular dilation with an area of 6.6 cm^2 (Z score 6.5), with dilation almost entirely in the AP dimension. The annular mechanics are abnormal, with a more planar shape to the annulus in systole. There is a large triangular coaptation defect at A2/P2 with extension into A1/P1. There is also a smaller coaptation defect in the medial aspect of A3/P3. The annular component of the posterior leaflet is rigid.

Comprehensive repair, addressing both leaflet mobility and improved leaflet coaptation will be complex. The matted chords and PM attachments to the leaflets will need to be transected, to improve diastolic excursion and open up the inflow. Further resection of some of the superior aspect of the PMs may be considered. Artificial chords will be needed to support the leaflet edges. The shape of the annulus is quite unusual in that is elongated in the AP dimension. An annuloplasty using a complete or partial ring will likely be performed. Each component of the surgical technique will ultimately be decided intra-operatively. The 3D model will be available in the OR for intraoperative guidance.

Courtesy Reena Ghosh



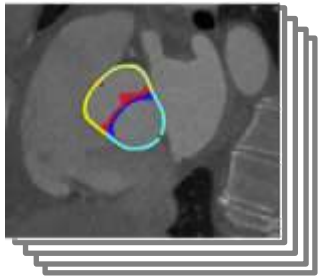


Courtesy Allison Pouch and UPENN Team

4D (3D + time) images

Echo

CTA



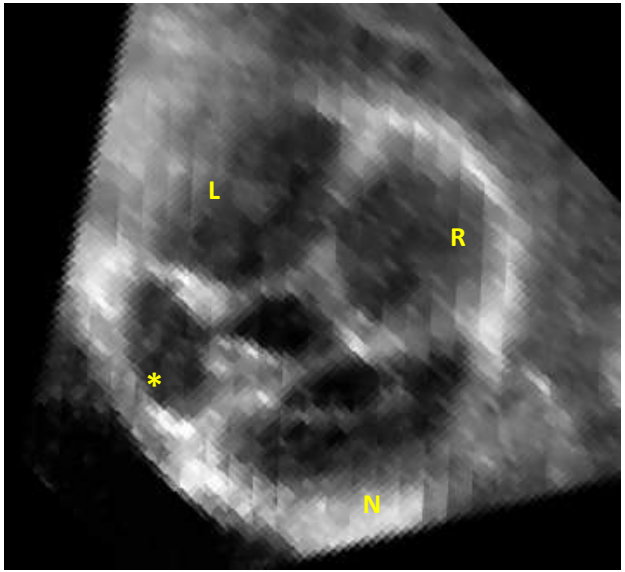
4D Models

MEASUREMENTS
(*static and time varying*)

Annular area
Aortic sinus area
Effective cusp height
Coaptation height
Commissural angle
Commissural height
Cusp free margin length
Geometric cusp height
Leaflet Strain
Orifice area
Raphe height
Root volume
Sinotubular junction area

Courtesy Allison Pouch and Team

Valve Morphology in a Pressure-Loaded State: TEE

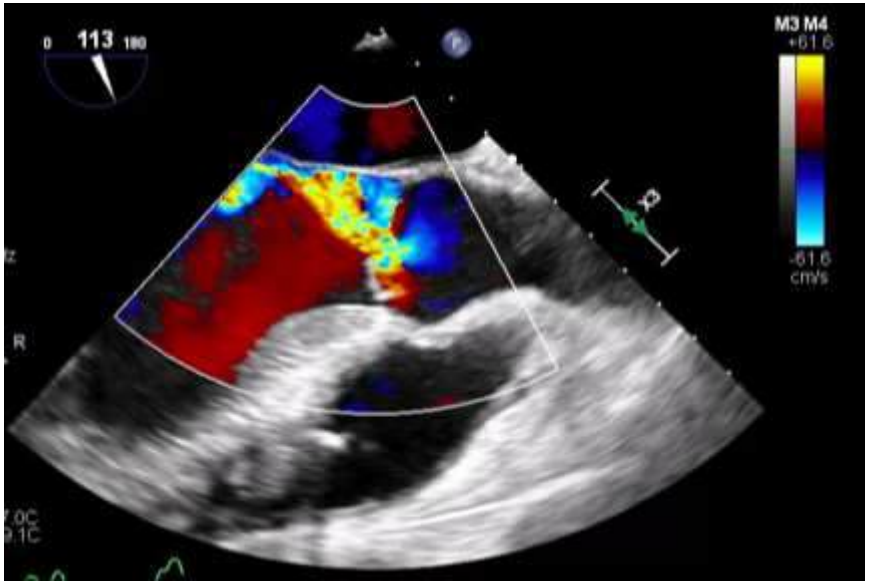


Possible Quadricuspid Valve

Confirmed Quadricuspid Valve

Courtesy Allison Pouch, UPENN

Identification of mechanism(s) of regurgitation



Severe Asymmetric Prolapse of Conjoined Cusp

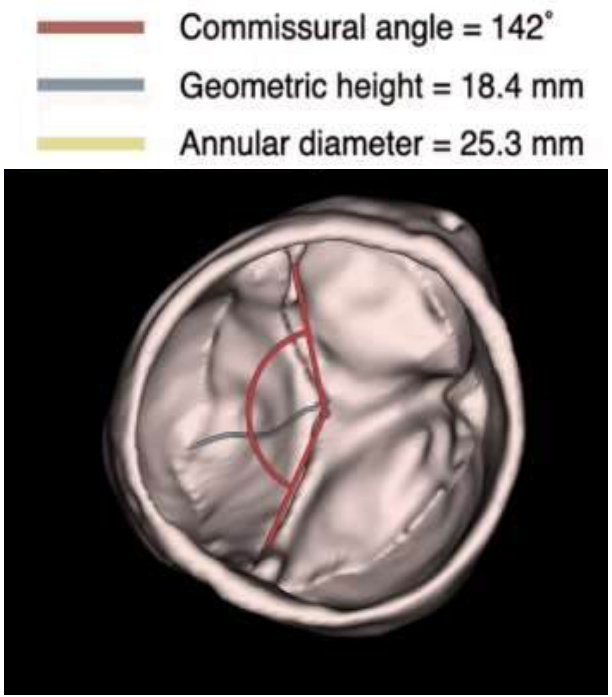
Courtesy Allison Pouch, UPENN

Risk stratification: repair vs. replacement

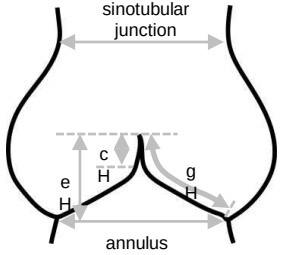
L

TEE Pre-Repair

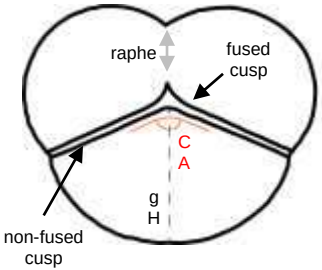
R



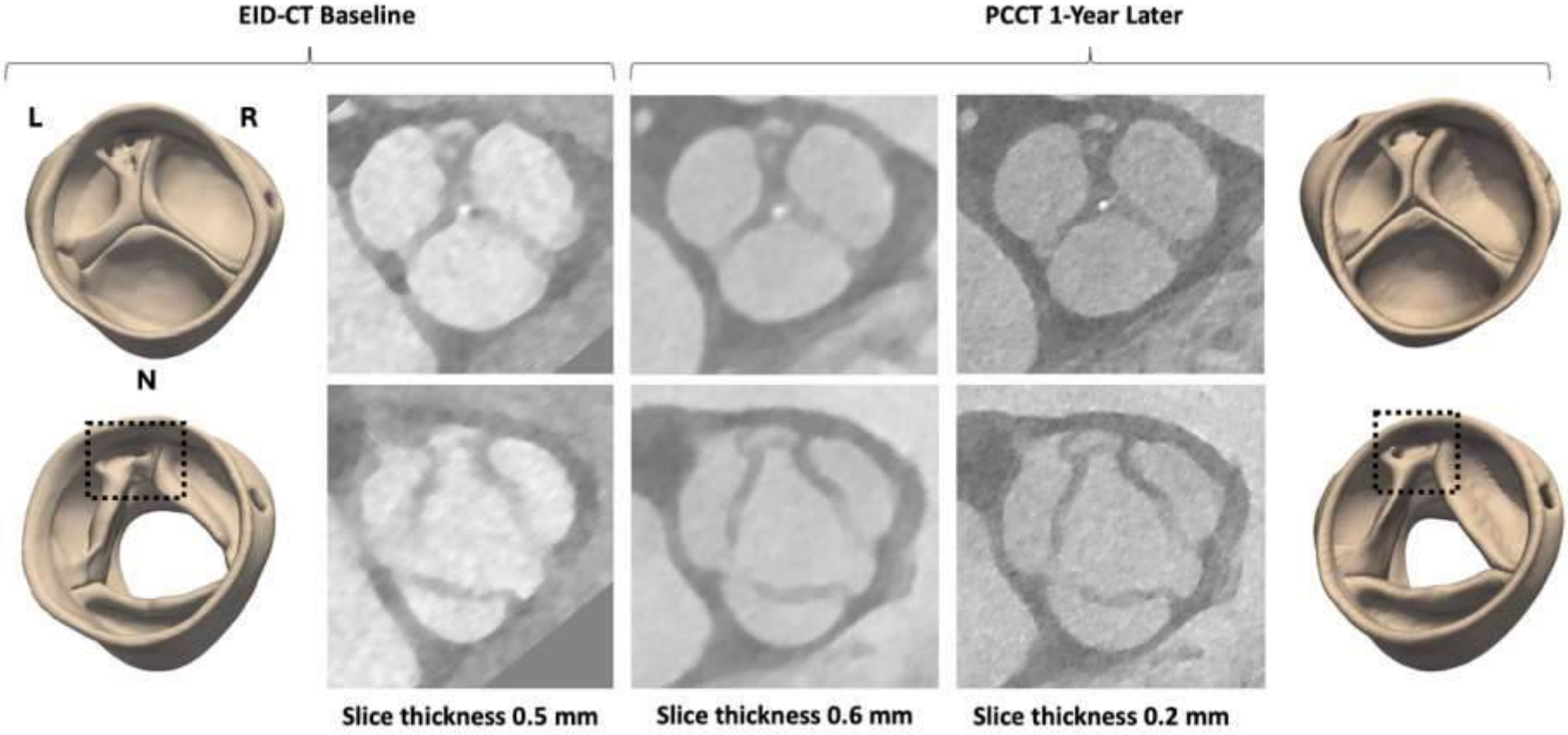
long axis view



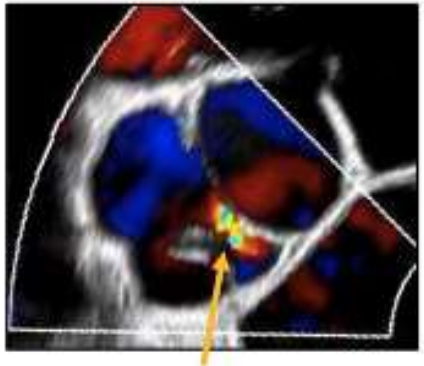
short axis view



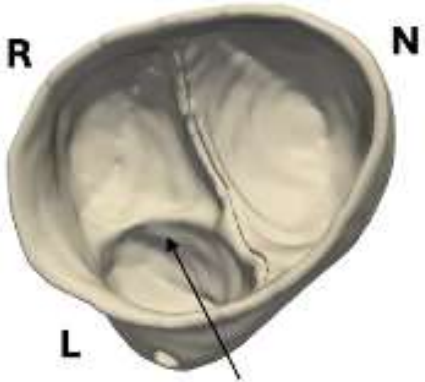
Courtesy Allison Pouch, UPENN



Pouch et al, Submitted, 2025



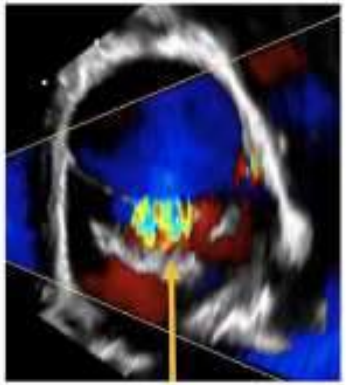
coaptation defect (mild AR)



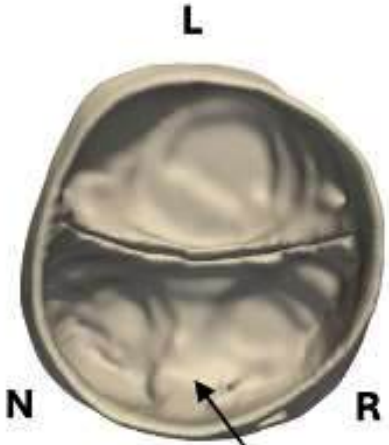
raphe

raphe

coaptation



coaptation defect
(severe AR)

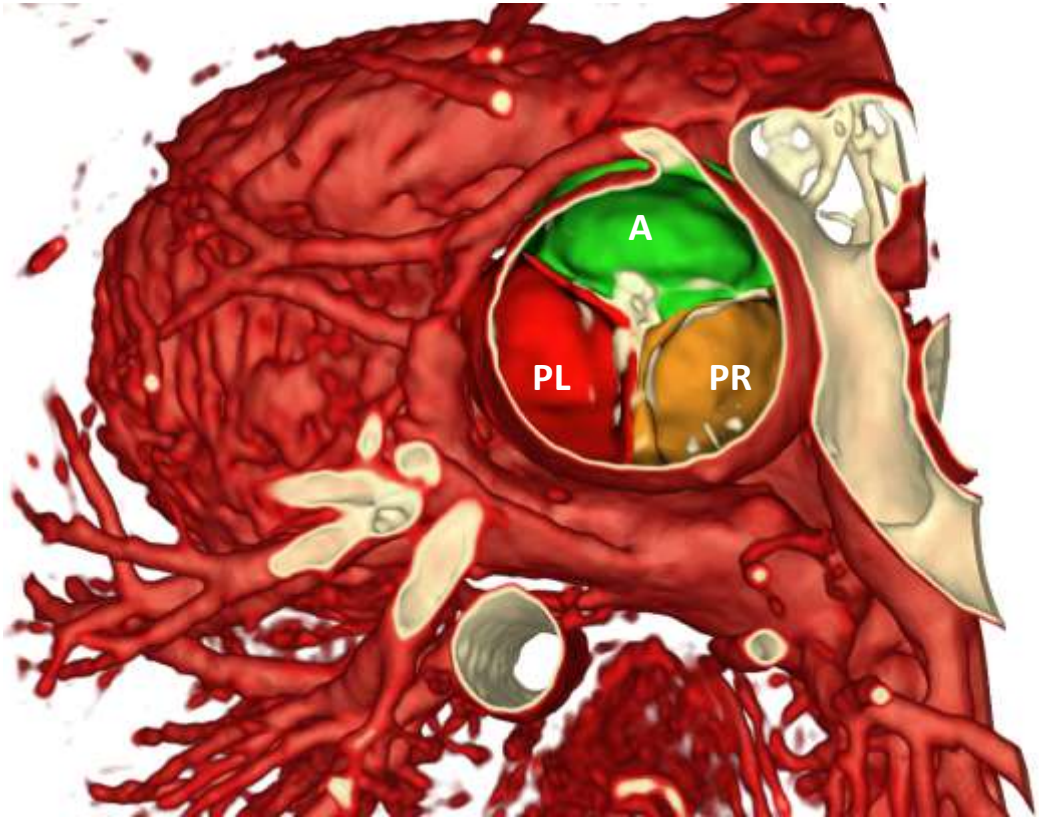


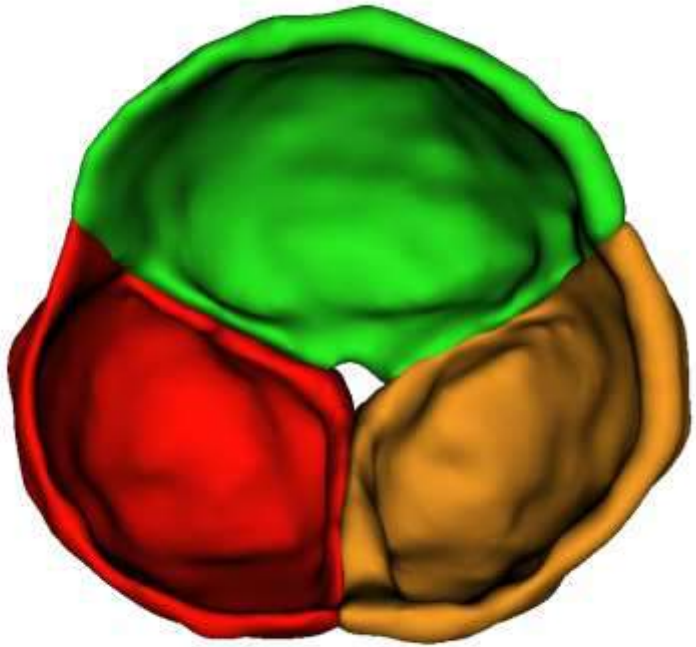
raphe

raphe of R/N conjoined cusp

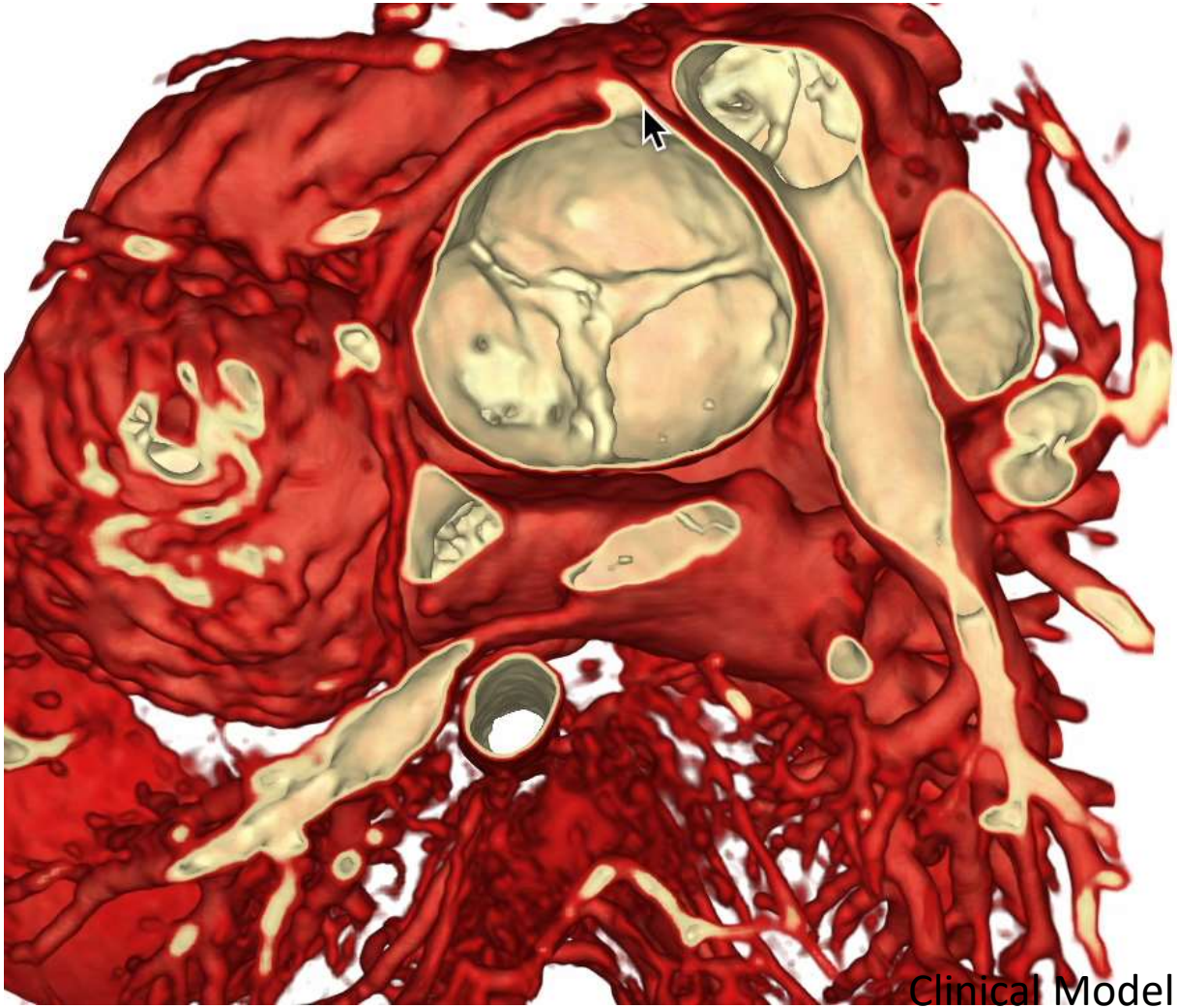
Pouch et al, Submitted, 2025

Williams et al, Circulation Imaging, 2022.

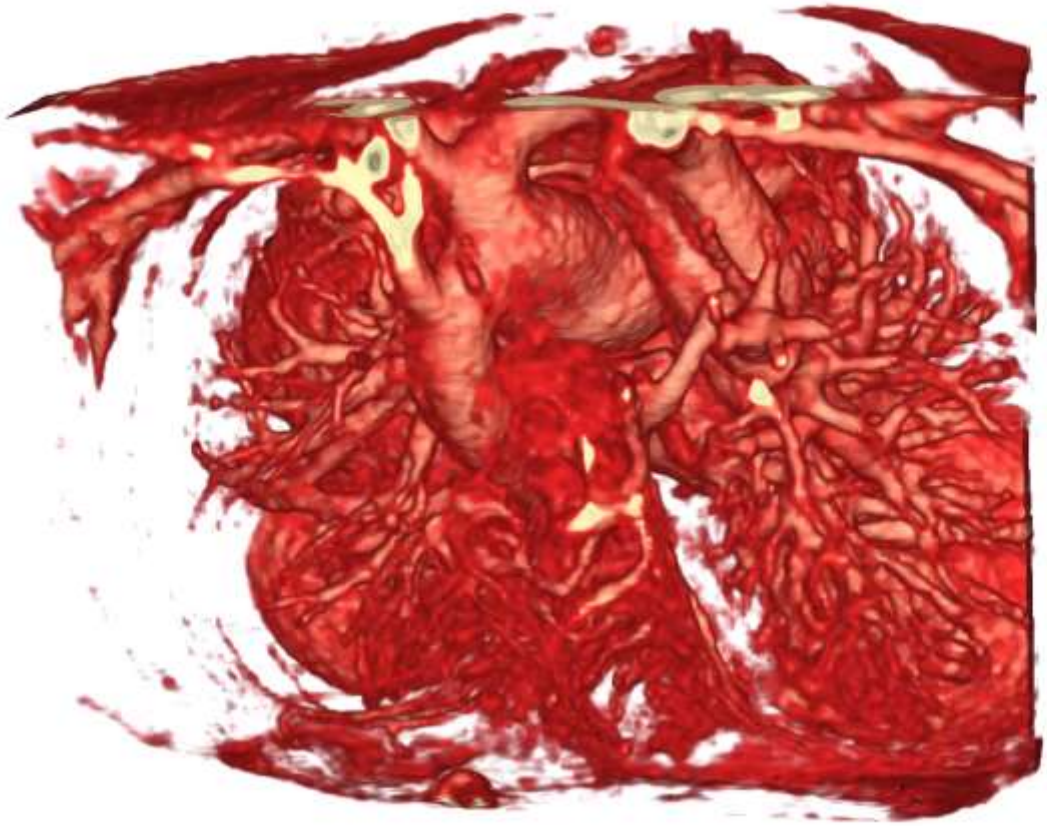




Clinical Modeling Program, CHOP



Clinical Modeling Program, CHOP



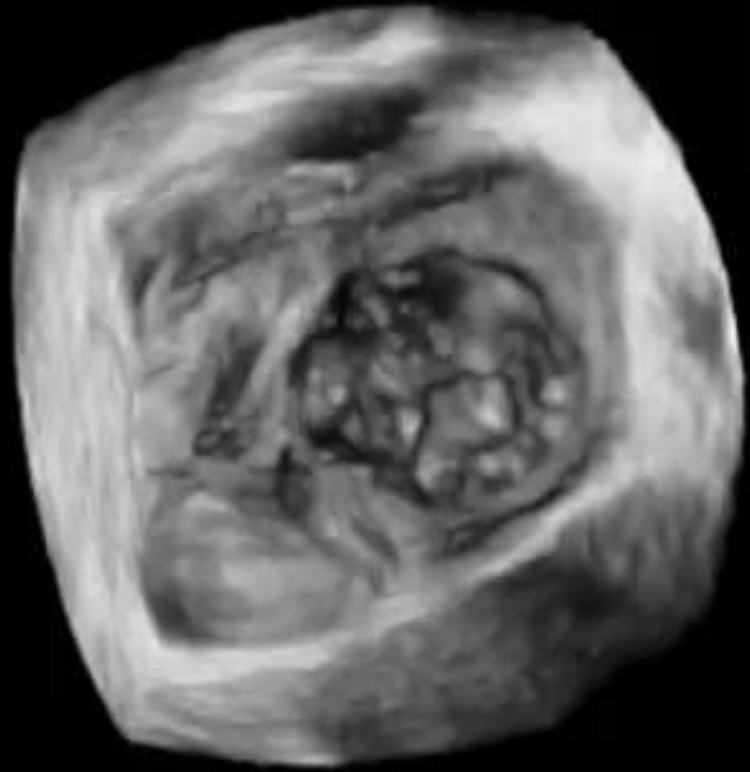
MRI Team, Jolley Lab

Jolley Lab, in preparation

Volume Rendering of Patient's CMR

Ching et al, ATS Short Reports 2023

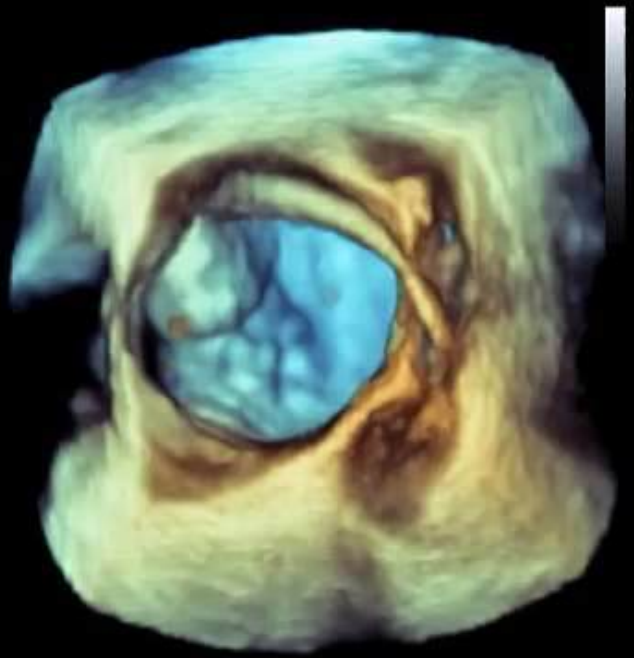
Atrial View



Atrial View

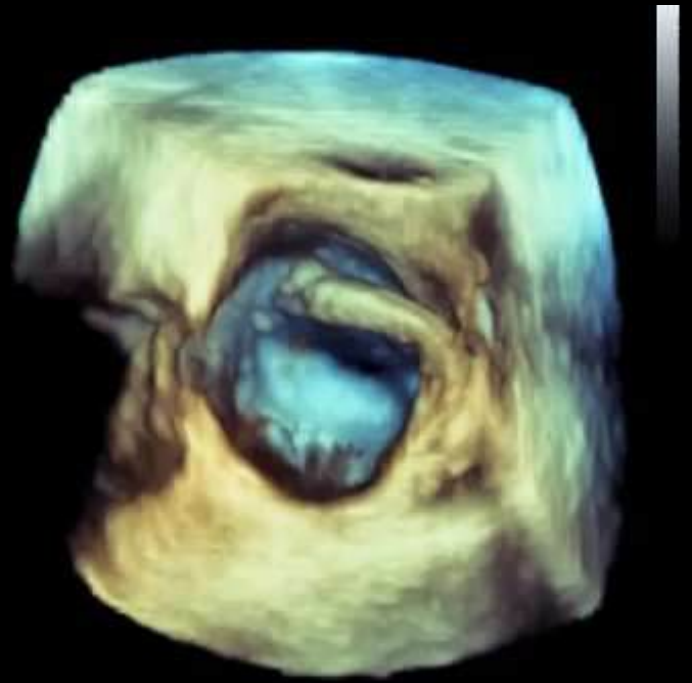
Jolley et al, CCI, 2024

Access via Fenestration



Atrial View

Delivery of Guide

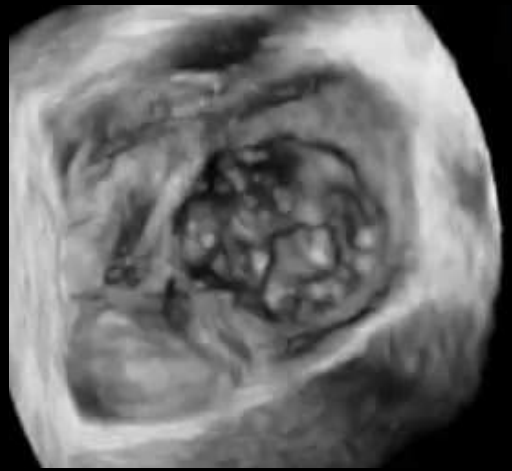


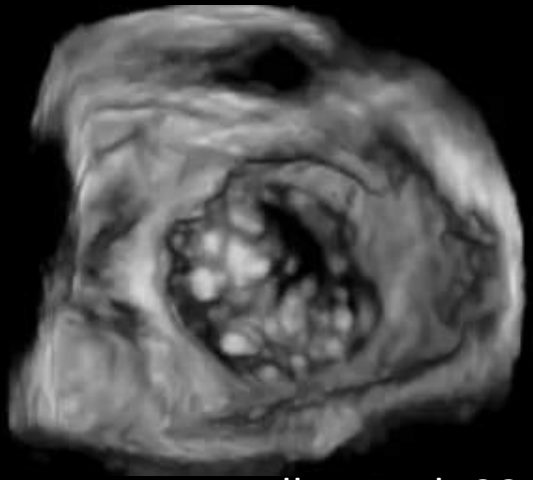
Atrial View

Jolley et al, CCI, 2024

Pre-intervention

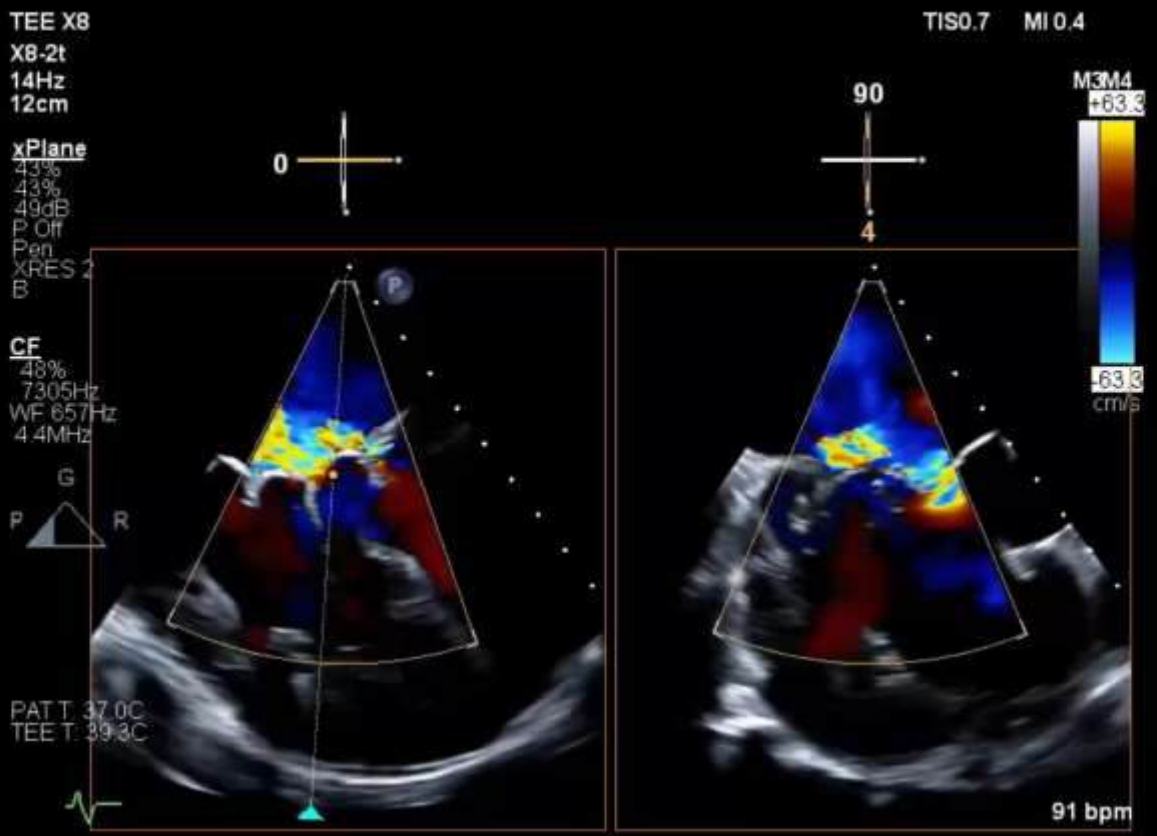
Post-intervention





Jolley et al, CCI, 2024

Pre-Procedural Imaging
2D Color Doppler



Jolley et al, CCI, 2024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MEMBERS OF
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Jolley et al, CCI, 2024

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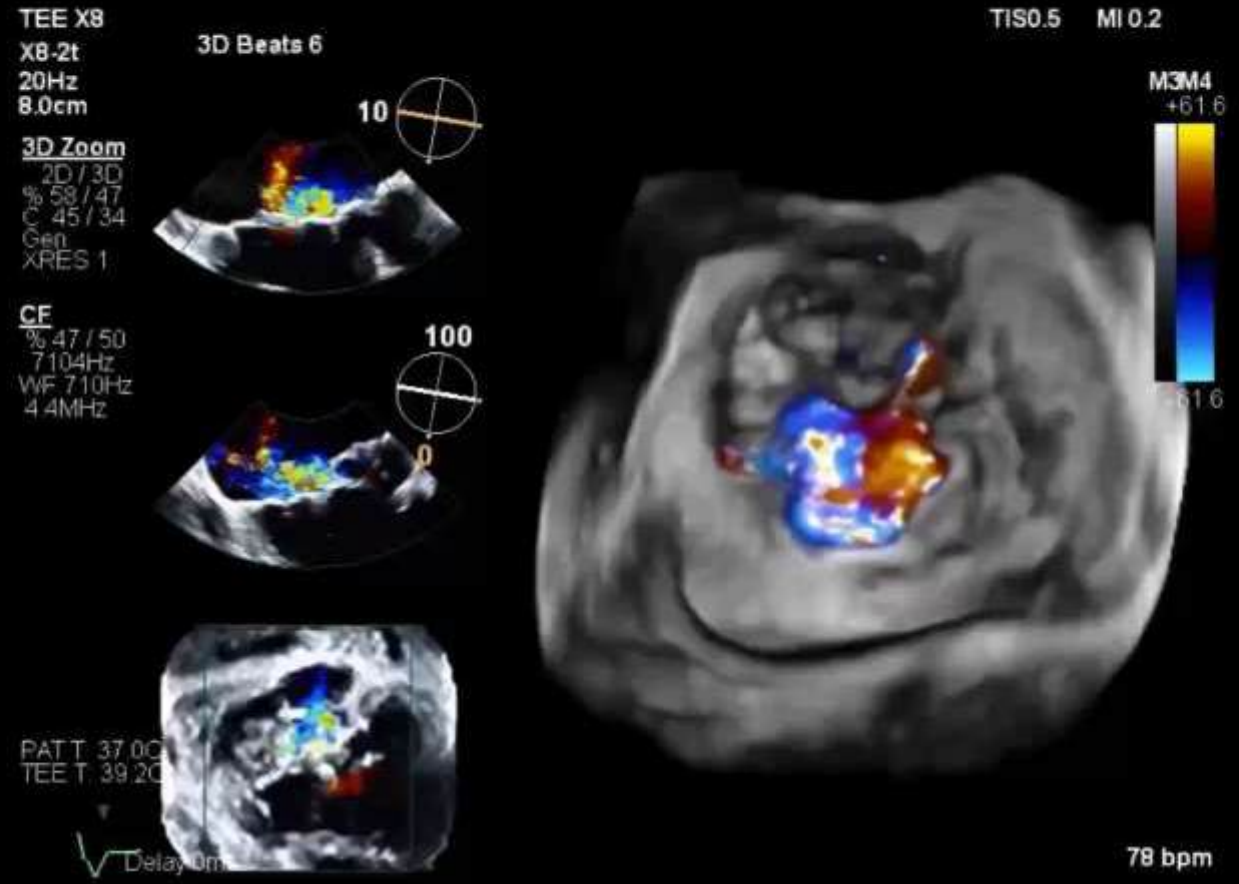
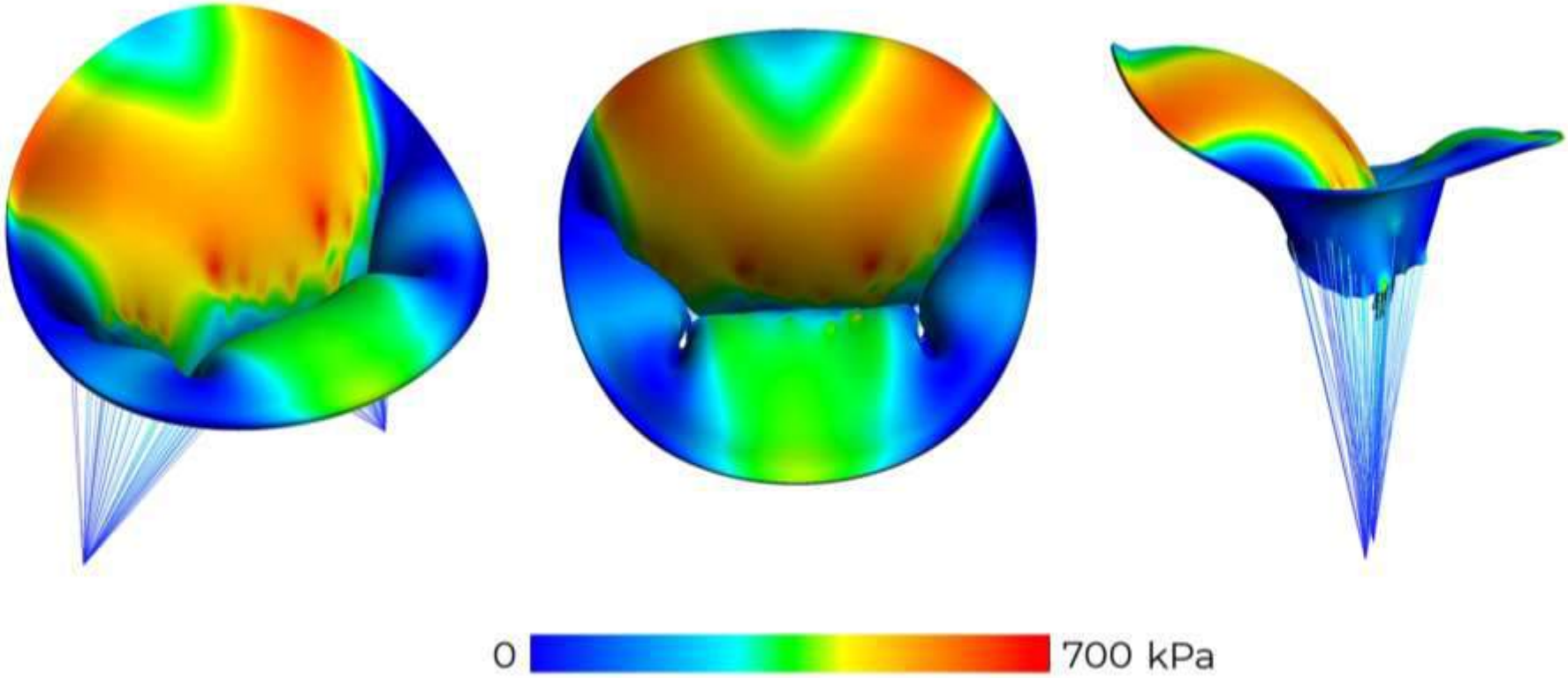
Pre-Procedural Imaging
3D Color Doppler



WHAT IS NEXT?

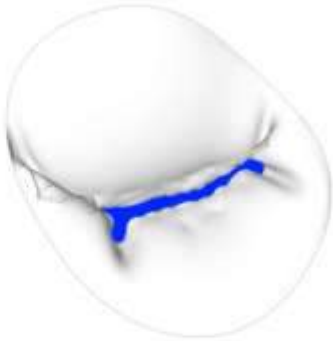


Wu et al., J. Biomechanical Engineering, 2022.

Metrics of Valve Function

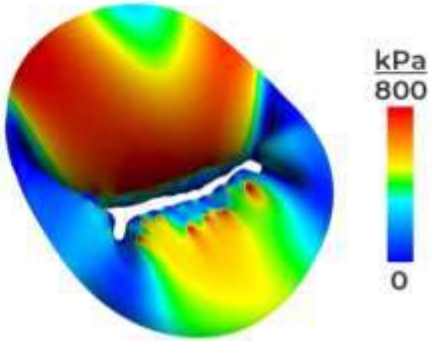
Contact Area

Regurgitant Orifice Area

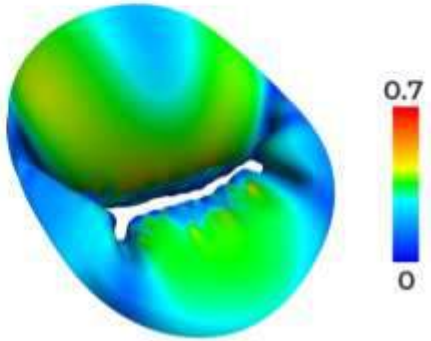


Metrics of Durability

1st Principal Stress



1st Principal Strain



Wu et al. J Mech Behav Biomat Mater. 2023.

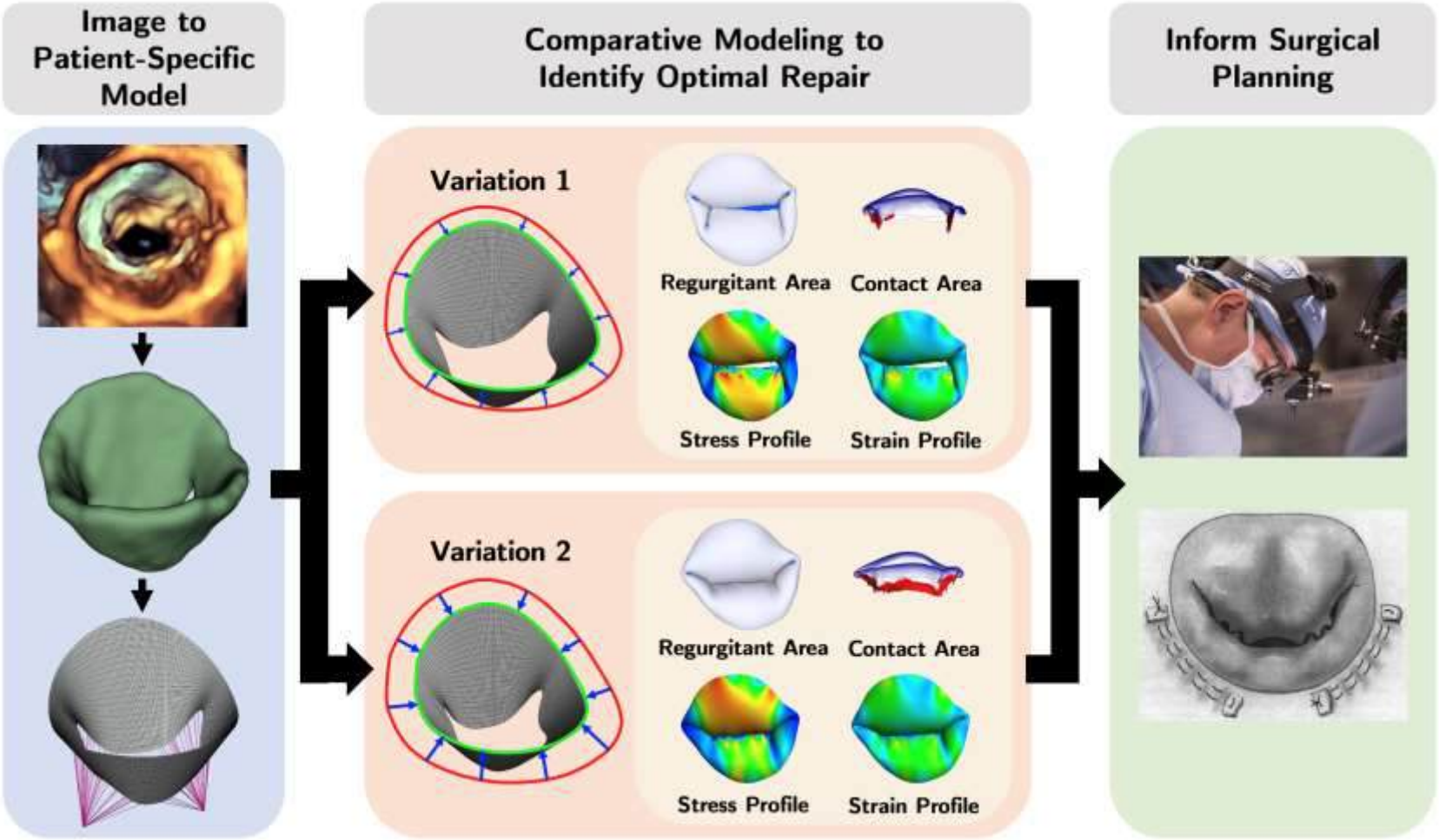
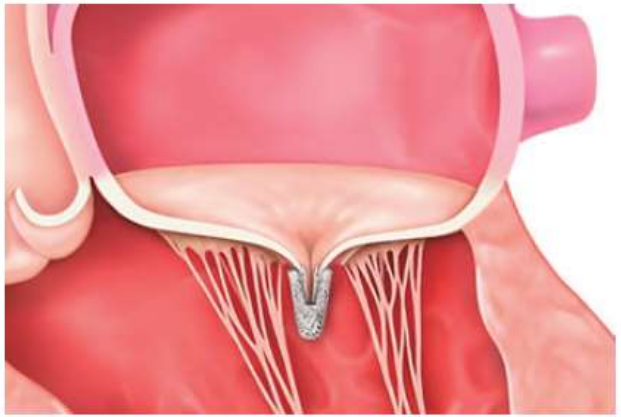
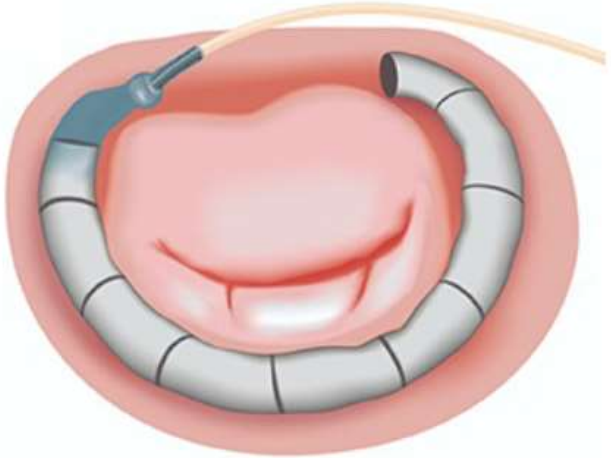


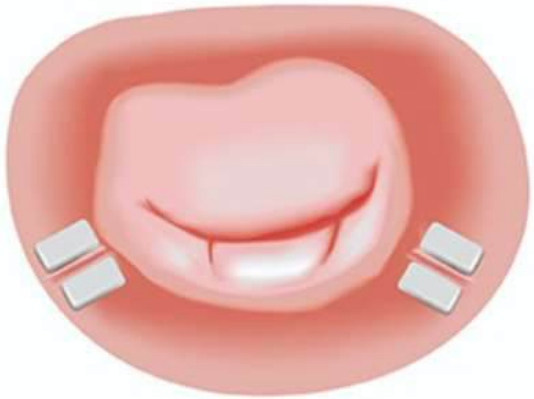
Image to Patient-Specific Model
Comparative Modeling to Identify Optimal Repair
Inform Surgical Planning
Variation 1
Regurgitant Area
Contact Area
Stress Profile
Strain Profile
Variation 2
Regurgitant Area
Contact Area
Stress Profile
Strain Profile



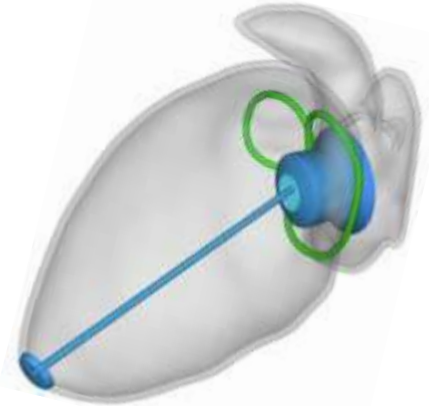
TEER



Ring Annuloplasty

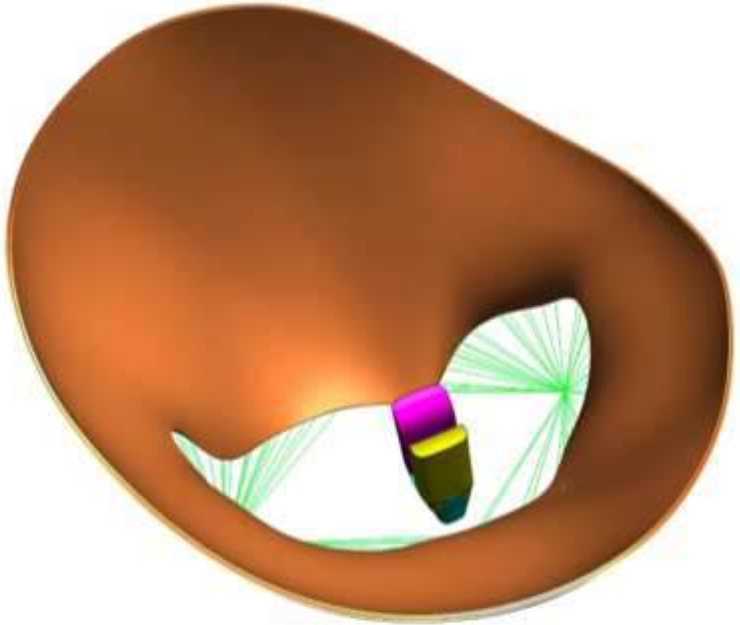


Suture Annuloplasty

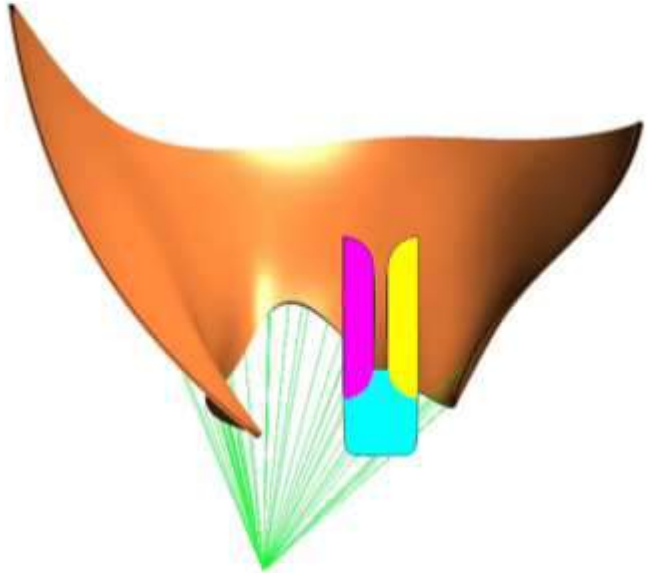


Valve Replacement

Atrial View

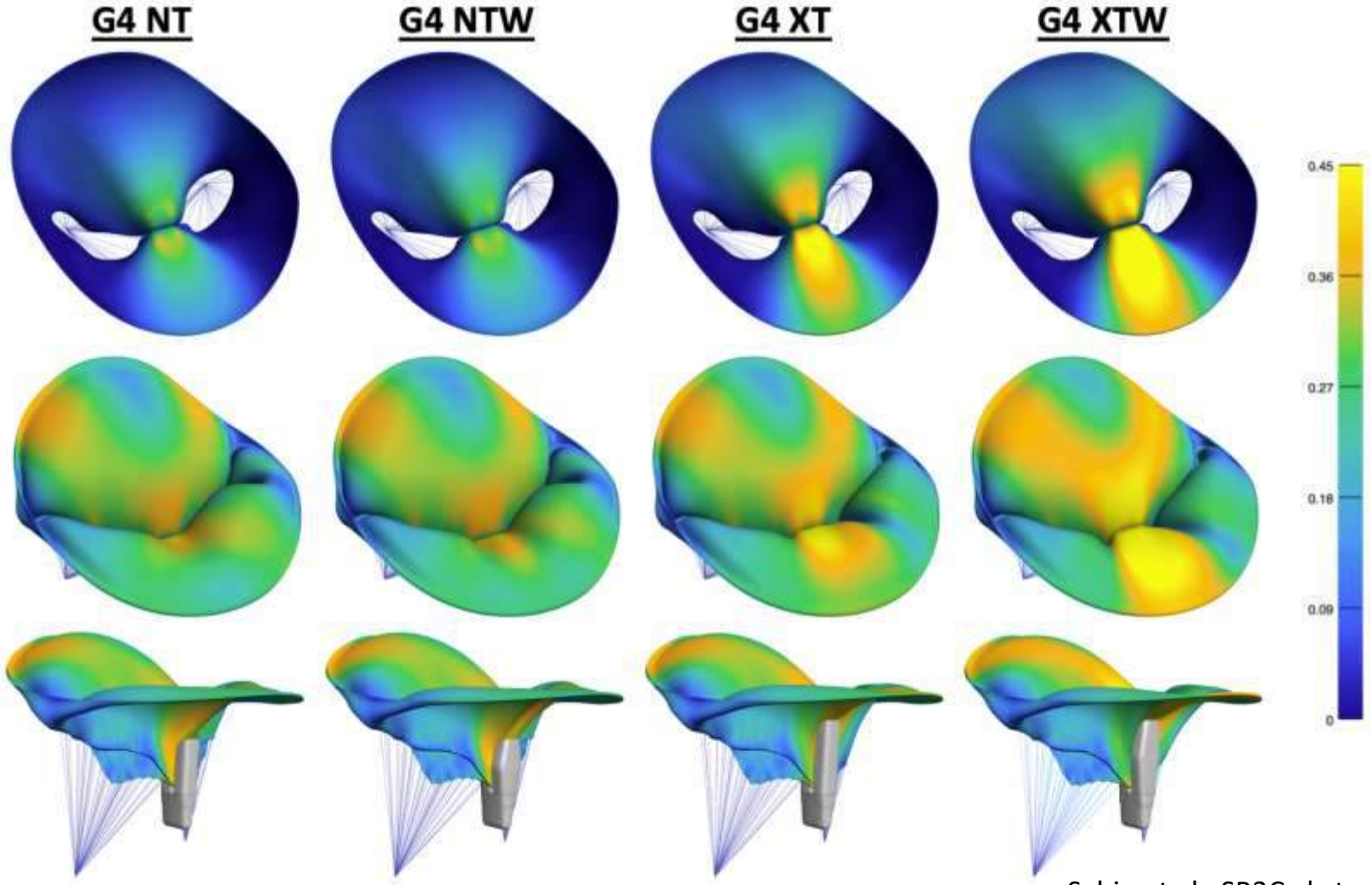


Cut View



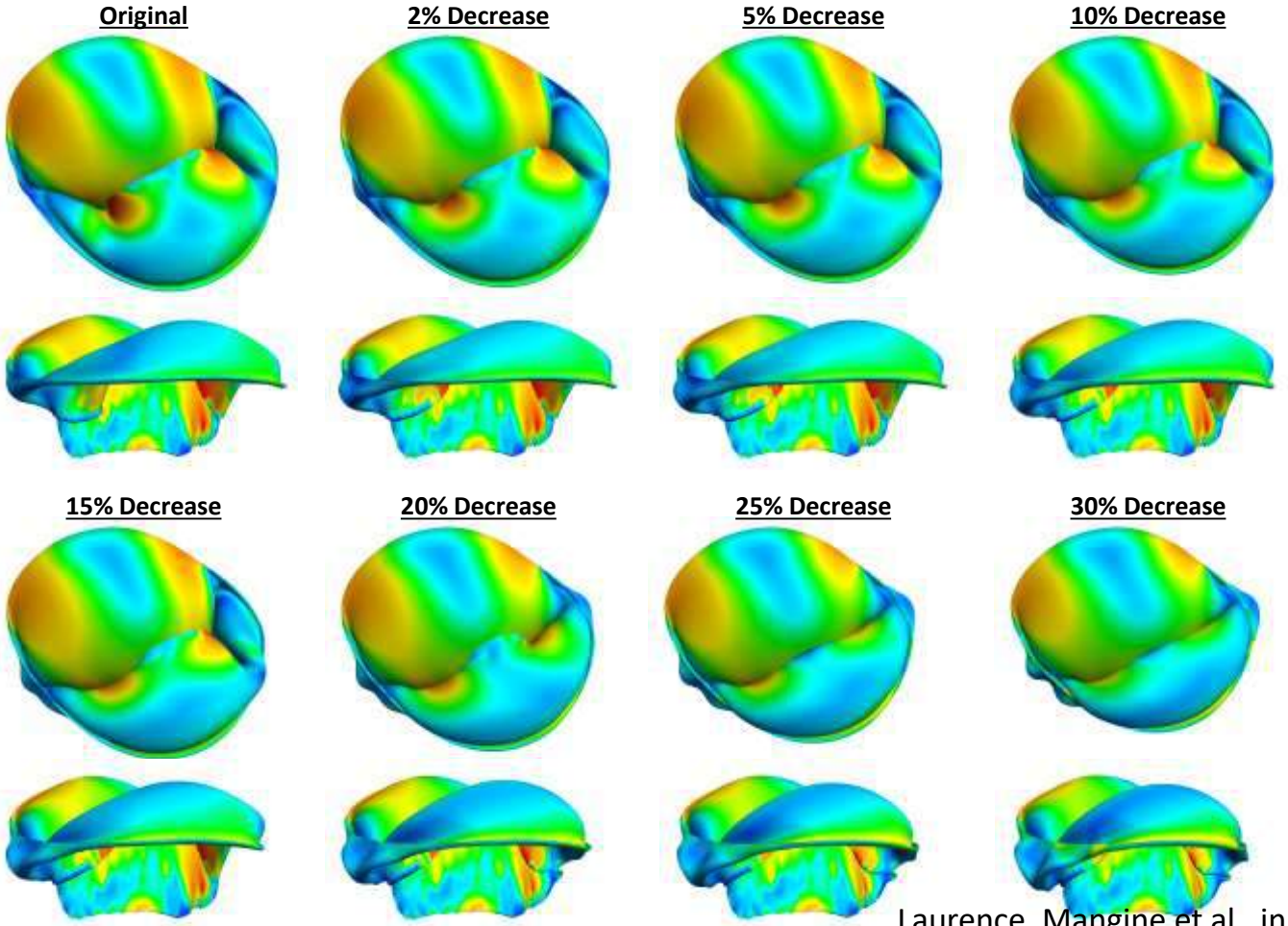
1. Clip Insertion

Sabin et al., SB3C abstract, 2024.

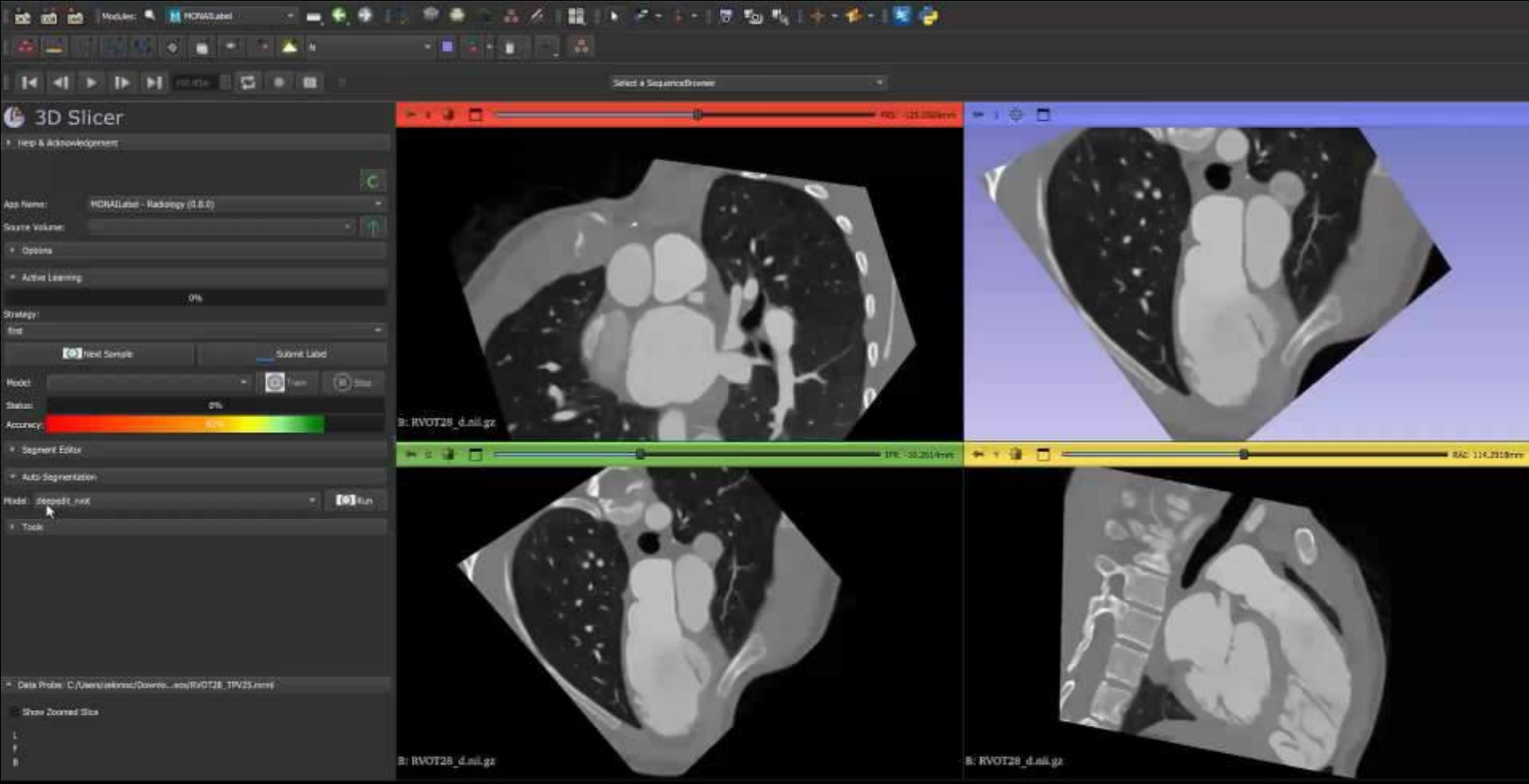


Sabin et al., SB3C abstract, 2024.

Band Annuloplasty – P2 Prolapse

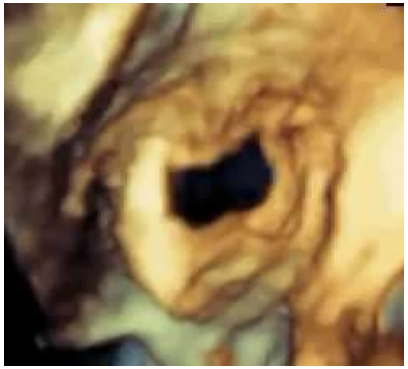


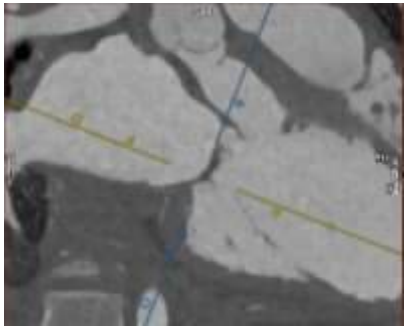
Laurence, Mangine et al., in preparation, 2024.



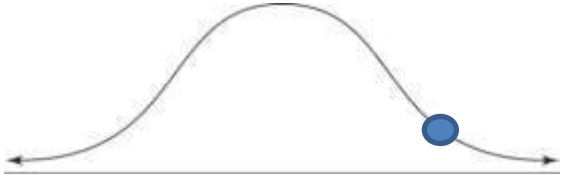
Auto Segmentation with MONAILabel

Images → **Modeling** → **Individualized Repair**





Multiparameter Assessment

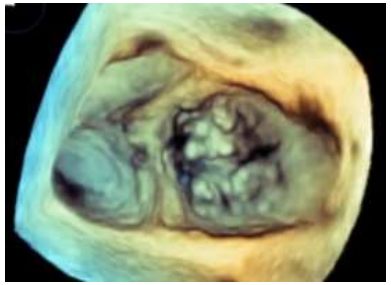


Physical Simulation

***In Silico* Simulation**

Surgical

Transcatheter



CONCLUSION

- Increasing use of clinical valve modeling
- Requires teams and interdisciplinary engagement
- Garbage in, garbage out
- Think multi-modality, not “my modality”
- Emerging multi-physics simulation techniques

Thank You

JolleyLab

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