

State of the Art Single Ventricle Evaluation Using MRI - No Need for Invasive Diagnostics

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McCormick

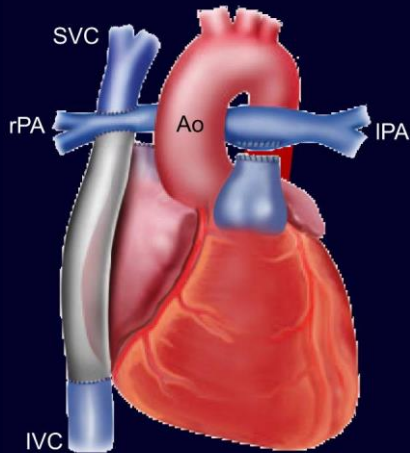
Northwestern Engineering

October 2016

Disclosures

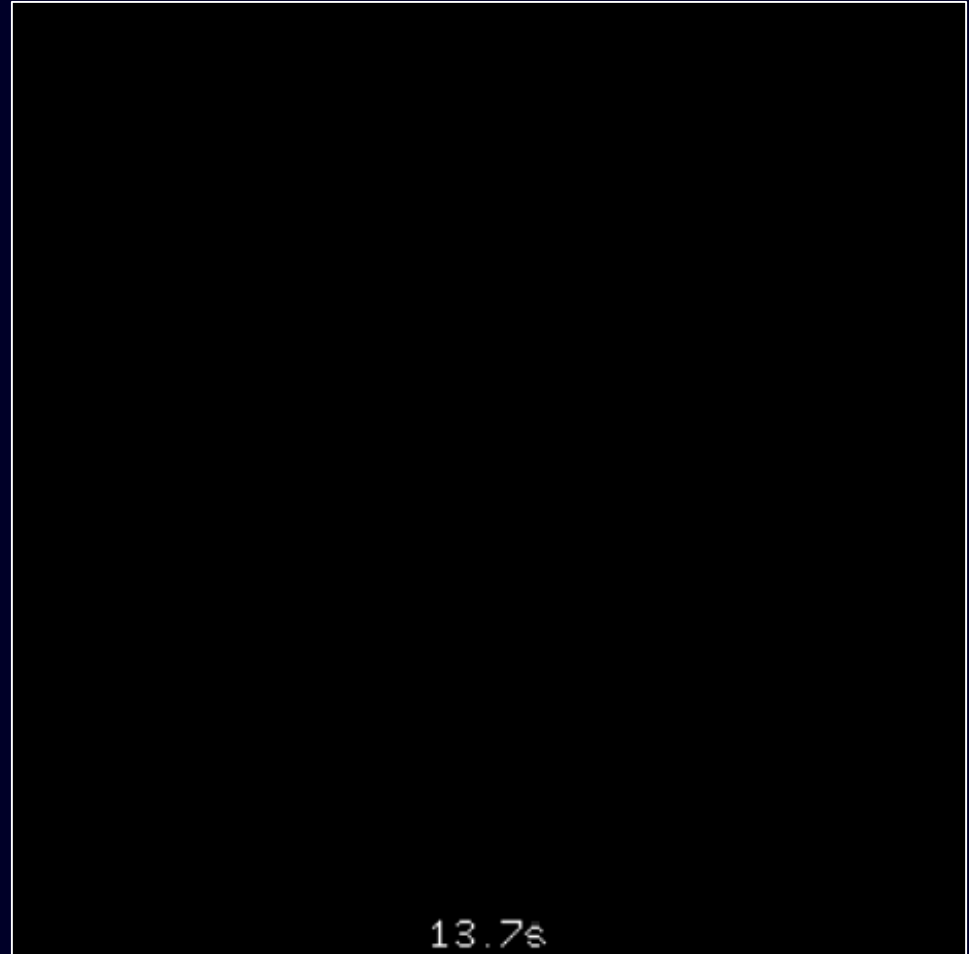
- Research Support for Northwestern Cardiovascular Imaging Program: *Siemens*
- Consultant: *Circle Cardiovascular Imaging Inc.*

Single Ventricle Physiology Fontan Circulation



22 year old patient
post Fontan repair

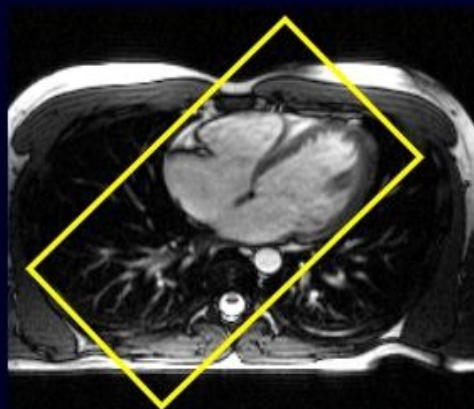
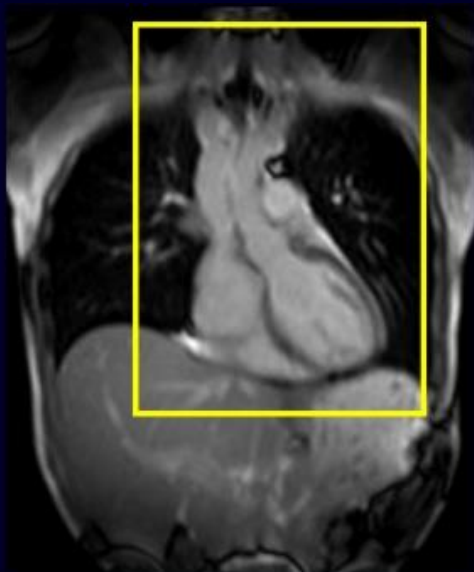
- tr-CE- MRA: flow distribution to left and right lung



Carotid Hemodynamics

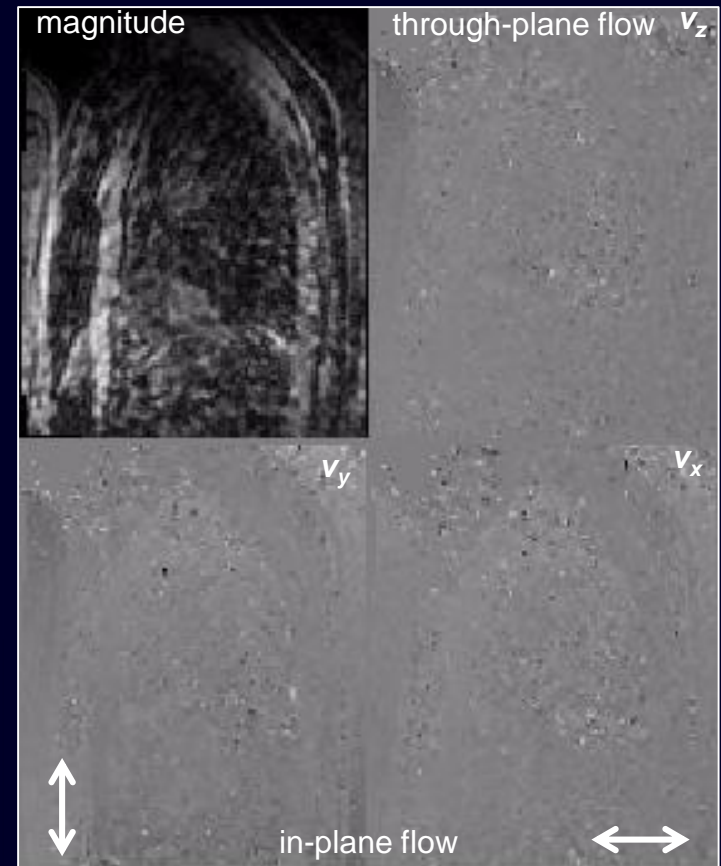
4D Flow MRI

Full Volumetric Coverage



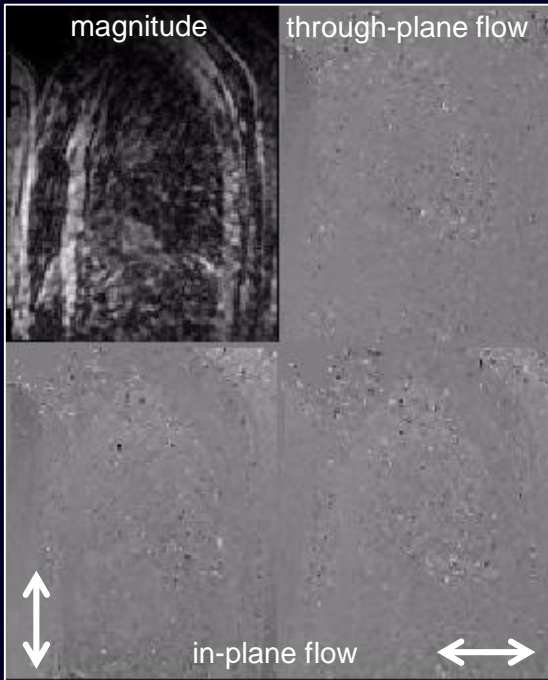
efficient flow
encoding
partial echo
parallel
imaging

4D Flow MRI Data



- ECG gating
- $T_{Res} \sim 40-60ms$
- Res. $\sim (1\text{ mm})^3$
- $T_{Acq} \sim 10-15min$

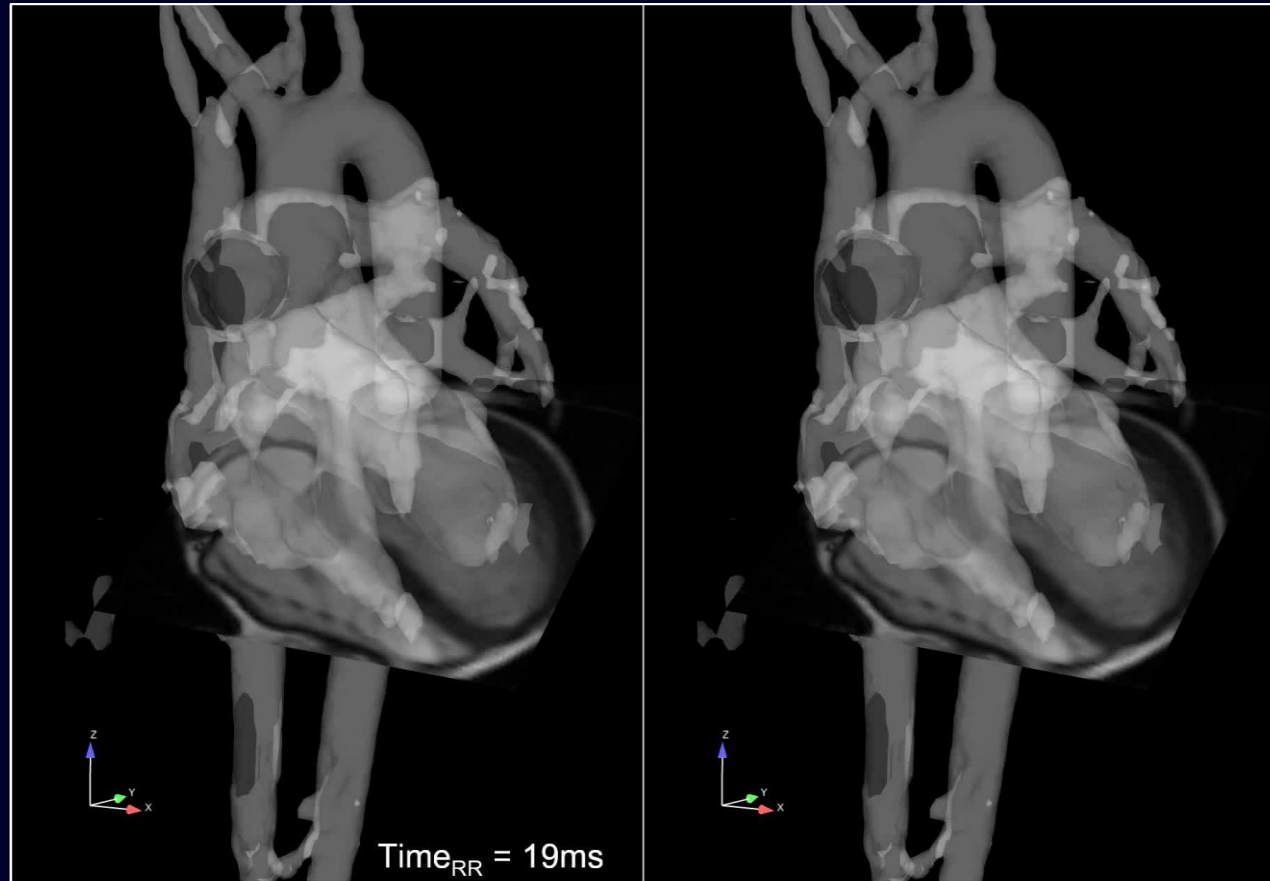
4D Flow MRI Data



- Res. $\sim 2\text{-}3\text{mm}^3$
- $T_{Res} \sim 40\text{ms}$
- $T_{Acq} \sim 5\text{-}15\text{min}$

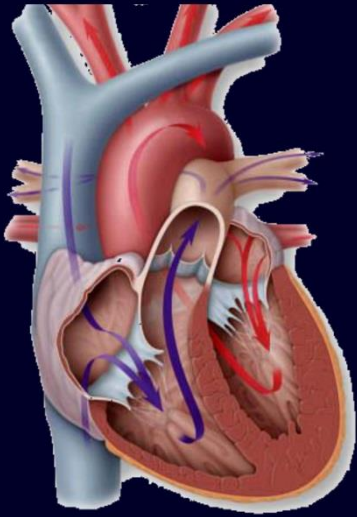
> 2000 & up to
10000 images

3D Blood Flow Visualization



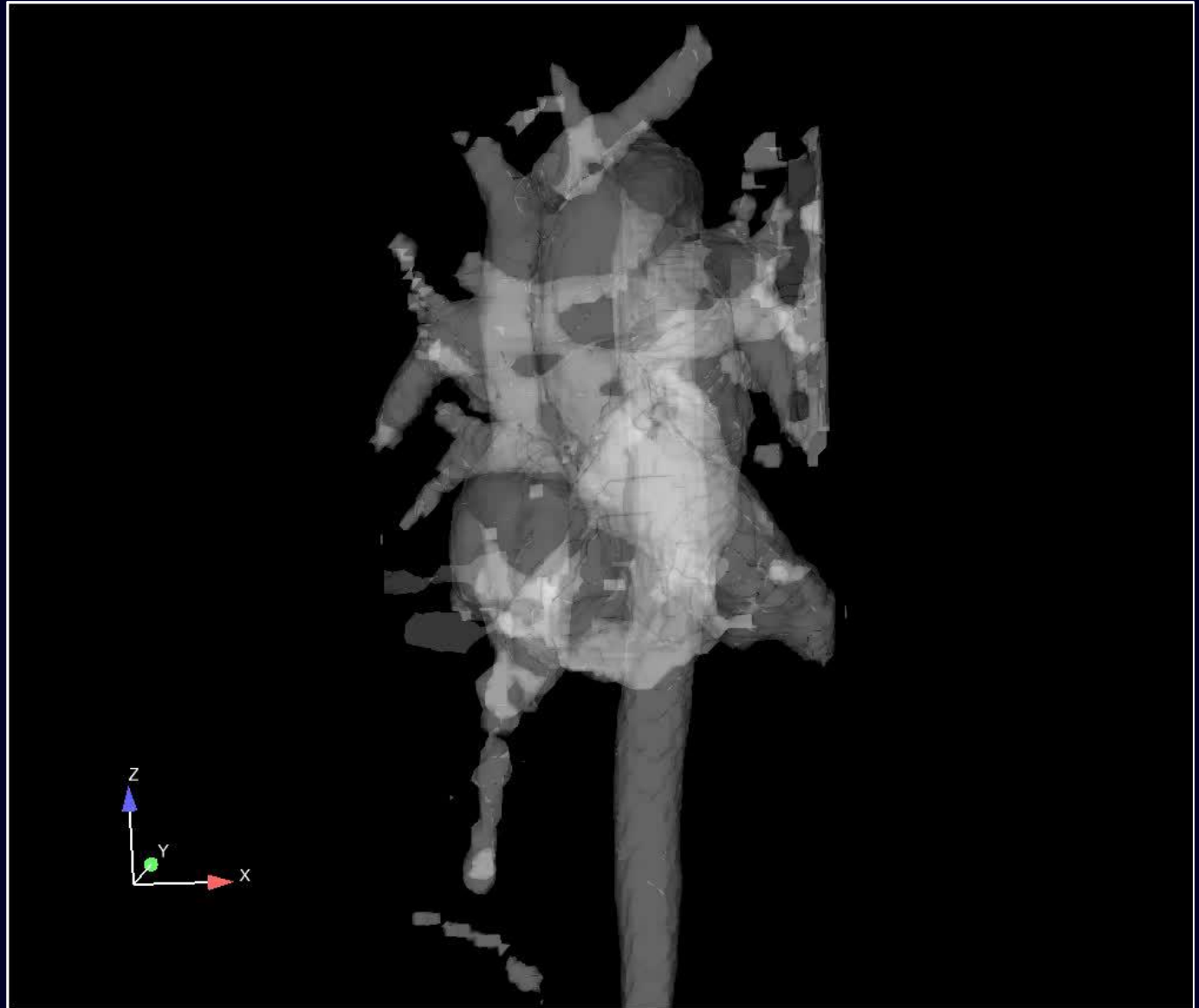
→ **4D** (3D volume + time)
flow (3-dir. velocity encoding) **MRI**

normal heart



Blood Flow Origin

- Left ventricle (LV) & aorta (Ao)
- Left pulmonary vein (IPV)
- Right pulmonary vein (rPV)
- Pulmonary artery (PA)
- Inferior vena cava (IVC)
- Superior vena cava (SVC)

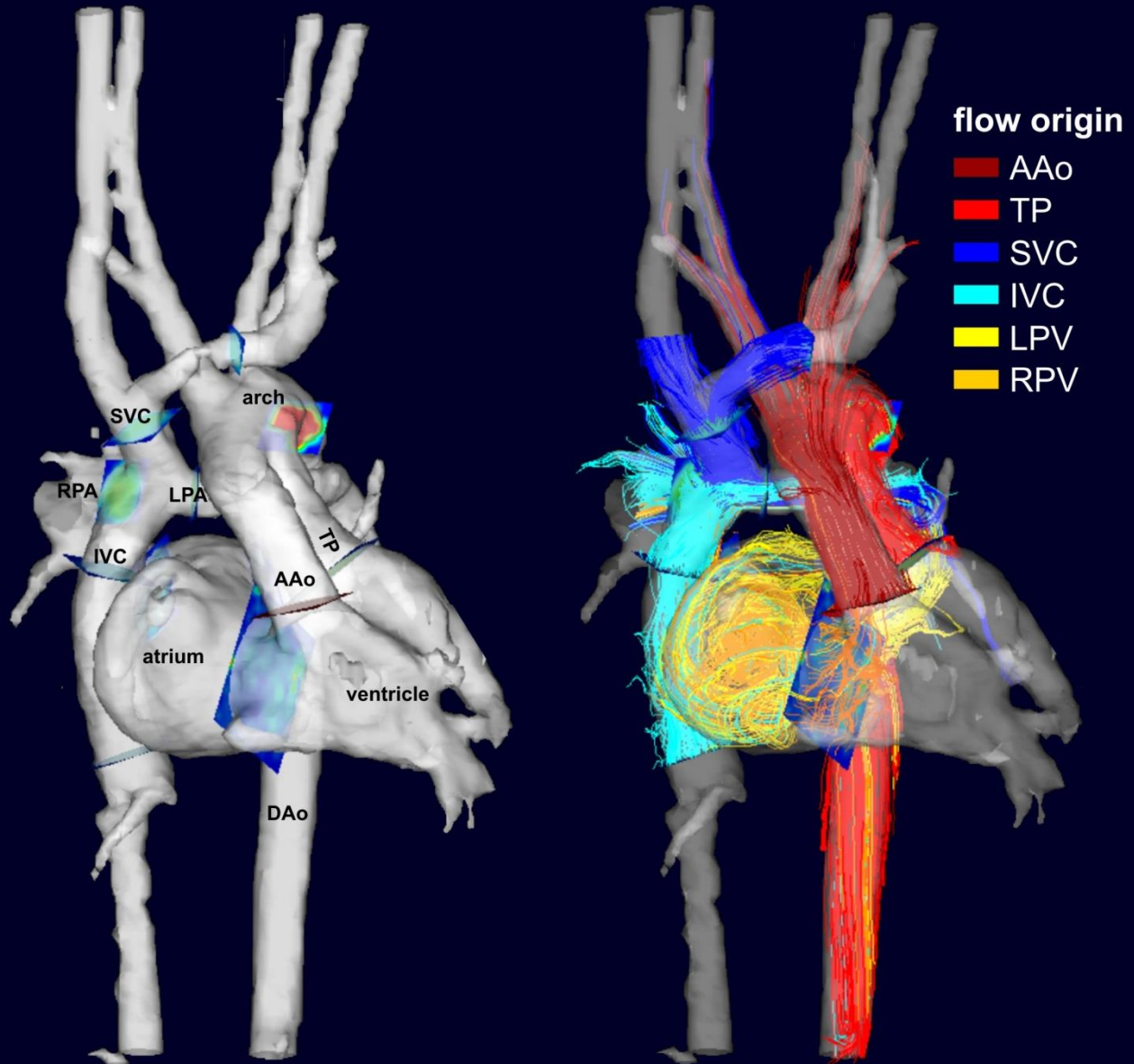


4D Flow MRI

Single Ventricle

5 year old patient

- Left heart hypoplasia
- Double outlet RV
- Transposition of great arteries
- Ventricular septal defect
- Aortic coarctation
- Total cavopulmonary connection (TCPC)



Single Ventricle Physiology: Fontan Circulation

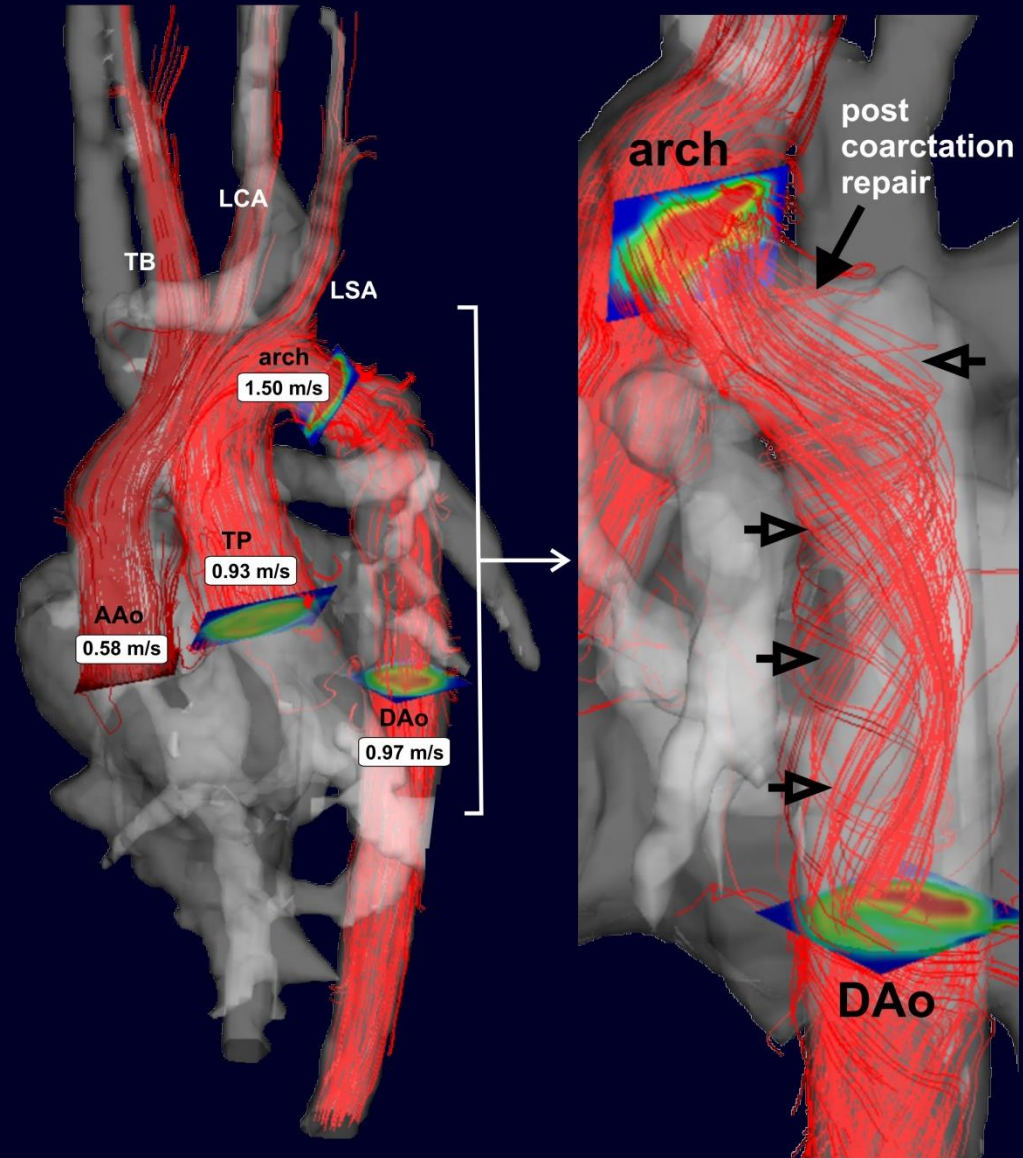
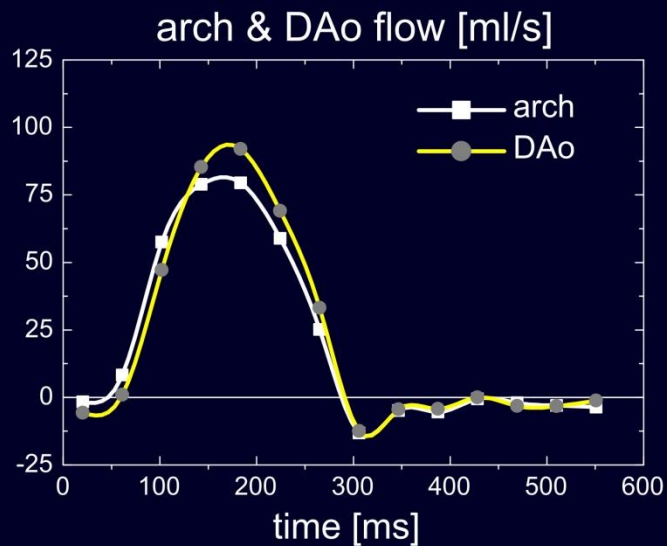
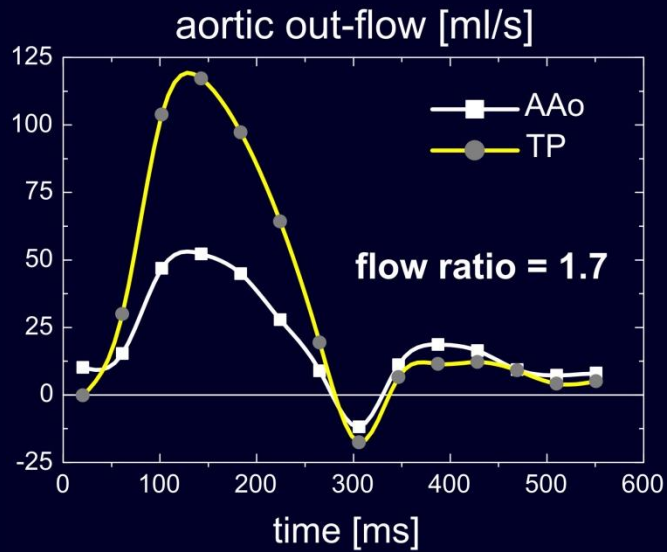
flow origin

- AAo
- PA
- IVC
- SVC
- RRV
- LPV



4D Flow MRI

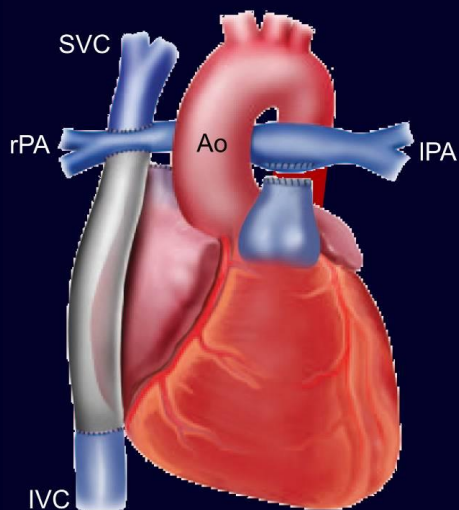
Single Ventricle



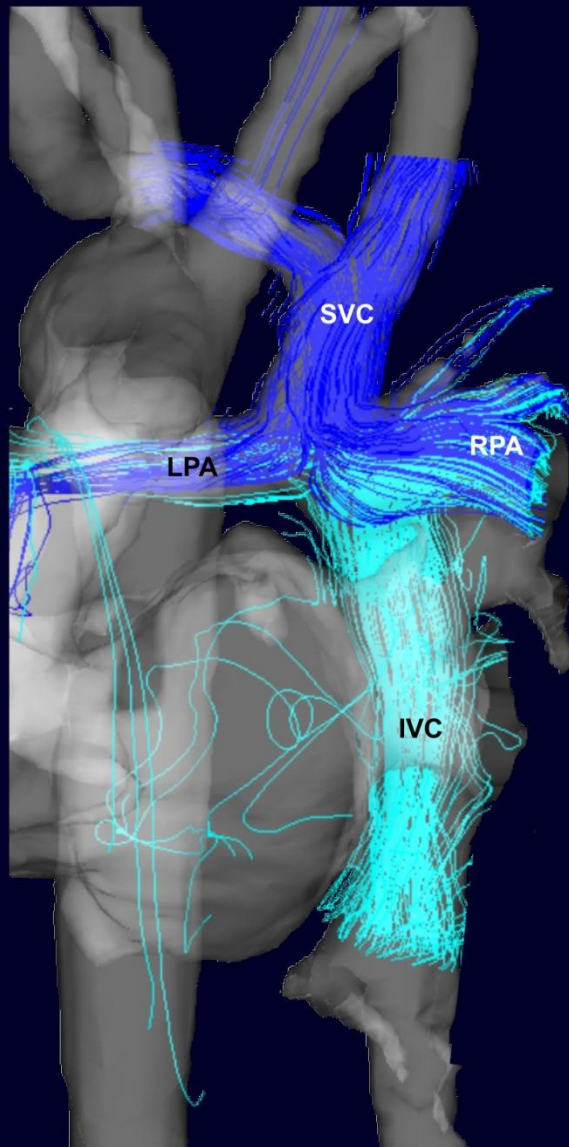
4D Flow MRI

Single Ventricle

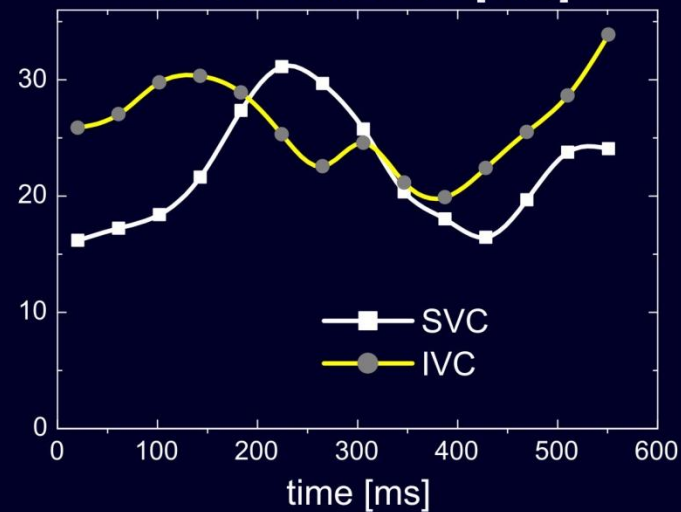
Single Ventricle Physiology



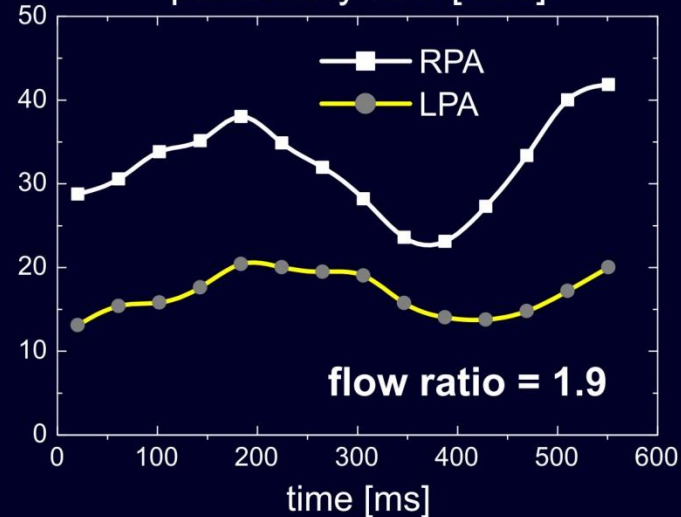
single ventricle
extracardiac TCPC



caval venous flow [ml/s]

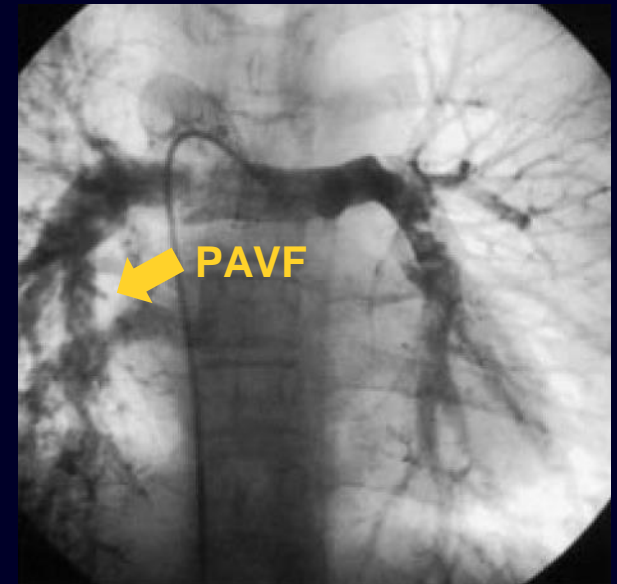
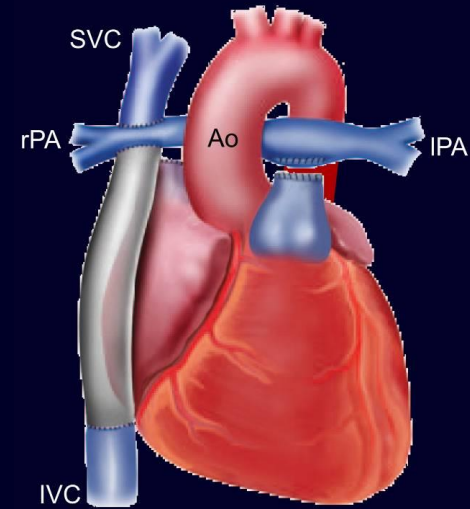


pulmonary flow [ml/s]



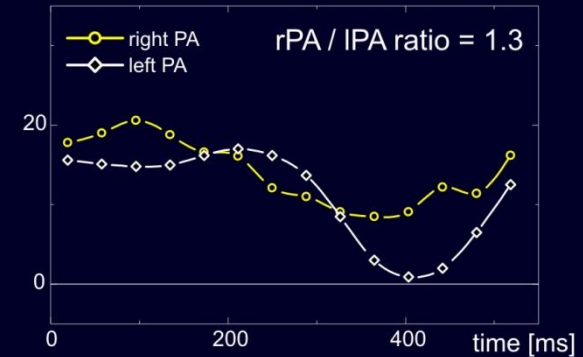
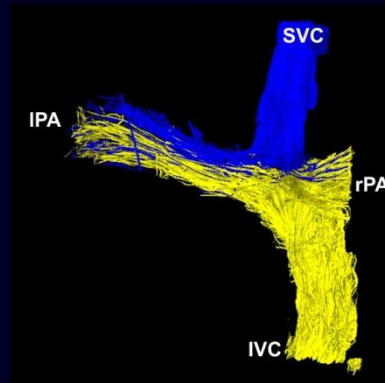
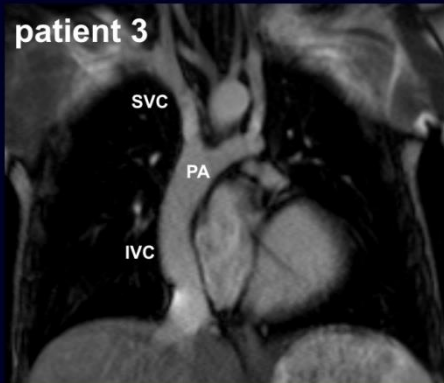
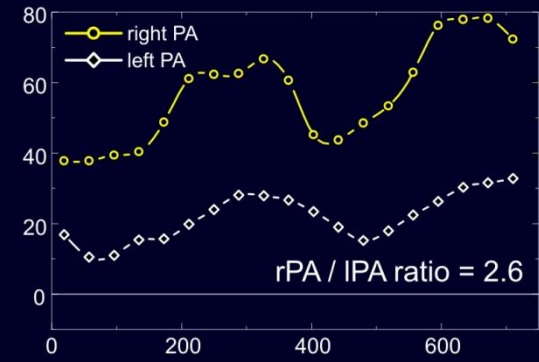
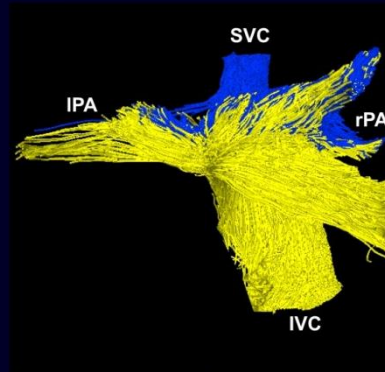
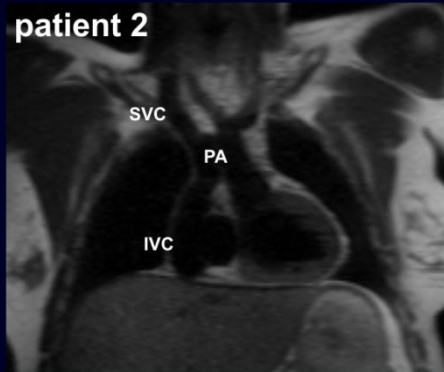
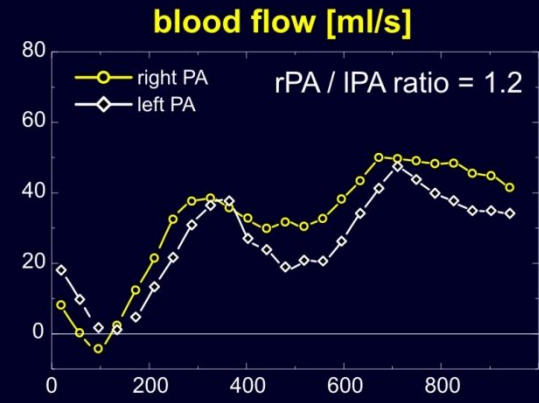
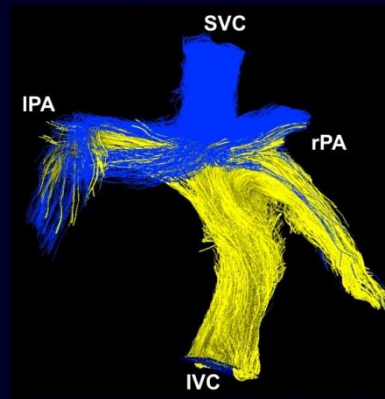
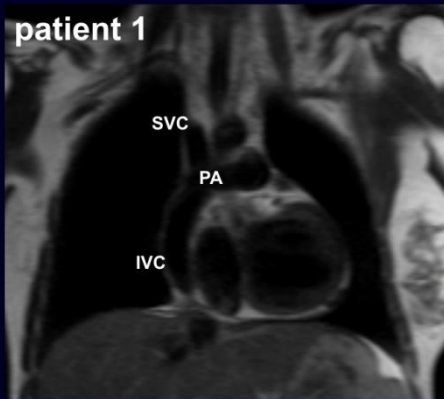
Background Fontan Circulation

- Some patients develop *'Failing Fontan physiology'*
- **Caval blood distribution to PAs**
 - Suspected to influence patient outcome through delivery of protein-rich venous return
 - Pulmonary arteriovenous malformations, fistulas (PAVF)



4D Flow MRI

Single Ventricle



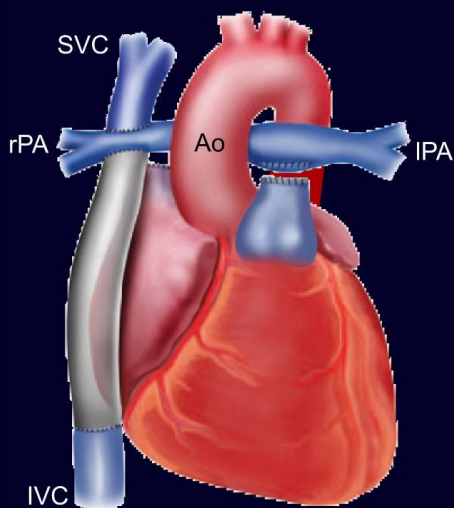
4D Flow MRI

Fontan Flow Distribution

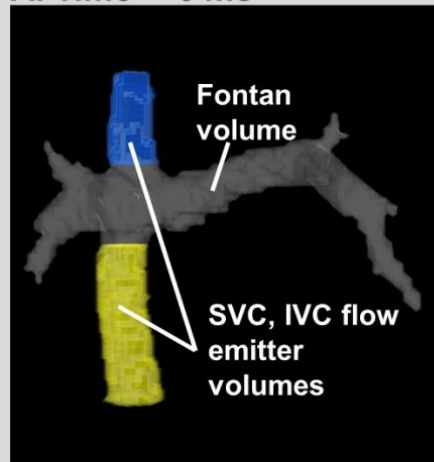
Fontan Circulation

Caval

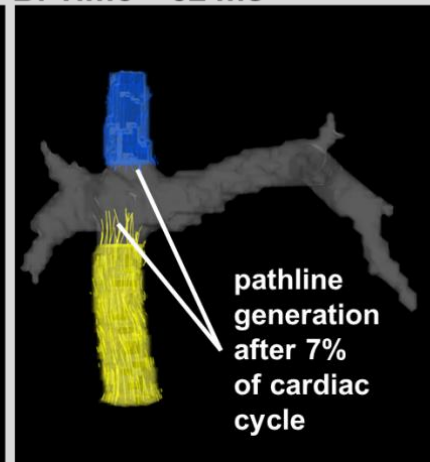
→ IPA/rPA flow distribution



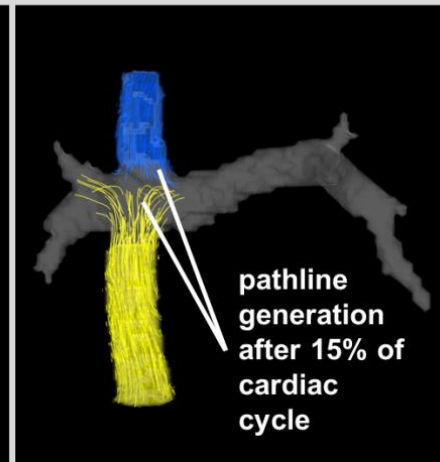
A: Time = 0 ms



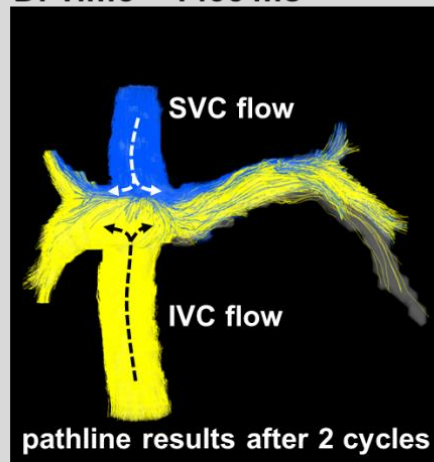
B: Time = 52 ms



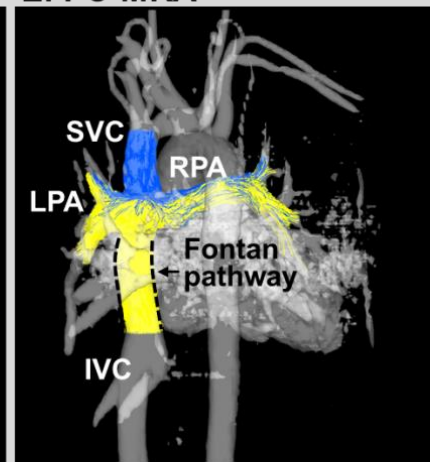
C: Time = 104 ms



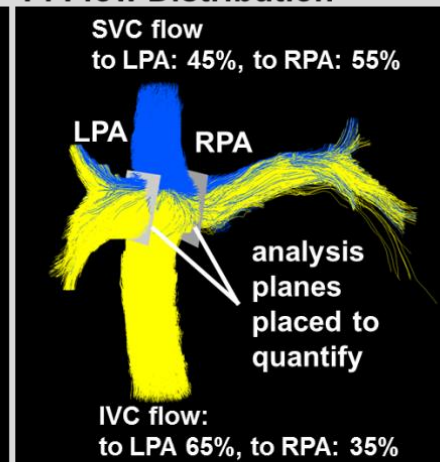
D: Time = 1435 ms



E: PC-MRA



F: Flow Distribution

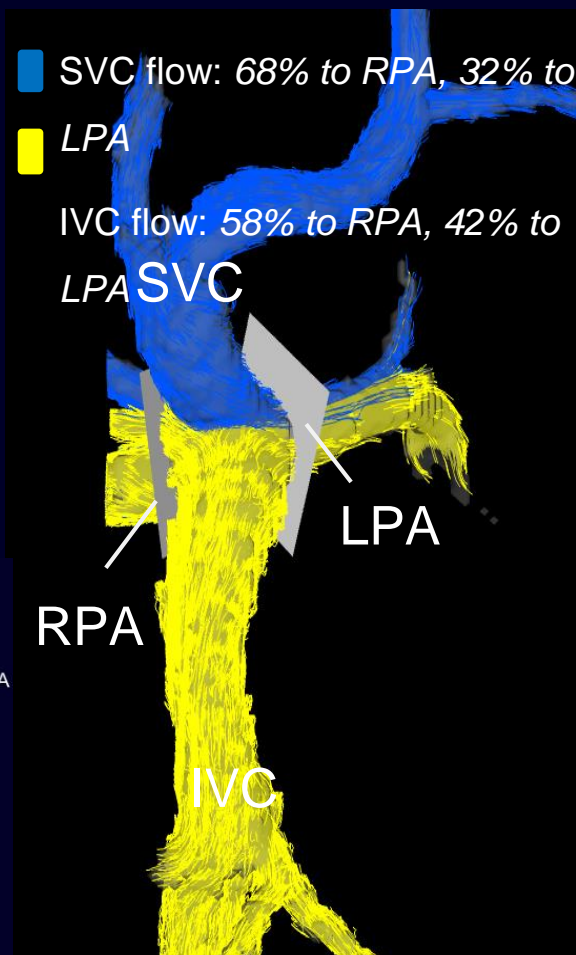


SVC flow
 IVC flow

4D Flow MRI

Fontan Flow Distribution

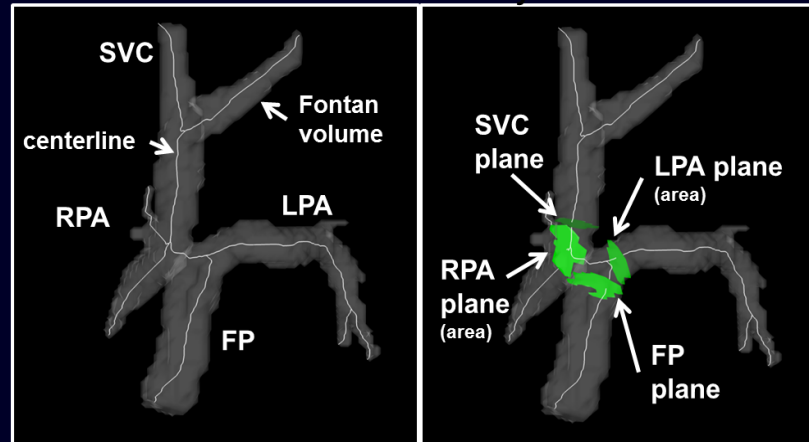
Fontan Flow Distribution



Area, Caval Offset, Vessel Angle

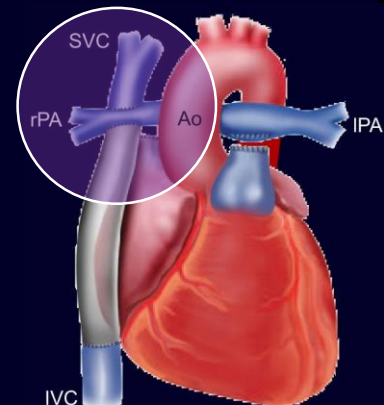
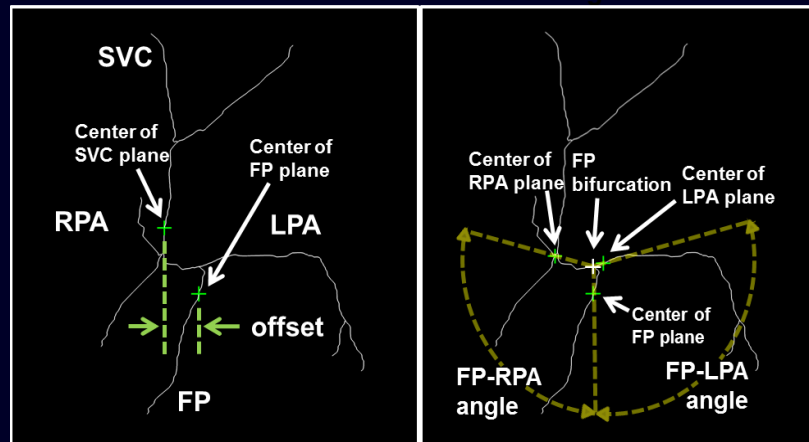
A: Centerline Calculation

B: Analysis Plane Placement



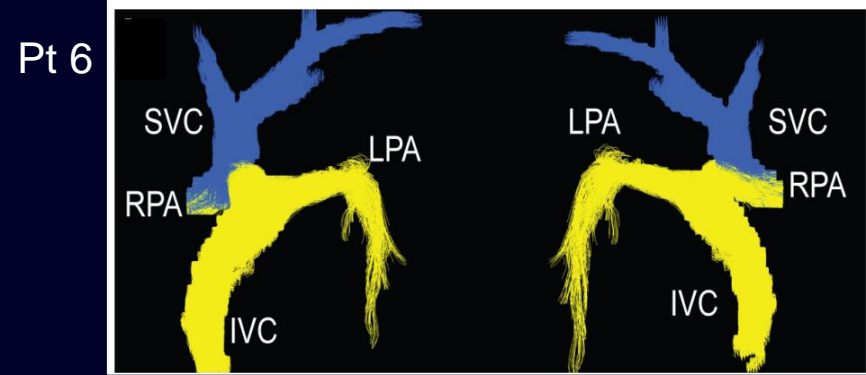
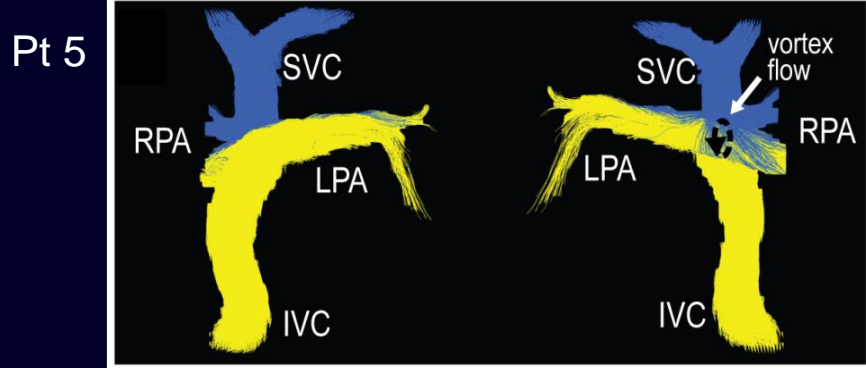
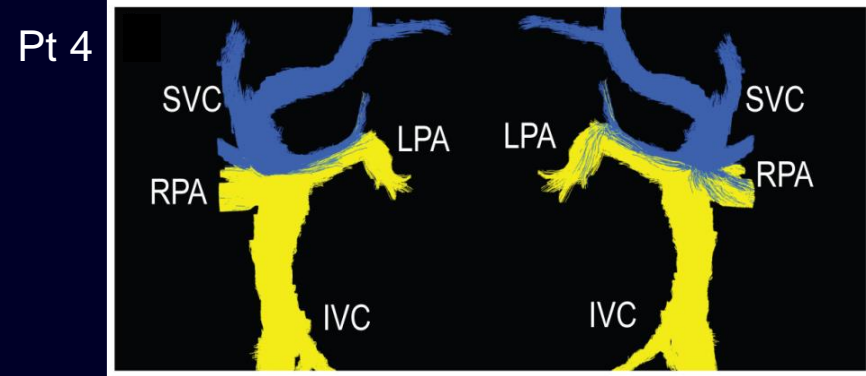
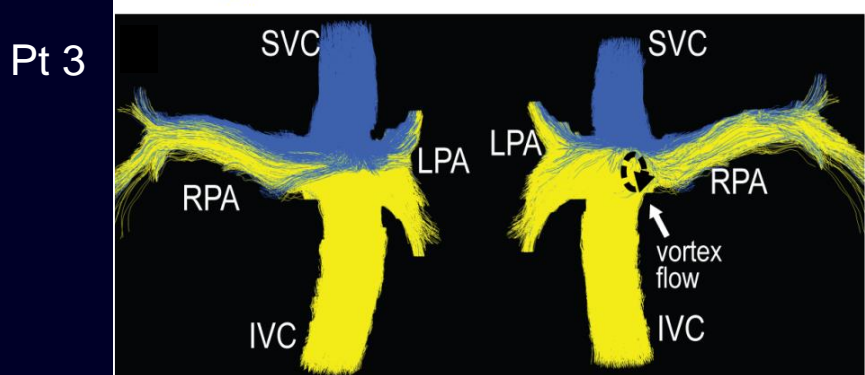
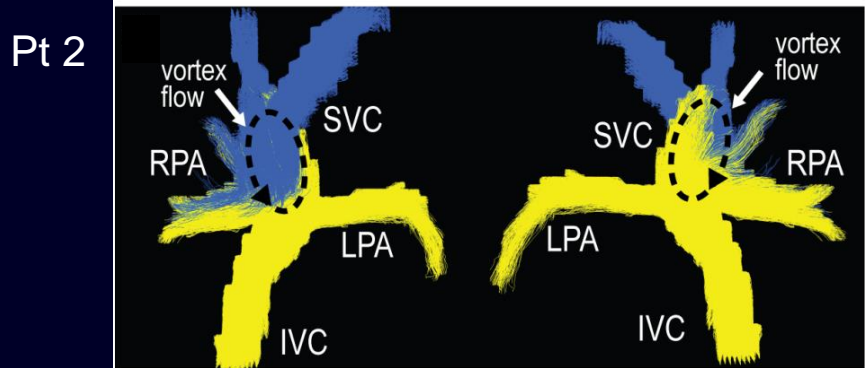
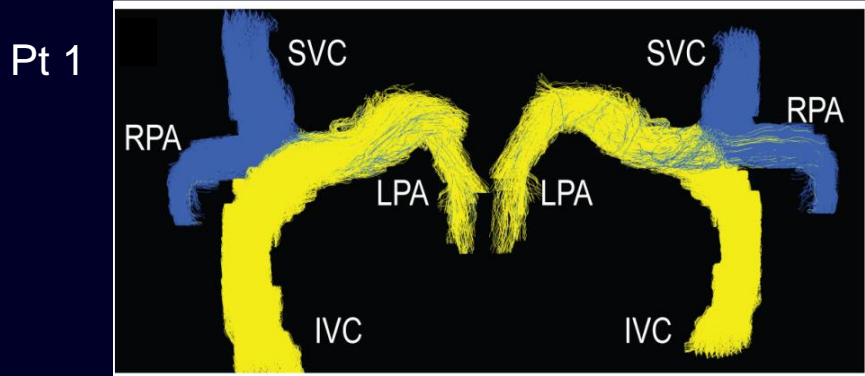
C: Caval offset Measurement

D: Vessel Angle Measurement



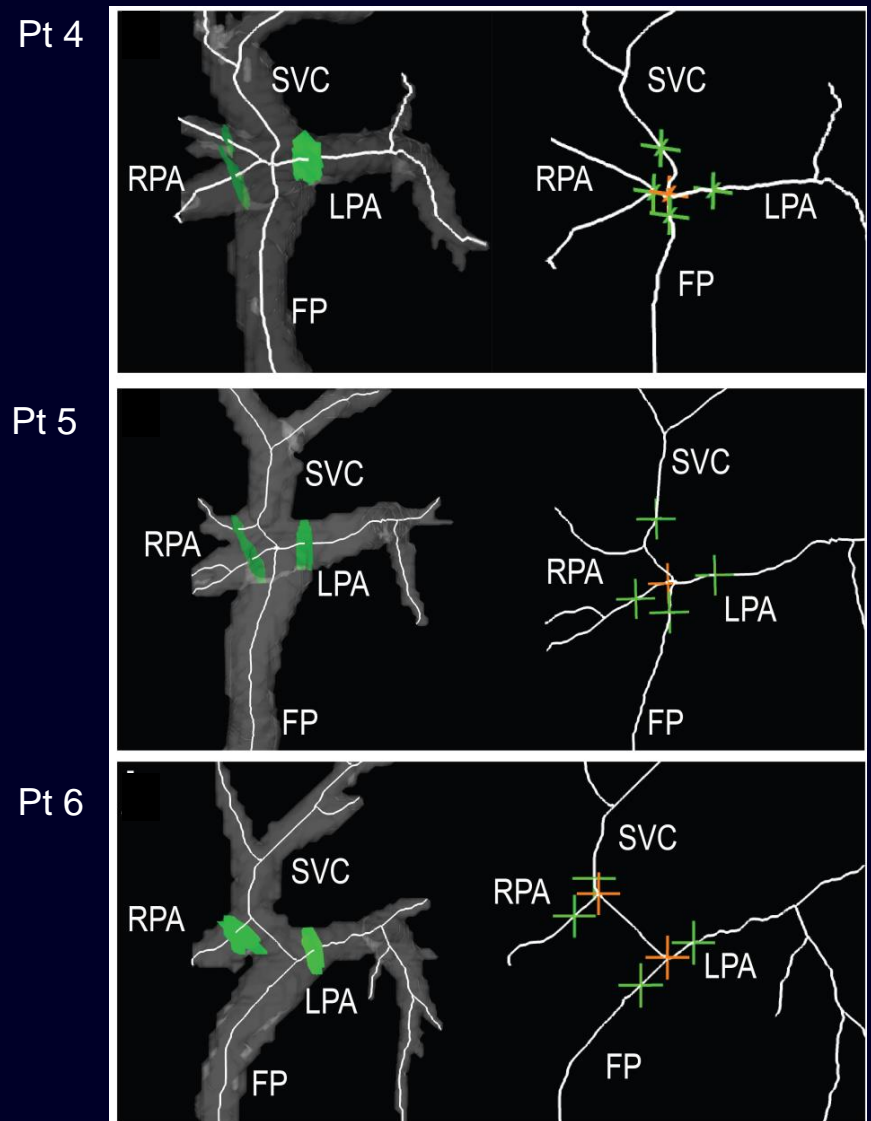
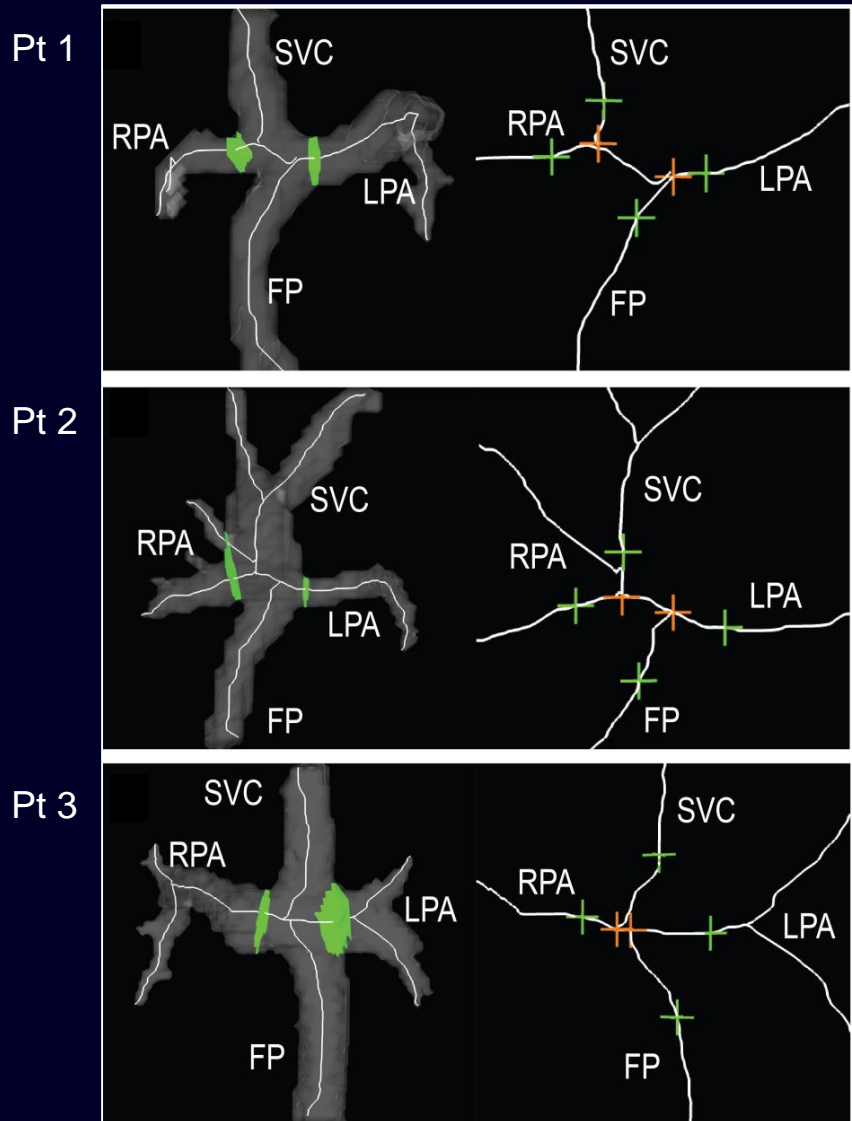
4D Flow MRI

Fontan Flow Distribution

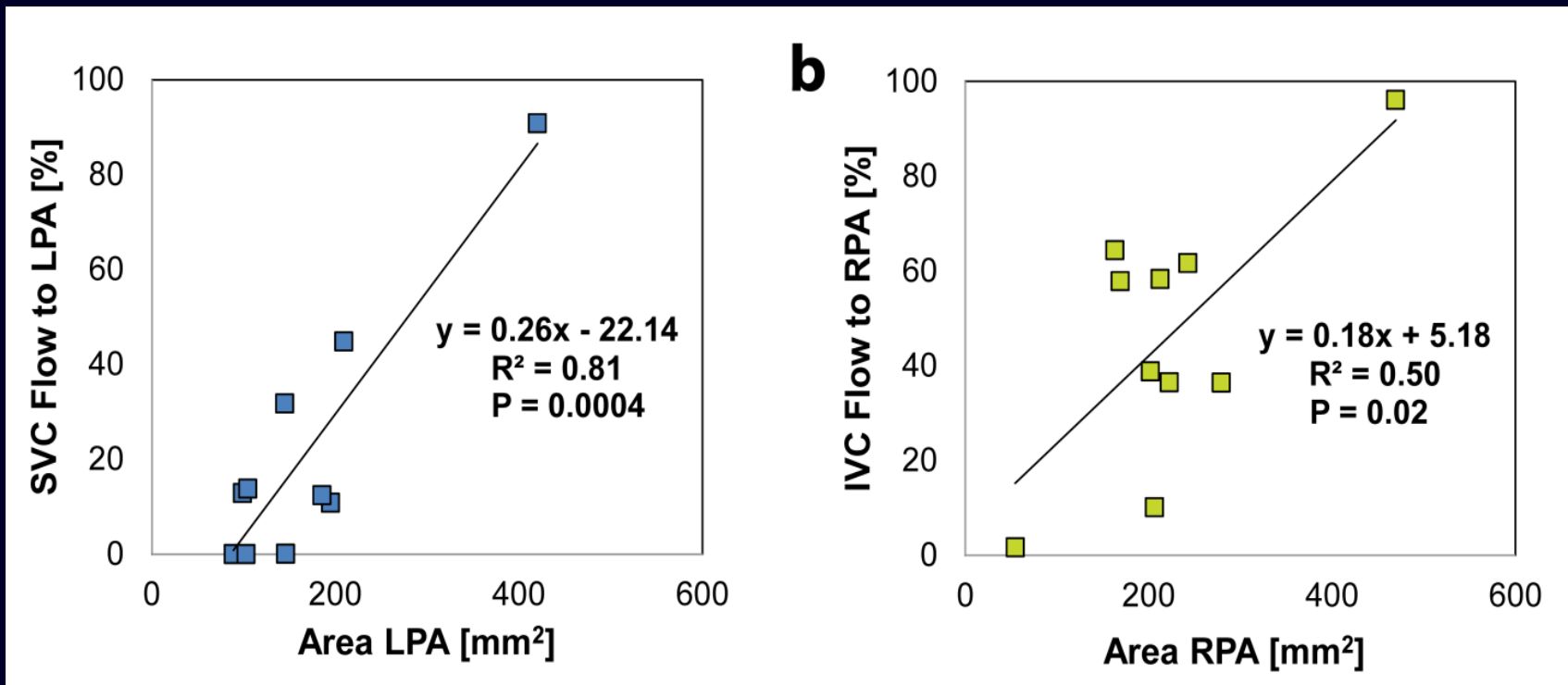


4D Flow MRI

Fontan Geometry



- 4D flow MRI: Comprehensive analysis of complex flow pathways and vascular geometry
- Relationships between PA size and flow distribution (10 Fontan Patients 16±4 [9–21] years)



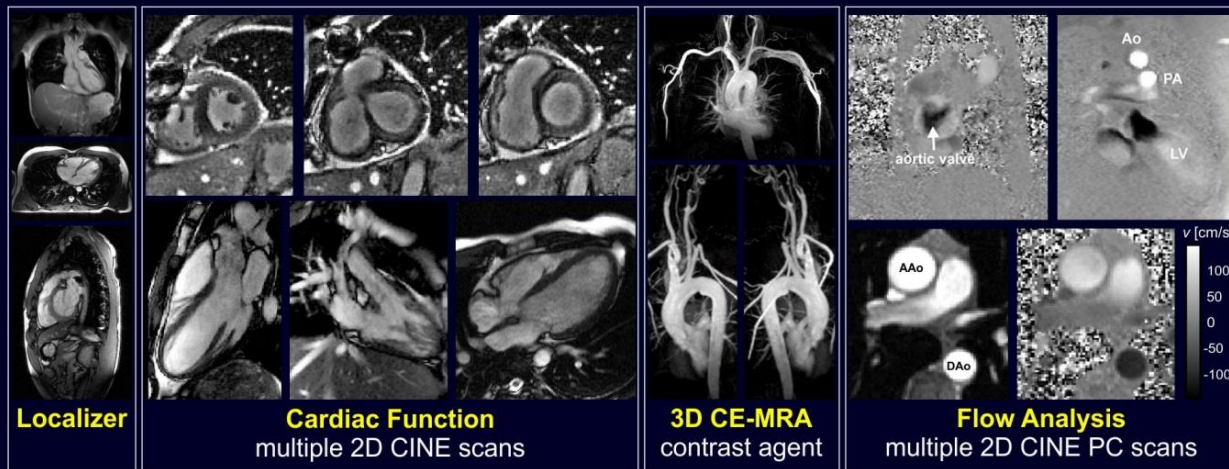
4D Flow MRI

Congenital Heart Disease

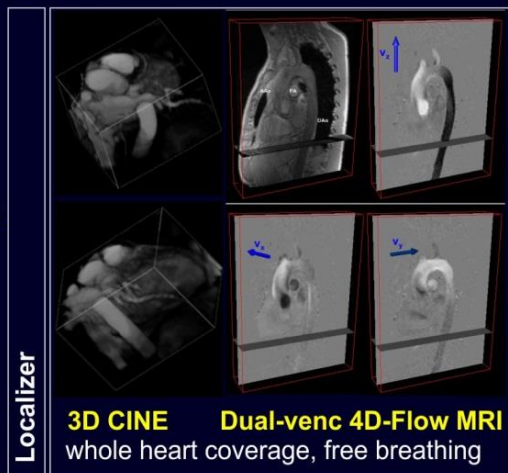
Congenital Heart Disease



Standard MR Exam



Functional 4D MRI



20-30 min

40-60 min

60-90 min

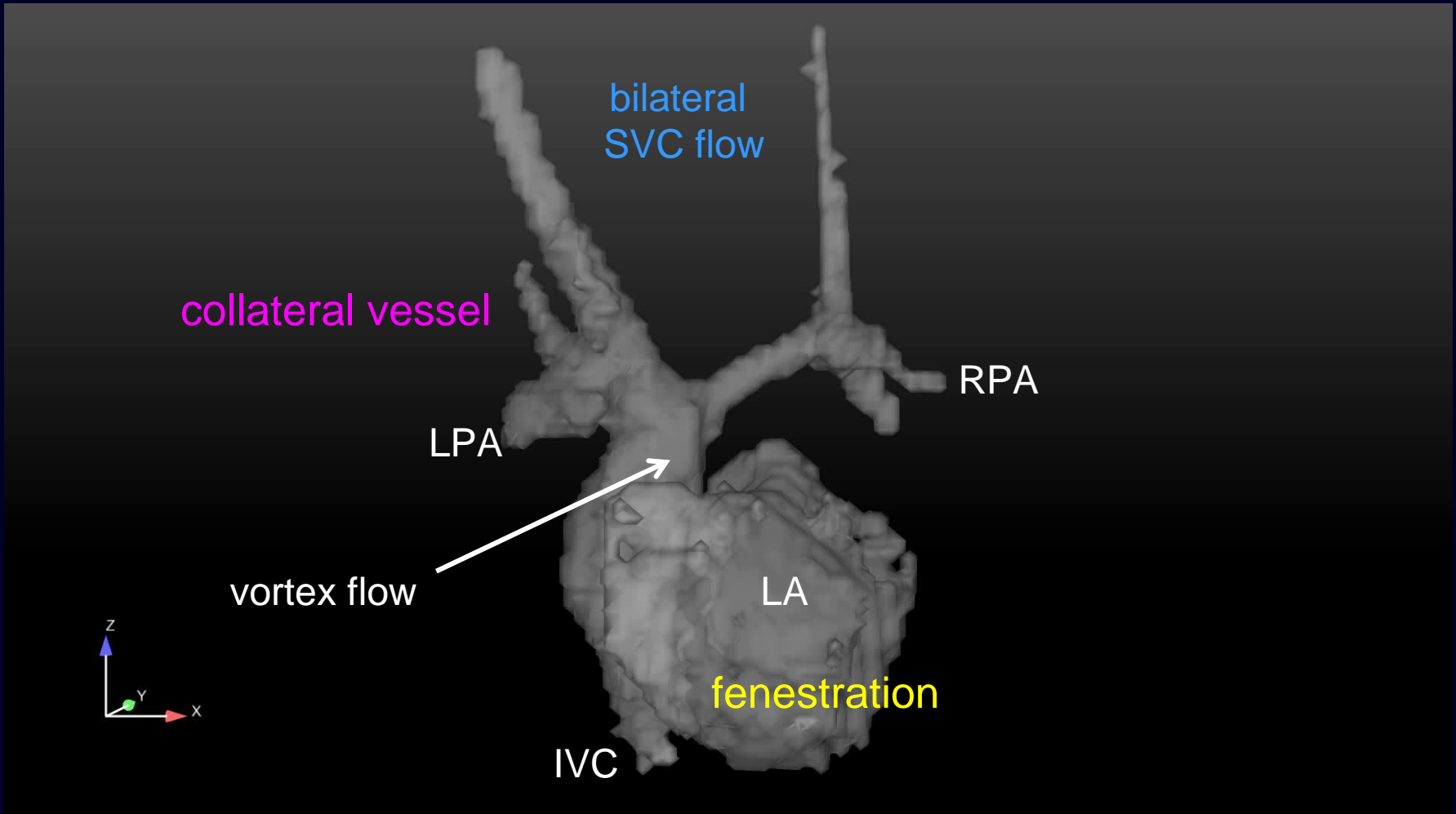
Retrospective Data Analysis

Cardiac Function & Anatomy
global cardiac function, 3D PC-MRA

3D Hemodynamics
3D flow visualization, flow quantification
pressure difference mapping, WSS

no restrictions to predefined locations

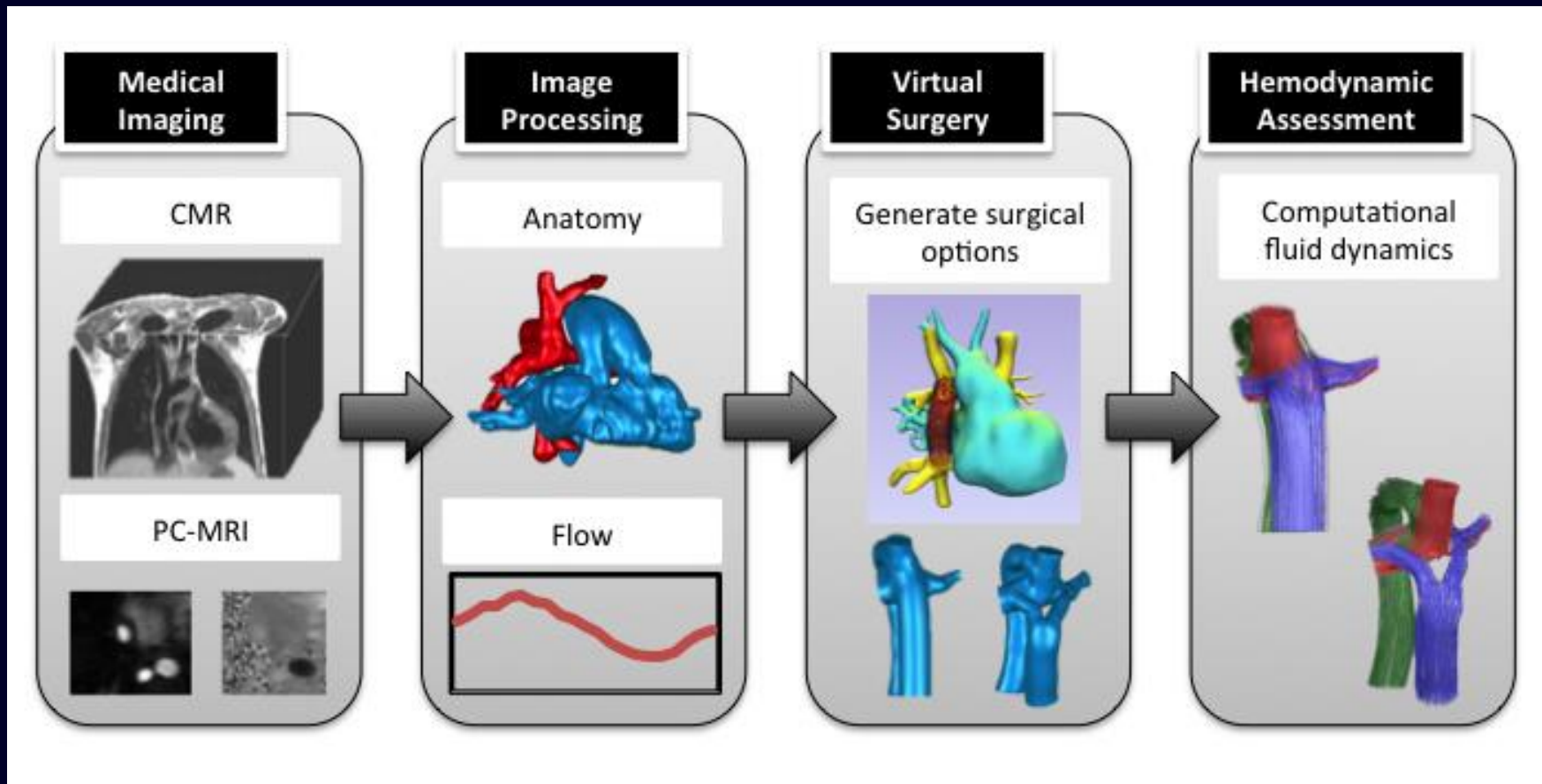
Fontan Circulation



4D Flow MRI

Single Ventricle Physiology

Computational Fluid Dynamics (CFD)



de Zelicourt, D.A., et al. J Thorac Cardiovasc Surg, 2011. 141(5): 1170-7.
Sundareswaran, K.S., et al. JACC Cardiovasc Imaging, 2009. 2(8): 1024-30.
Frakes, D.H., et al. J Cardiovasc Magn Reson, 2005. 7(2): 425-32.
Sundareswaran, K.S. et al. J Magn Reson Imaging, 2009. 29(1): 155-65.
Zélicourt, D.d., et al. Computers & Fluids, 2009. 38(9): 1749-1762.

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AHA - pre/postdoc fellowships

McCormick Catalyst Award

