CARDIOLOGY 2025

February 21, 2025

Imaging Data & the Fontan Circulation:

FORCE
FONTAN REGISTRY

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Disclosures

- Rahul Rathod has research grant support from Mezzion Pharmaceuticals as the Global PI for the FUEL-2 randomized controlled trial in Fontan patients

FUEL-2

www.fuel2study.com

- FORCE is funded through grants from

ADDITIONAL VENTURES

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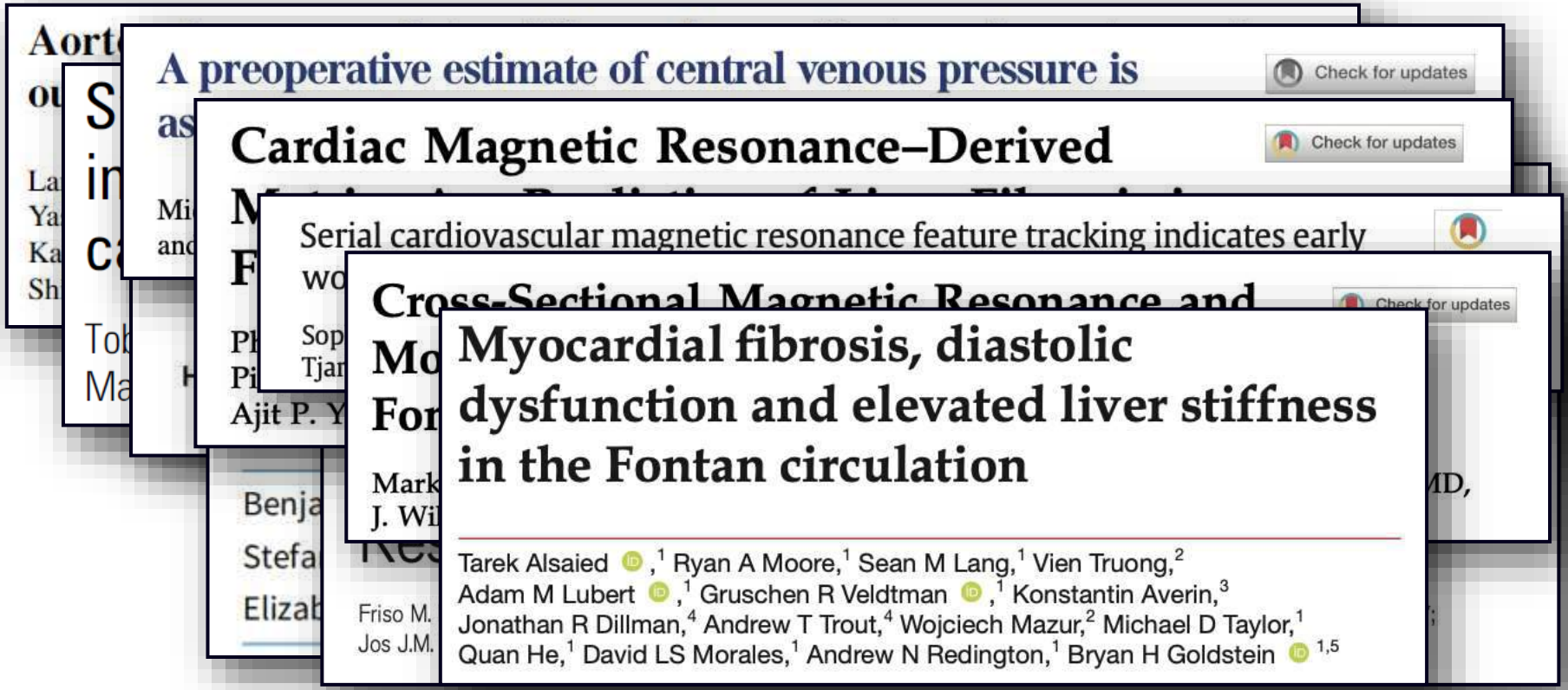
Why cardiac MRI (CMR) for Fontan patients?

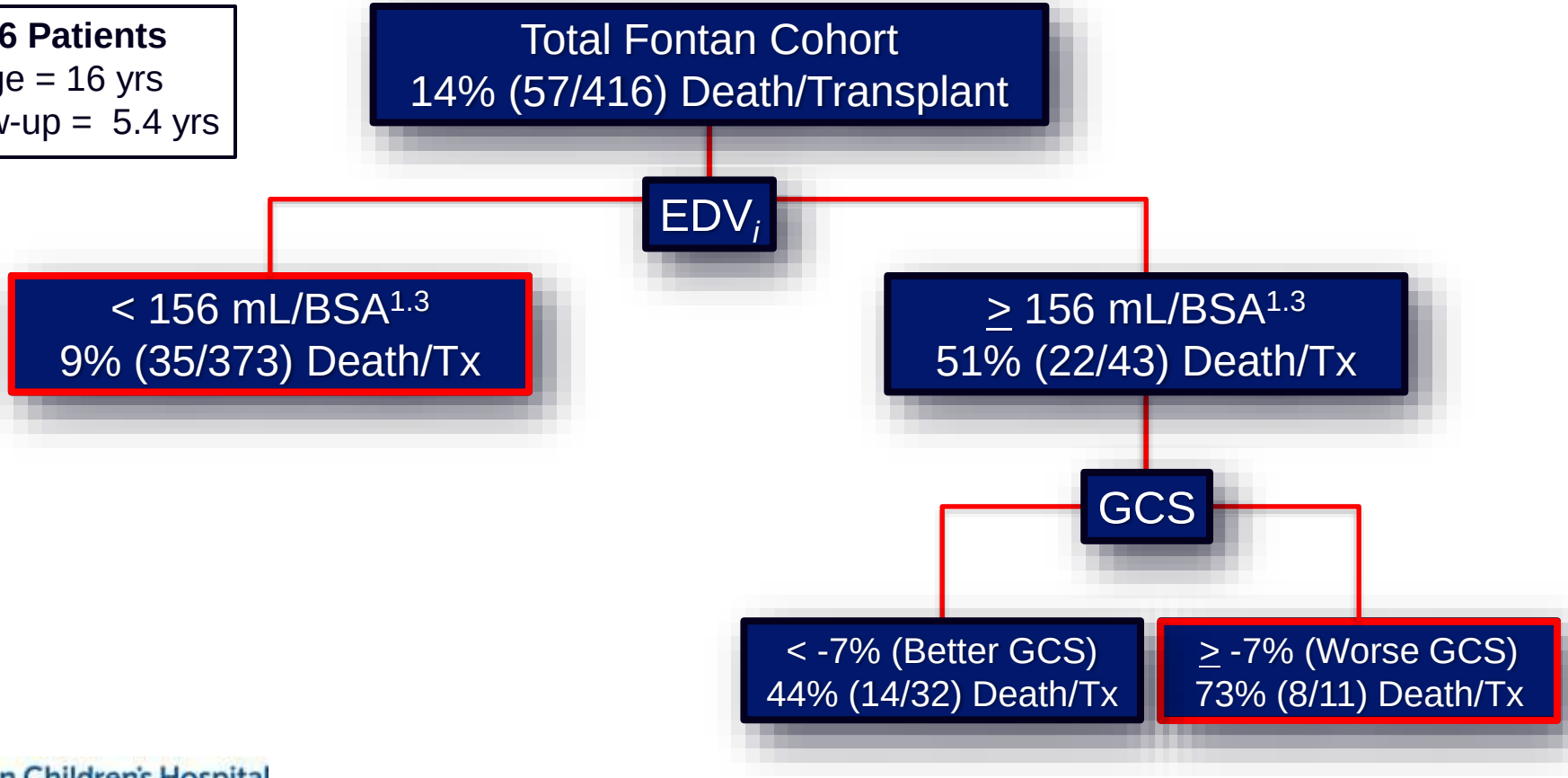
Many papers showing utility of CMR in Fontan Pts



CMR = cardiac magnetic resonance imaging

CMR parameters predict death and transplant

416 Patients
Age = 16 yrs
Follow-up = 5.4 yrs



Boston Children's Hospital Heart Center

(EDV = end-diastolic volume, Tx = transplant, GCS = global circumferential strain)

Meyer SL, Rathod RH. *JACC* 2021:2480-9

CMR parameters predict death and transplant

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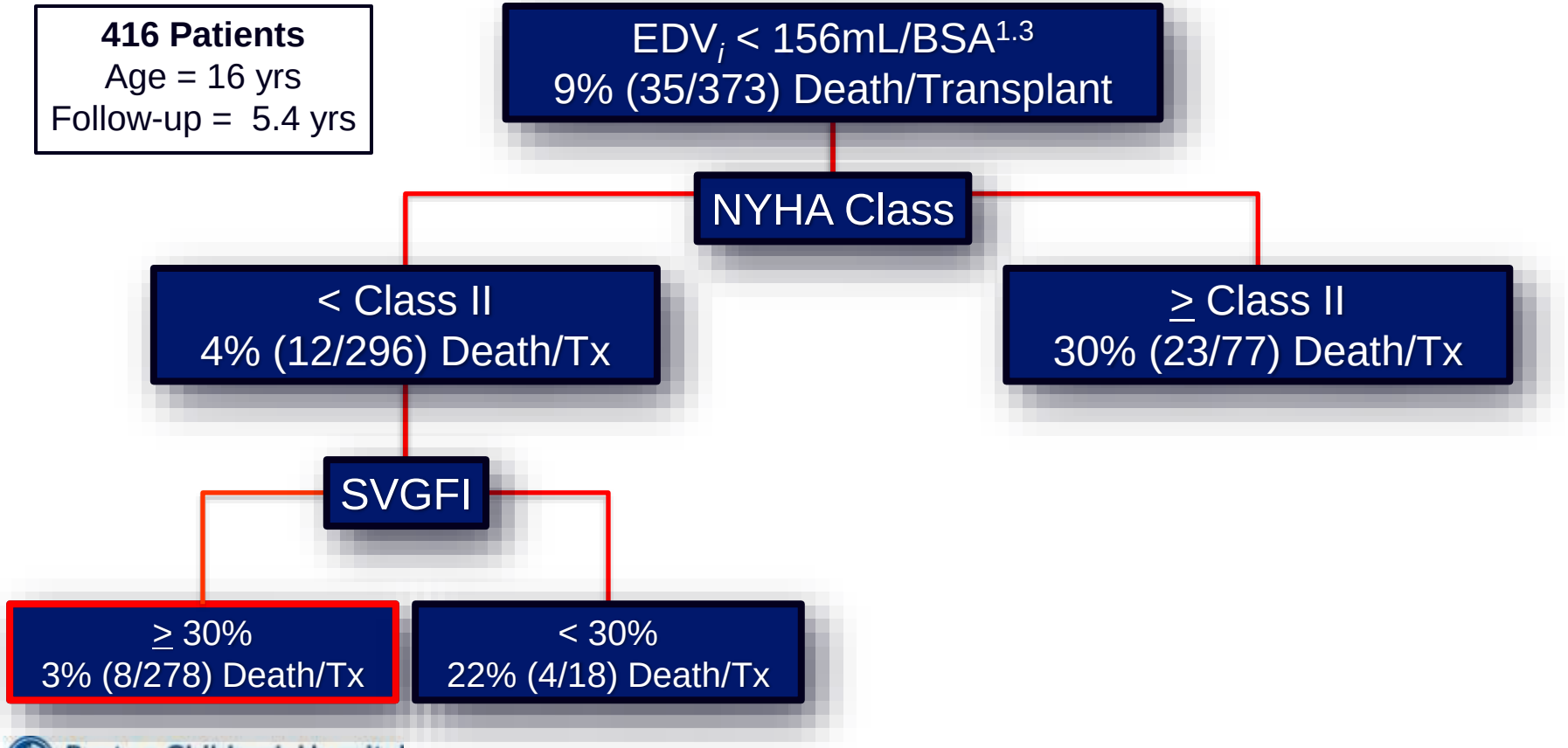
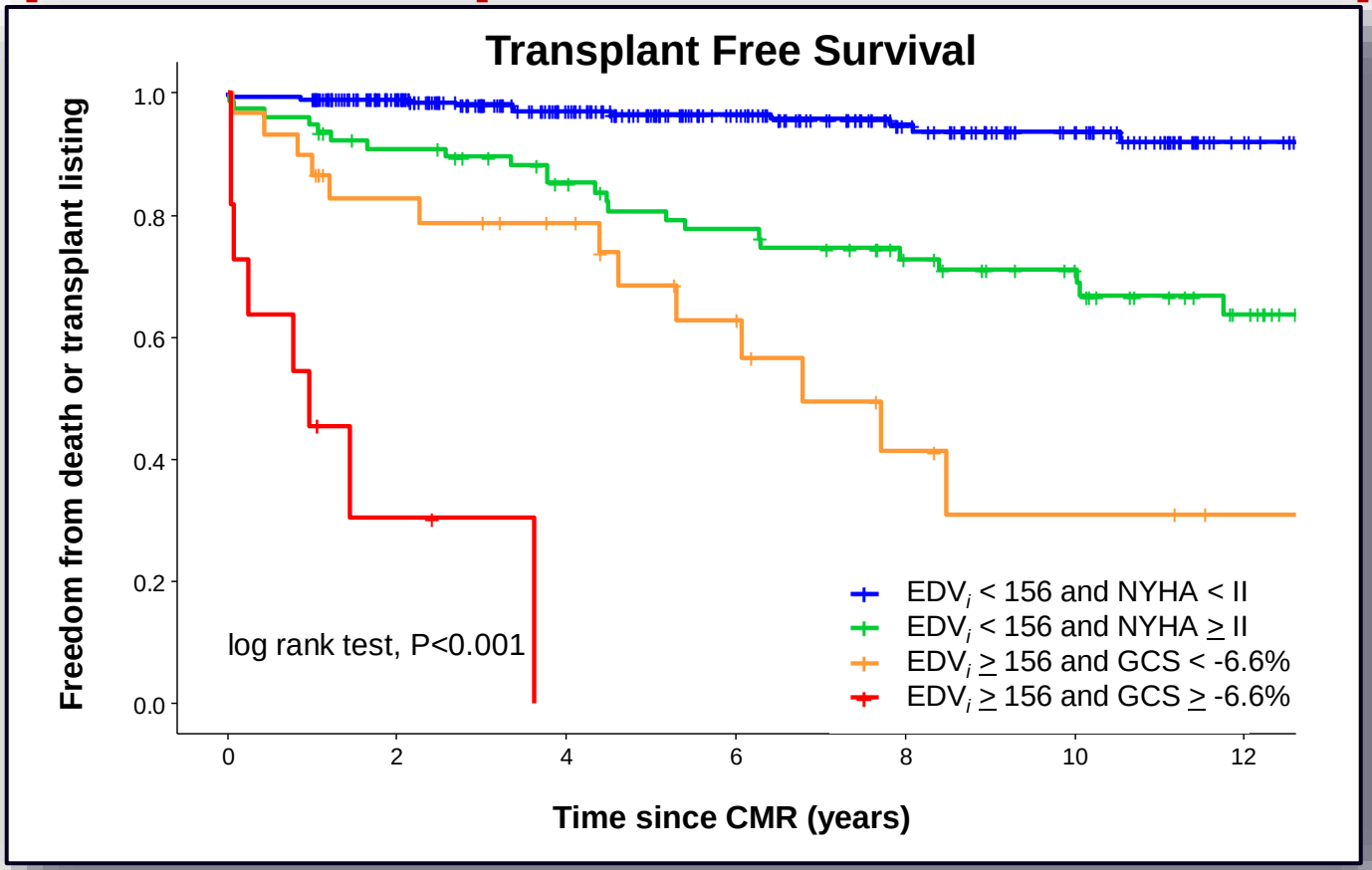


Boston Children's Hospital Heart Center

(NYHA = New York Heart Association, SVGI = SV global function index)

Meyer SL, Rathod RH. *JACC* 2021:2480-9

CMR parameters predict death and transplant



Boston Children's Hospital
Heart Center

Meyer SL, Rathod RH. *JACC* 2021:2480-9

Single Center

Multicenter

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Fontan **O**utcome **R**egistry using **C**MR **E**xaminations

Launched Nov 2020

www.FORCEregistry.org

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Fontan **O**utcome **R**egistry using **C**MR **E**xaminations

42 Centers

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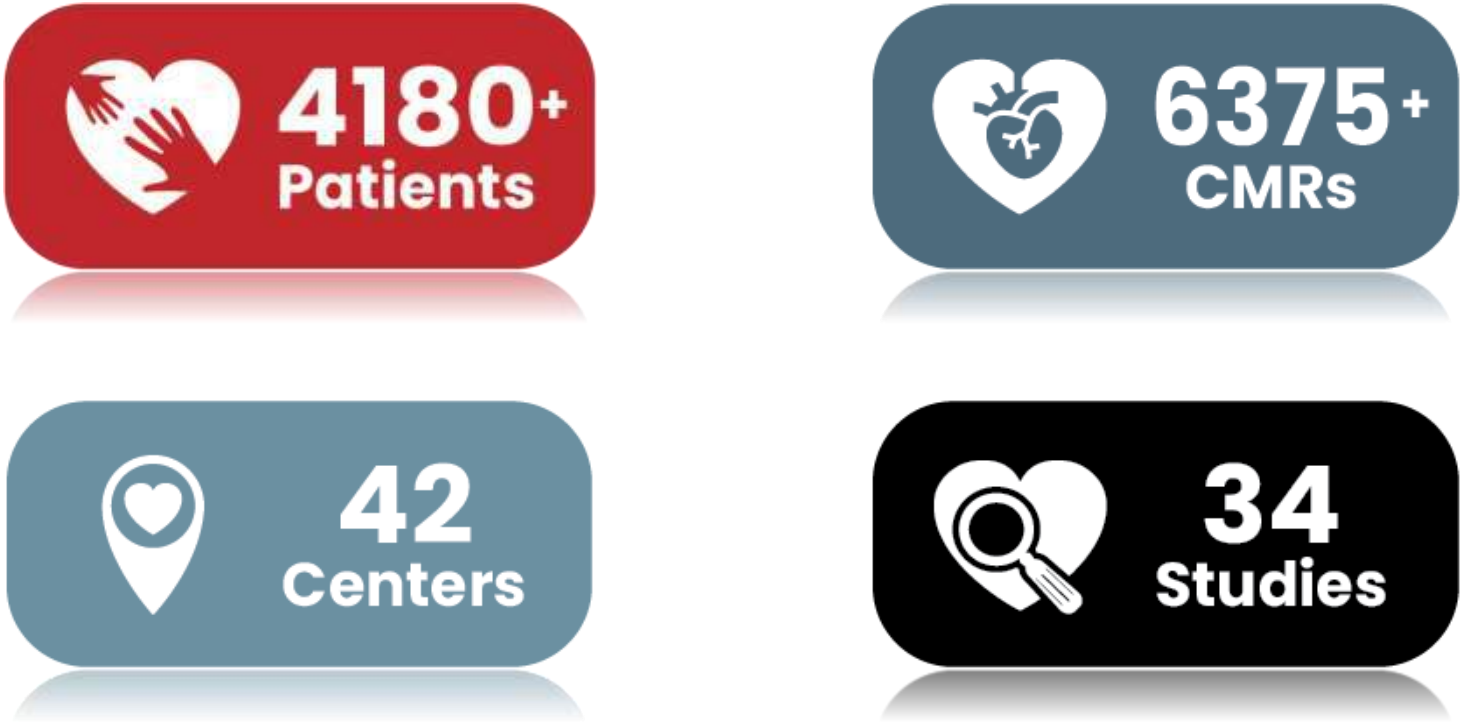
Fontan **O**utcome **R**egistry using **C**MR **E**xaminations



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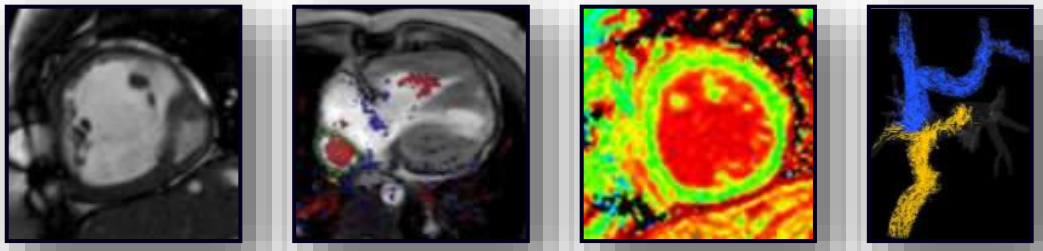
Fontan **O**utcome **R**egistry using **C**MR **E**xaminations

www.FORCEregistry.org

FORCE data sources

Clinical History | Surgical History | Testing Data | Outcome Events

→ REDCap Research Electronic Data Capture



Raw CMR Images

→ AMBRA An Intelerad Company

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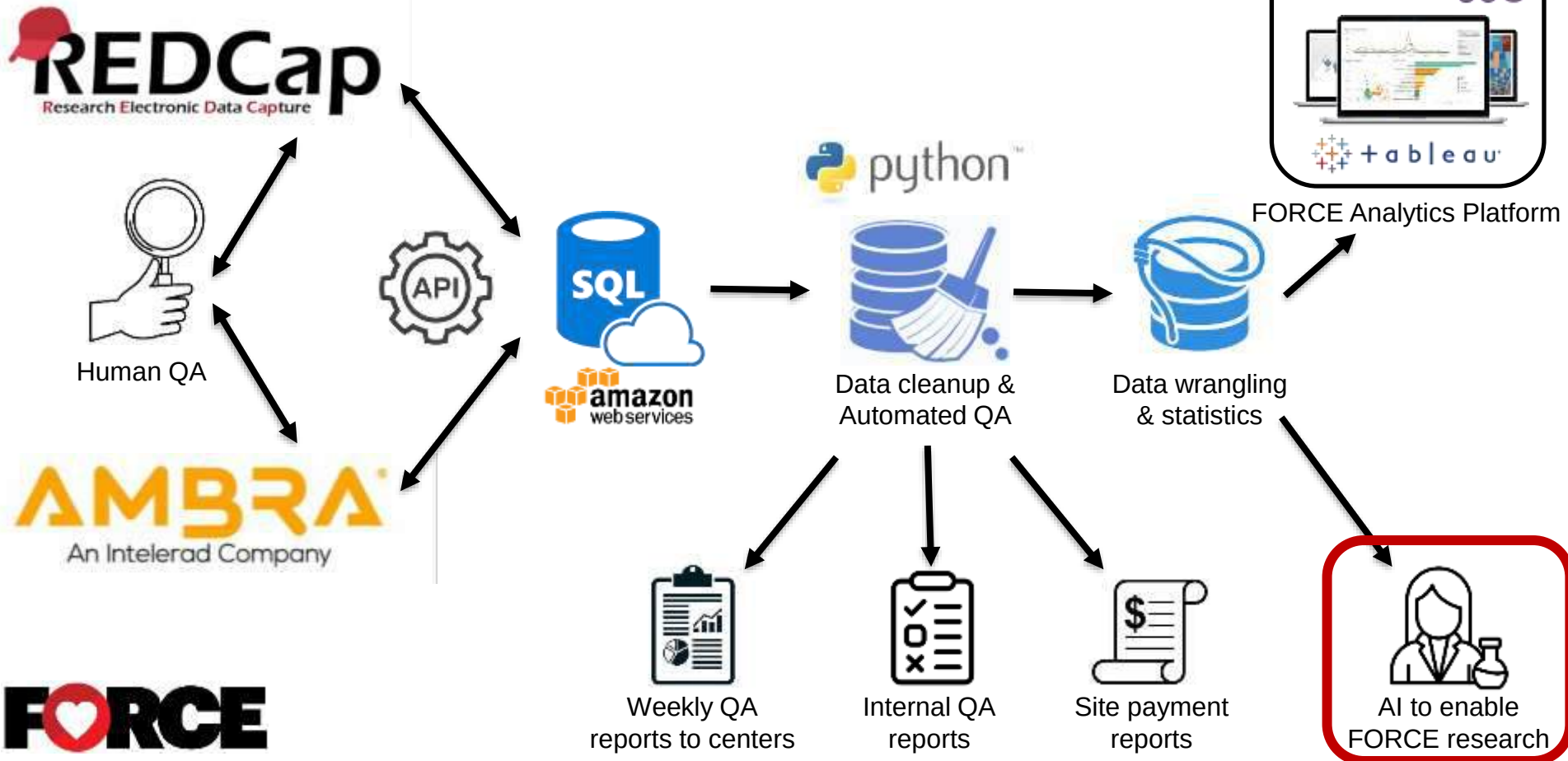
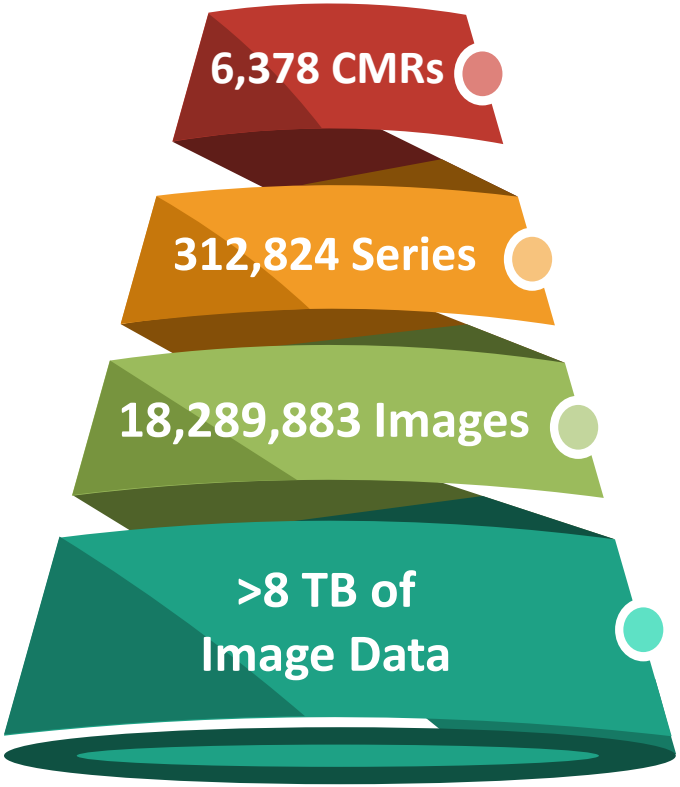
FORCE data workflows



FORCE has a big data problem



- Poor reproducibility of CMR-derived measures across centers
- Not enough time or resources to manually core lab metrics
- Researchers need a common set of CMR-derived metrics

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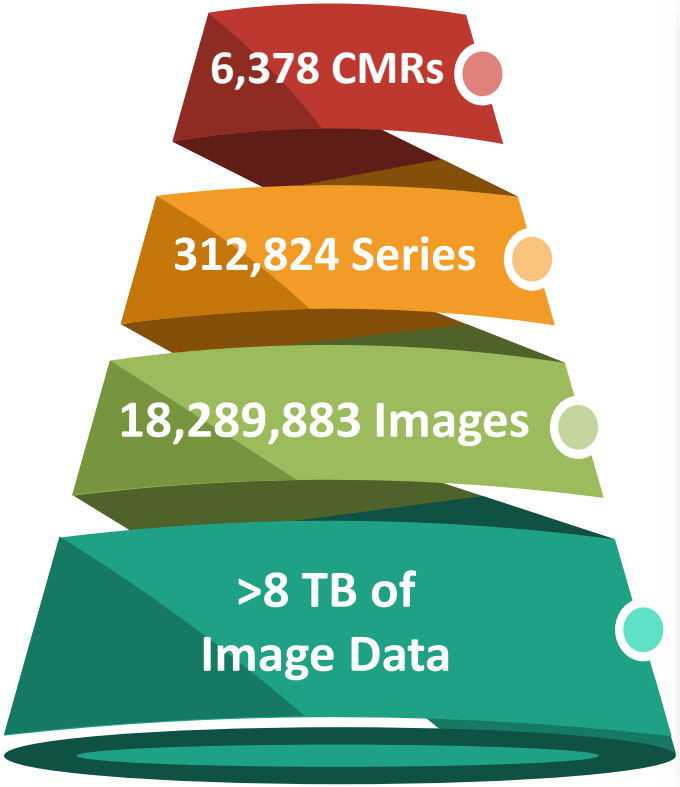
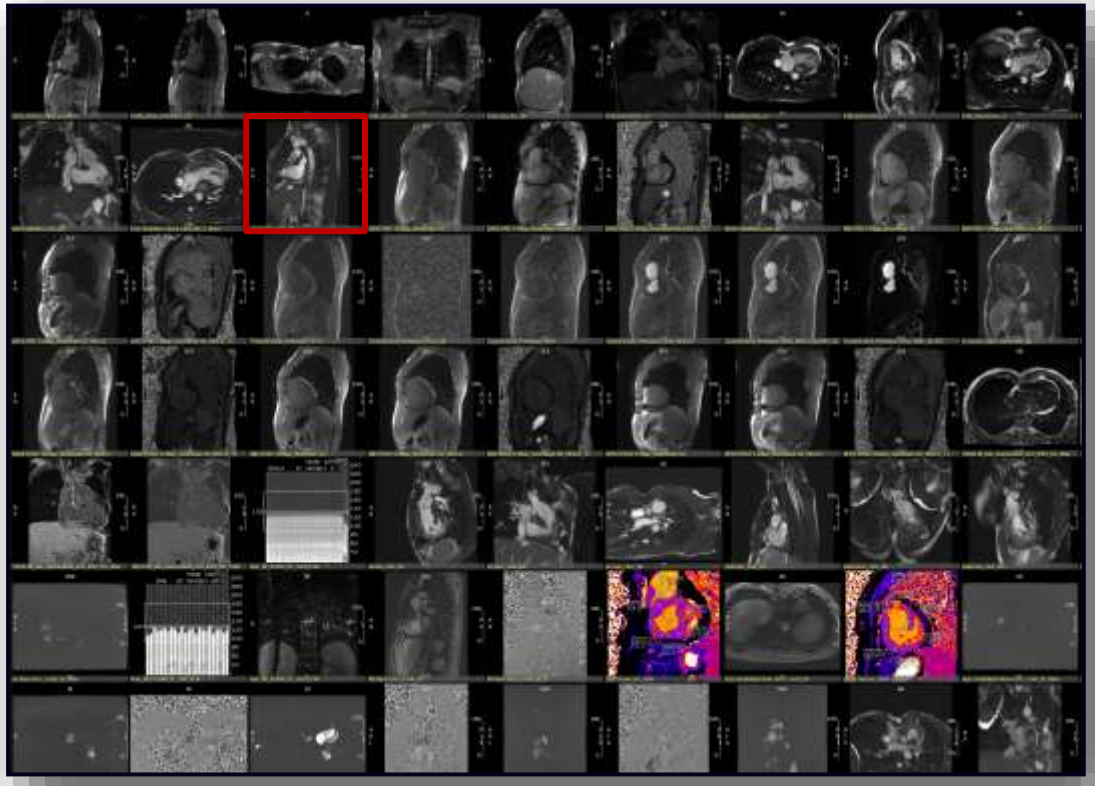
FORCE has a big data problem





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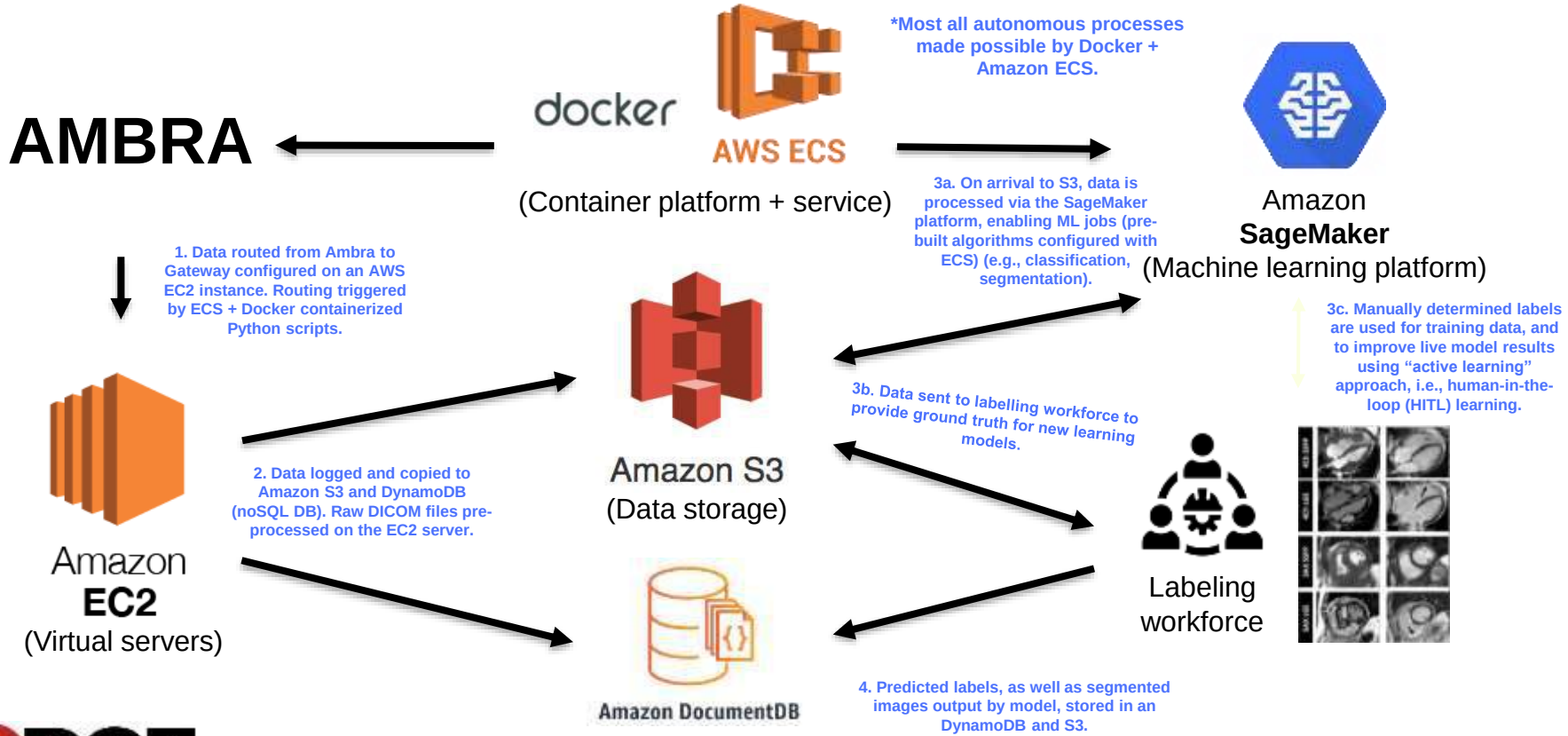
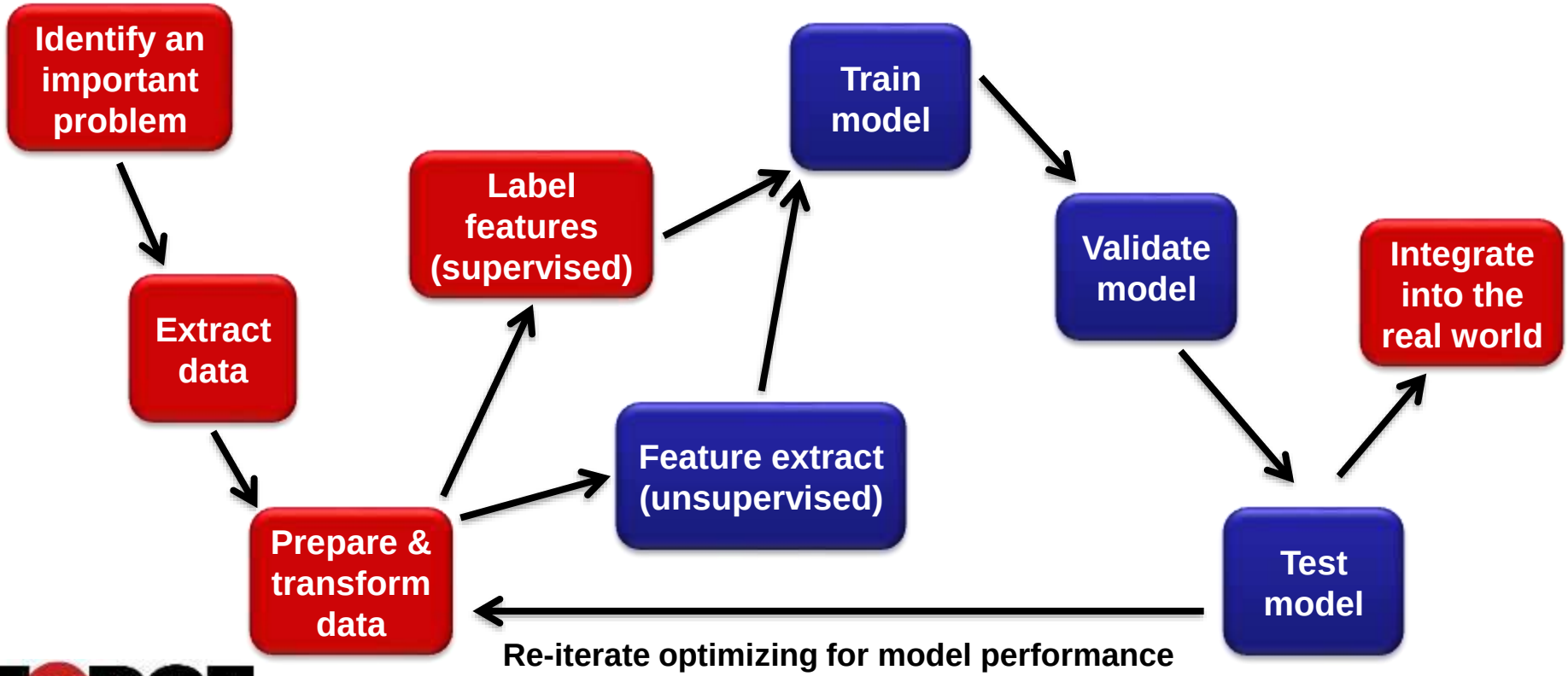
Created new infrastructure to support AI/DL



AI = artificial intelligence; DL = deep learning

A framework for AI to have meaning

Red squares represent the hard work



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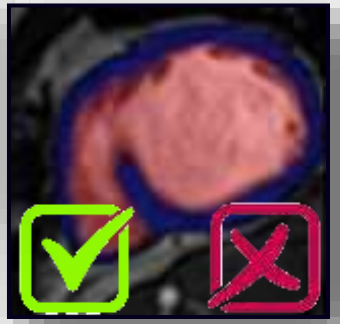
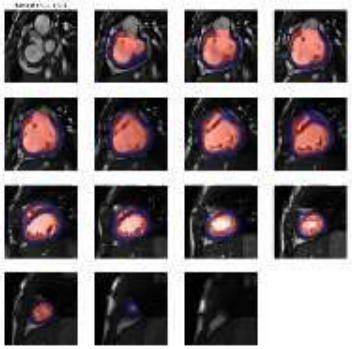
Using AI/deep learning in layers

AI to identify sequences → AI to identify the heart → AI to segment the ventricles → AI to QA the segmentation

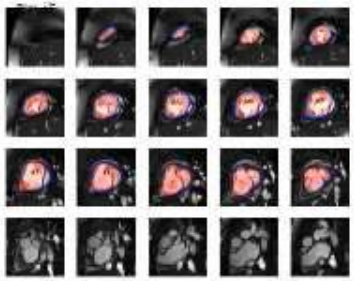
Human = 30 minutes (EDV/ESV only)
Human = 3 hours (all phases)
AI = 90 seconds (all phases)



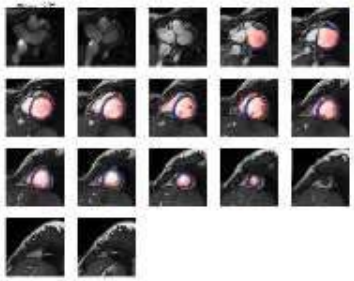
EDV = end diastolic volume; ESV = end systolic volume



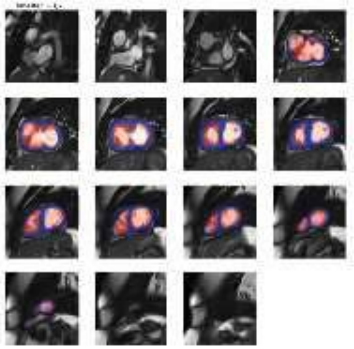
CHP



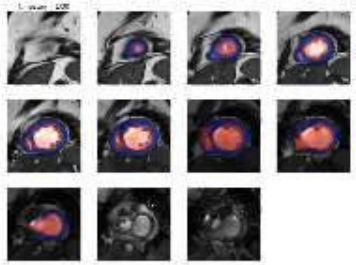
LCH



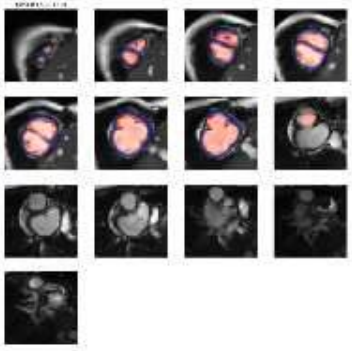
NCH



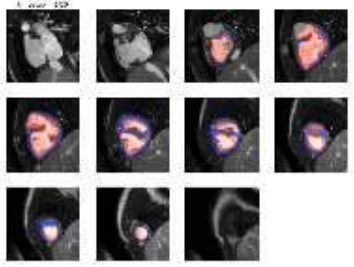
TCH



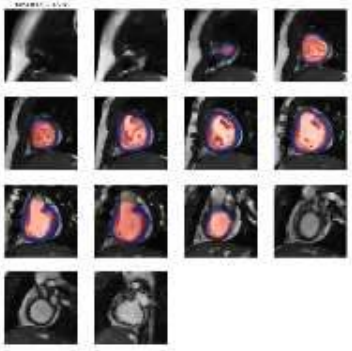
MTS



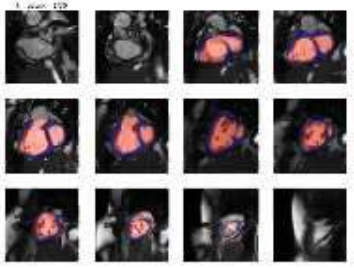
YAL



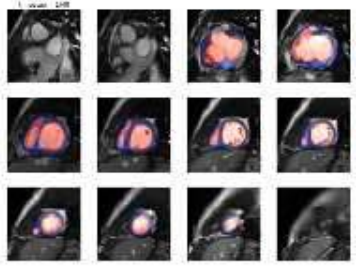
TSK



PIT



BCH



GOS

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Radiology: Artificial Intelligence

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Original Research

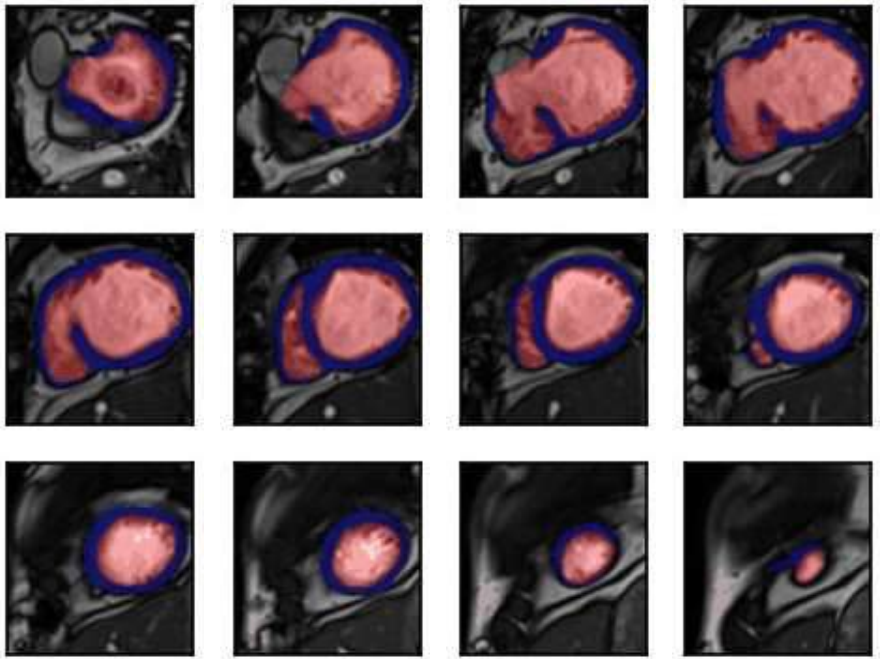
A Deep Learning Pipeline for Assessing Ventricular Volumes from a Cardiac Magnetic Resonance Image Registry of Single Ventricle Patients

Tina Yao*, Nicole St. Clair*, Gabriel F. Miller, Adam L. Dorfman, Mark A. Fogel, Sunil Ghelani, Rajesh Krishnamurthy, Christopher Z. Lam, Michael Quail, Joshua D. Robinson, David Schidlow, Timothy C. Slesnick, Justin Weigand, Jennifer A. Steeden, Rahul H. Rathod, Vivek Muthurangu

Validation of AI/DL for ventricular size/function

- Scaled algorithms against 5,447 CMR examinations
- Completely autonomous process
- Manual human review of every segmentation

Estimated hours saved = 16,341



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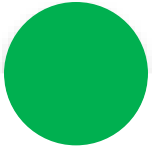

Excellent

Edits needed

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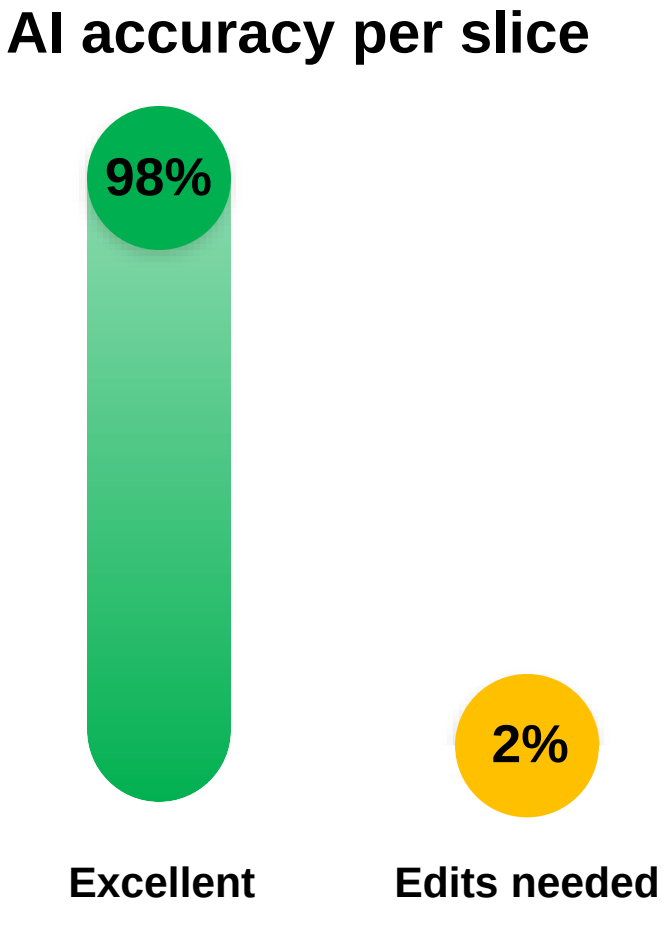
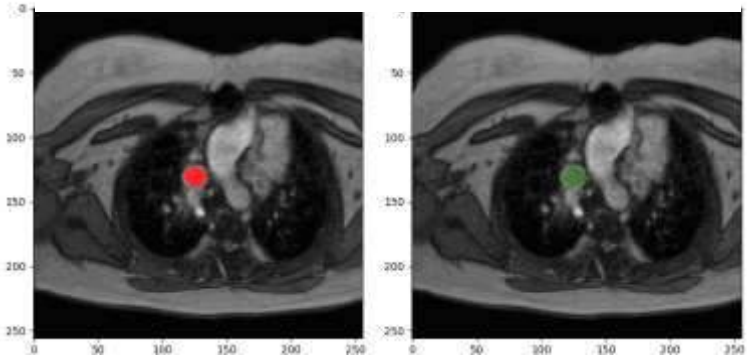
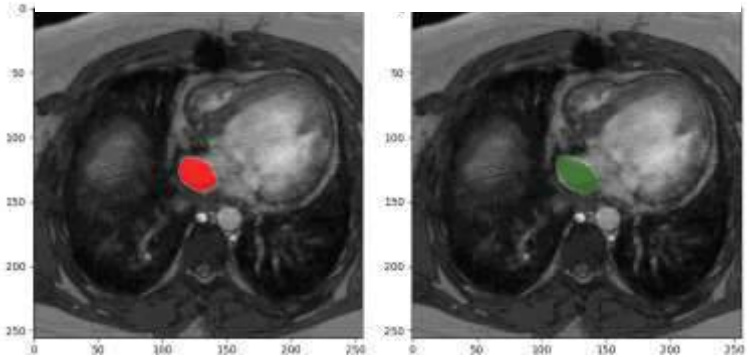


Autonomous AI/DL pipeline for 2D flow

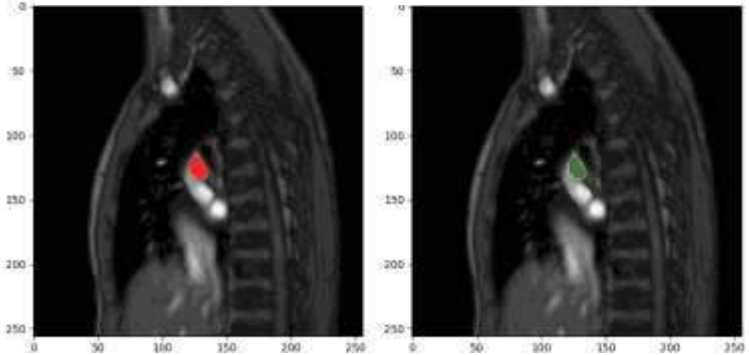
AI SVC Human



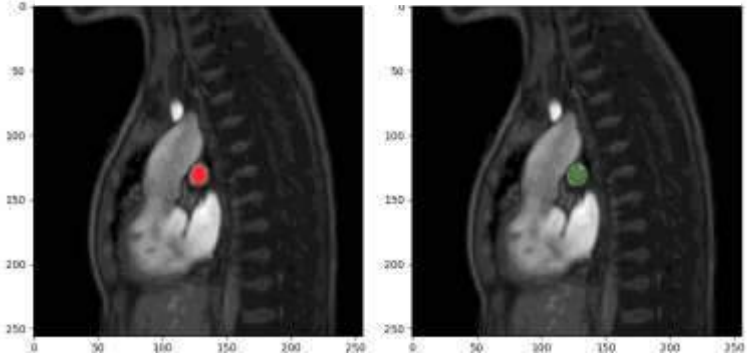
AI Fontan Human



AI RPA Human



AI LPA Human

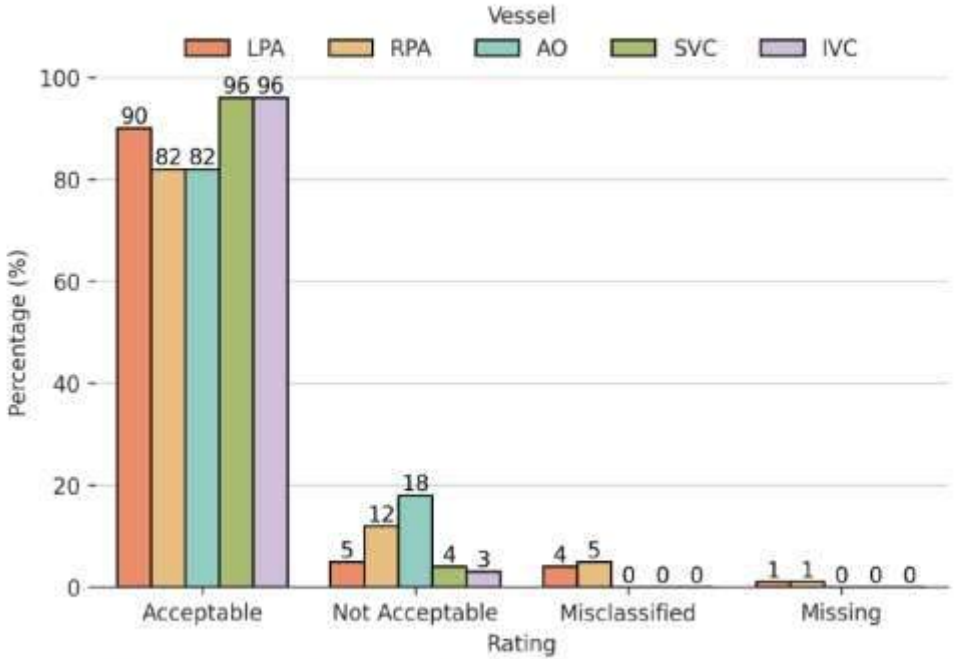


Early validation of AI/DL for 2D flow is promising

Test pipeline on 1987 patient exams

Qualitatively assessed pipeline segmentation

FORCE Registry

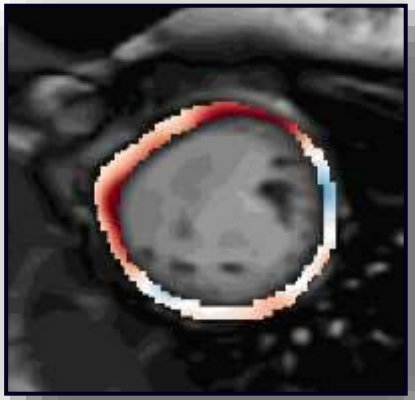


Classification Success = 98%

Segmentation Success = 89%

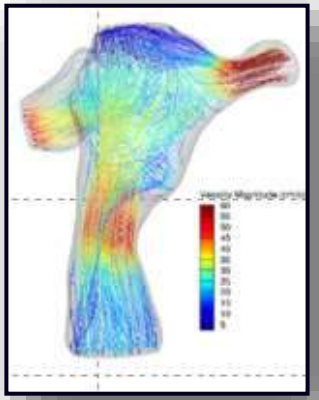
AI = artificial intelligence; DL = deep learning

Other AI/DL pipelines in progress

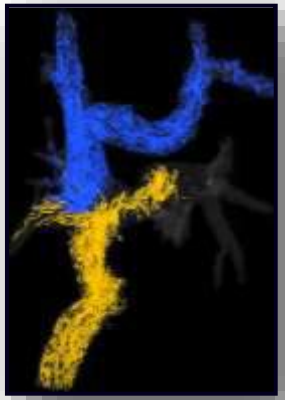


Ventricular Strain

3D Fontan + PA Segmentation



CFD Modeling



4D Flow

CFD = Computational Fluid dynamics

Why is this important?

- To be a research platform, efficient centralized infrastructure and processes are essential
  - Our data sources (especially the CMR images) are complex and often too big for researchers to digest
  - There are many common image post-processing needs for research projects
- This infrastructure will facilitate and accelerate the number of centers and researchers who can exploit this very large and rich dataset

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FORCE research studies in progress

1. CMR Phenotyping after TCPC using hierarchical cluster analysis
2. Expected Volume and Functional Data for Fontan Patients by CMR. Does Ver
3. Automa investig
4. Single irculation – The E
5. Validati Predict Outcom e
6. Predictors of Supranormal Exercise Capacity in Fontan Patients (high-performing Fontan)
7. Associations between cardiac magnetic resonance-derived myocardial fibrosis and hepatic/splenic fibrosis
8. Function, Flow and Follow up in Fontan (F4 CMR) Study
9. Methodol
10. Ventric ng
11. Ventric ne
12. Definin Statistical Shape
13. Predicto
14. A machine learning 3D segmentation data pipeline for Fontan baffles and pulmonary arteries
15. Native versus reconstructed aortas in Fontan patients: impact on ricular function using 4D flow
16. Predictors of Diastolic Dysfunction in Fontan
17. Creation of a robust risk prediction score for death/transplant
18. Predi Single Vent
19. Delin ardiac Cond
20. Eval tion with clinic
21. A Paradi Connection
22. Fenestration Status in Fontan patients and its association with clinical outcomes
23. Atrioventricular valve regurgitation in Fontan patients and the association with hemodynamics and outcomes
24. Impact of right ventricular-dependent coronary arteries in patients with Fo
25. Multi al Arterial Hem omes
26. Direc ion using 4D flow
27. ECG ients
28. Extracar anges over time and affects clinical outcomes
29. Automated segmentation of the Fontan aorta in 4D Flow MRI using deep learning
30. Intracardiac Flow Analysis of the Single Ventricle in Fontan patients

34 Studies

4 Papers

18 Abstracts

5 Papers under review

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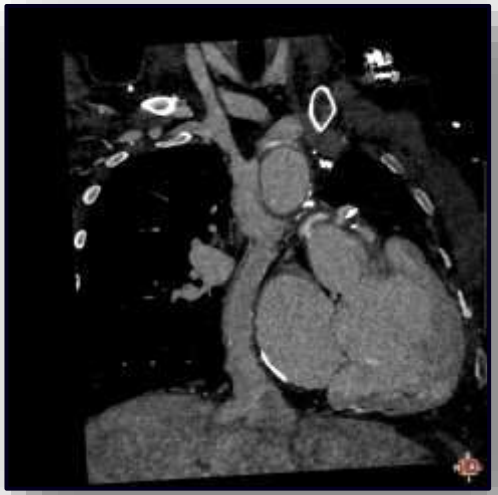
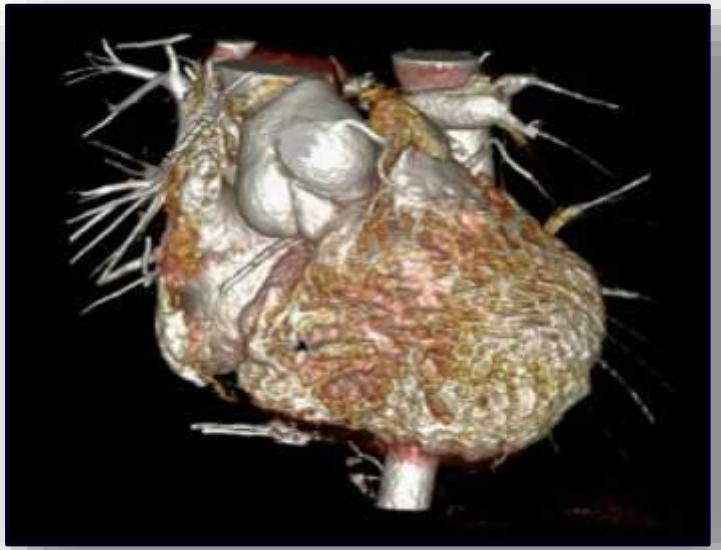
Fontan **O**utcome **R**egistry using **C**MR **E**xaminations

FORCE Expansion: Cardiac CT

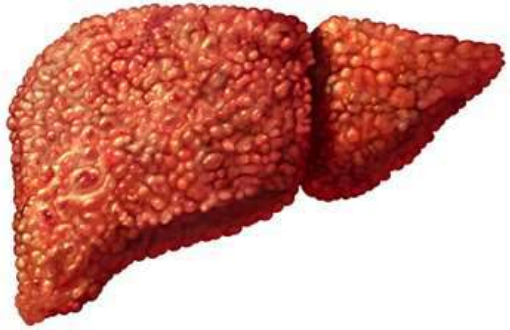
- FORCE registry to include patients with a Cardiac CT (CCT)
- New CCT module with targeted data points + image upload
- Addresses important selection bias
- Introduces new topics for research studies

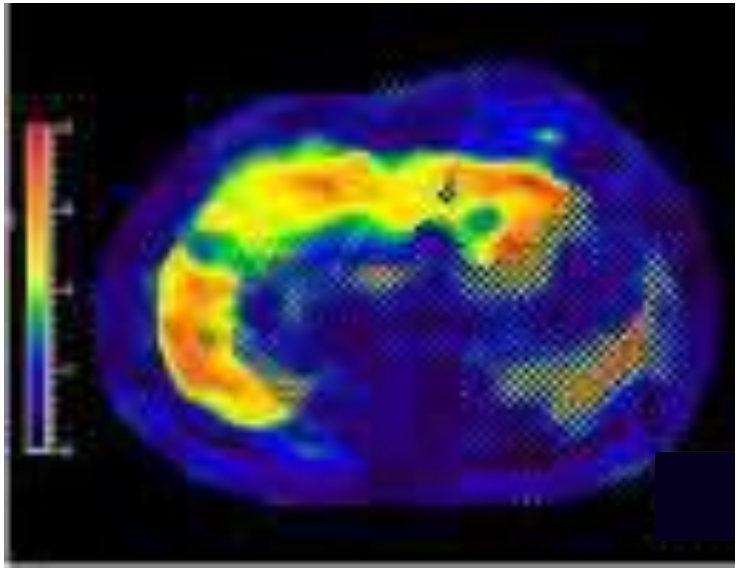




FORCE Expansion: FALD

- Tremendous clinical and scientific interest in Fontan-associated liver disease (FALD)
- New FALD module that includes targeted data points + image upload
  - MRI + CT liver
  - MR + Ultrasound elastography





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Conclusions

- FORCE AI tools enable
  - Considerable time savings
  - Reproducible, consistent analyses, and derivative data
- Unparalleled opportunities for research with large, robust datasets
- Demonstrates the power of collaboration
- FORCE is a mission-directed research platform aimed at accelerating scientific discovery to improve the lives of patients with single ventricle heart disease

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Thank You

rahul.rathod@childrens.harvard.edu

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