

Echo Hawaii
Jan 18, 2018

3D Printing & Echocardiography

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Rapid Prototyping 101



Complex Geometry + Multi-Material Fusion = Functional Anatomy (?)



1		2		The Periodic Table of Materials		3		4	
PA	AL	Rank		MC	RE	multicolor		high detail resin	
polyamide	alumide	Symbol		material		7		8	
5	6	material		ABS	TI	abs		titanium	
RE	RE	material		7		8			
paintable resin	transparent resin	material		7		8			
9	10	11		12		13		14	
ST	AG	AU	PG	BS	BZ	brass		bronze	
stainless steel	silver	gold	prima gray	brass		bronze			
15	TOTAL								
CE	HS								
ceramics	high detailed stainless steel								

ARS Question # 1

Audience poll



Finish this sentence....At my institution we use 3D printing to:

1. Plan all complex structural heart procedures.
2. Plan for selected complex structural heart procedures.
3. As a research tool with very little clinical usage.
4. What the heck is 3D printing? We never use it.

ARS Question # 1


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Finish this sentence....At my institution we use 3D printing to:

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CV 3D Print Applications




Anatomic Teaching Tools

Functional Flow Modeling

Procedural Planning

Device Innovation

The 3D printing steps



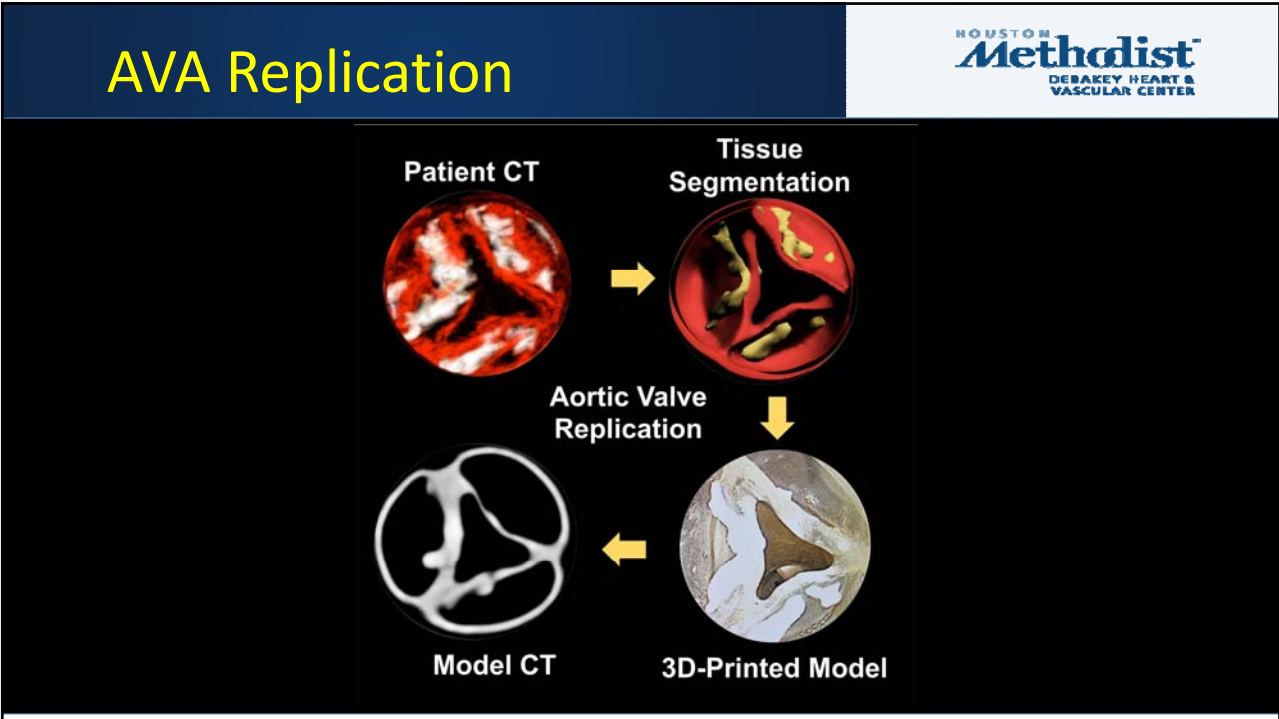
Step 1: CT Images

Step 2: Segmentation

Step 3: 3D Reconstruction

Step 4: Digital Patient-specific 3D Model

Step 5: Multi-material 3D-Printed Patient-Specific Model

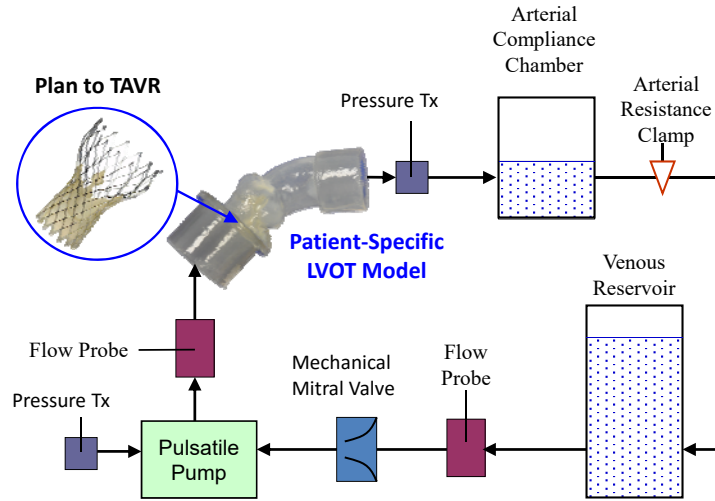


Aortic Root Replication

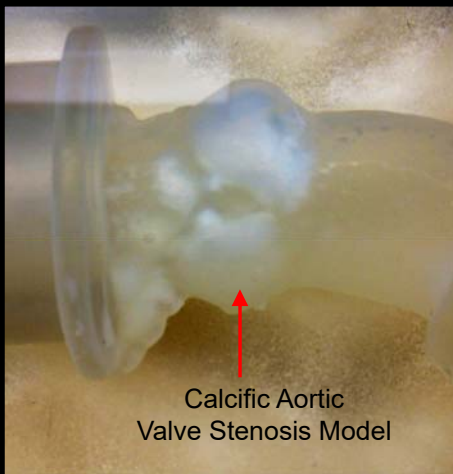
Full Model View	Aortic View	Full Model View	Aortic View
1. Tricuspid AVA 1.1cm ²		5. Tricuspid AVA 0.7 cm ²	
2. Tricuspid AVA 0.74cm ²		6. Bicuspid AVA 0.71 cm ²	
3. Tricuspid AVA 1.1 cm ²		7. Tricuspid AVA 0.89 cm ²	
4. Tricuspid AVA 0.85 cm ²		8. Bicuspid AVA 1.29 cm ²	

Maragiannis et al. *Circ Cardiovasc Imaging*. 2015


HeartBeat Simulator™ Setup

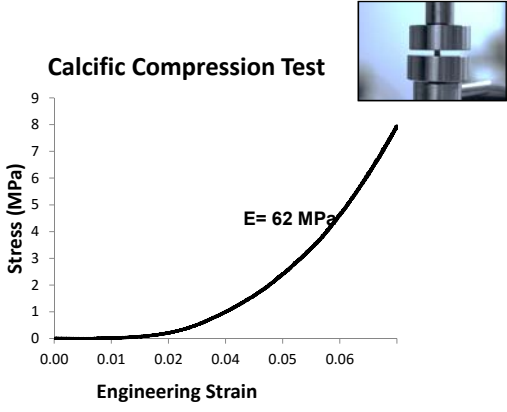


Patient-Specific LVOT Model



Mechanical Testing of Print Materials



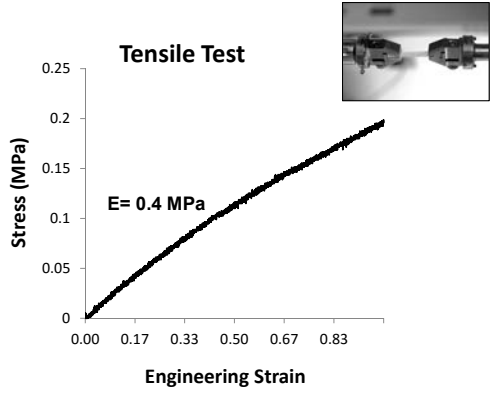


Calcific Compression Test

Stress (MPa)

Engineering Strain

$E = 62 \text{ MPa}$




Tensile Test

Stress (MPa)


Engineering Strain

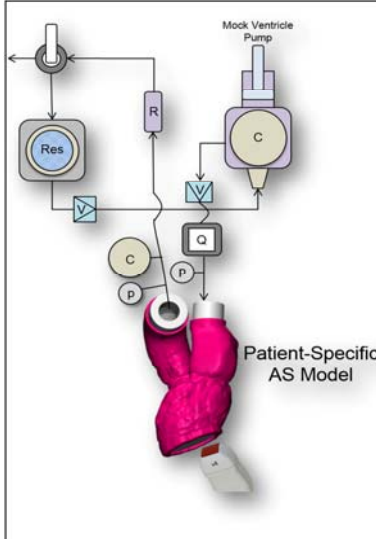
$E = 0.4 \text{ MPa}$

Compression testing for rigid calcific nodules and tensile testing for soft tissue structures.



Replicating AS pressure gradients





Mock Ventricle Pump

Res


C

P

Q


R

Patient-Specific AS Model



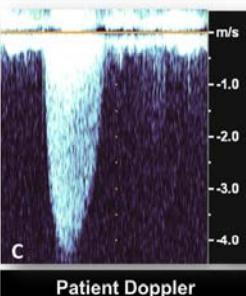
A

Patient Echo



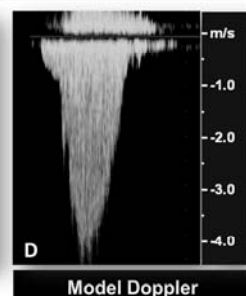
B

Model Echo



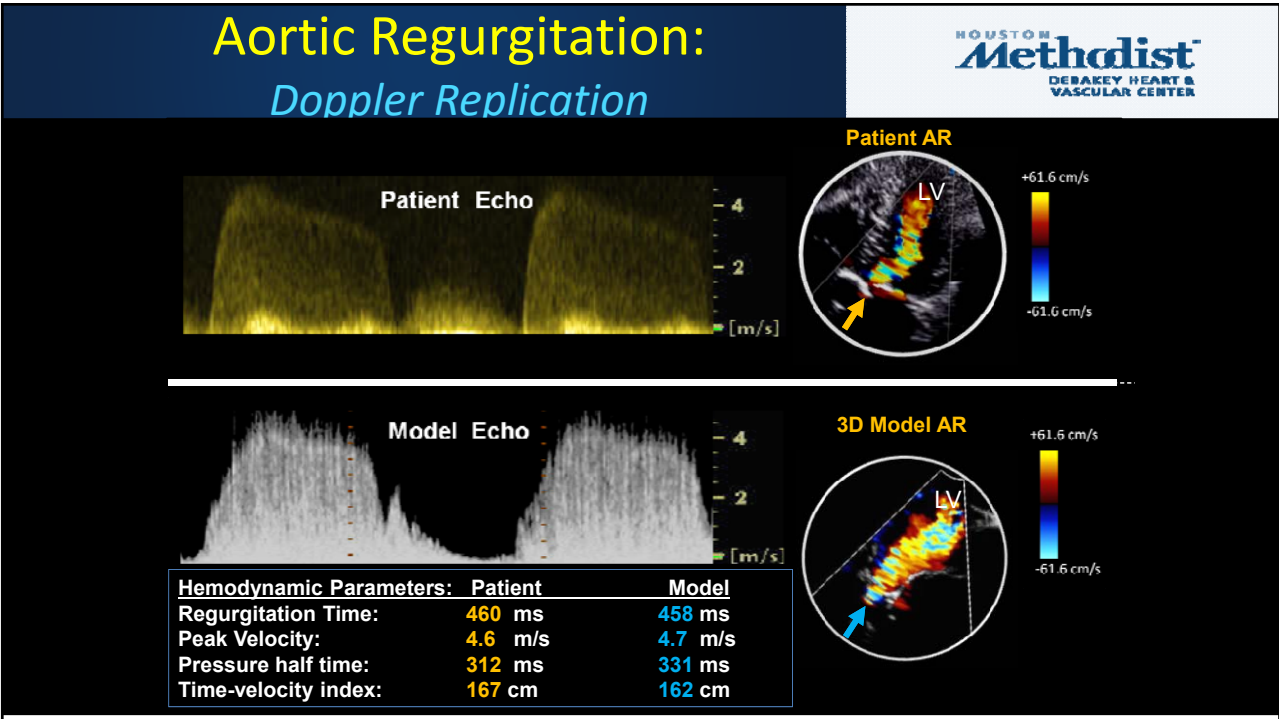
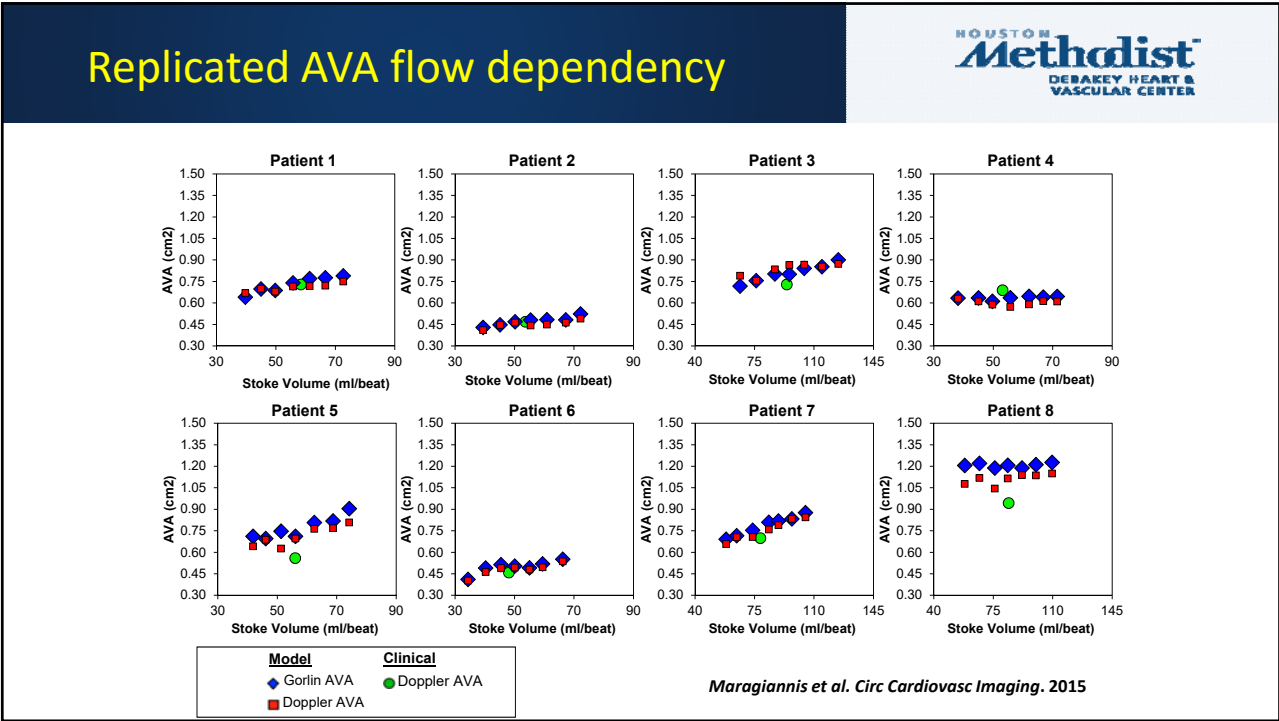
C

Patient Doppler

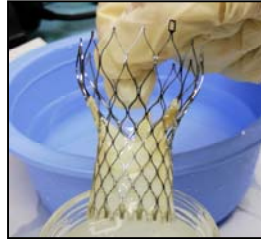


D

Model Doppler



Bench-top TAVR



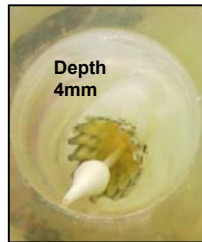
CoreValve Prosthesis



Sheathed Transcatheter CoreValve Prosthesis



Crossing Stenotic Aortic Valve



CoreValve Deployment
Depth 4mm

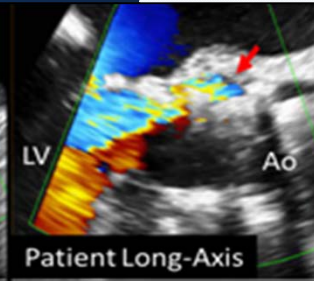


CoreValve Expanded Within LVOT Model

Replicating PVL



Patient Short-Axis

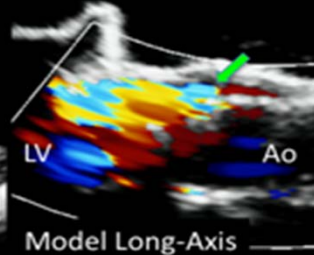


Patient Long-Axis

Patient Echo

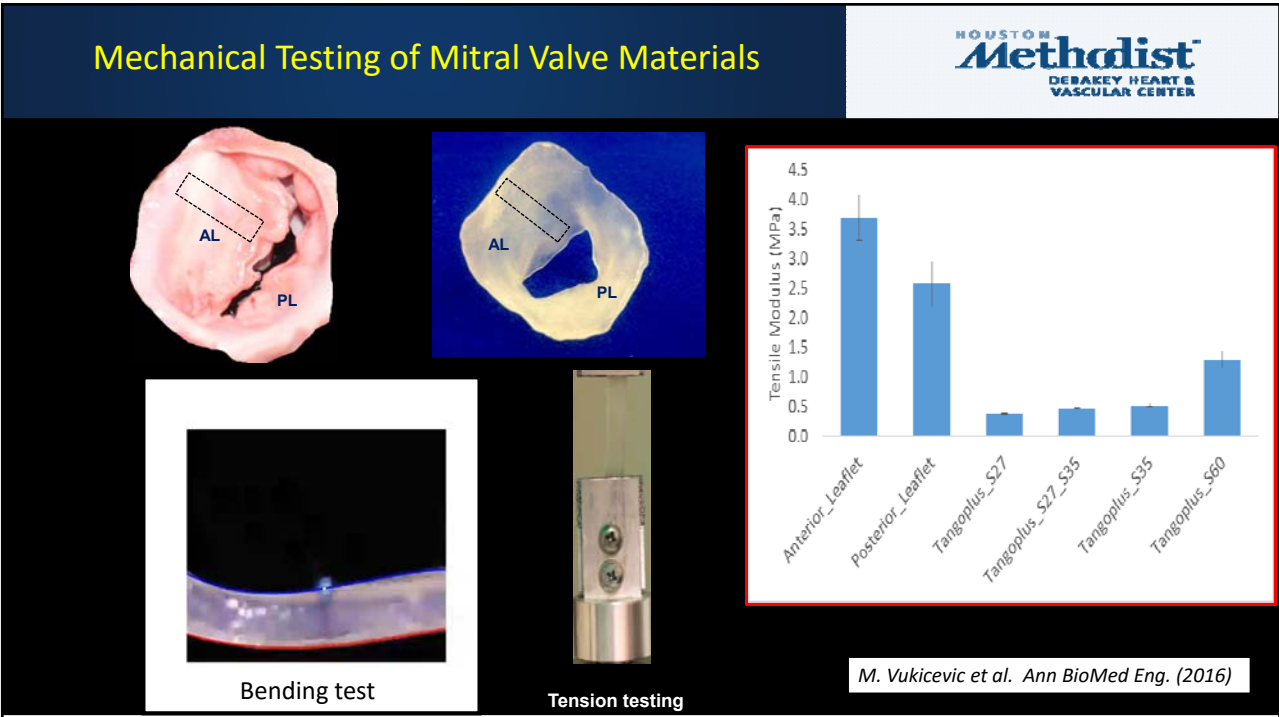
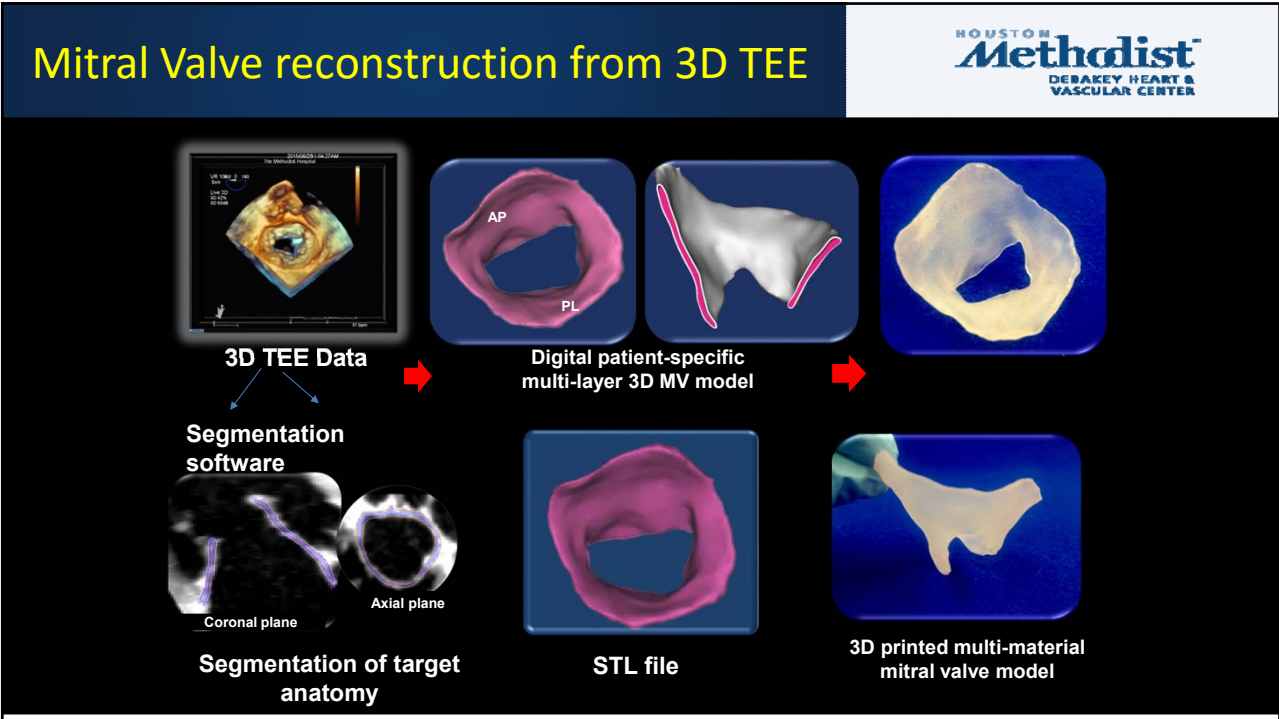


Model Short-Axis



Model Long-Axis

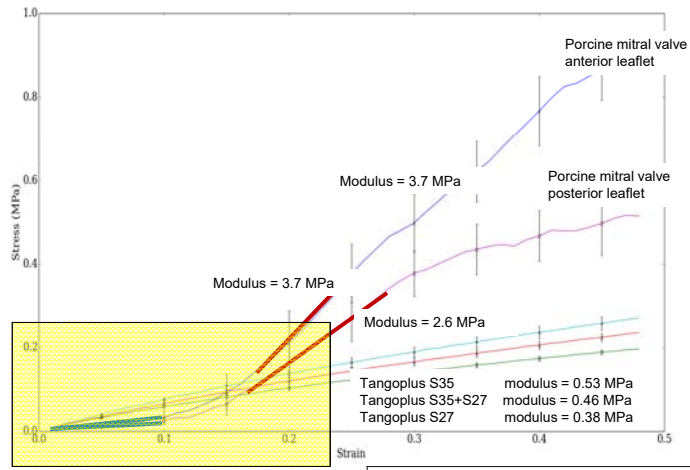
Model Echo



Mitral Leaflet Response to Stress




Tension Testing

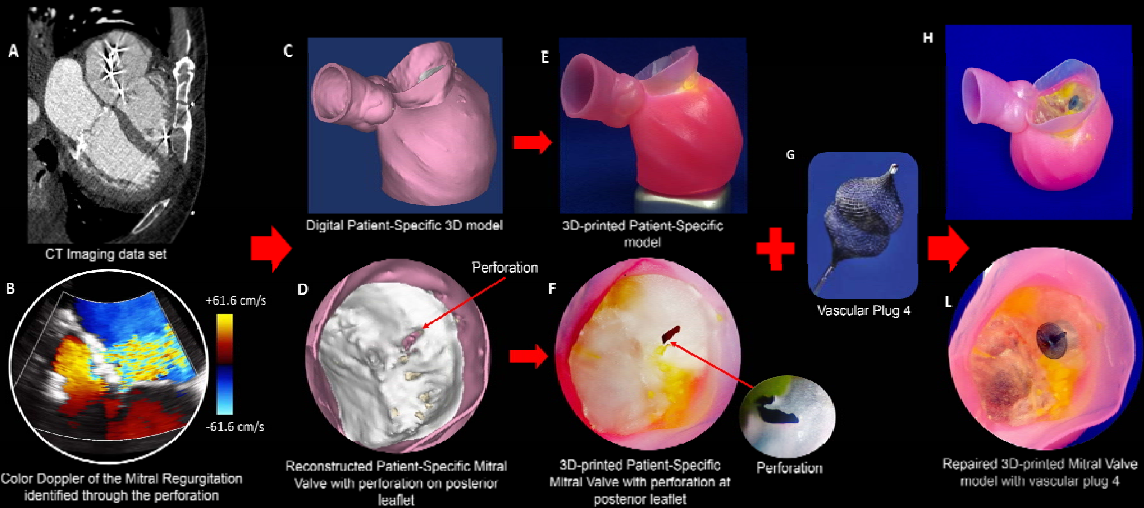


M. Vukicevic et al. Ann BioMed Eng. (2016)

P2 perforation & central MR

Pre-procedural Planning of perforated mitral valve repair





A CT Imaging data set

B Color Doppler of the Mitral Regurgitation identified through the perforation

C Digital Patient-Specific 3D model

D Reconstructed Patient-Specific Mitral Valve with perforation on posterior leaflet

E 3D-printed Patient-Specific model


F 3D-printed Patient-Specific Mitral Valve with perforation at posterior leaflet

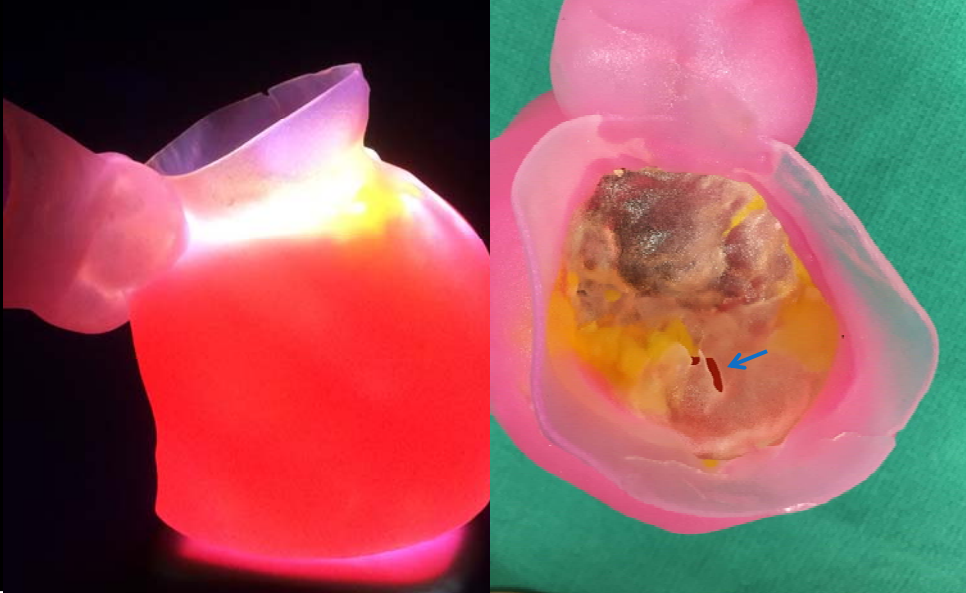
G Vascular Plug 4

H Repaired 3D-printed Mitral Valve model with vascular plug 4

L Repaired 3D-printed Mitral Valve model with vascular plug 4

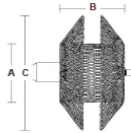
Patient-Specific 3D Print P2 perforation





What device will fit?

Ductus Diameter	Ductus Length				
	<5mm	5.0 – 8.0mm	8.1 – 10.0mm	10.1 – 11.0mm	11.1 – 12.0mm
<2.5mm	ADO II 03-04	ADO II 03-06	ADO II 04-06	ADO II 05-06	ADO II 06-06
2.5 – 3.5mm	ADO II 04-04	ADO II 04-06	ADO II 05-06	ADO II 06-06	ADO II 06-06
3.6 – 4.5mm	ADO II 05-04	ADO II 05-06	ADO II 05-06	ADO II 06-06	ADO II 06-06
4.6 – 5.5mm	ADO II 06-04	ADO II 06-06	ADO II 06-06	ADO II 06-06	ADO II 06-06

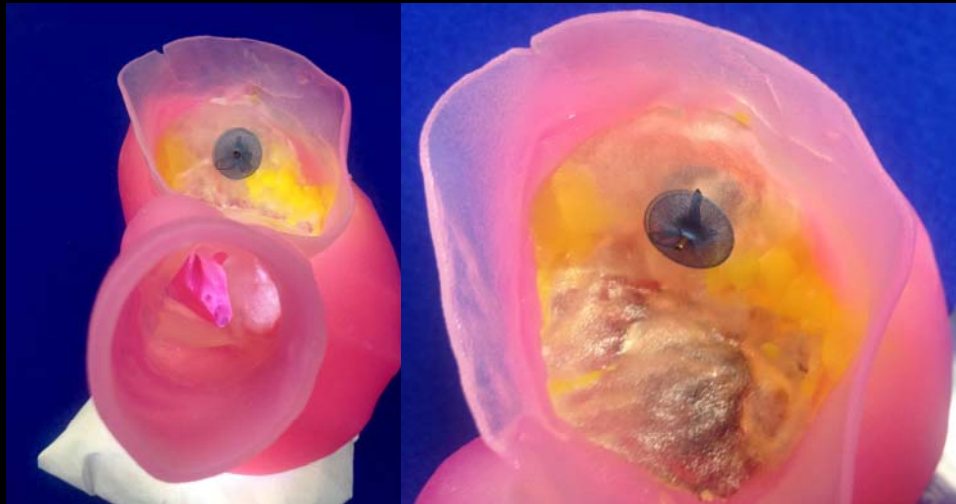


Model / Recorder Number	(A) Waist Diameter (mm)	(B) Device Length (mm)	(C) Disc Diameter (mm)	Recommended Catheter Size (with AMPLATZER® TorqVue LP Delivery System)
®FDA2-03-04	3	4	9	4F
®FDA2-03-06	3	6	9	4F
®FDA2-04-04	4	4	10	4F
®FDA2-04-06	4	6	10	4F
®FDA2-05-04	5	4	11	5F
®FDA2-05-06	5	6	11	5F
®FDA2-06-04	6	4	12	5F
®FDA2-06-06	6	6	12	5F

Amplatzer Duct Occluder II

ST. JUDE MEDICAL
MORE CONTROL. LESS RISK.

Patient-Specific 3D Print Modeling for Leaflet Repair



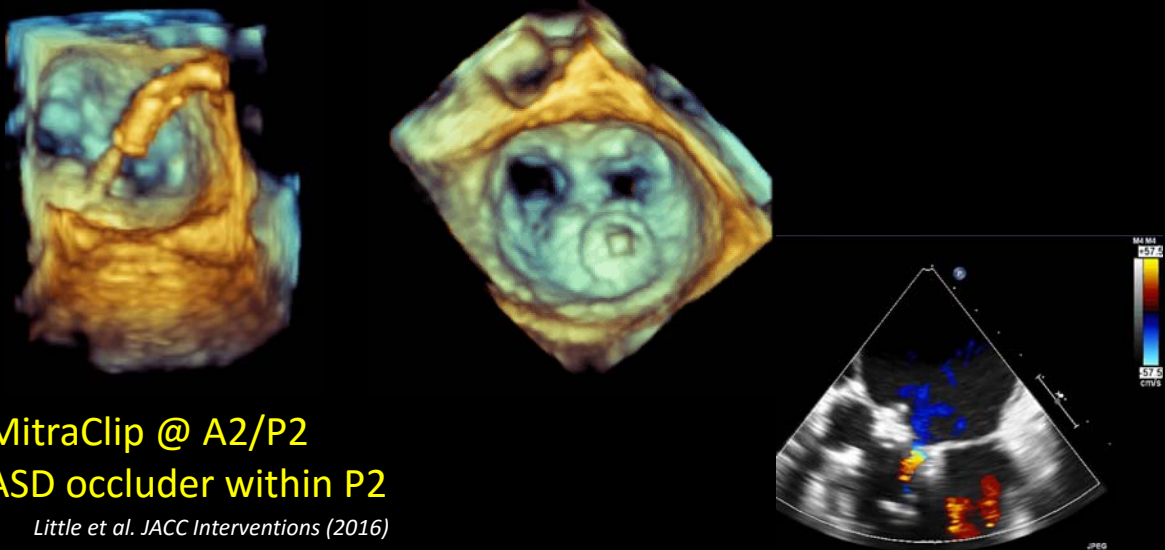
Atrial View

Replicating the calcium too



Ventricular View

Guiding the practiced procedure



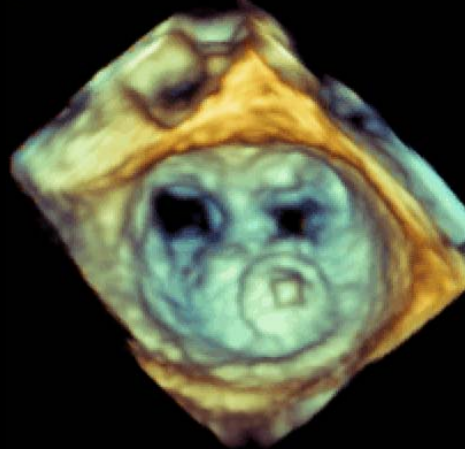
MitraClip @ A2/P2
ASD occluder within P2

Little et al. JACC Interventions (2016)

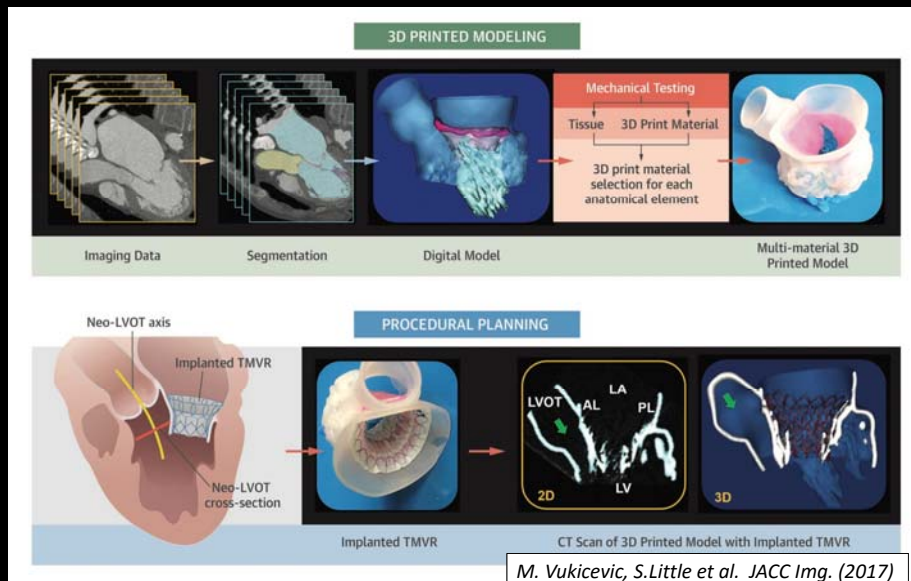
A familiar result?



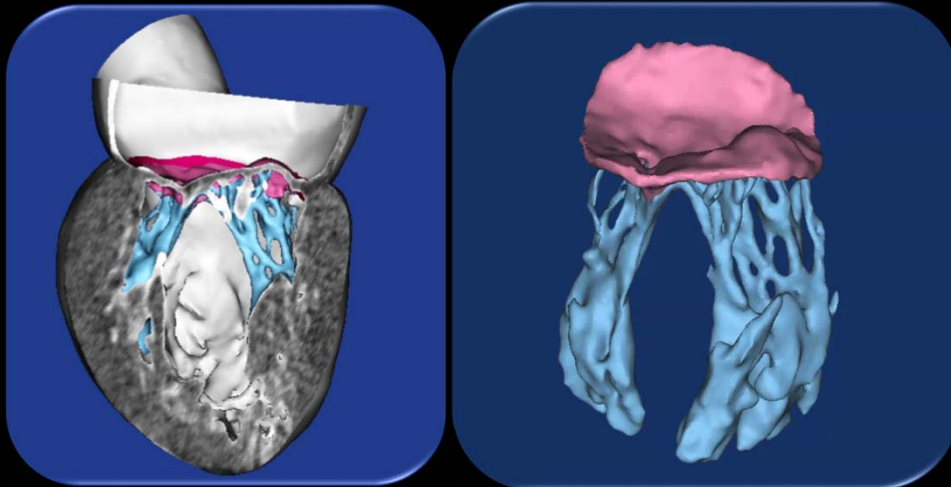
The Never Ending story dog



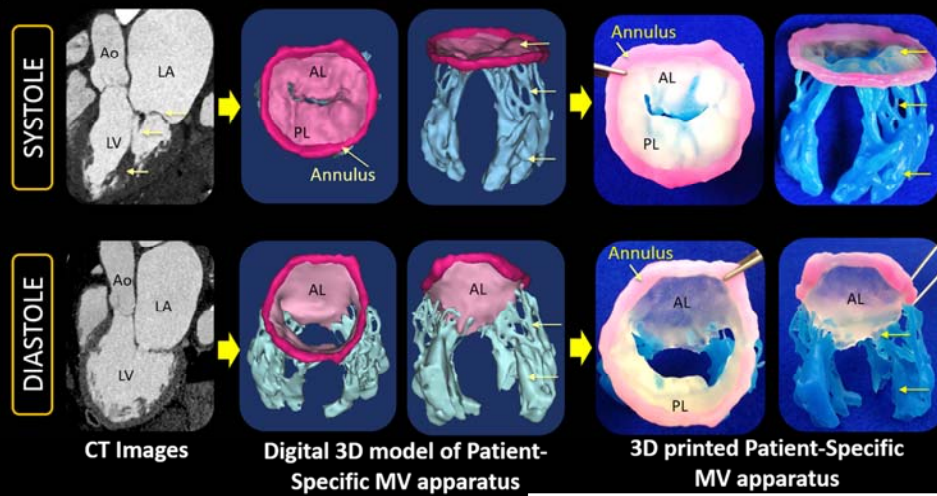
Modeling LVOT obstruction



CT-based patient-specific MV



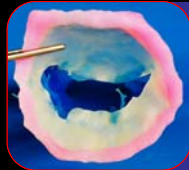
Mitral valve 3D printing



M. Vukicevic, S. Little et al. JACC Img. (2017)

MitraClip implantation in a patient-specific 3D printed MV apparatus

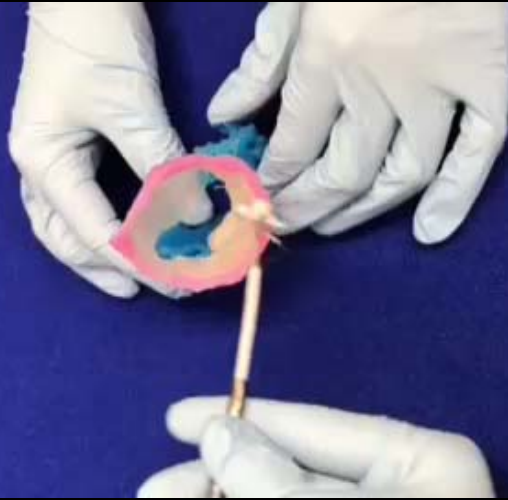
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Methodist
DEBAKEY HEART &
VASCULAR CENTER



MV model



MitraClip



MitraClip implantation

Why do we need models?

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3D-Printed Valve models:

- Can replicate patient-specific geometry
 - Can be coupled to physiologic flow
- Provide a reproducible testing environment
- Are a cheap arena for mistakes and innovation
- Have already changed how we practice and perfect structural heart interventions



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