3D Medical Image Modeling Research & Applications

Update from

The Lynn & Arnold Irwin APIL Advanced Perioperative Imaging Lab

Grand Rounds

Department of Anesthesia & Pain Management

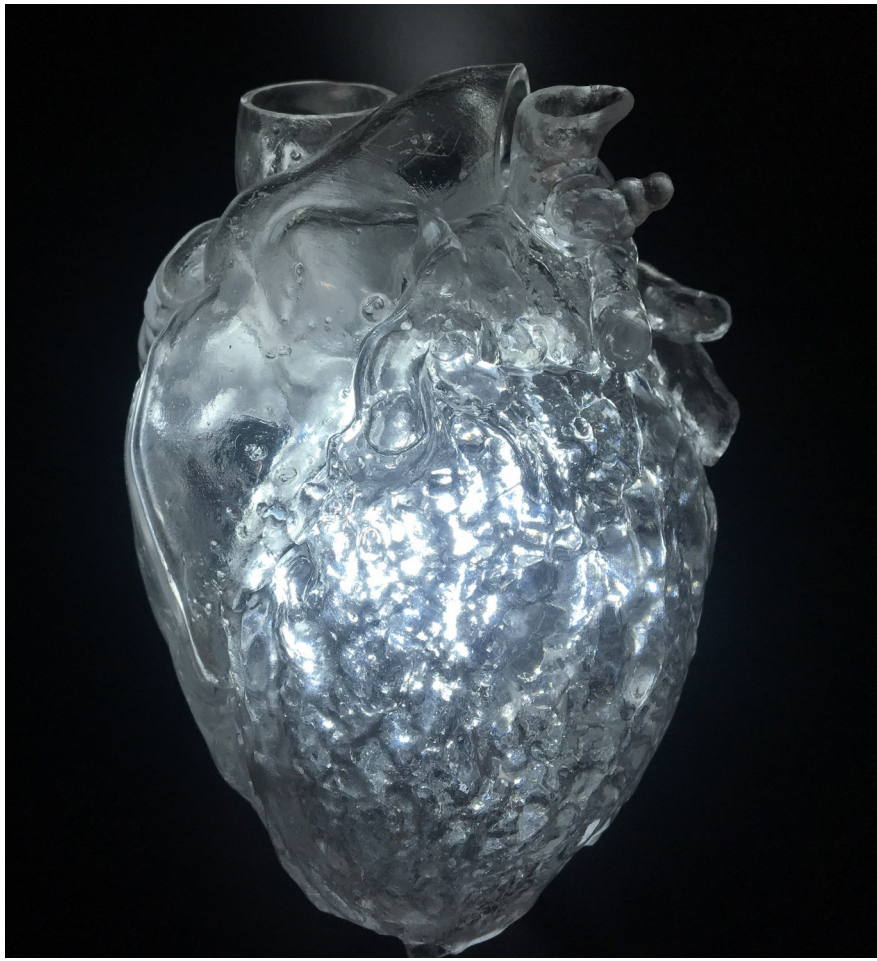
Toronto General Hospital

2019.10.04

Azad Mashari

Joshua Qua Hiansen

Erika Haskings



UHN Peter Munk Cardiac Centre

CC BY

Competing Interests

Financial Support from Peter Munk Cardiac Center Foundation

Infrastructure support from Autodesk residency program

Research software: Epsilon Imaging, Siemens, Vuforia, Children's Hospital of Philadelphia

Collaboration with Glia Inc.

Objectives & Outline

What and where is APIL?

What is APIL doing?

What can APIL do for you now?

What should APIL do for you?

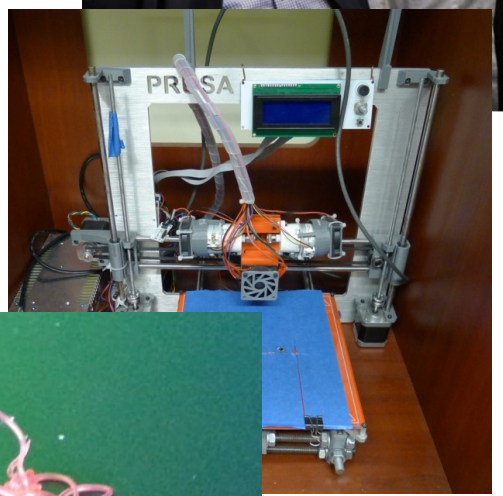
Story of APIL

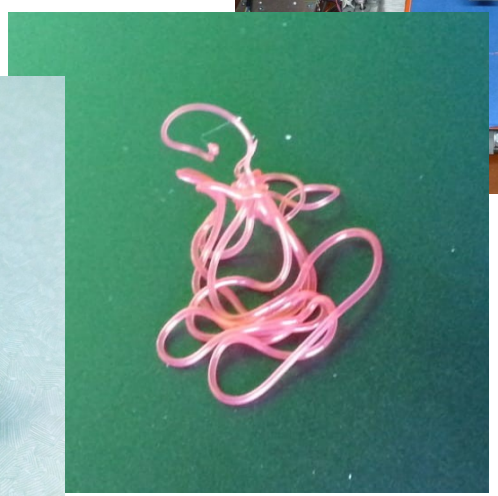
Founded in 2014-2015 by **Max Meineri** with funding from **PMCC Foundation**

Primarily to explore clinical and education applications of 3D echocardiography

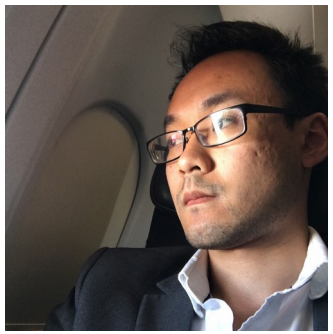
First 3D printer: Prusa Mark 1 built at a weekend workshop in Montreal 2015

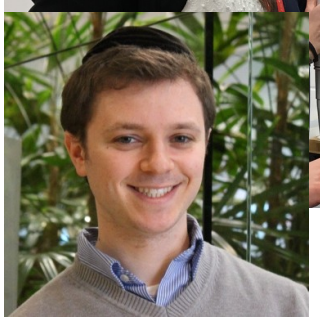
Location **1GW-525**





Team



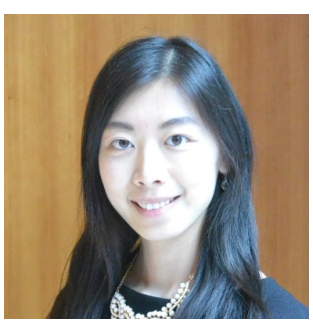


Leadership/PIs: Azad Mashari, Joshua Hiansen, Jacobo Moreno, Micheal Dinsmore, Max Meineri

Research Fellows: F Ballocca, G Ruggeri, E Paradis, A Mbadjeu Hondjeu, G Gadotti

Clinical Fellows: Y Amador, D Centenaro, I Lembrikov, J Saran, S Schiavo, M Zhu, M Buys, E Neethling, M Lenihan, J Beuth

Residents & Students: F Massouh, E Aziza, S Zhou, R Chaudhary, M Irwin, E Zheng, E Haskings, R Ramos, A Woltersom, A Berardino, N Almohamad, M Mahran, S Khargie



Many More …

All the layers of support …

TGH Department of Anesthesia, Pat Murphy, Annette Vegas and the PEG Group, Ahmad Omran, Adriaan van Rensburg, Sarah Russell, Bilal Ansari, Eva Bowman, Jo Carroll, Samareh Ajami, Nour Ayach, Joe Fisher, Dallas Duncan, Stuart McCluskey, Rita Katznelson, Carlos Ibarra, Coimbatore Srinivas, Keyvan Karkouti, Barry Rubiun and Many others…

Phoebe Lam, Eric You-Ten, Lisa Bahrey, Sharon Peacock, Mini Pakkal, Rafa Alonso, Erwin Oechslin, Krish Nair, Eric Horlick, Tirone David, Anuj Bhatia

UHN CV Surgery, Cardiology (Interventional, EP, ACHD), JDMI/Radiology, Techna, TGH Simulation Center, TGH CVICU Education, Alan Waters Simulation Center, Wilson Center,

External: Glia (T Loubani, UWO),
Children's Hospital of Philadelphia (M Jolley)

Funding

PMCC Foundation start-up grant

Research Grants

- Educational Development Fund $4800 (Mashari)
- PMCC Innovation Fund $52 000 (Moreno)

Educational Model Sales $7000

Output 2015-2019

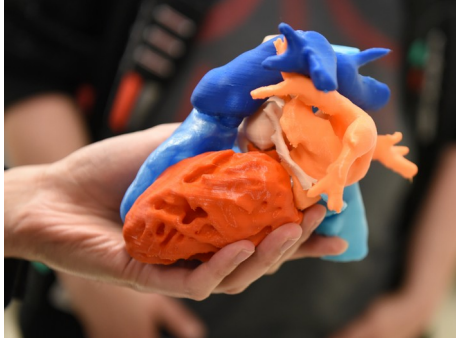
8 Peer-reviewed publications

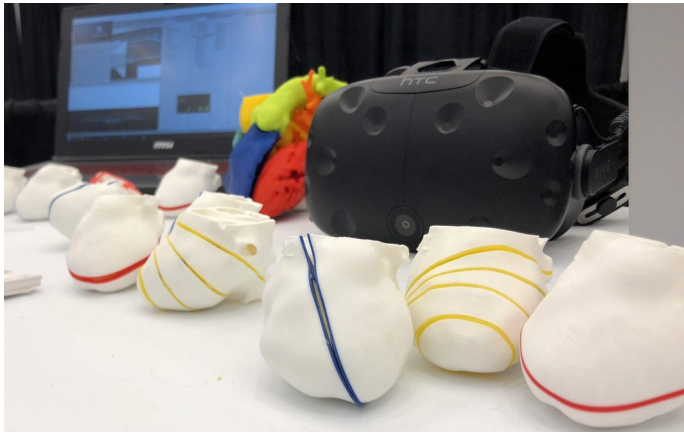
35 Abstracts and posters

12 Oral presentations

Media coverage: Toronto Star (Print), Globe & Mail (Print), U of T Magazine (Print), Autodesk Research (Web), Vuforia (Web).

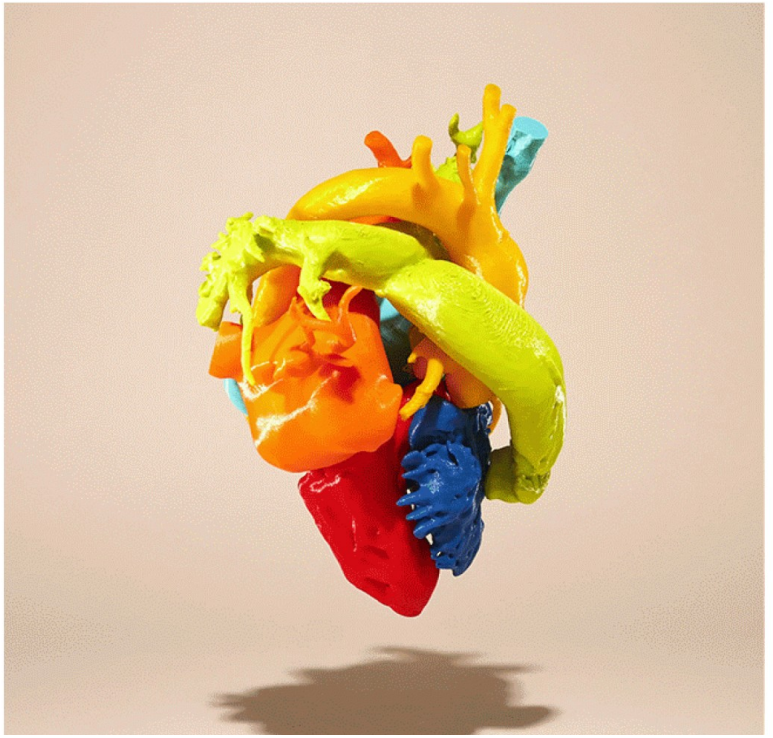
Conference booths: CAS 2018; 28th International Adult with Congenital Heart Disease Symposium 2018; Toronto Perioperative TEE Symposium 2017, 2018





APIL

"Small Windowless Room" Raves U of T Magazine



TECHNOLOGY

Pumped Up

These 3-D printers create perfect models of life-sized human hearts, spines and other body parts

By Kurt Kleiner

October 3, 2019

In a small, windowless room at Toronto General Hospital, a bank of seven 3-D printers runs day and night, patiently laying down layer after layer of coloured plastic. When the printing is done, the pieces are trimmed and fitted together into perfect models of human hearts, life-sized and correct down to the smallest detail.

Infrastructure

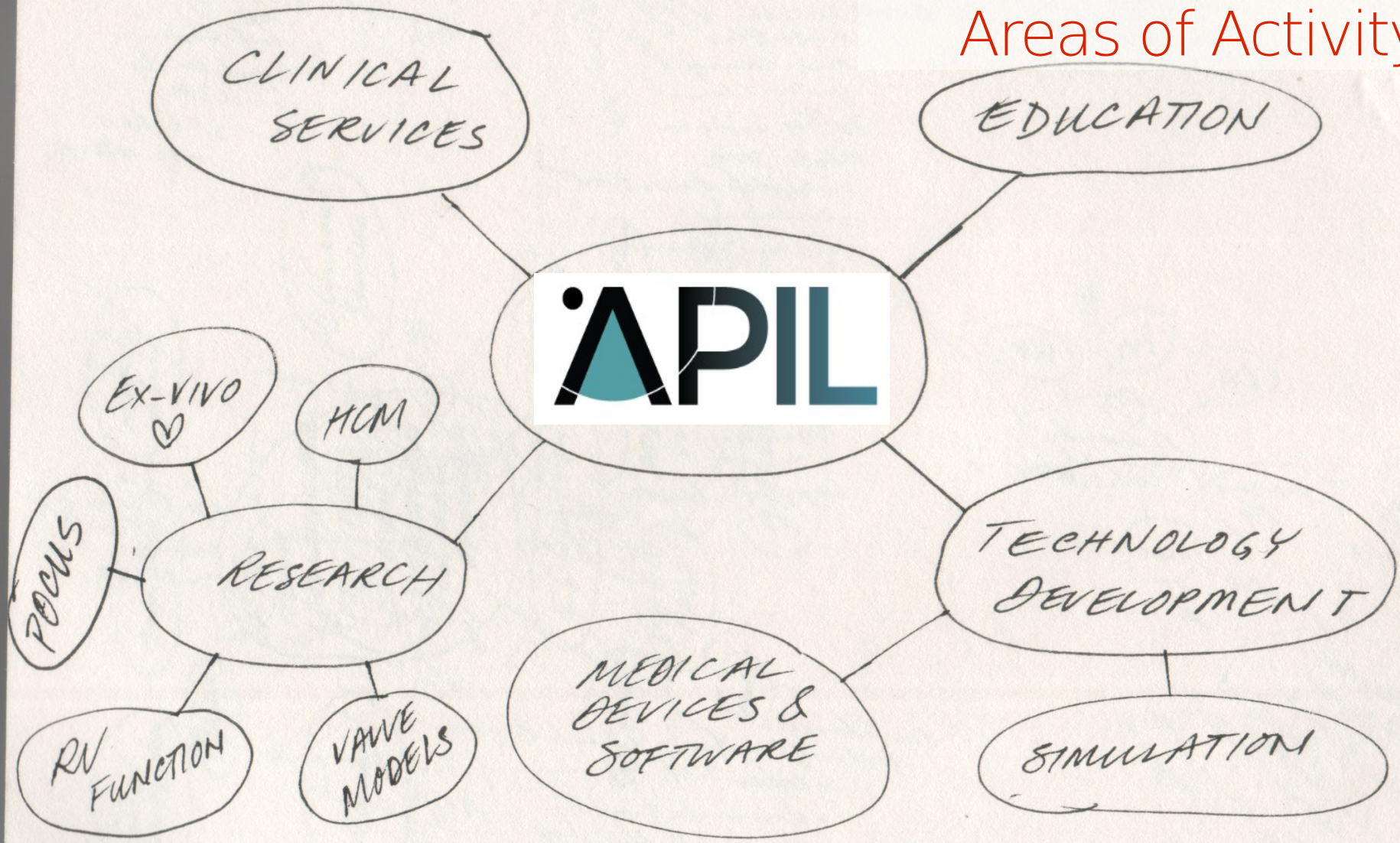
Lab & workshop **1GW-525** (come visit the SWR!)

CT, MRI and Ultrasound Data

Software for 3D image processing, analysis, visualization, modeling and micromanufacturing

Access to Autodesk workshops in MaRS (Window, 3D printing, laser cutting, full workshop, milling & metalwork, electronics)

Areas of Activity



Clinical Modeling & Printing Services

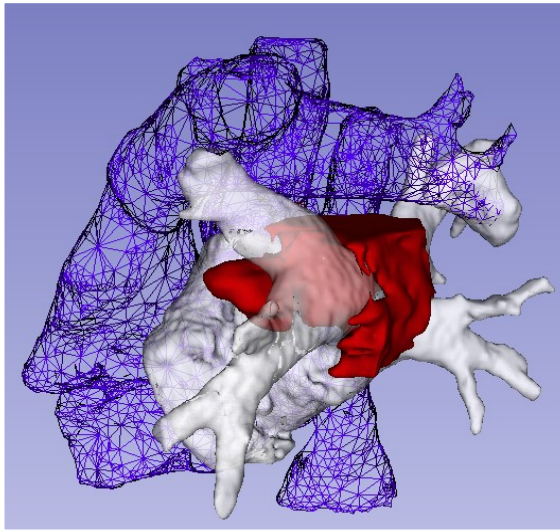
Patient-specific models from **Cardiac CT**

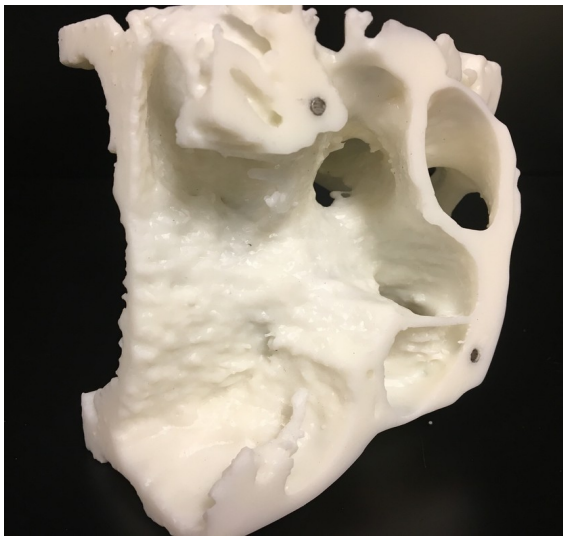
Interventional cardiology, electrophysiology, cardiac surgery

Provided thus far on research basis at no cost or ordering service.

Working with JDMI and Techna to create business plan and **UHN-wide ordering and payment interface** for services.

~ **60 cases** to date





Research

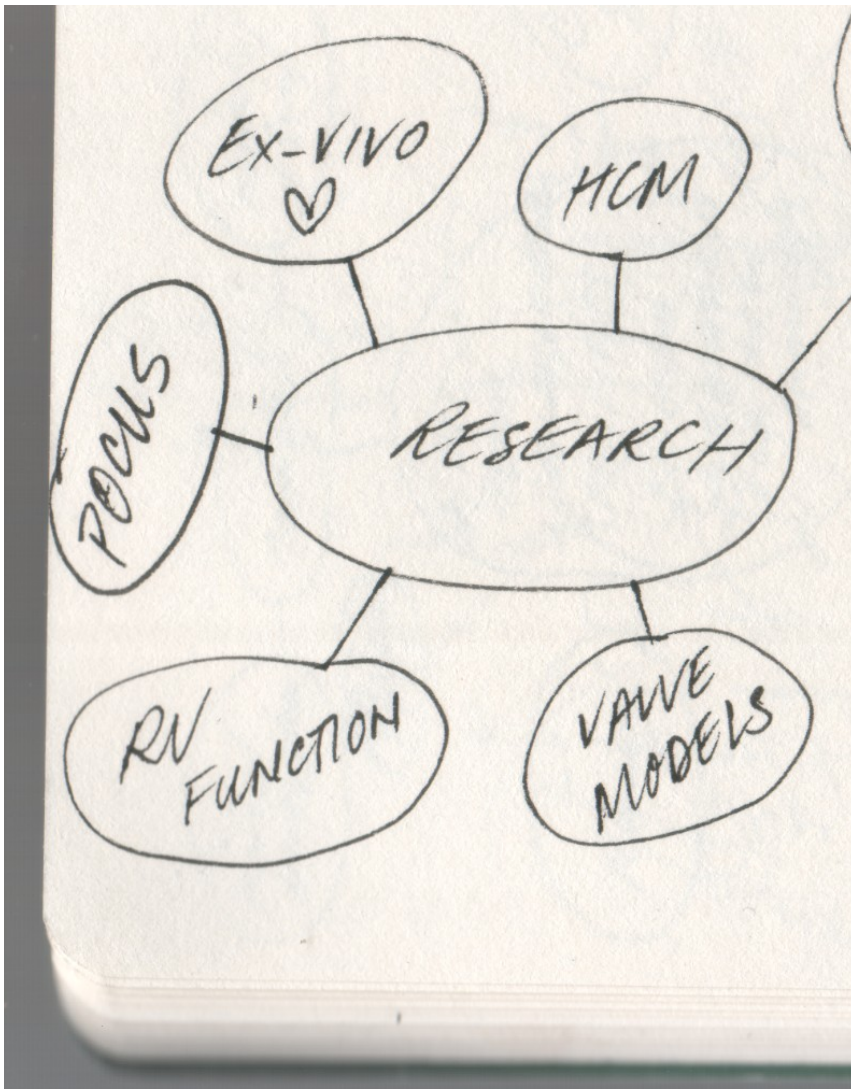
Cardiac **valve** modeling

Ex-vivo donor heart evaluation

Applications of **POCUS**

Perioperative TEE in **HCM**

Predictive value of perioperative **RV function** measures



Valve Modeling: Translating 3D analysis to clinical practice

In collaboration with UHN Divisons of Cardiac Surgery and Cardiology

Aortic valve complex (Centenaro, Haskings, Balloca, Irwin)

- Predictive value of Aortic Valve Asymmetry Index
- Validation of aortic root segmentation of 3D printing process

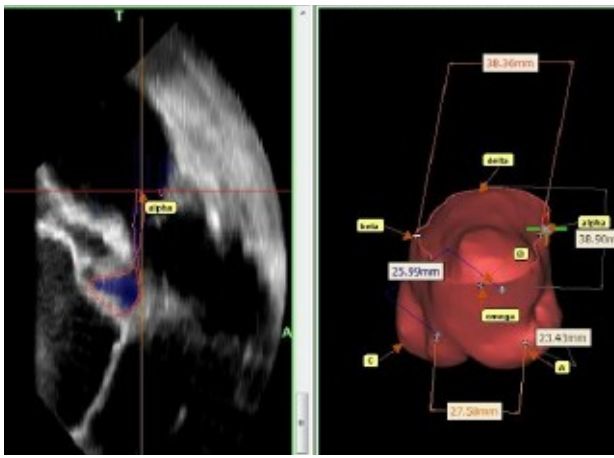
Ballocca et al. (2019) Aortic root changes before and after surgery for chronic aortic dilatation: A 3D echocardiographic study. **Echocardiography.** 2019;36(2):376–85.

Mitral valve (Amador, Gadotti, Ballocca, Mbadjeu Hondjeu)

- Comparion of commercial of MV software packages
- Validation of open source MV analysis software from Children's Hospital of Philadelphia (M. Jolley Lab)

Ballocca et al. (2019) Validation of Quantitative 3-Dimensional Transesophageal Echocardiography Mitral Valve Analysis Using Stereoscopic Display. **J Cardiothorac Vasc Anesth** . ;33(3):732–41.

Amador et al. (2019) 3D Mitral Valve Quantification: A comparison of off-line analysis software and techniques. SCA Annual Conference 2019. **Best of Meeting Oral Abstract Presentation** .



Aortic Valve Complex: Comparison of 3D Models

Erika Haskings, D Centenaro, M Irwin, J Hiasen, M Meineri, A Mashari

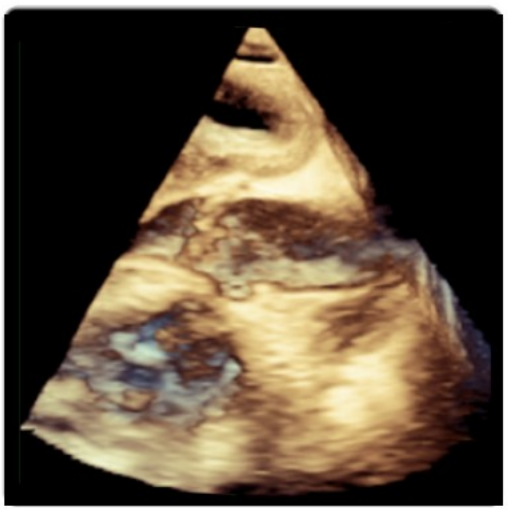
Understanding **aortic root anatomy** is essential for diagnosing **mechanism of aortic regurgitation** & guiding surgical repair.

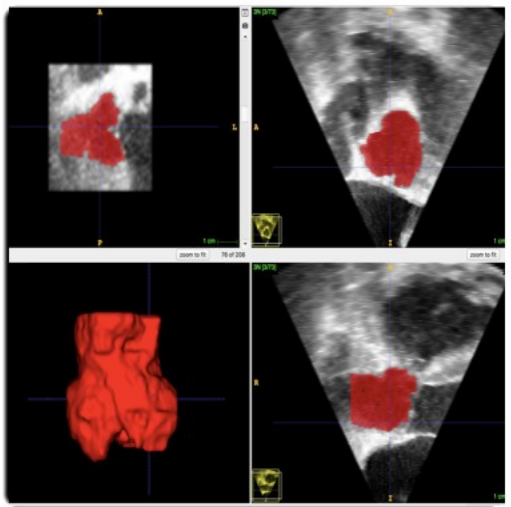
Currently no gold-standard for characterizing anatomic alterations of functional aortic regurgitation.

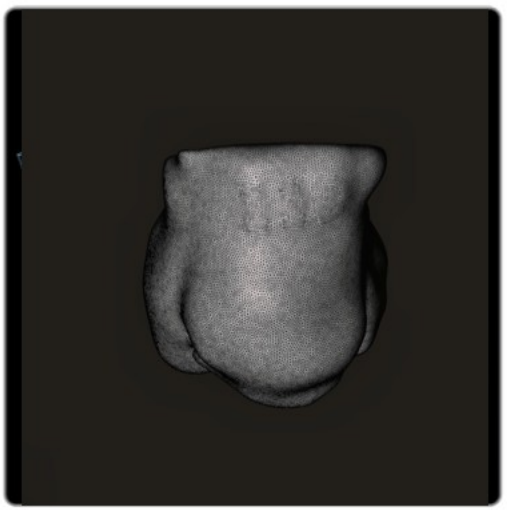
2D-TEE used routinely but **3D-TEE & 3D models may provide better visualization**.

Low-cost, high resolution printers allow creation of accurate patient-specific models from 3D TEE data.

Aortic Valve Complex: Modeling Process







3D Dataset
Proprietary encrypted data in DICOM object

→ *Format conversion* →

Philips "Cartesian DICOM" Format

→ *Segmentation* →

Voxel Model (Label Map)
e.g. NIFTI, NRRD

→ *Mesh generation* →

Triangular Mesh Surface Model
e.g. STL, PLY, OBJ

→ *Slicing* →

Printer code
e.g. gcode

→

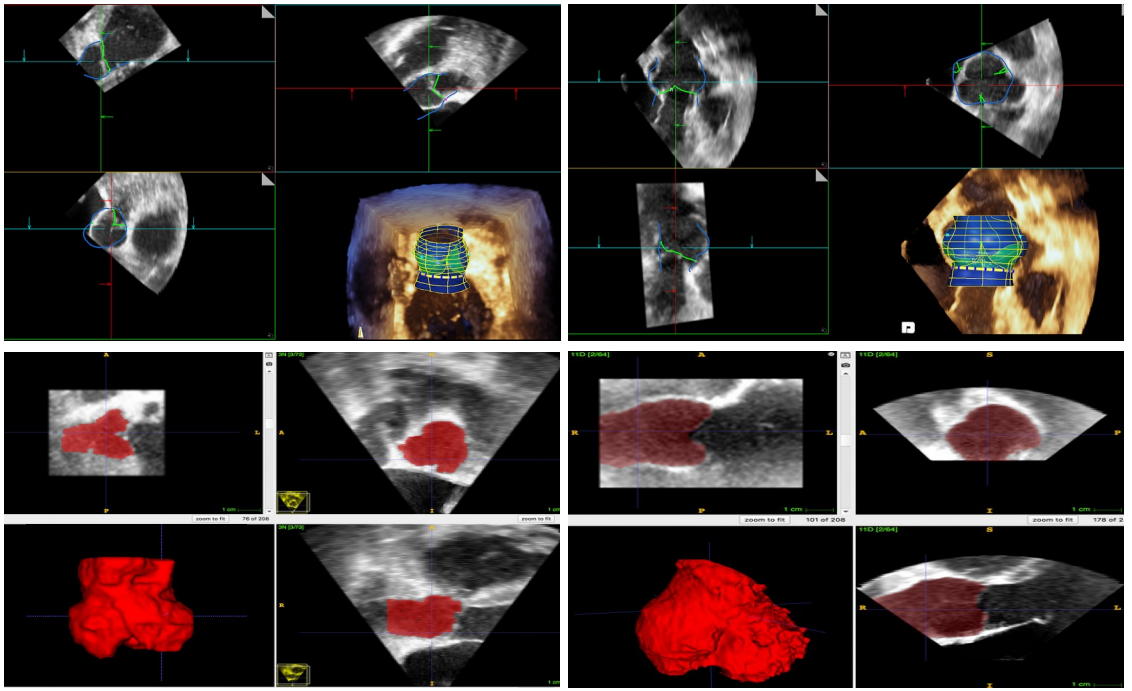
Printed Model

Aortic Valve Complex: Comparison of 3D Models

Study Objectives:

1) Compare semi-automated segmentation tools to automatic segmentation and manual measurements in MPR (clinical standard)
2) Compare open and closed-source software tools

SIEMENS
eSie Valve



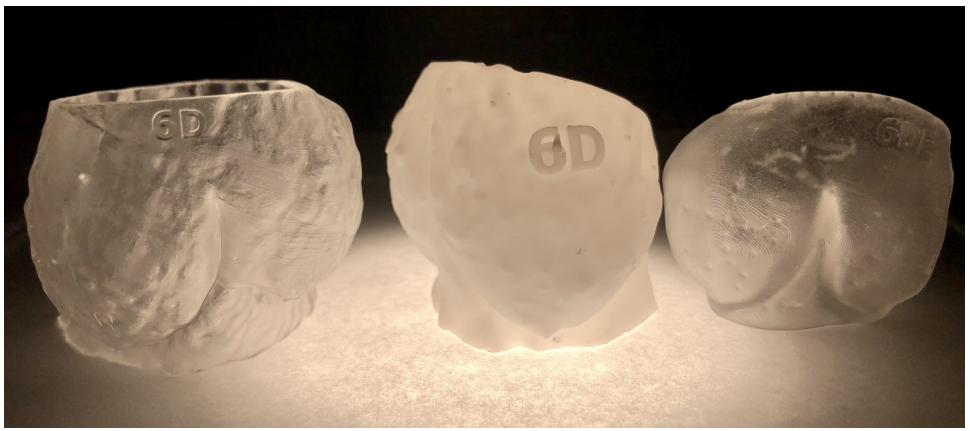
itk-SNAP

Aortic Valve Complex: Comparison of 3D Models

3D-printed models:

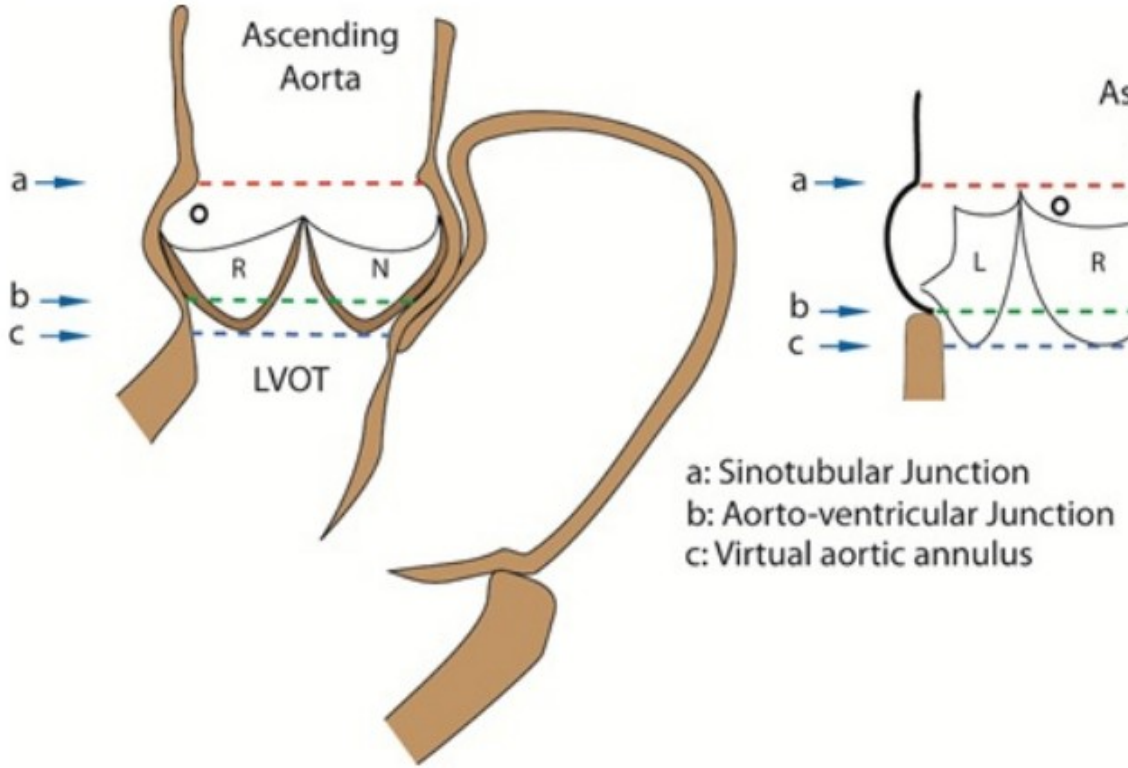
- 60 datasets were modeled with three different software
- Valves models were printed with < $5.00 USD per valve in photopolymer.

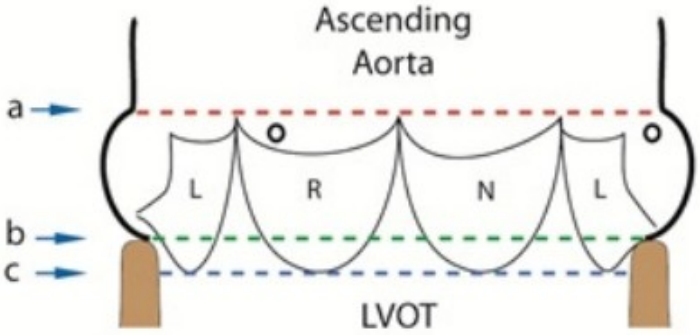
Normal aortic root



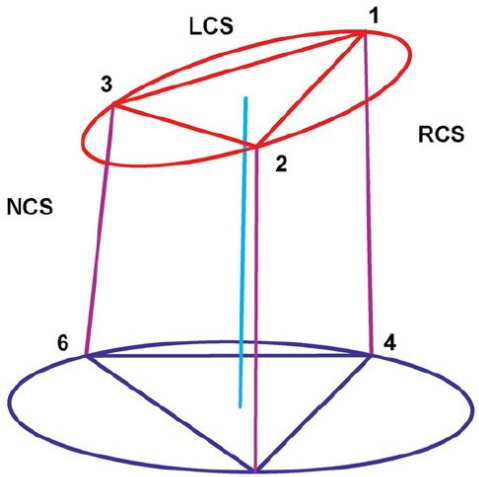
Dilated aortic root

Aortic Root Anatomy & Measurements





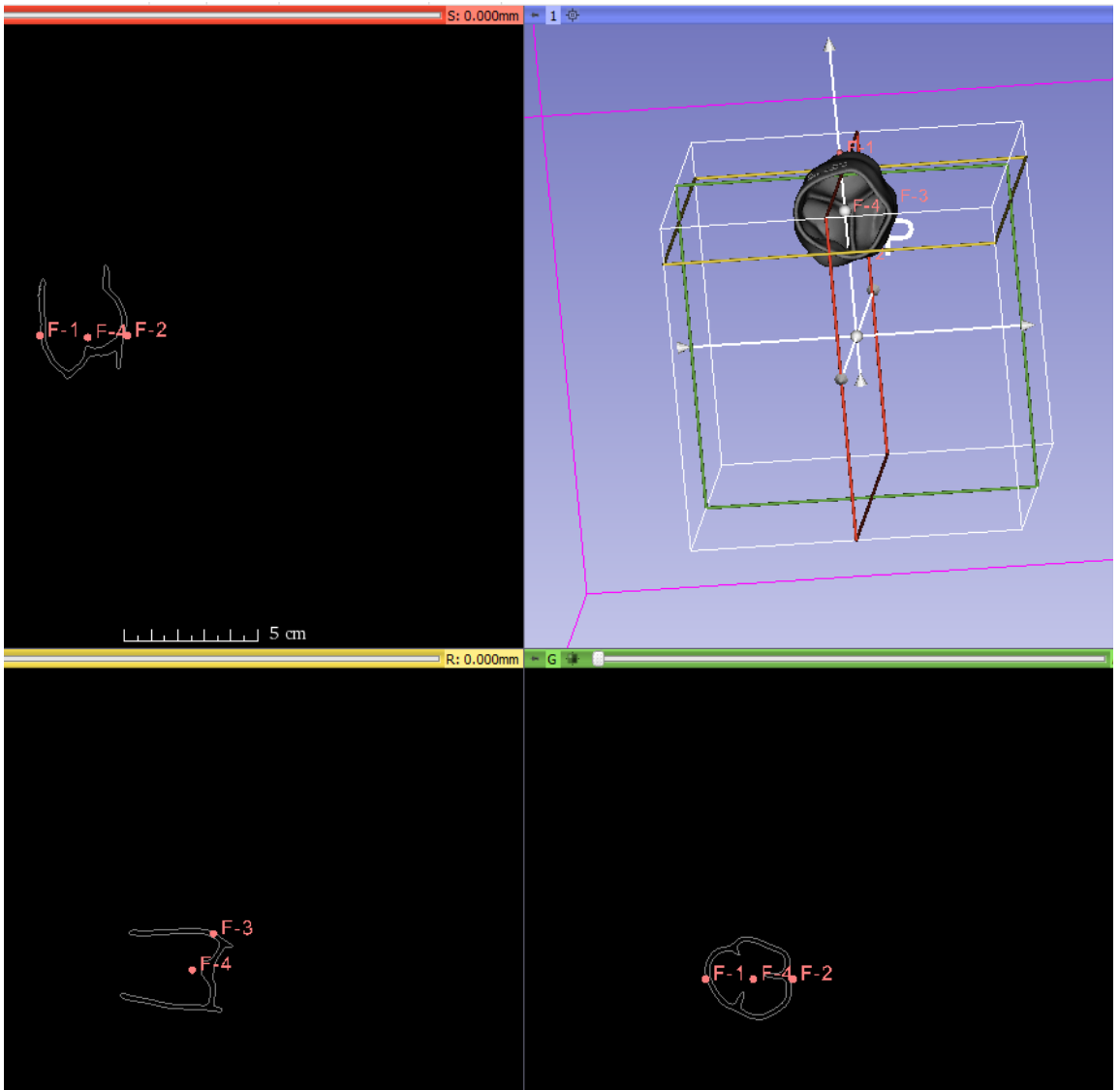
a: Sinotubular Junction
b: Aorto-ventricular Junction
c: Virtual aortic annulus



Reference points:

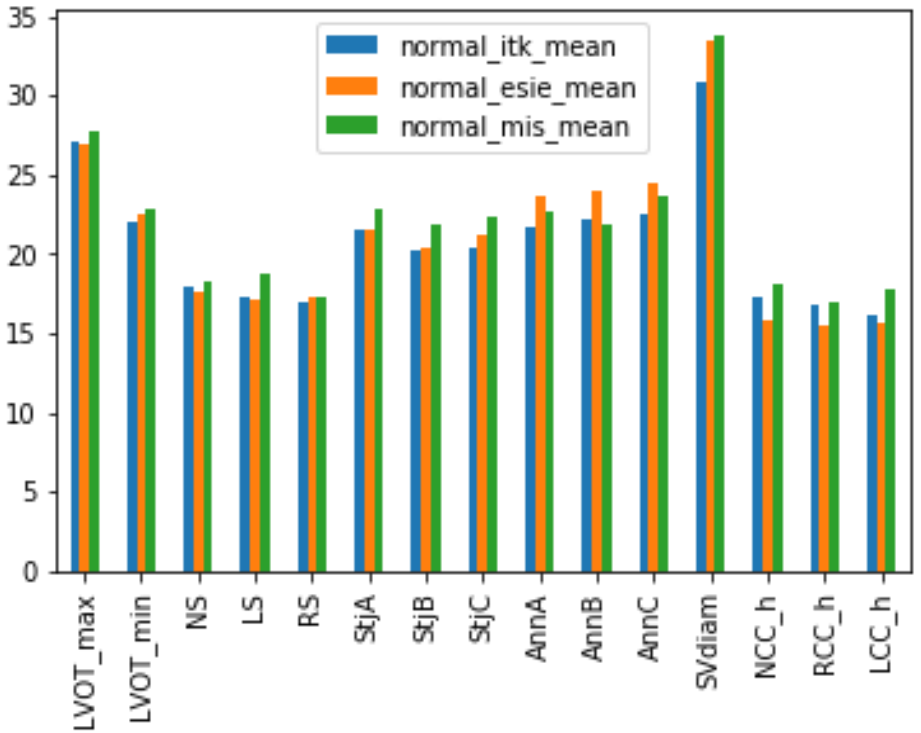
- AV annulus
- SOV diameters & heights,
- STJ and Asc. aorta diameters

Digital & printed model measurement

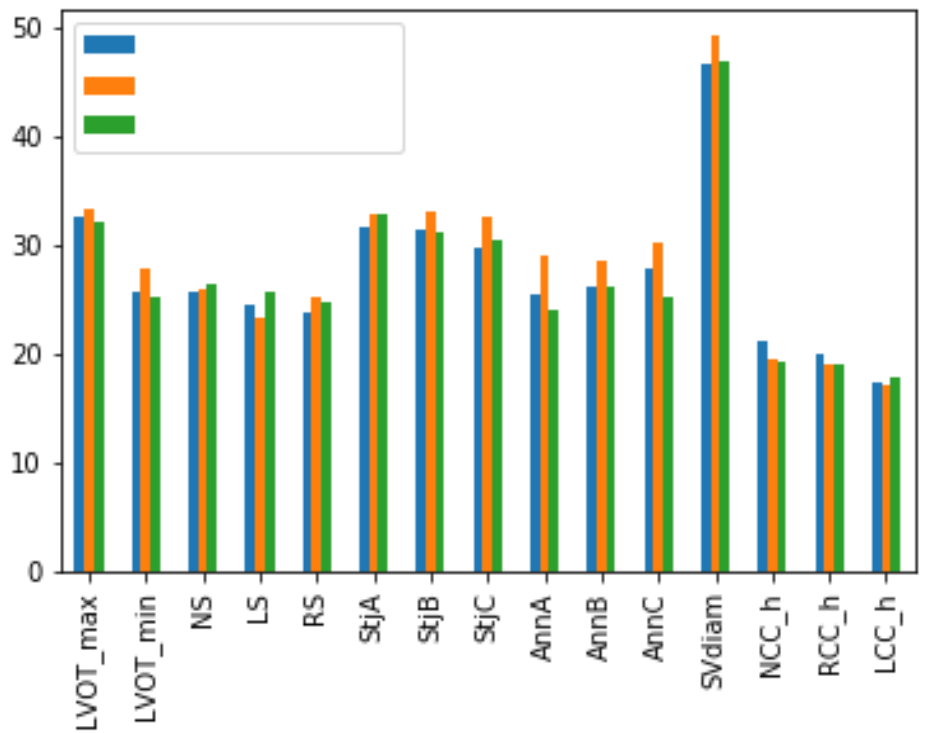


Preliminary Results

Normal aortic root cohort (30)



Dilated aortic root cohort (30)



Aortic Valve Complex: Comparison of 3D Models

Preliminary analysis suggests that aortic valve complex **models** from ITK-SNAP, Siemen's eSie Valve, and Mimics Innovation Suite are **similar**.

Comparison with manual measurements of the 3D datasets using multi-planar reconstruction is in progress.

Ex-vivo Donor Heart Evaluation

Ruggeri, Paradis, Mbadjeu Hondjeu, Beuth, Lembrikov; In collaboration with Badiwala/Rao research group, Division of Cardiac Surgery.

System for prolonged storage, reconditioning & **ex-vivo functional evaluation** of **donor hearts**

APIL's role: developing enclosure system & validating echocardiographic evaluation techniques

Ruggeri et al (2018) Description of a novel set-up for functional echocardiographic assessment of left ventricular performance during ex vivo heart perfusion. **Anesth Analg**. Sep;127(3):e36-39.

Ruggeri et al (2018) Anesthesia and Intensive Care Final Residency Thesis. Universita' Degli studi di Milano, Milan ,Italy. Echocardiographic assessment of loaded beating heart during ex-vivo heart perfusion (EVHP). **Thesis** Supervisors: M Meineri, A Pesenti. Defended on Sept 2018 "Cum Laude".

Ribeiro et al. Hearts Donated After Circulatory Death and Reconditioned Using Normothermic Regional Perfusion Can Be Successfully Transplanted Following an Extended Period of Static Storage. **Circ Heart Fail**. Apr;12(4):e005364.

Ribeiro et al. (2019) A Pre-Clinical Porcine Model of Orthotopic Heart Transplantation. **J Vis Exp**. Apr 27;(146).

Beuth et al. (2019) New Strategies to Expand and Optimize Heart Donor Pool: Ex Vivo Heart Perfusion and Donation After Circulatory Death: A Review of Current Research and Future Trends. **Anesth Analg**. Mar;128(3):406–13.

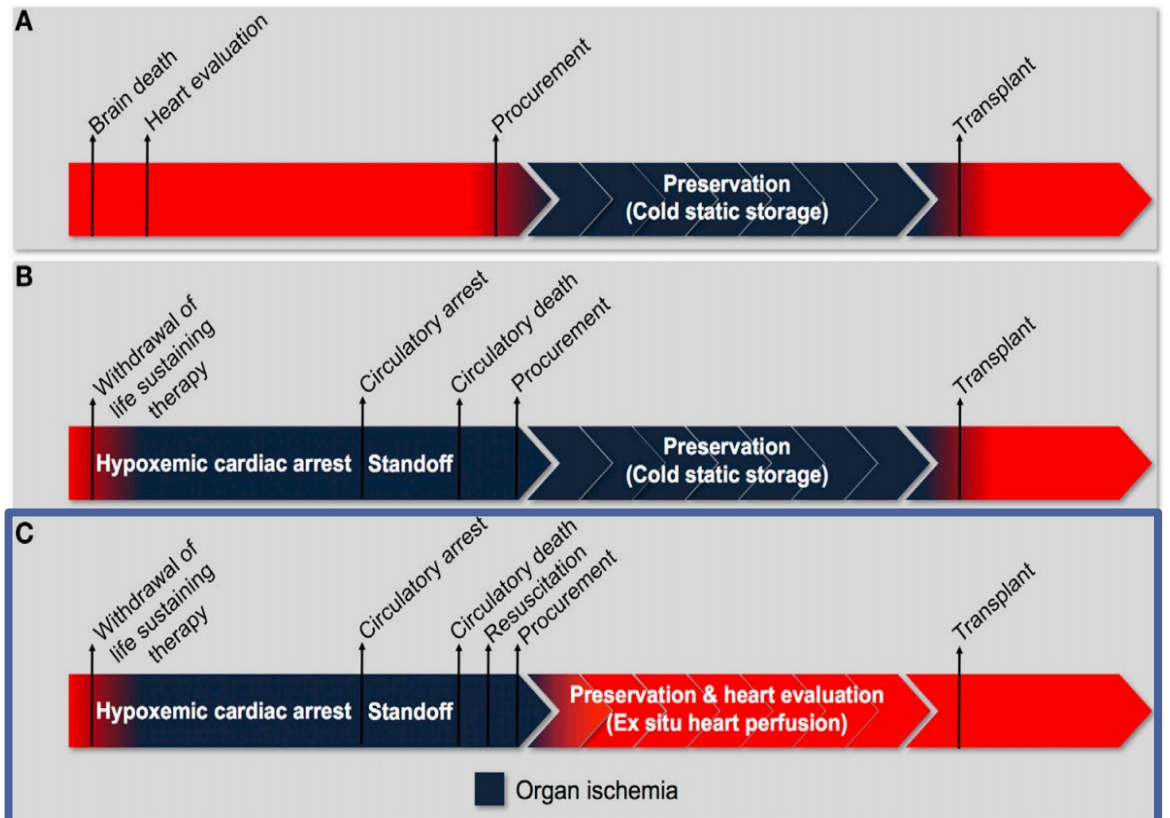
Mbadjeu Hondjeu et al. (2019) Echocardiographic Evaluation in a Porcine Model of Donation after Circulatory Death and Normothermic Regional Perfusion Prior to Heart Transplant. **SCA Annual Conference 2019. Best of Meeting Oral Abstract Presentation**.

Process of Heart Transplantation

A. Donation after Brain Death (DBD)

B. Donation after Circulatory Death (DCD): Traditional Approach

C. DCD: With NRP/EVHP



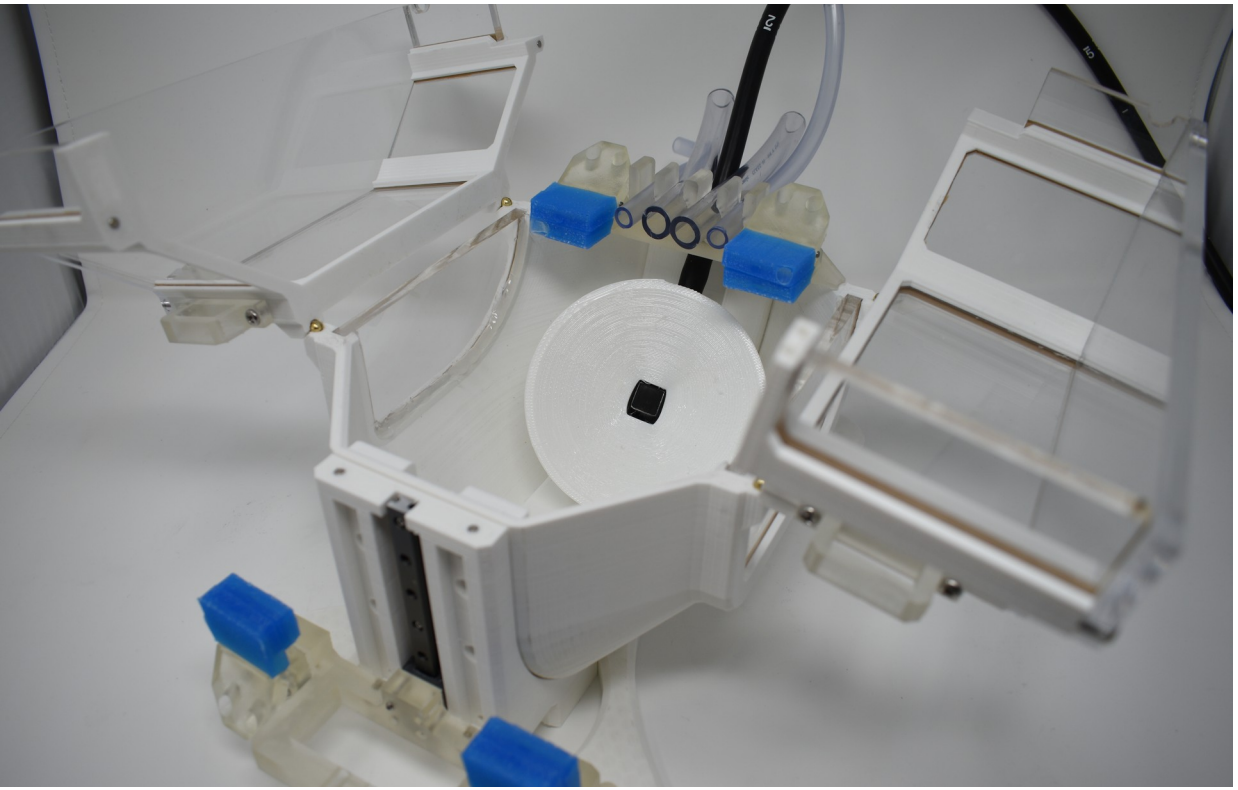
NRP

Normothermic Regional Perfusion

EVHP

Ex Vivo Heart Perfusion

CW White et al., Transplantation of Hearts Donated after Circulatory Death, Front Cardiovasc Med, 13 February 2018



Ex-Vivo Heart Evauluation: Objectives

Identify **echocardiographic parameters**

of left & right ventricular function after NRP

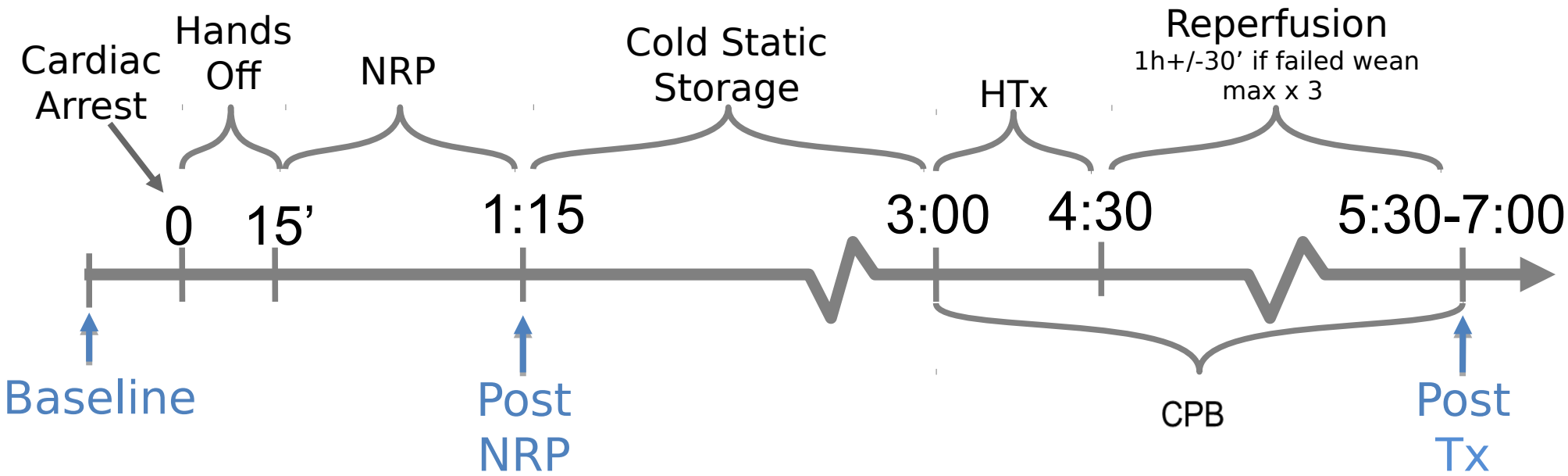
that are most predictive of

early post-transplantation cardiac function

(Porcine Model)

Ex-vivo cardiac function evaluation in DCD HTx with NRP

N = 12 Adult Yorkshire Pigs



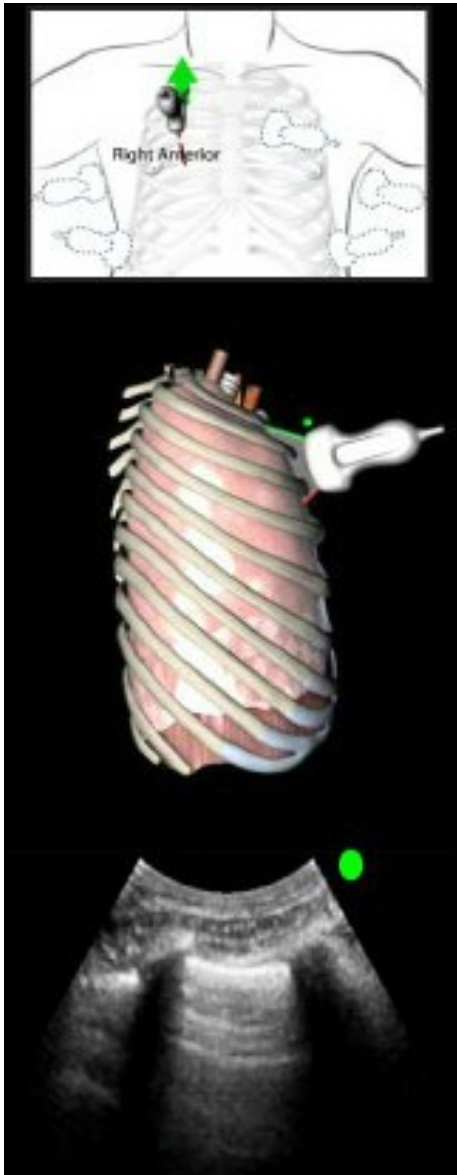
POCUS: ICU RN Lung US to detect pneumothorax

J Moreno, K Karkouti, C Fielding, M Meineri, A Goffi, V Rao Rao, M Pakkal, K Ladha, E Neethling, M Zhu, J Hudson

- Pneumothorax post chest drain removal: 2%.
- Diagnostic standard method: **CXR**.
- Reliability CXR: up to **30% misdiagnosis** PTx.
- Consequences: delay in patients transfers, cost.

Would **lung US performed by ICU RN be as accurate as CXR** for the detection of pneumothorax following mediastinal chest tube removal in a cardiac surgery patient population?

Prospective, single-center, observational, cross-sectional cohort study



Perioperative Echo in Hypertrophic Cardiomyopathy

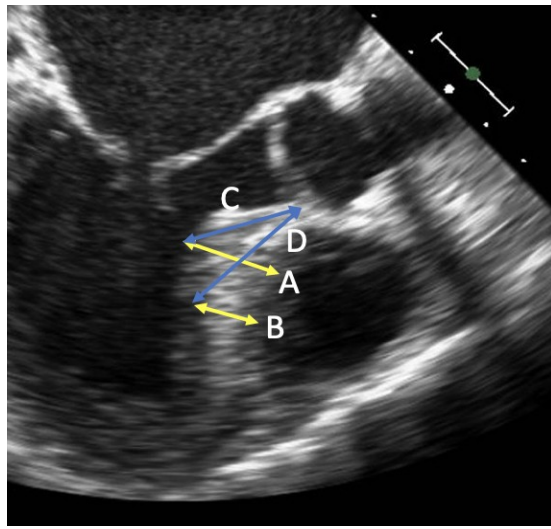
Intraoperative **3D TEE minimum LVOT area** post surgical myectomy predicts post-op LVOT gradient (in review)

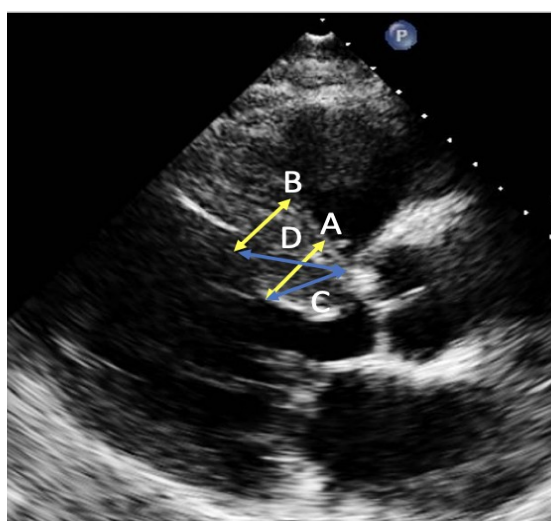
Quantitative assessment of **aorto-mitral angle** with 3D TEE in surgically treated HOCM patients (MS preparation)

Comparison of **preoperative TTE vs TEE** for the assessment of HOCM (analysis)

Intra-operative dobutamine stress test for evaluation of HOCM (design)

Use of **3D modeling for planning septal myectomy** (design)





Other

Prognostic value of perioperative RV function quantification (classical measures plus 2D RV strain)

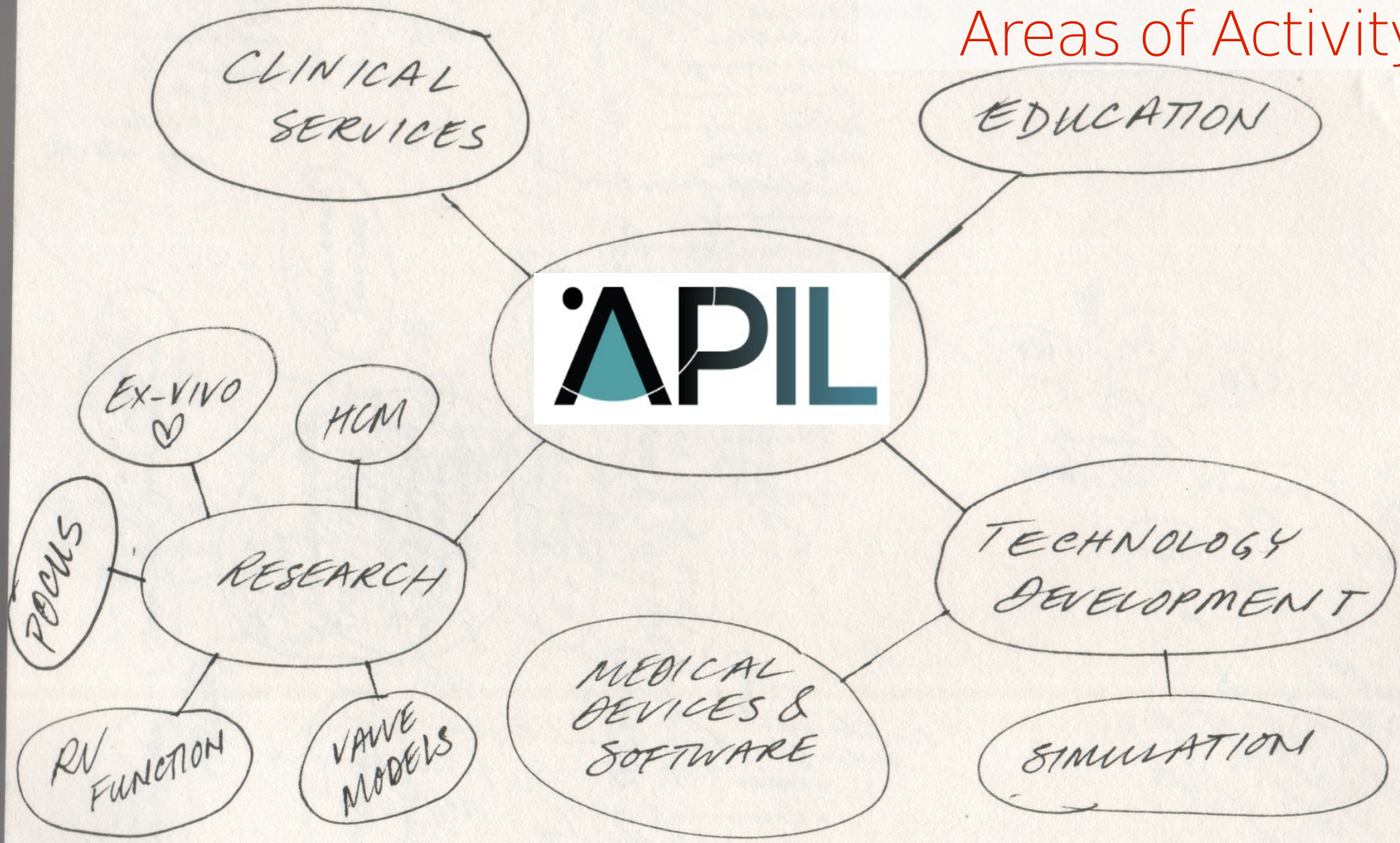
- Pulmonary Thromboembolectomy (Gadotti, Neethling, Berardino, Al-Mohammad, De Perrot)
- Tetralogy of Fallot (Buys, Neethling, Saran, Oechslin)
- Ebstein's anomaly tricuspid valve interventions (Lenihan, Al-Mohammad, Heggie, Hickey, Oechslin)

Acute and chronic effects of **hyperbaric oxygen therapy** on biventricular function (Schiavo, Katznelson)

Prognostic value of perioperative echocardiography in **liver transplant** (Gadotti, McCluskey)

Prognostic value of perioperative echocardiography in **kidney transplant** (Gadotti, McCluskey)

Areas of Activity



Open-source Medical Technology Development

Clinical **Devices & Software**

- Stethoscope (Health Canada Approved)
- Co-oximeter (Clinical validation trials)
- Human-powered laryngoscope (Development)
- ECG (Clinical validation)
- 3D valve analysis software

glia equal care

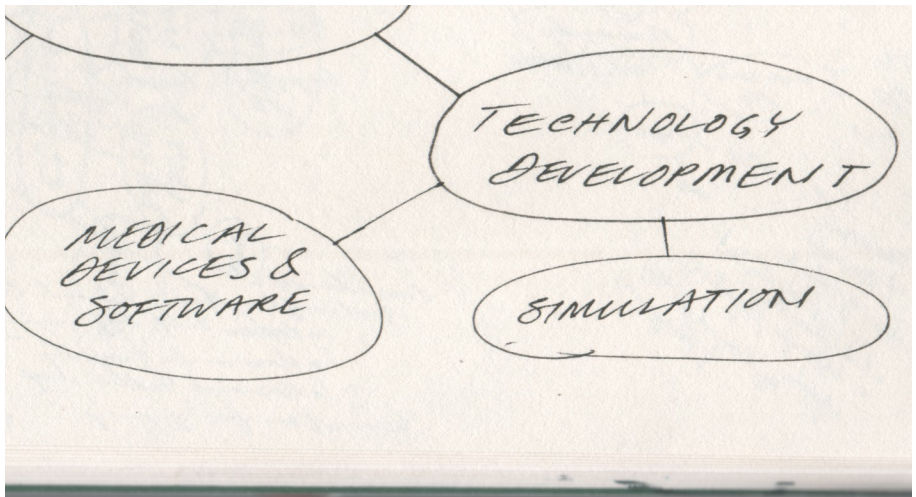
Children's Hospital of Philadelphia℠

3DSlicer

AUTODESK.

Educational **Models & Simulators**

- Demonstration models
- Procedural phantoms
- On-line, augmented reality and virtual reality simulators



Technology development model: open source

An open model that makes all technical detail, manufacturing and quality control processes **openly available for reuse and modification**

De-centralized manufacturing and quality control

Sustainable financing model

Why?

- Not feasible to patent many innovations, especially new combinations of old devices or educational tools
- Larger pool of contributors & ability to use solutions in the commons
- **Faster; lower development & production costs**
- Improved access
- More **adaptable** to changing needs of users
- Encourages **nail-first approach**

Free/Libre Open Source Software & Hardware

Medical Image Computation Software

- **3D Slicer** slicer.org (Everything)
- **ITK-snap** itksnap.org (Segmentation only)

3D printing

- Lulzbot, Prusa, Ultimaker

open software

open hardware

THE WALL STREET JOURNAL.

English Edition ▾ | October 3, 2019 | Print Edition | Video

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TEXT

31

CARS | RUMBLE SEAT

The Next Tesla? Rimac's All-Electric Hypercar Is Built to Race the Big Boys

Mate Rimac has crafted ingenious battery tech for the likes of Aston Martin and Koenigsegg. Now the 31-year-old Croatian engineer has built his own beast in the Rimac C_Two, an all-electric hypercar that puts out 1,914 hp. Dan Neil sits down with 'the next Elon Musk'

"Last month, a Rimac-boosted Regera set a world record for 0 to 249 mph and back to 0 in 31.49 seconds"

"Conservative is one thing Rimac isn't. For example, none of the company's technology is currently patented. 'We believe that if somebody is that good that they can copy us, go ahead, man, you deserve it. We are so fast that we are already two generations in front before [we] can protect it."

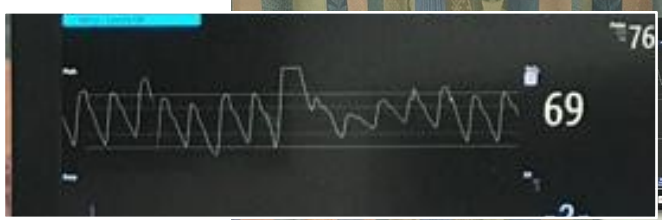
Technology Development: Devices & Software

PLOS ONE

RESEARCH ARTICLE

Validation of an effective, low cost, Free/open access 3D-printed stethoscope

Alexander Pavlosky[1], Jennifer Glauche[2], Spencer Chambers[1], Mahmoud Al-Alawi[3], Kliment Yanev[2], Tarek Loubani[1,3,4,5,6]*



THORNHILL MEDICAL
INSPIRING INNOVATION

Technology Development: Devices & Software

Journal of Medical Systems (2019) 43: 143
https://doi.org/10.1007/s10916-019-1275-8

PATIENT FACING SYSTEMS

Check for updates

Design and evaluation of a novel and sustainable human-powered low-cost 3D printed thermal laryngoscope

Michael Dinsmore [1,2,3] · Sachin Doshi [4] · Vivian Sin [5] · Clyde Matava [1,2]

Technology Development: Educational Simulation

Toronto Heart Atlas (Aziza, Ramos, ACHD Cardiology and CV Surgery)

Echocardiography simulators and phantoms (on-line, virtual reality, gel phantom)

Neuraxial anesthesia phantom – anesthesia resident training (E. You-ten)

Cricothyroidotomy phantom – CAS 2019 (E. You-ten)

Hand-needle coordination trainer – Toronto Regional Anesthesia Workshop 2019 (A. Bhatia)

Thoracentesis (R. Brydges, Internal Medicine)

Bronchoscopy (M. Parotto)

Vascular access

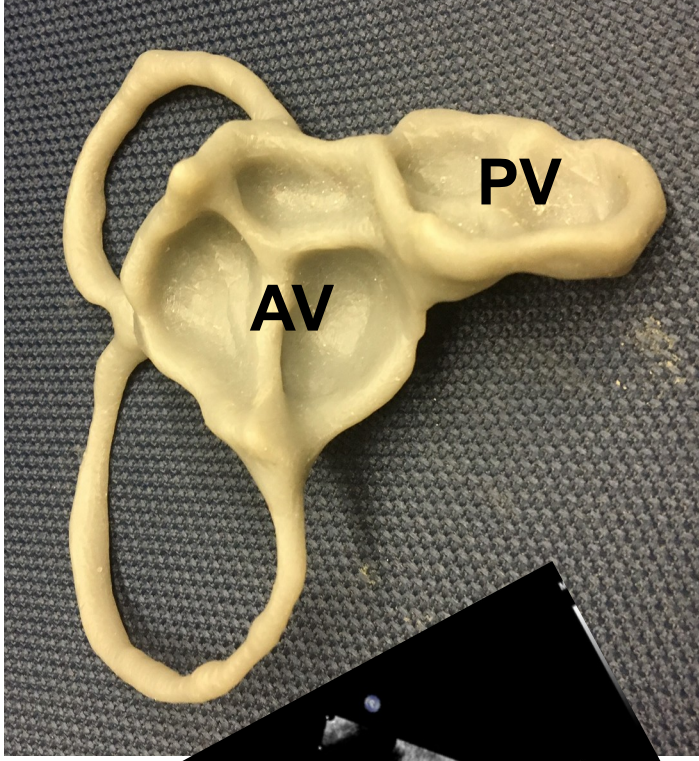
- Brachial (Terulli, Interventional Radiology)
- Subclavian access (S. Peacock)

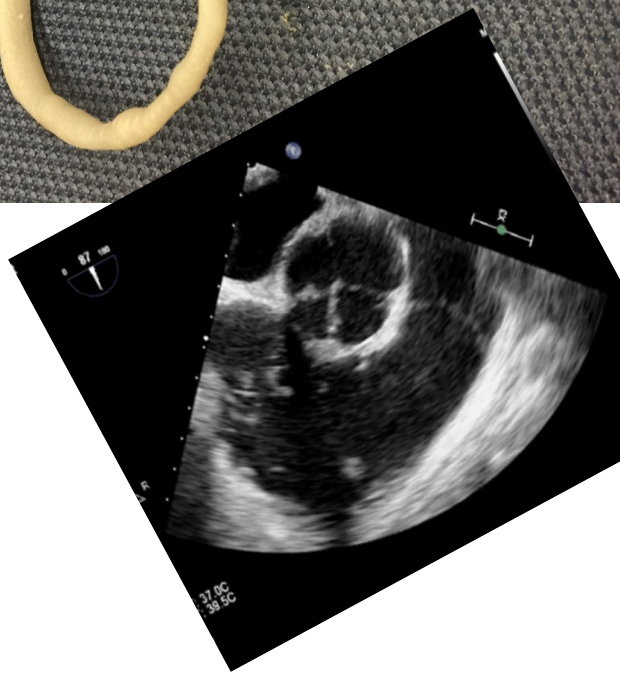
PLOS ONE

RESEARCH ARTICLE

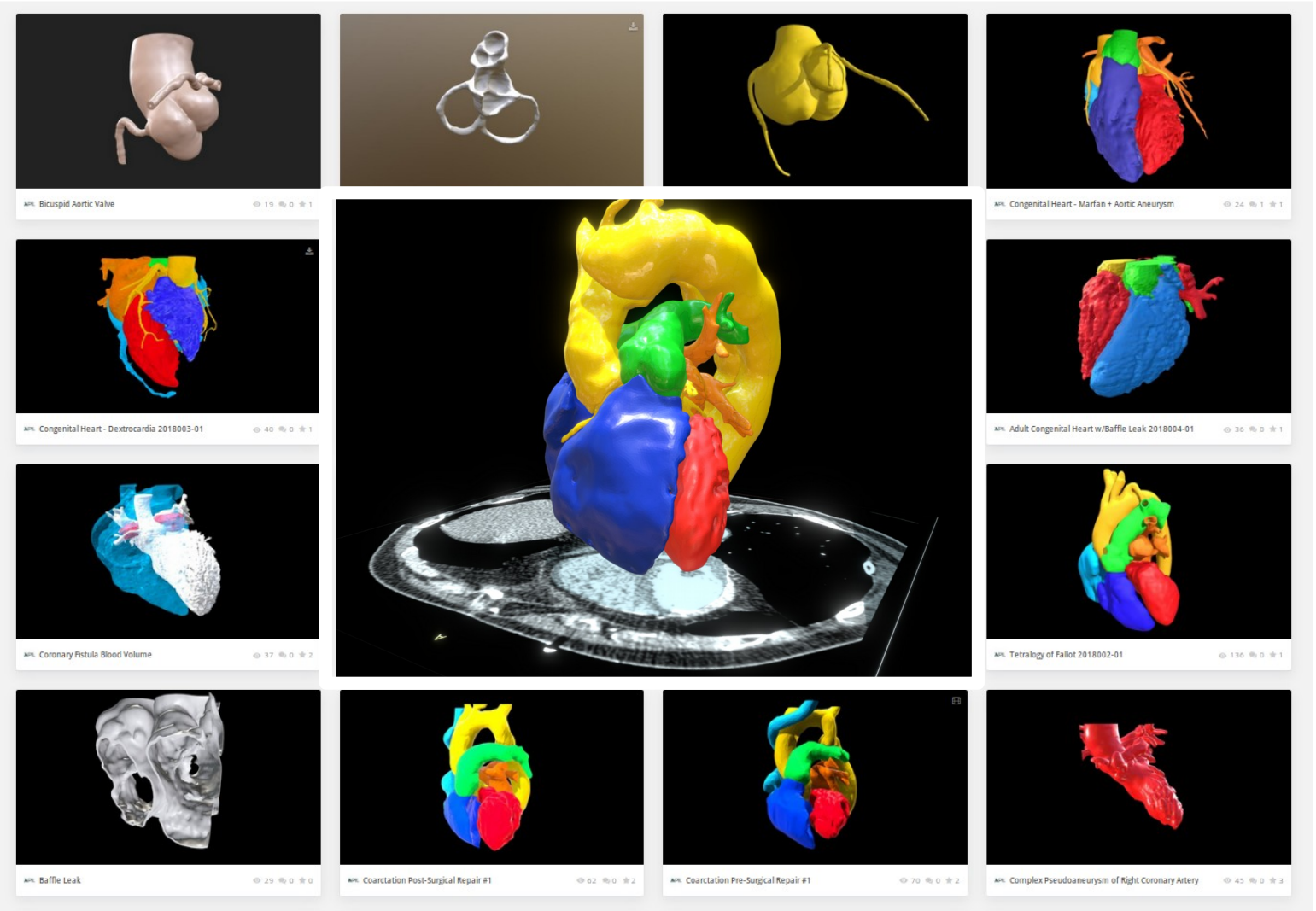
Low-cost three-dimensional printed phantom for neuraxial anesthesia training: Development and comparison to a commercial model

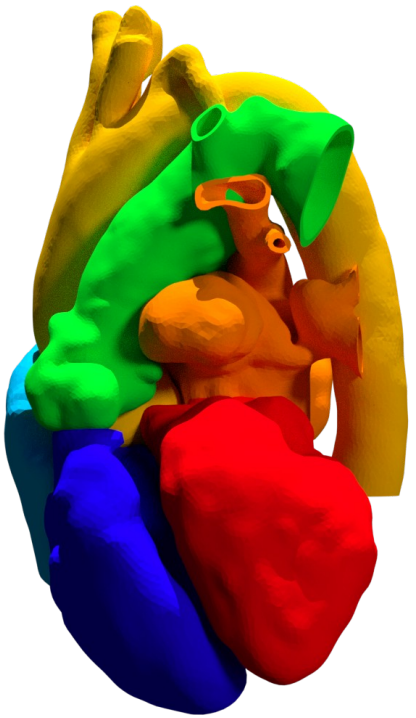
Azad Mashari[1,2,3☯*], Mario Montealegre-Gallegos[3☯], Jelliffe Jeganathan[3☯], Lu Yeh[3,4☯], Joshua Qua Hiansen[1☯], Massimiliano Meineri[1,2☯], Feroze Mahmood[3☯], Robina Matyal[3☯]


PV
AV

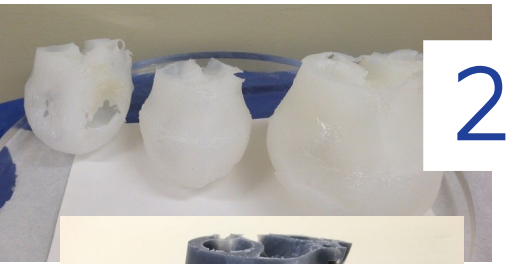


Toronto Heart Atlas apil.ca/toronto-3d-heart-atlas





Echocardiography Phantom



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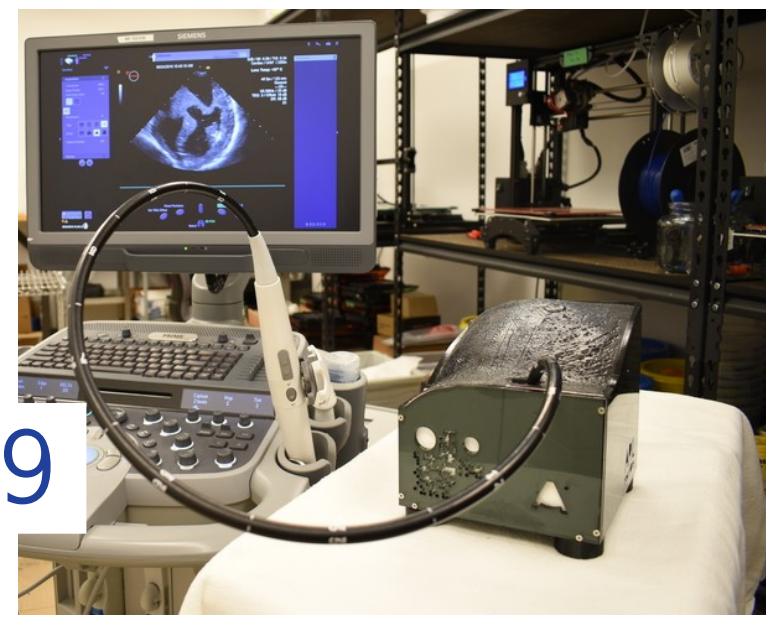


2019

Augmented & Virtual reality Simulation

Echo Education

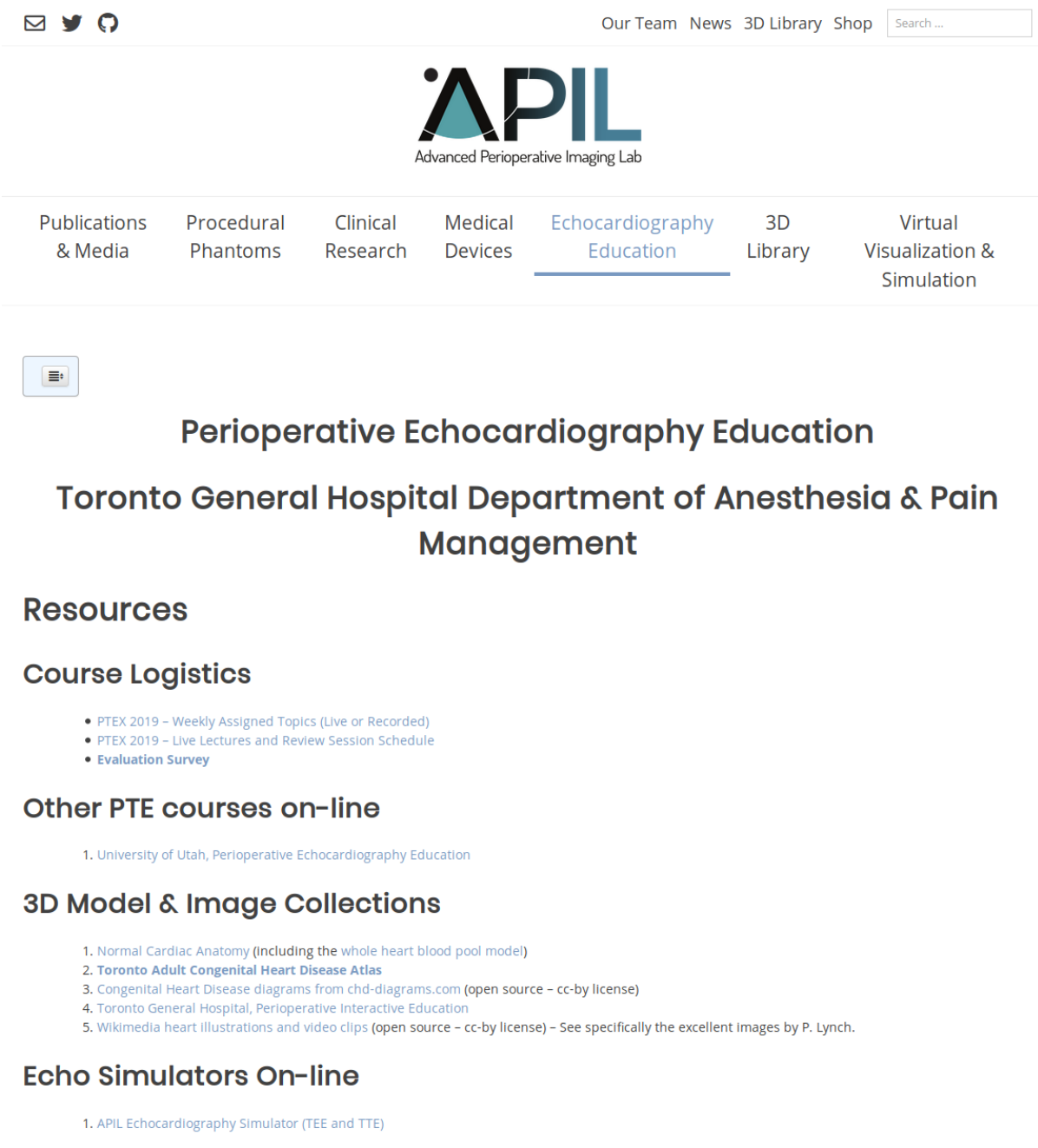
PEG Group, Annette Vegas, Ahmad Omran

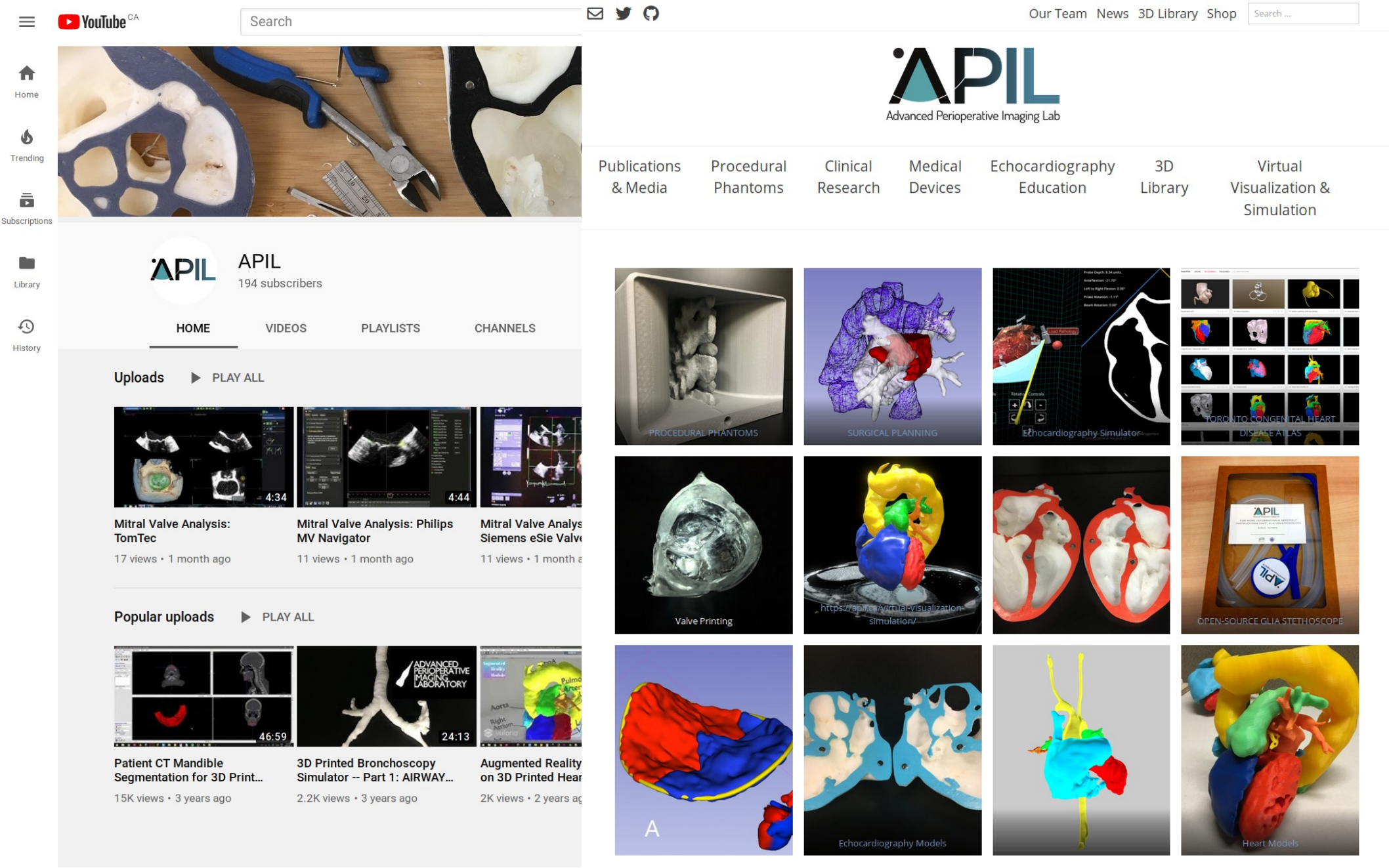
APIL.ca

- PTE Education
- TEE Conference Archive
- ACHD Atlas & echo simulator
- Models & Phantoms
- Web store

TEE Symposium 2019

- Full-day 3D TEE Course
- ACHD Workshop

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3D Printed Bronchoscopy Simulator -- Part 1: AIRWAY...
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Augmented Reality on 3D Printed Hear
2K views • 2 years ag
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Advanced Perioperative Imaging Lab
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Procedural Phantoms
Clinical Research
Medical Devices
Echocardiography Education
3D Library
Virtual Visualization & Simulation
PROCEDURAL PHANTOMS
SURGICAL PLANNING
Echocardiography Simulator
TORONTO CONGENITAL HEART DISEASE ATLAS
Valve Printing
https://apil.ca/virtual-visualization-simulation/
OPEN-SOURCE GLIA STETHOSCOPE
A
Echocardiography Models
Heart Models

Future

Clarify & increase the **coherence of research programs;** more structured approach to research grants with support of departmental research infrastructure

Increasing **collaboration** with **CBD** residency program and TGH/SMH **simulation centres**, Michener; apply tools to active teaching programs and evaluate effectiveness

Growing **clinical services & technology development** work as **financially self-sufficient program**

Make work **more accessible** on-line

Formalizing research **fellowship & studentships**

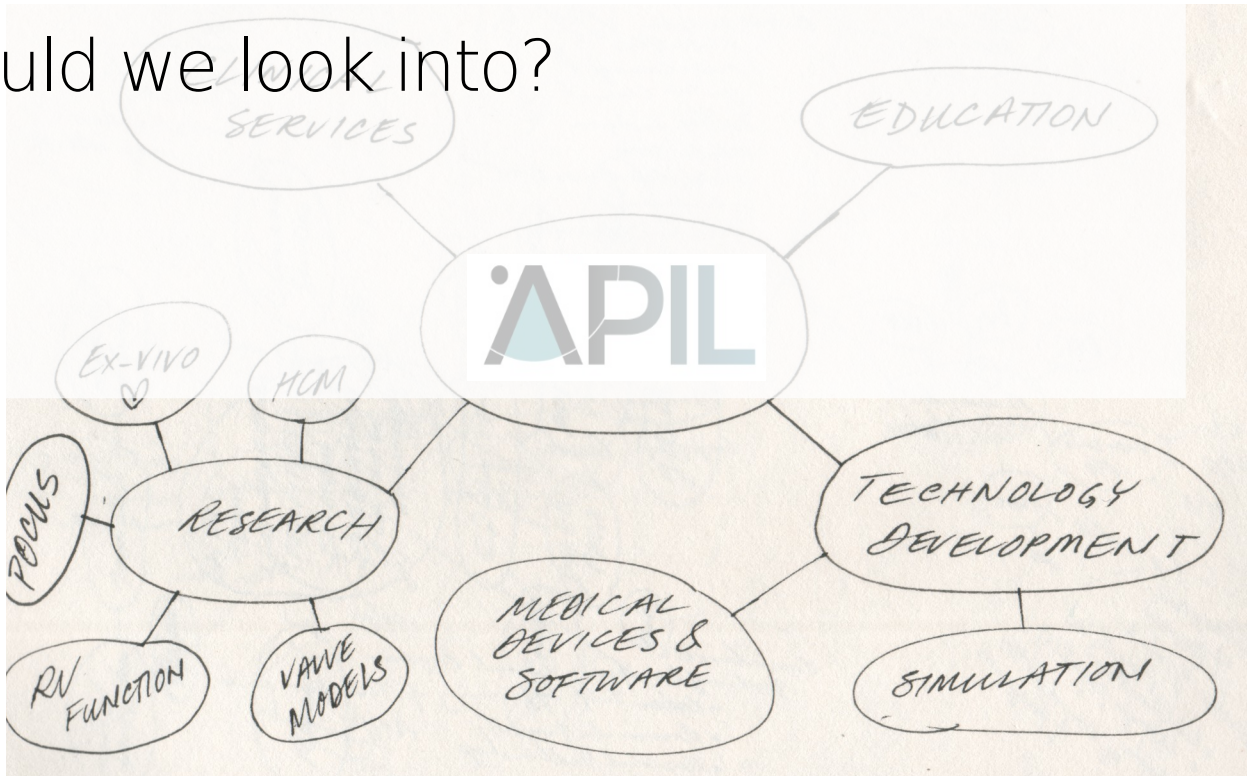
Improving **logistics infrastructure** for communication and project management

Get a **window** & improve lab ventilation

Thank you!

How can we support your clinical, education or research work?

What areas should we move away from?

What new areas should we look into?

Other suggestions?