Le Bonheur Children's Hospital
Methodist Healthcare Family

3D Fusion: What Do I Need From MRI to Perform Fusion?

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Le Bonheur Children's Hospital
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Disclosures

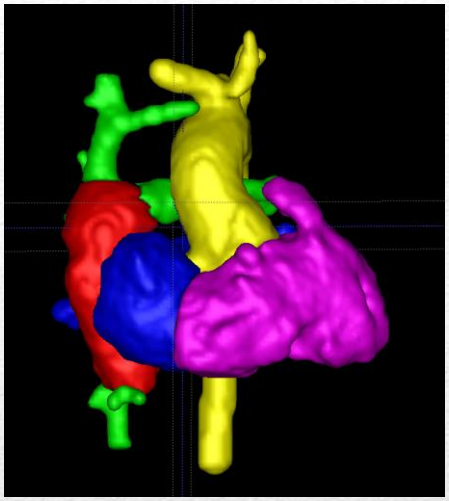
I have no financial relationships with any commercial interest related to the content of this presentation.

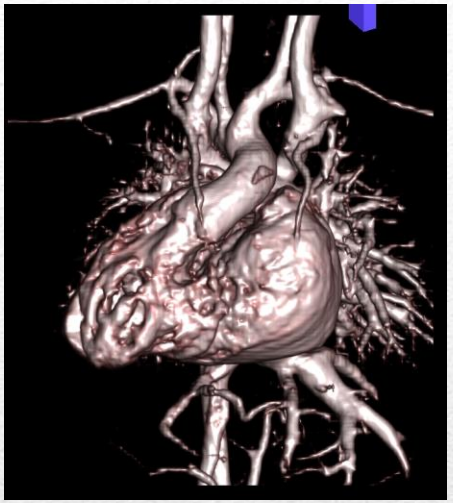
Definitions

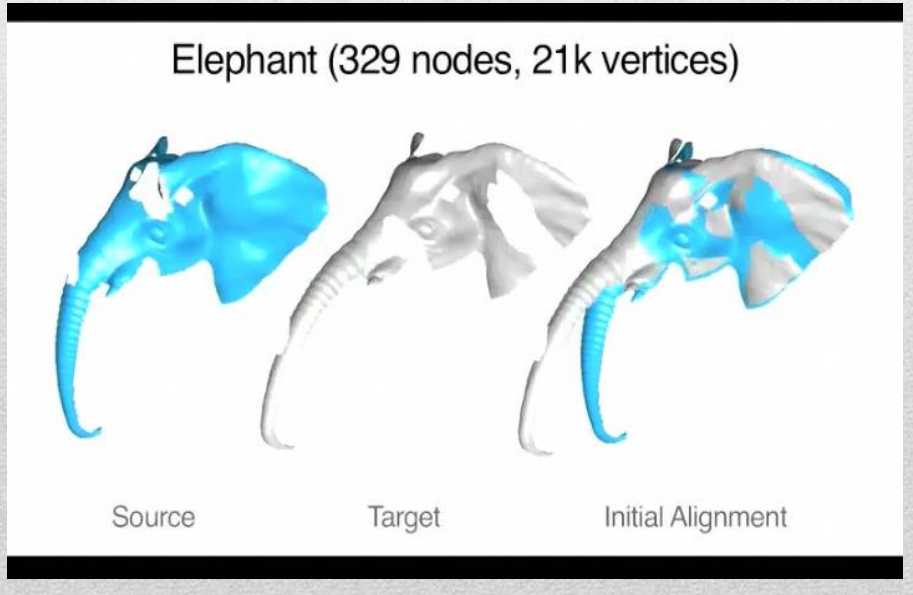
- Segmentation - Process of partitioning a digital image into multiple segments.

- Volume rendering - Techniques used to display a 2D projection of a 3D data.

- Registration - Process of transforming different sets of data into one coordinate system.





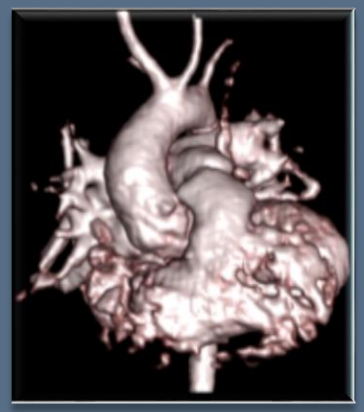


Reason For MR Fusion

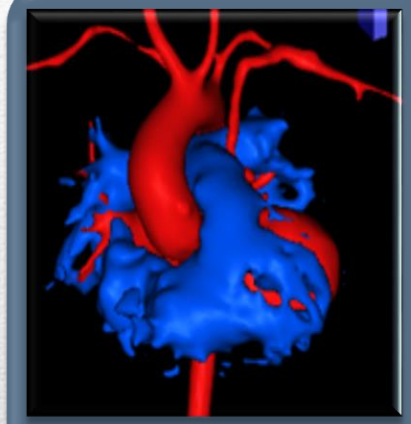
- No radiation required to obtain CMR
- Increasing use of MR for complex CHD
- Procedures are becoming more complex

- 3D overlay potential:
  - Reduce radiation, procedure time, and contrast load
  - Improve outcome
  - Allow for more complex procedures
  - Increase physician confidence

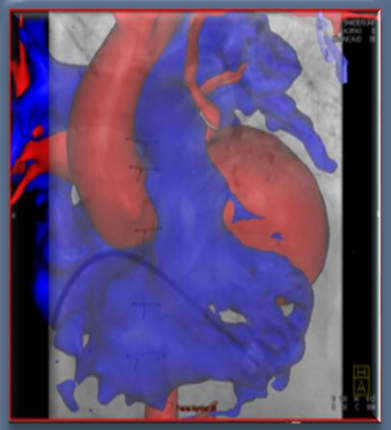
MR Fusion - Workflow



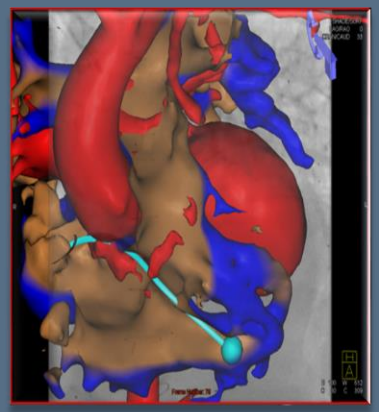
MRI acquisition



Segmentation And VR

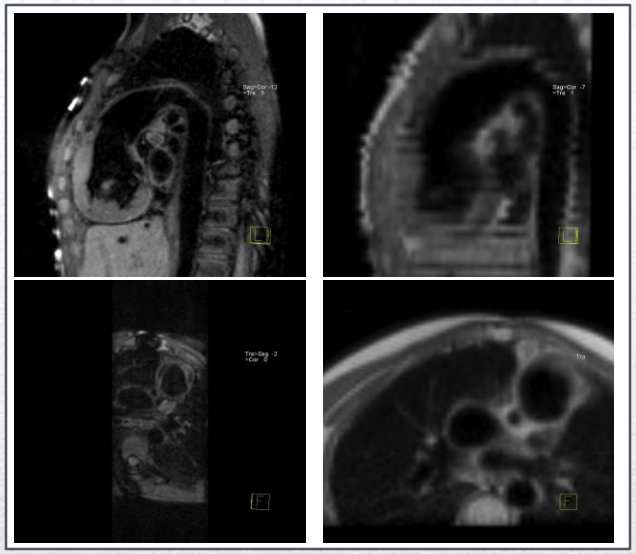


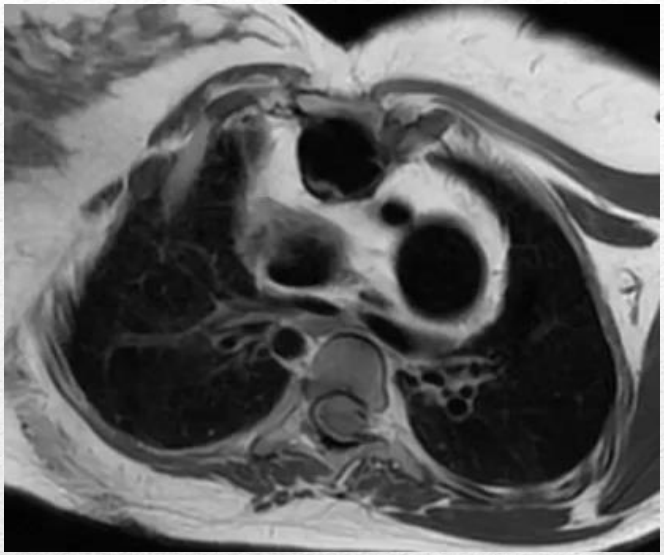
2D/3D Registration to Fluro

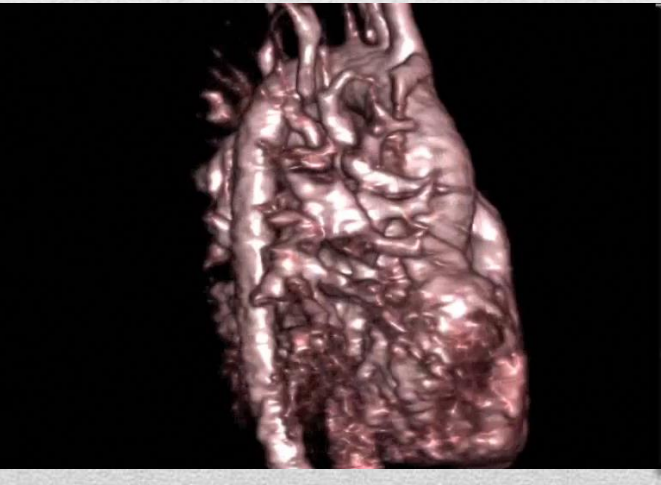


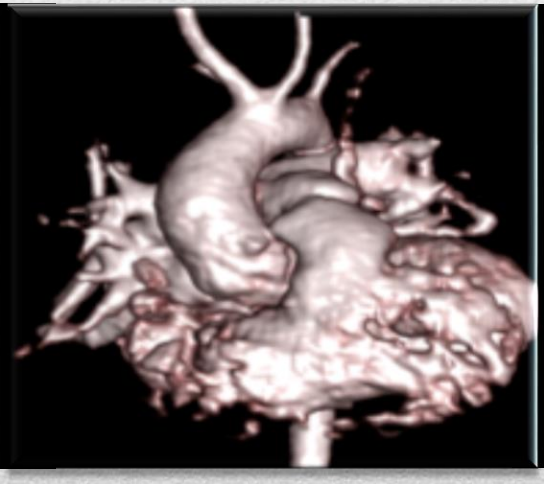
Visualization

High Resolution 3D Dark Blood Sequence









Ungated | Averaged | Gated

MRI acquisition → Segmentation → Registration → Visualization

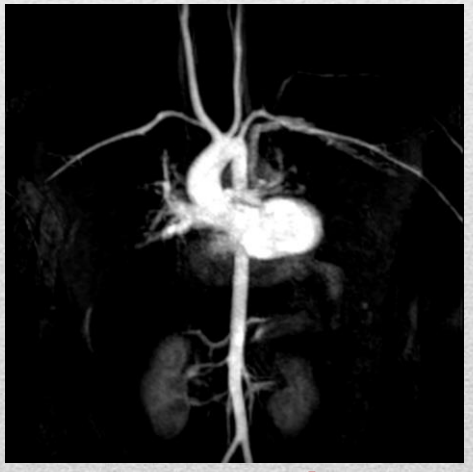
MRA Acquisition

Twist: (Time-resolved angiography With Interleaved Stochastic Trajectories) is a time-resolved 3D MRA technique with very high temporal (sub-second) resolution which will allow to capture the arterial, mixed and venous phase images during the passage of a contrast agent through the vascular anatomy.

✓ Good temporal resolution (sub-second) allows for separating right and left side

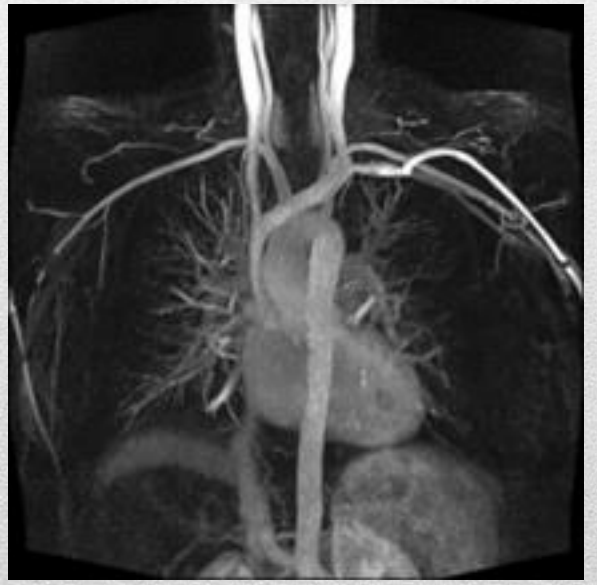
✗ Not gated

✗ Lower spatial resolution (sub-millimeter)



Twist right

Twist left

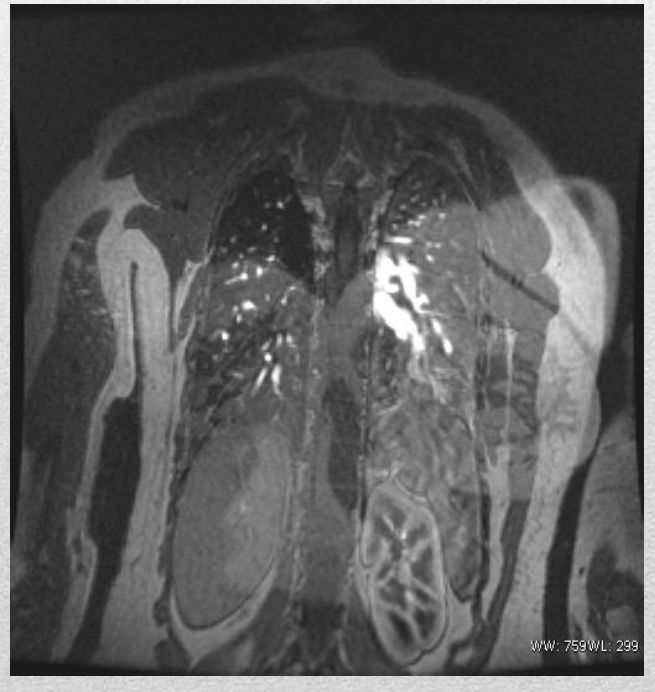


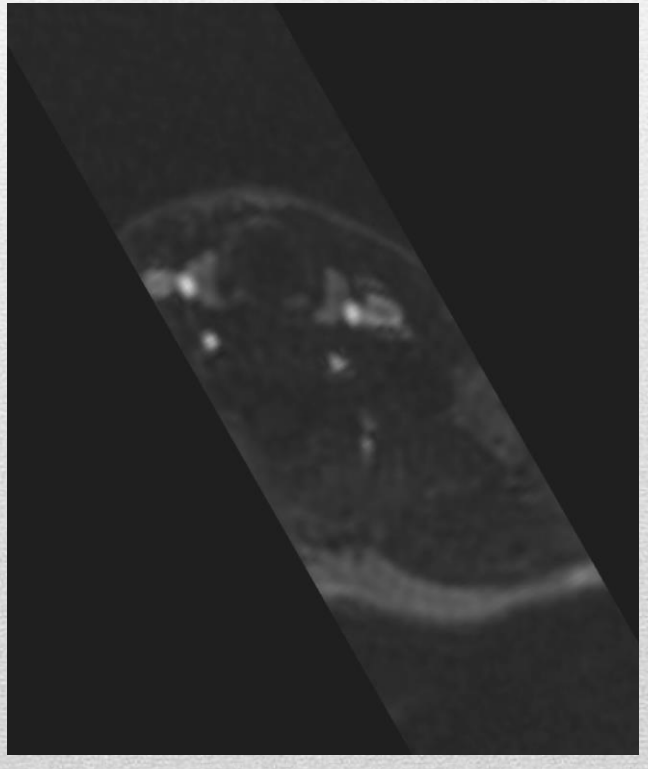
Parameter: TR 3 ms, TE 1 ms, flip angle 25°
FOV 250-400 mm, isotropic voxel -1.0 mm

MRI acquisition → Segmentation → Registration → Visualization

Bolus Triggered 3D MRA:

- ✓ Good temporal and spatial resolution
- ✓ Focus region of interest without losing critical information
- ✓ Gadolinium: 0.2 mmol/kg (0.4 ml/kg) @1.5 ml/sec
- ✗ Breath hold
- ✗ Non-ECG gated



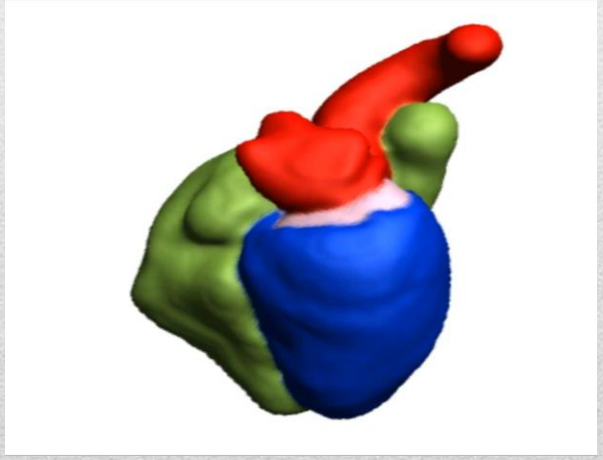


MRI acquisition → Segmentation → Registration → Visualization

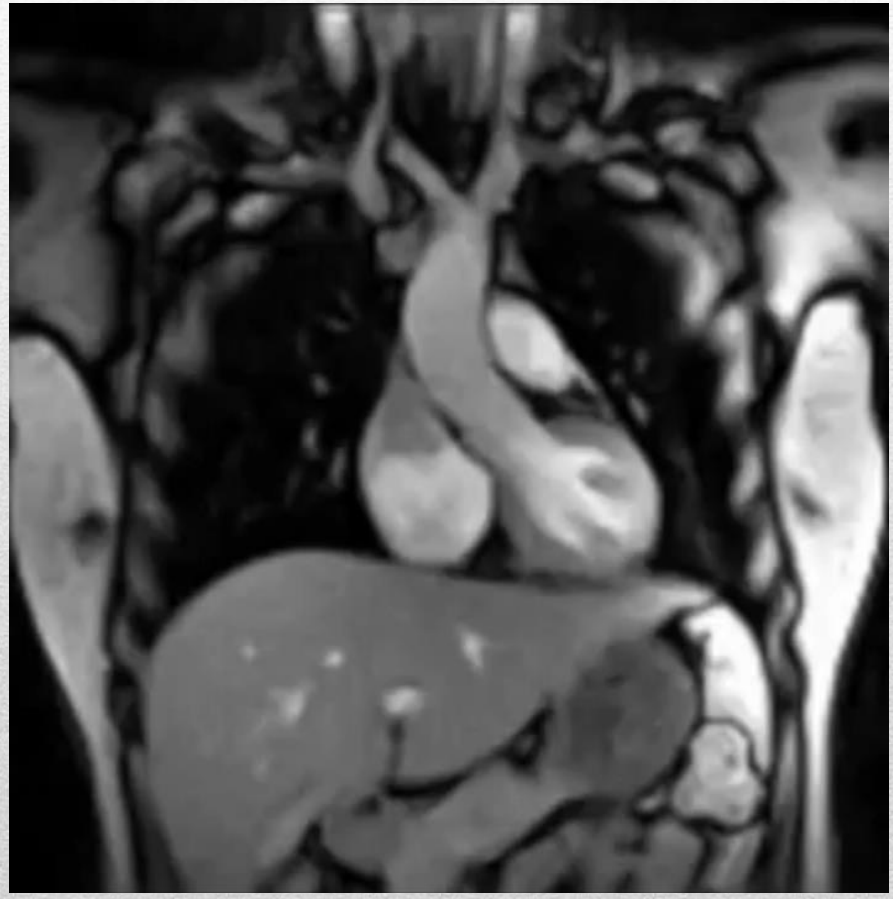
MRA Acquisition

Navigator gated 3D IR (Inversion Recovery) Flash sequence:

- ✓ High spatial but lower temporal resolution
- ✓ ECG and respiration gated
- ✓ Useful for real time MRI guided procedures
- ✗ Hard to separate right and left side



Isotropic voxels of 1.0 to 1.3 mm, TE 1.6 msec, TI 260 msec, and flip angle of 18 degrees.

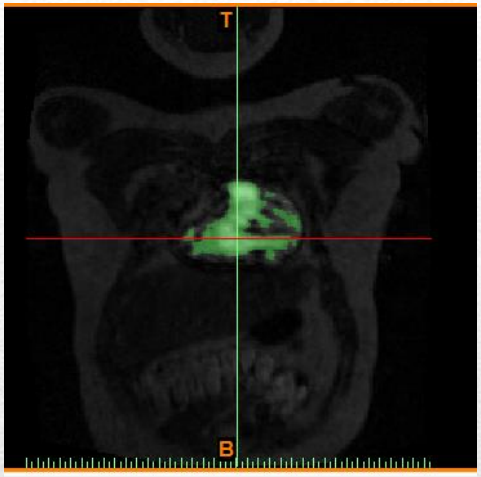


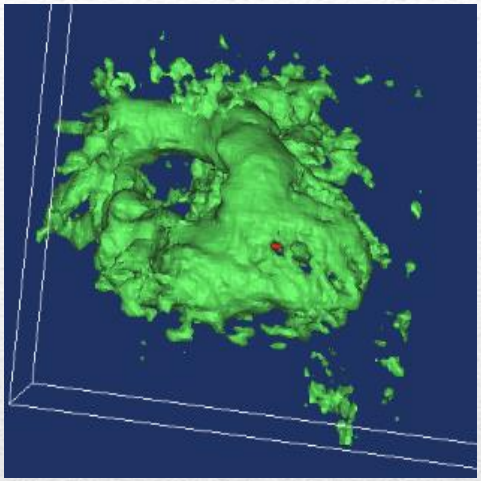
MRI acquisition → Segmentation → Registration → Visualization

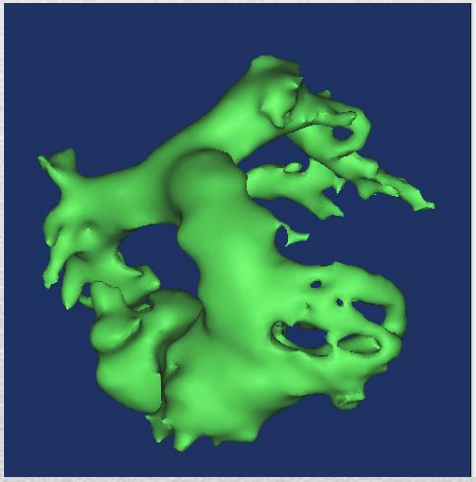
Segmentation

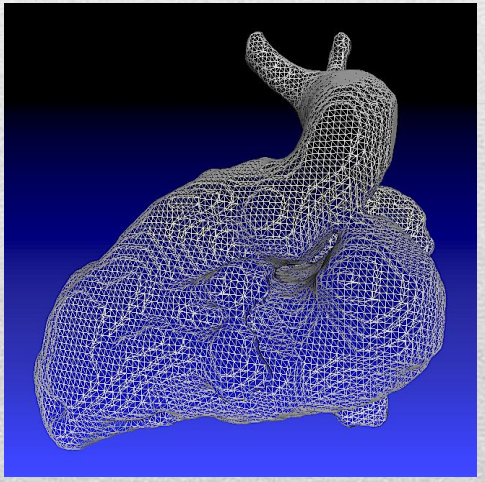
Using Mimics (Leuven, Belgium)

- Define a threshold
- Crop ROI
- Edit mask in 3D
- Smooth
- Export mask as surface model





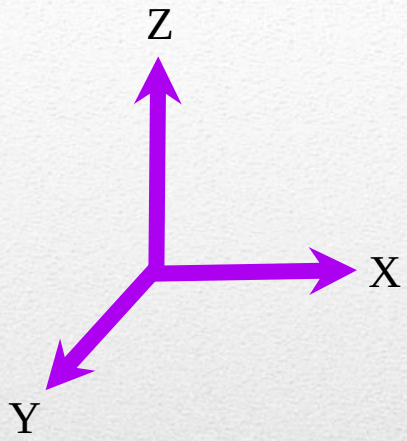




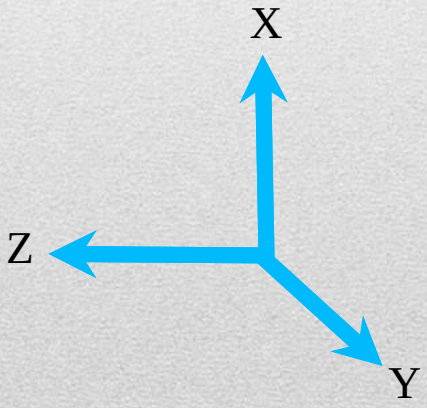
MRI acquisition → **Segmentation** → Registration → Visualization

Registration – Axis alignment

X-ray axis



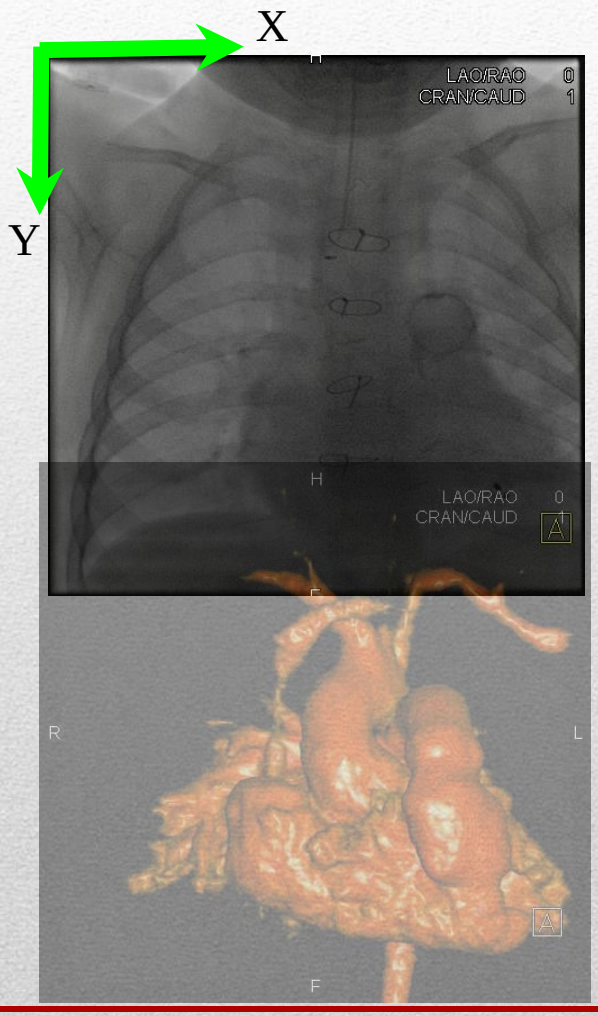
MRI axis



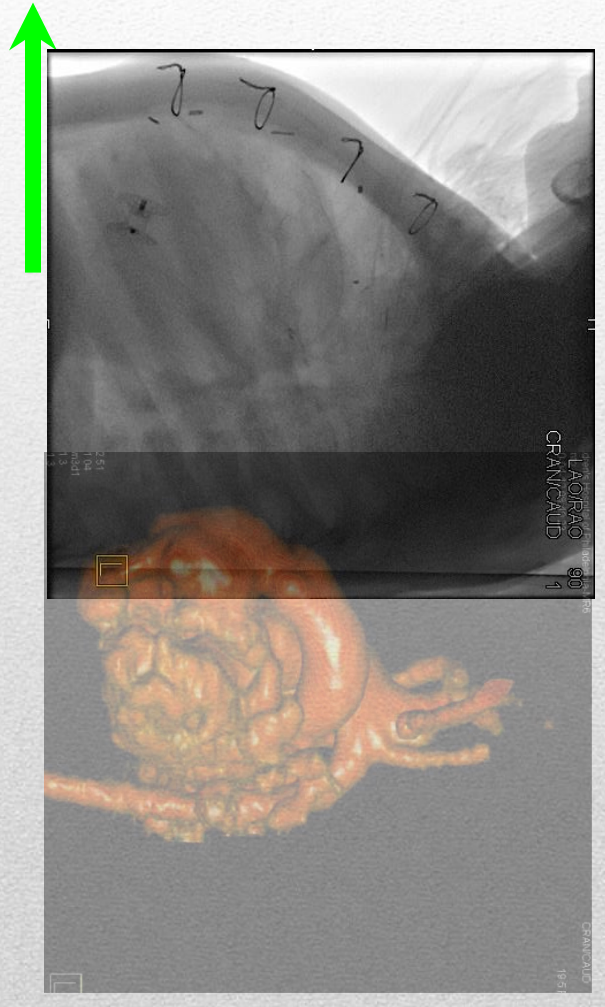
MRI acquisition → Segmentation → Registration → Visualization

Biplane 2D/3D Visual Matching Registration

AP projection

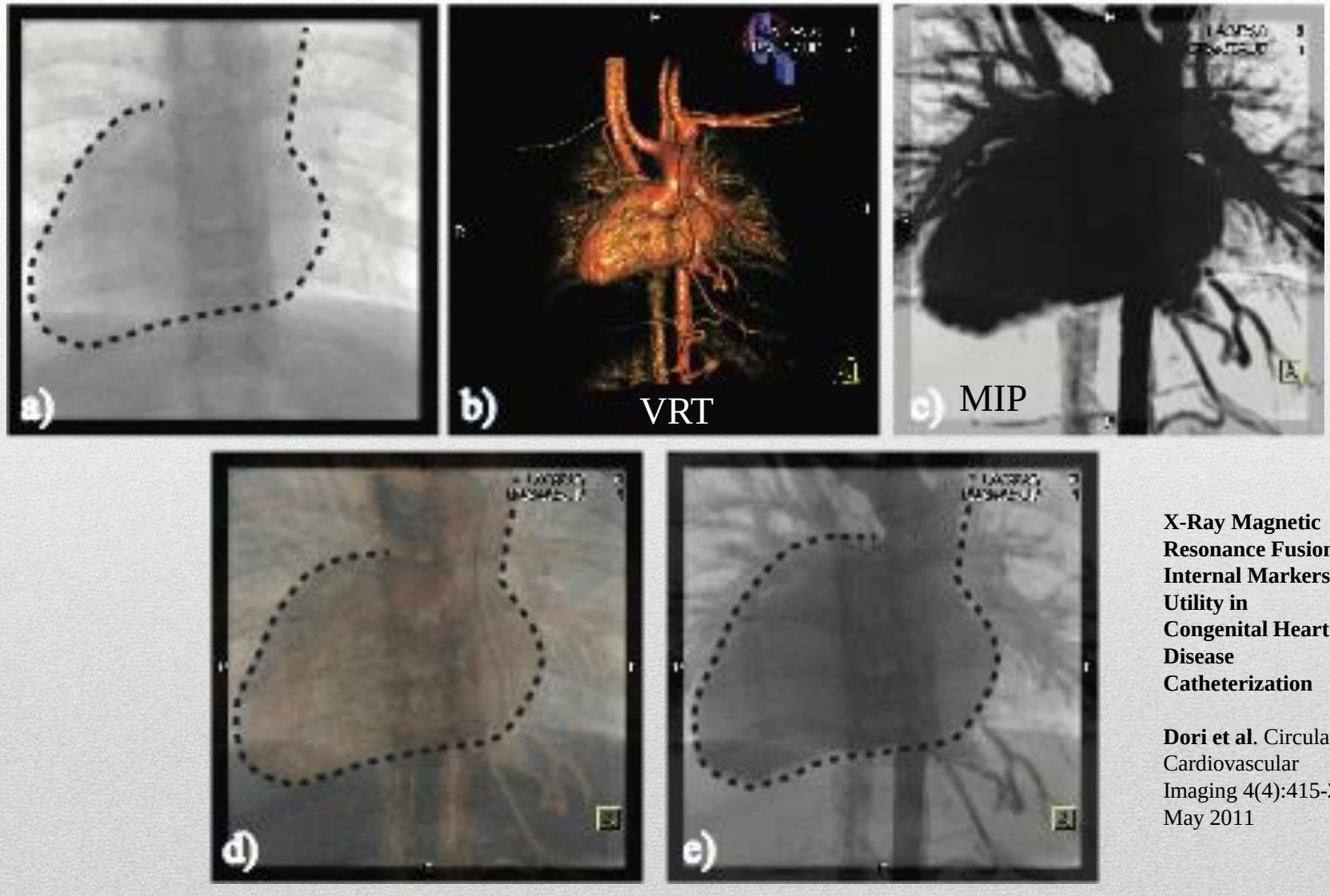


Lateral projection



MRI acquisition → Segmentation → Registration → Visualization

Internal Markers - Vessel Borders

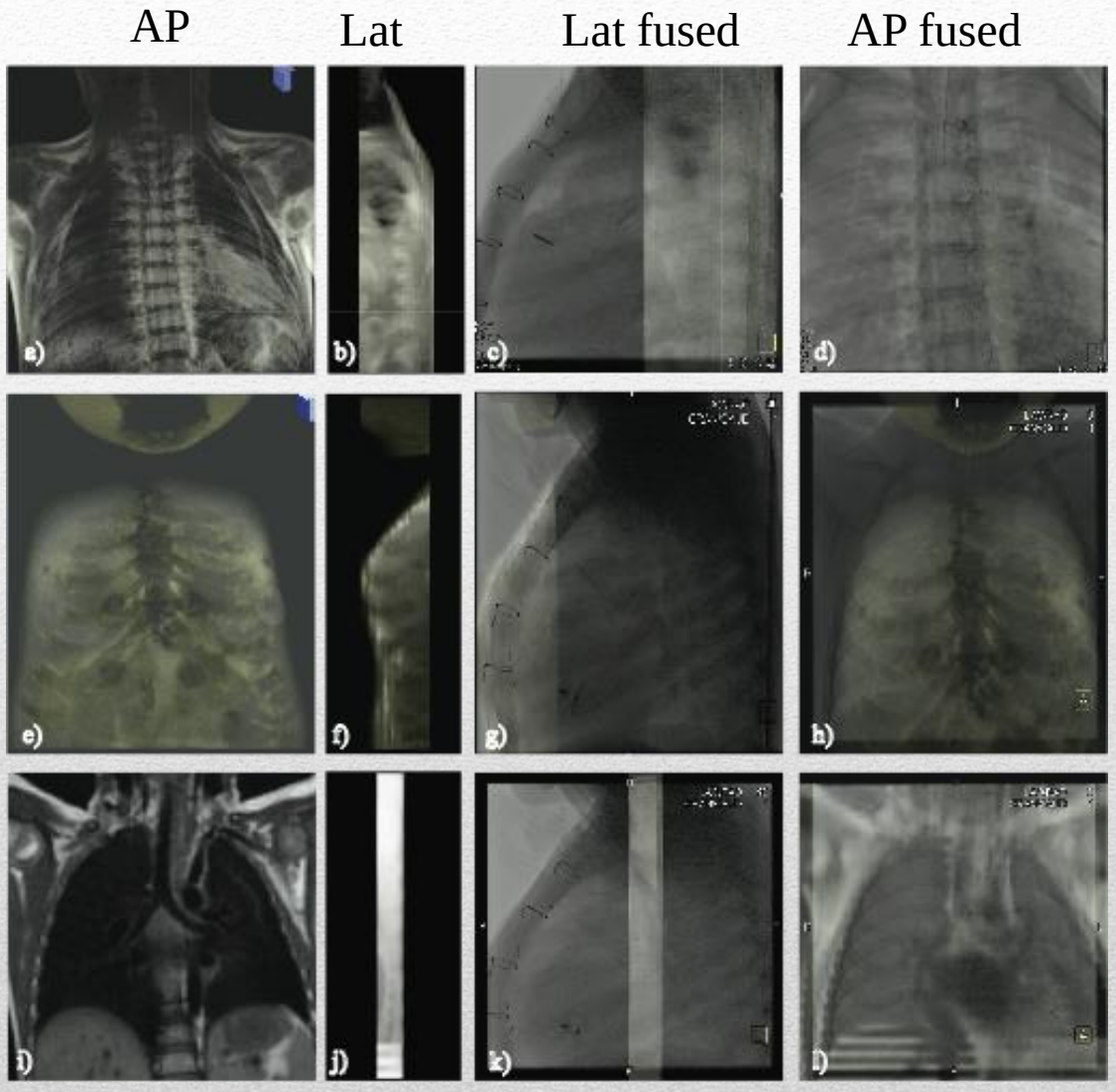


X-Ray Magnetic Resonance Fusion to Internal Markers and Utility in Congenital Heart Disease Catheterization

Dori et al. Circulation Cardiovascular Imaging 4(4):415-24 · May 2011

MRI acquisition → Segmentation → Registration → Visualization

Internal Markers - Bone and Airway



X-Ray Magnetic Resonance Fusion to Internal Markers and Utility in Congenital Heart Disease Catheterization

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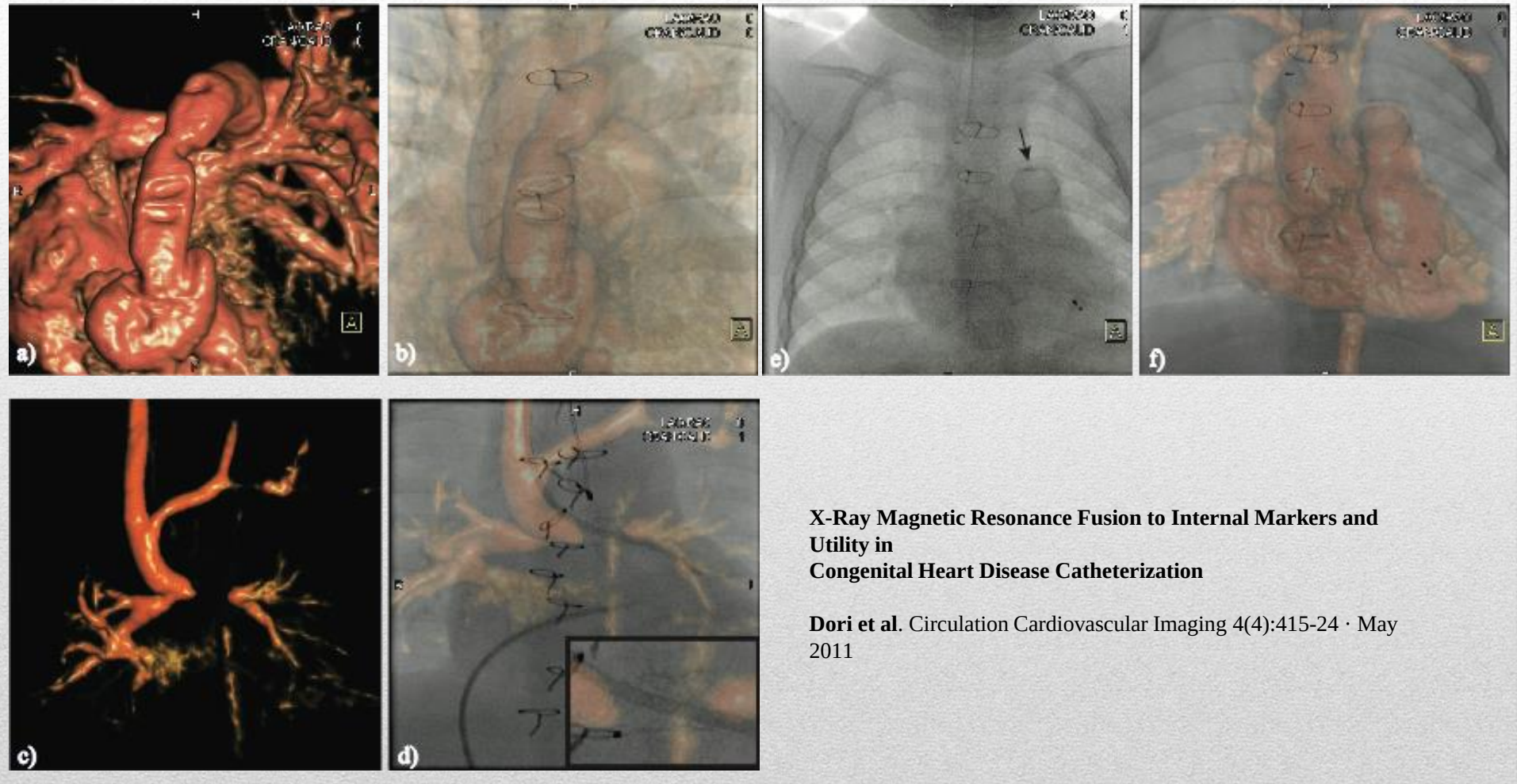
MRI acquisition → Segmentation → Registration → Visualization

Internal Markers - Imaging Artifact and Calcification

Artifact

Calcification



X-Ray Magnetic Resonance Fusion to Internal Markers and Utility in
Congenital Heart Disease Catheterization

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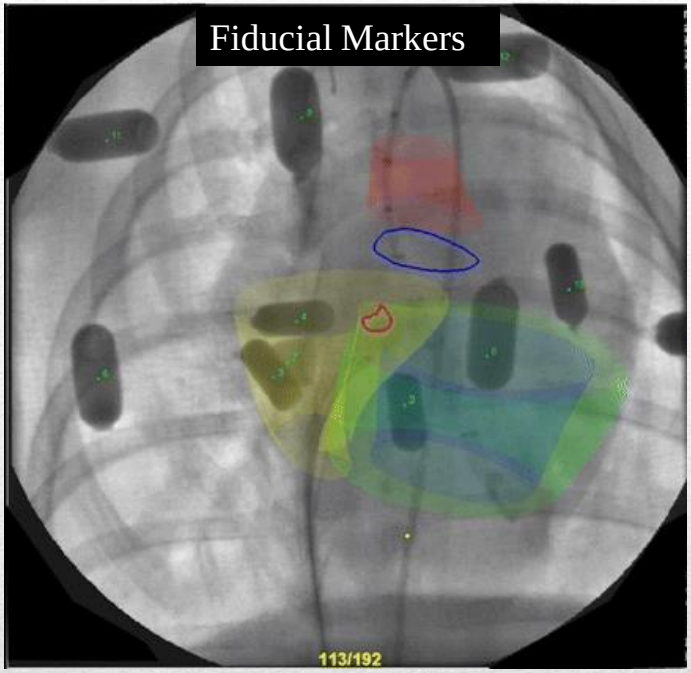
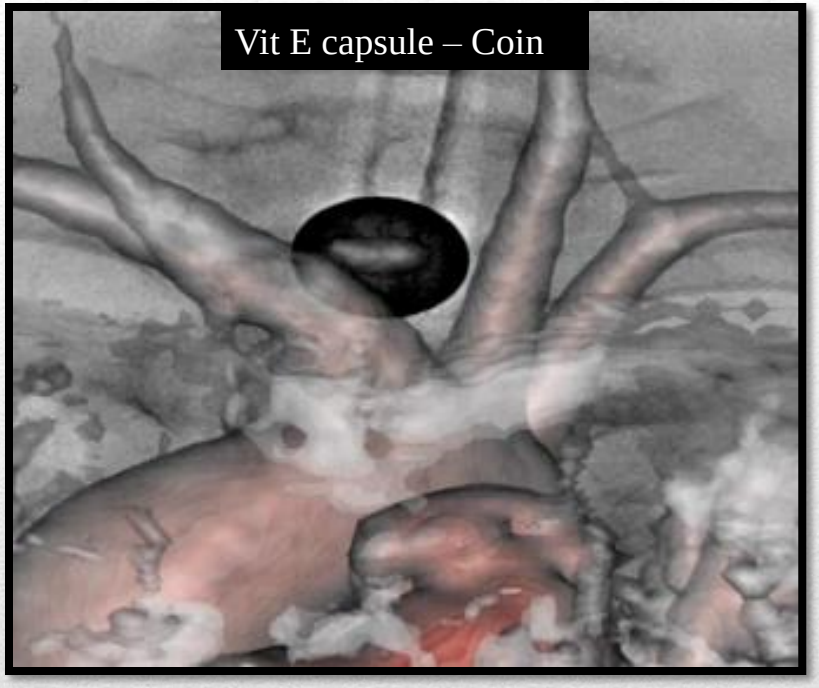
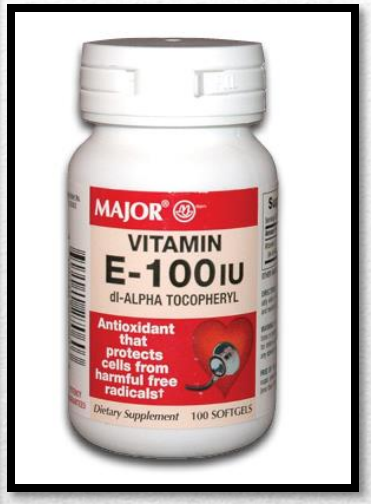
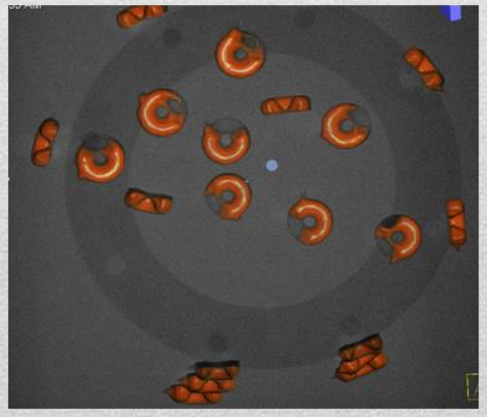
MRI acquisition → Segmentation → Registration → Visualization

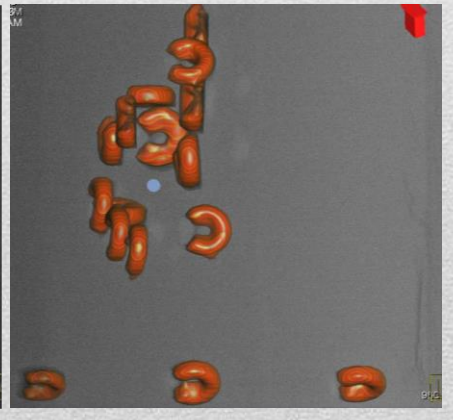
External Markers











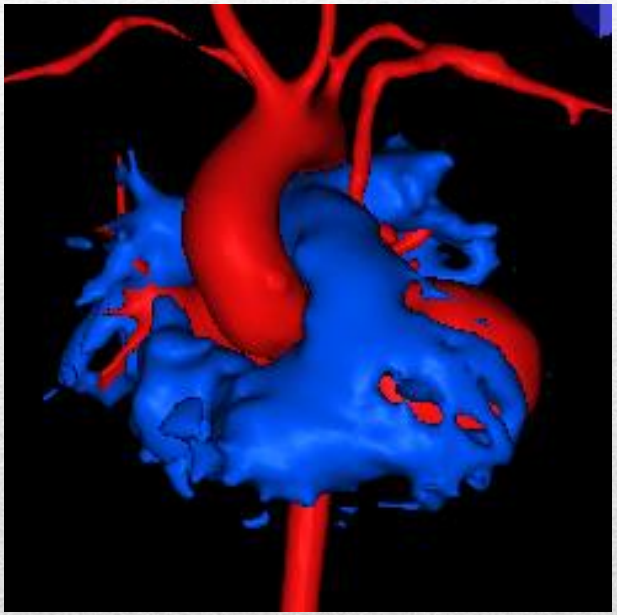
♥dual-modality markers

MRI acquisition → Segmentation → Registration → Visualization

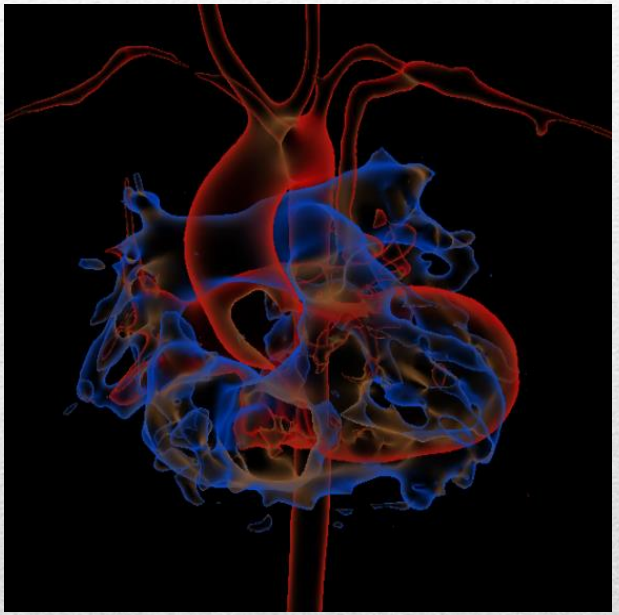
Visualization

Volume rendering
of MRI data set (voxel)

Solid rendering
of surface model



Contour rendering
of surface model



MRI acquisition → Segmentation → Registration → Visualization

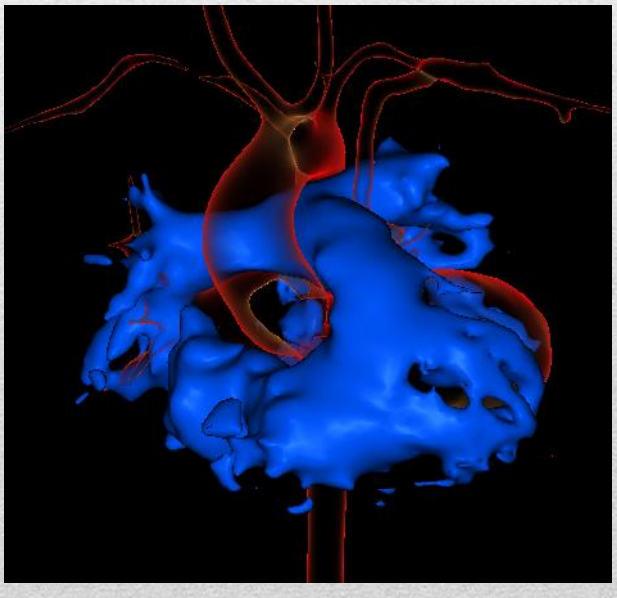
Visualization

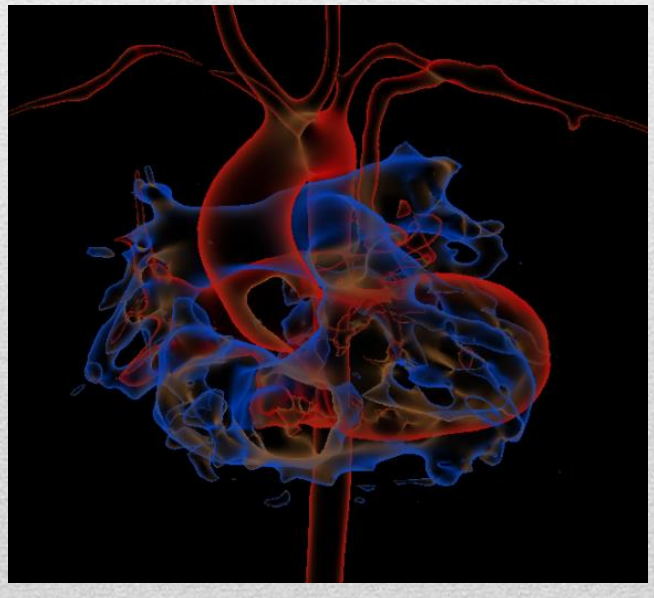
Solid rendered surface models:

- ✓ Allows for 3D relation between ostia and vessel
- ✓ Use carving to see the interior surface of the heart

Contour rendered surface models:

- ✓ See through relation
- ✓ Useful for smooth structures

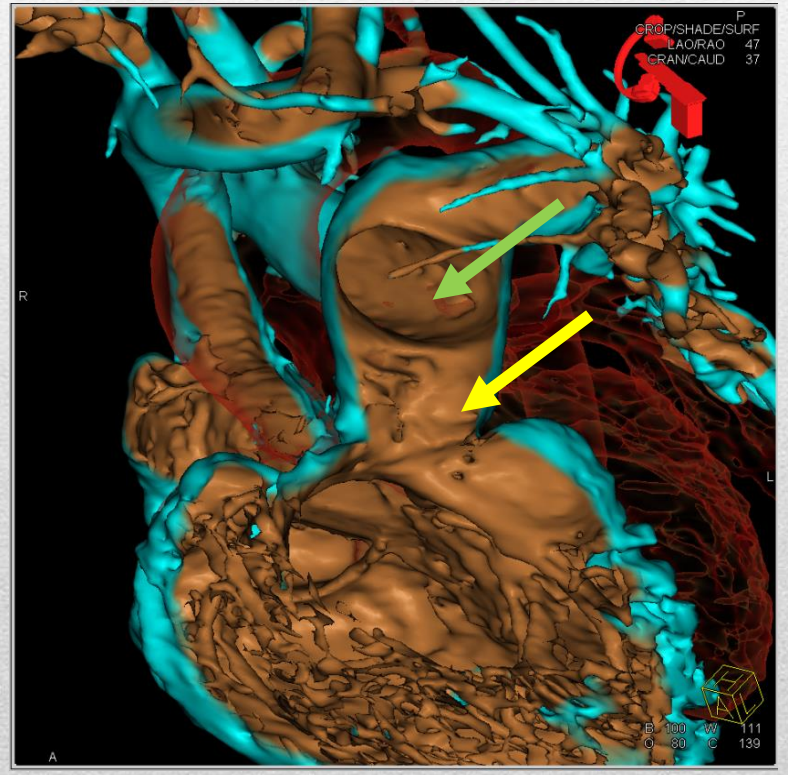


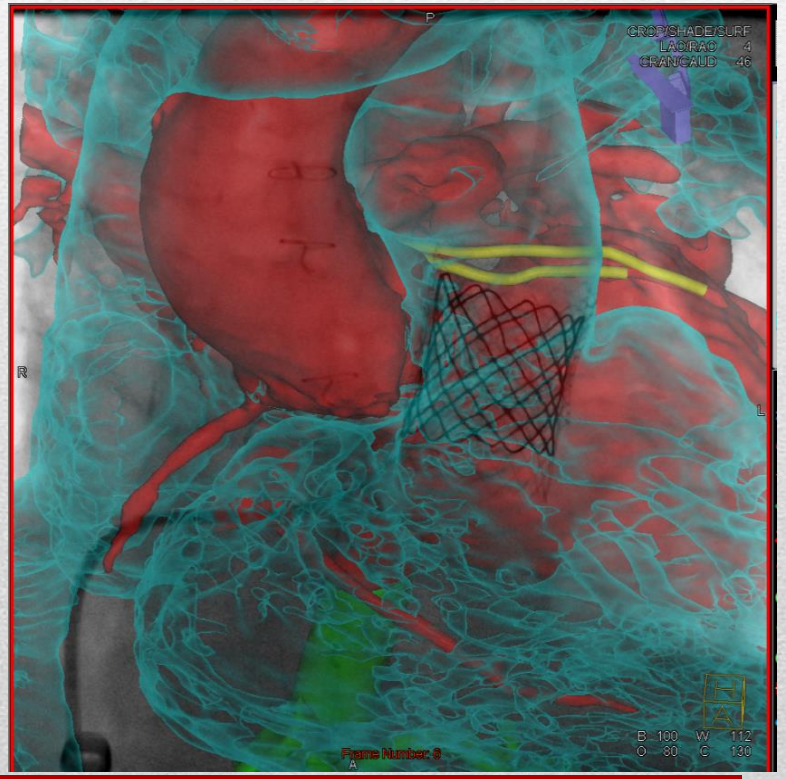


MRI acquisition → Segmentation → Registration → Visualization

Visualization

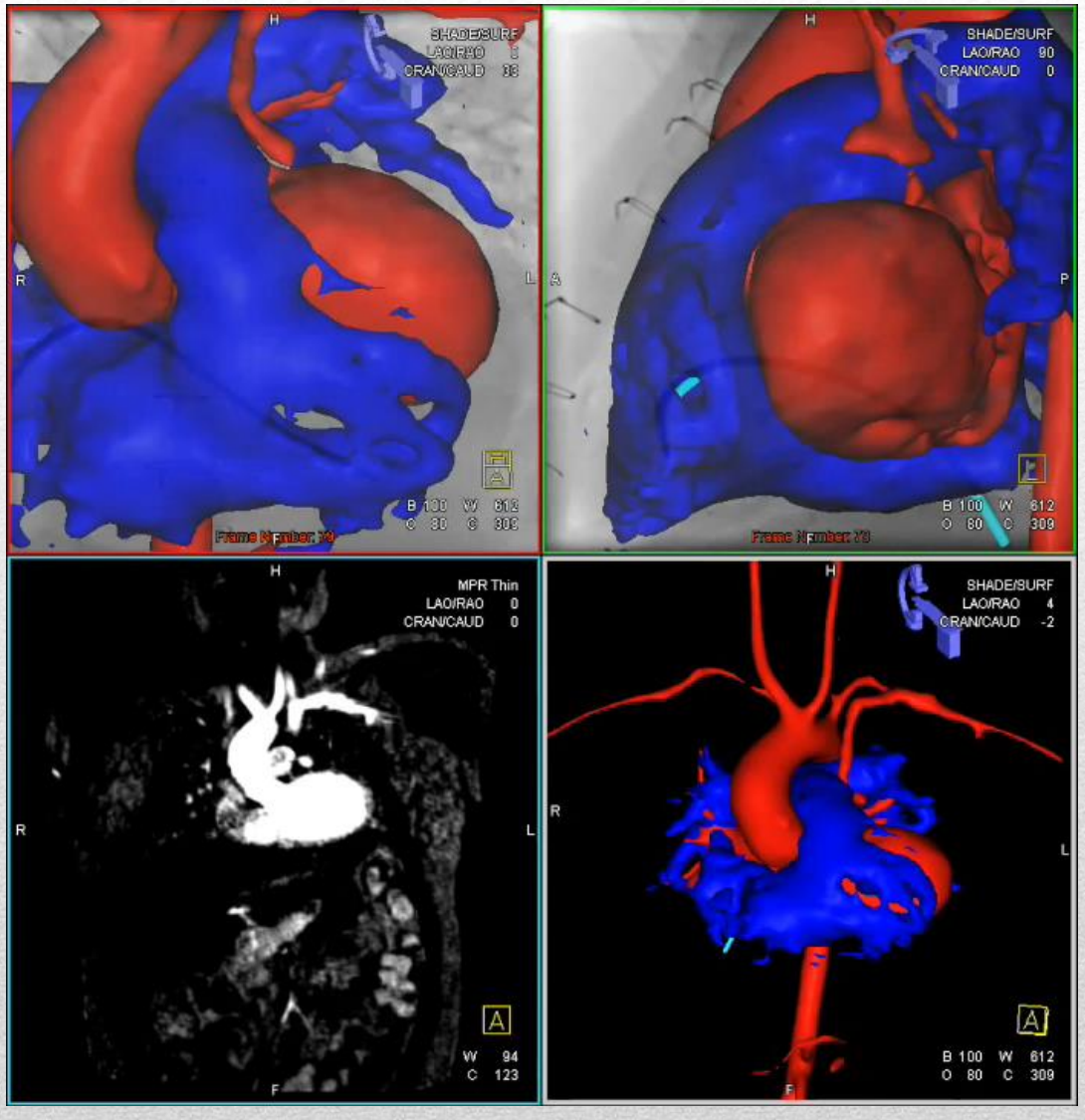
- Surface rendered models with carving provides an optimal display of complex 3D anatomy and internal anatomy
- Contour rendering in combination with solid rendered structures to get a see through 3D relation





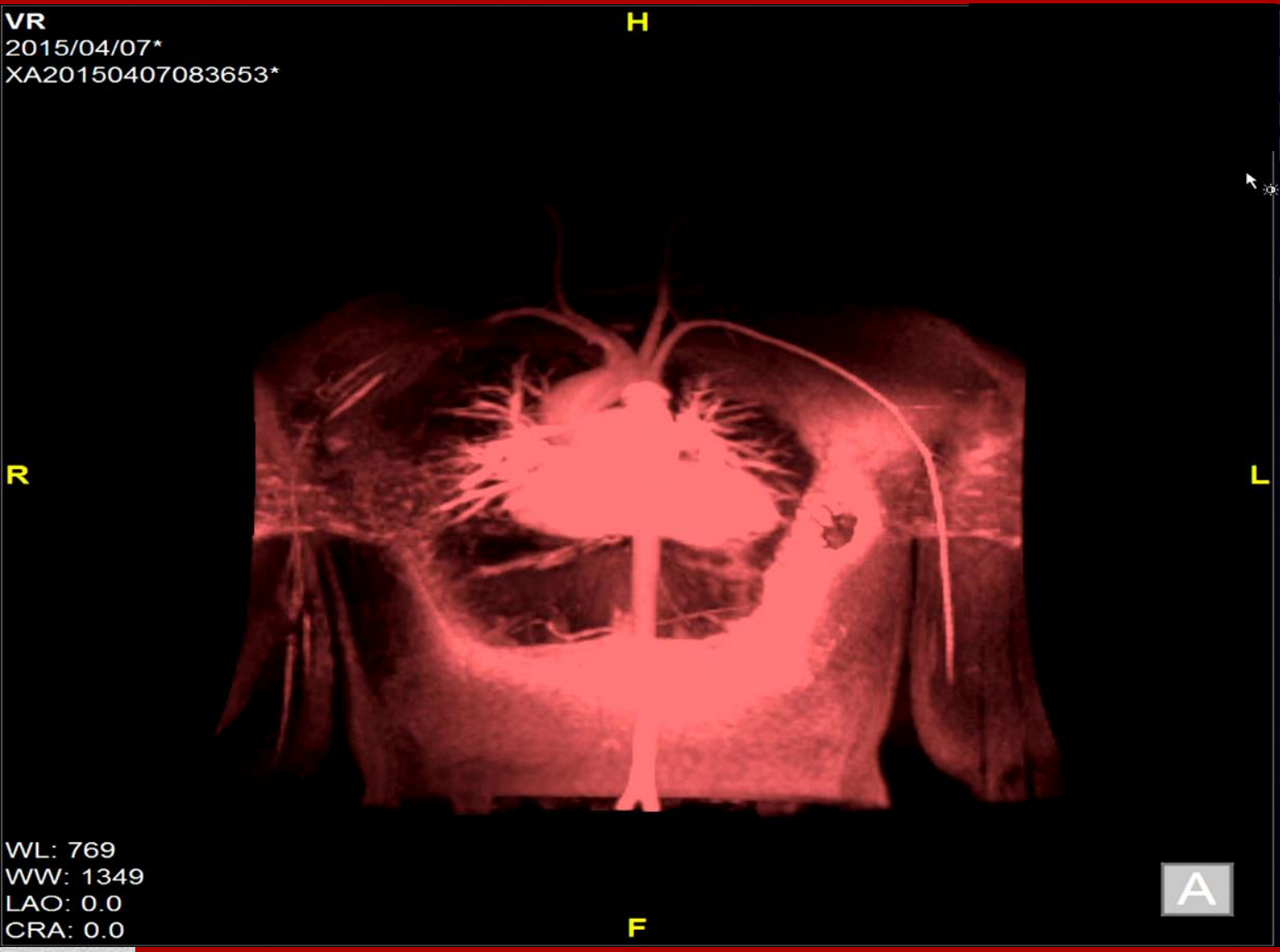
MRI acquisition → Segmentation → Registration → Visualization

Visualization



MRI acquisition → Segmentation → Registration → Visualization

MR Fusion – Segmentation & Registration

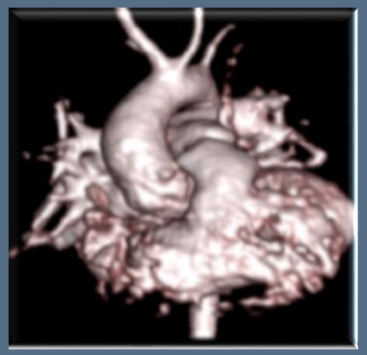


MRI acquisition → Segmentation → Registration → Visualization

MR Fusion – Segmentation & Registration

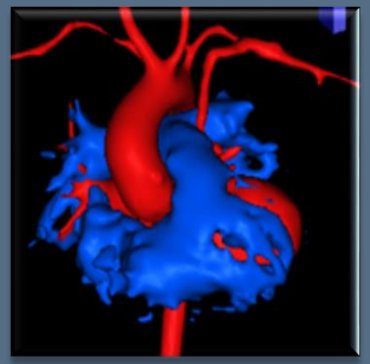
MRI acquisition → Segmentation → Registration → Visualization

Time From MRI to End of Registration



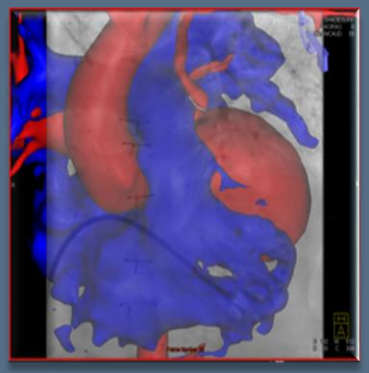
MRI/MRA acquisition

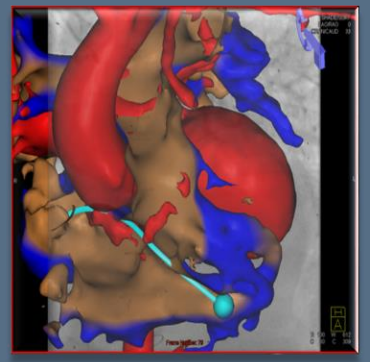
~ 30 minutes



Registration performed without:

- Contrast
- Additional radiation exposure
- Fiducial markers



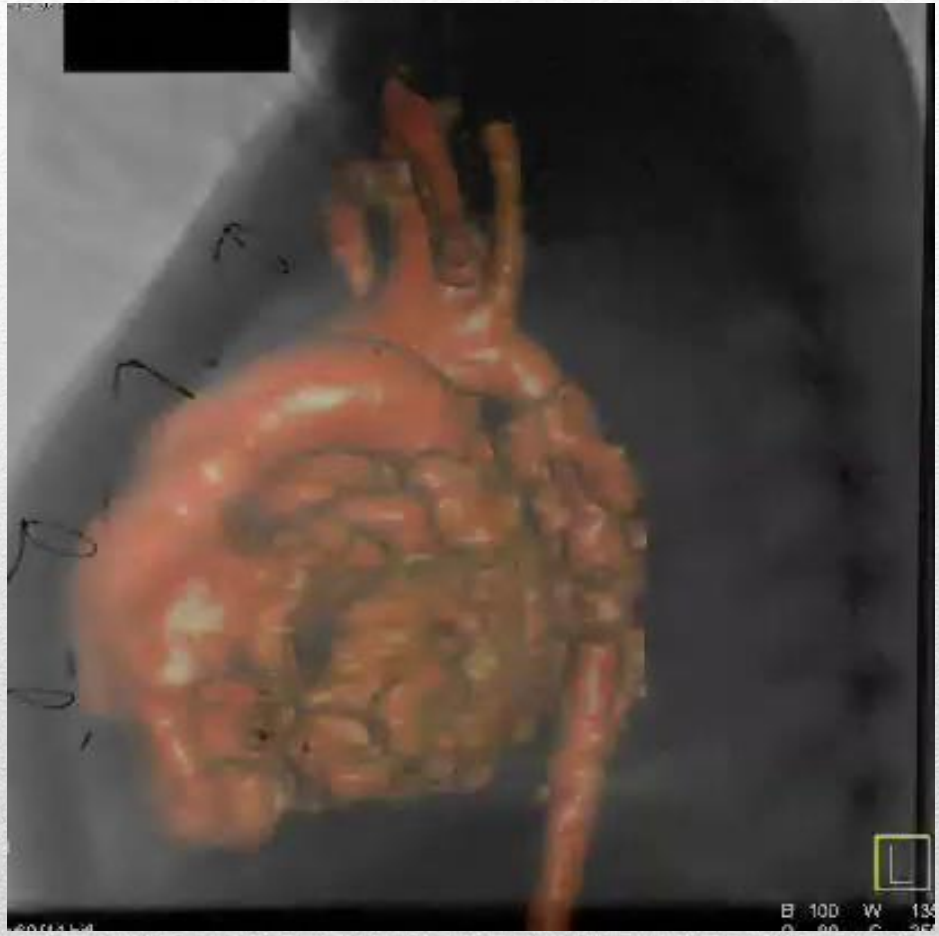


Visualization

as needed

MRI acquisition → Segmentation → Registration → Visualization

Utility of MR Fusion



- Interventional Planning
- Camera angle selection
- Radiation reduction
- Device positioning
- Roadmapping

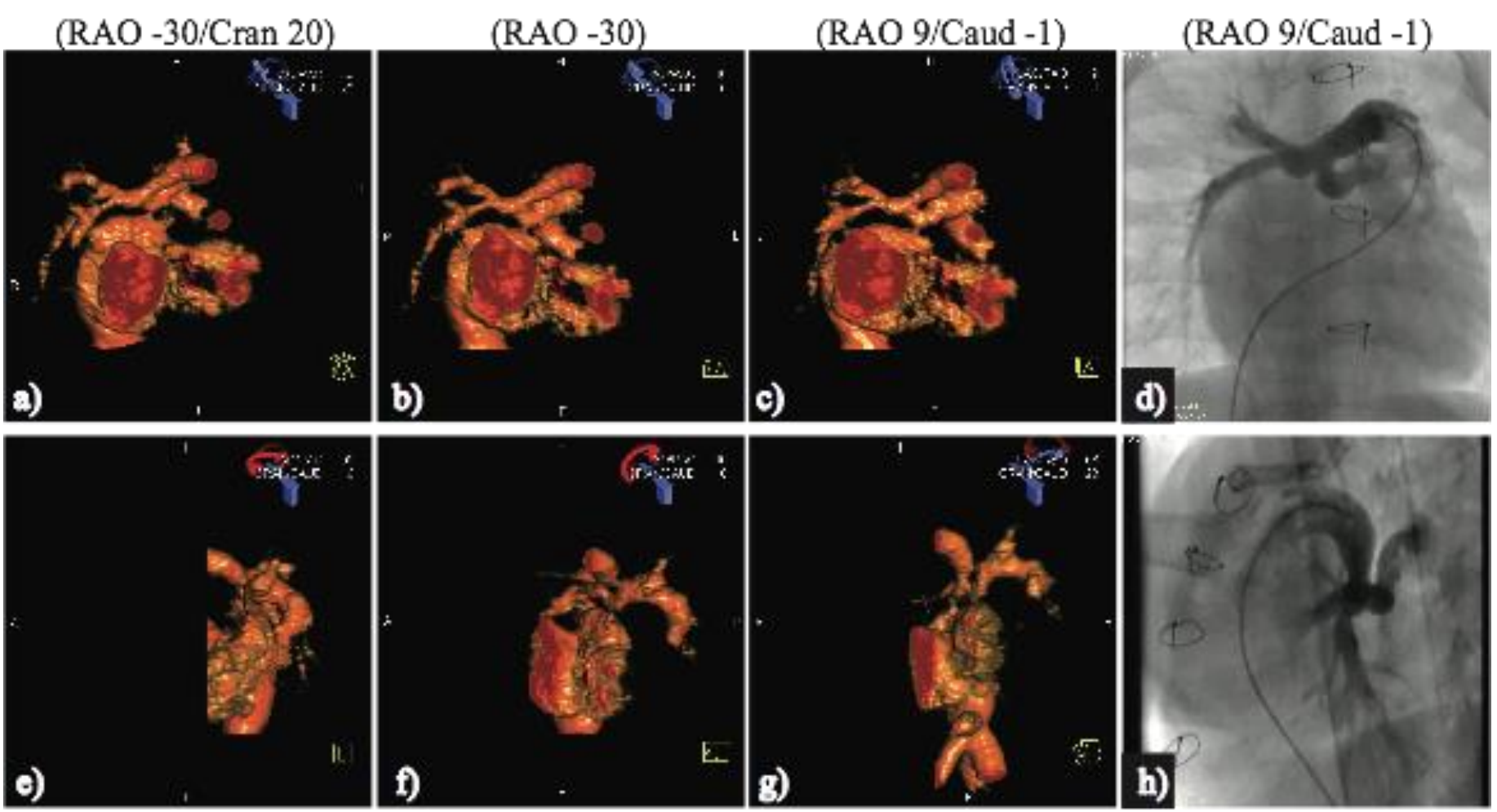
MR Fusion Utility - Interventional Planning

Interventional Planning

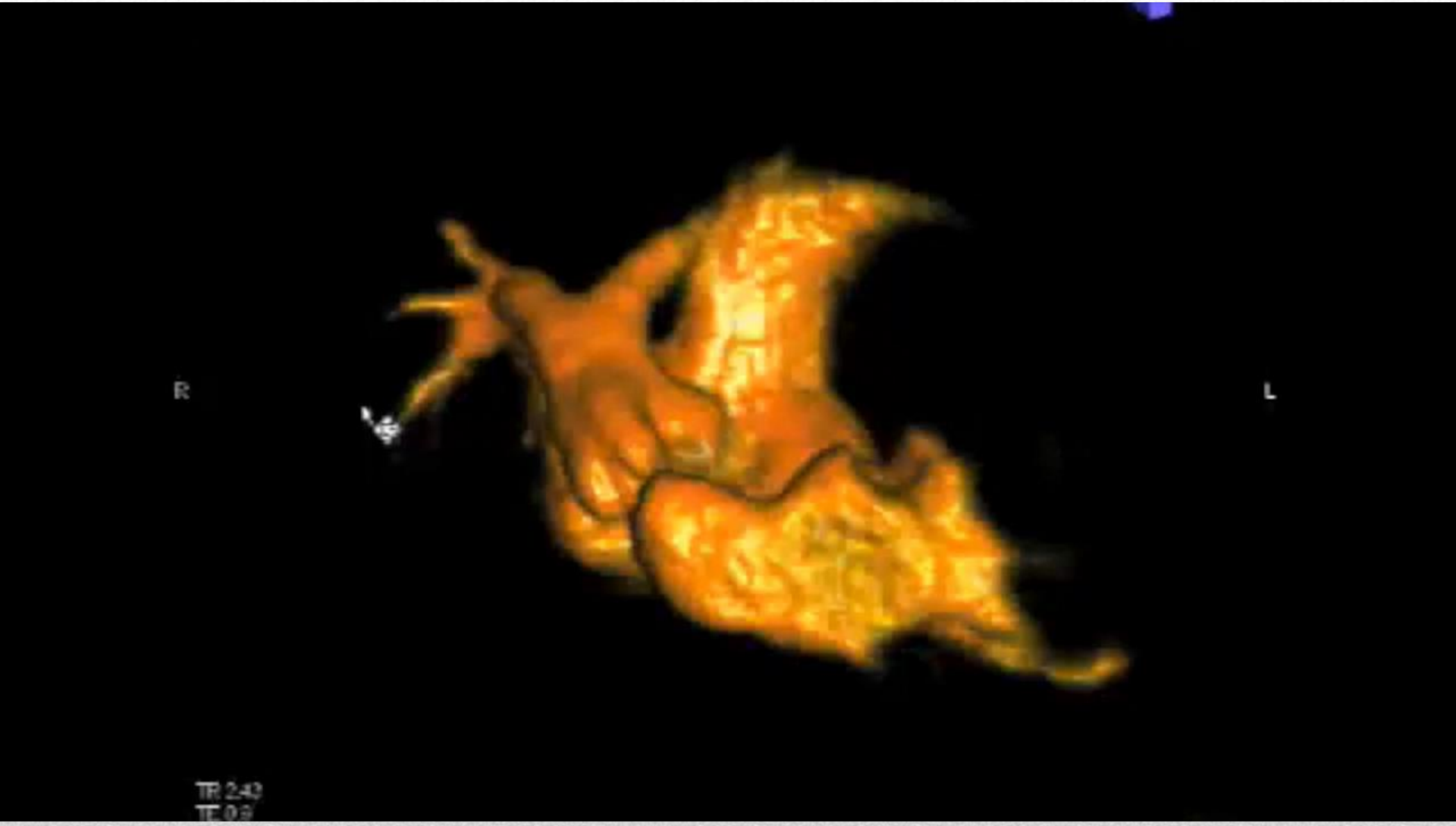
- ♥ Preliminary device sizing
- ♥ Planning interventional approach
- ♥ Hemodynamic calculations
- ♥ Modeling - CFD
- ♥ Virtual interventions
- ♥ 3D prototyping for mock interventions

MR Fusion Utility - Roadmapping

MR Fusion Utility – Camera Angle Selection

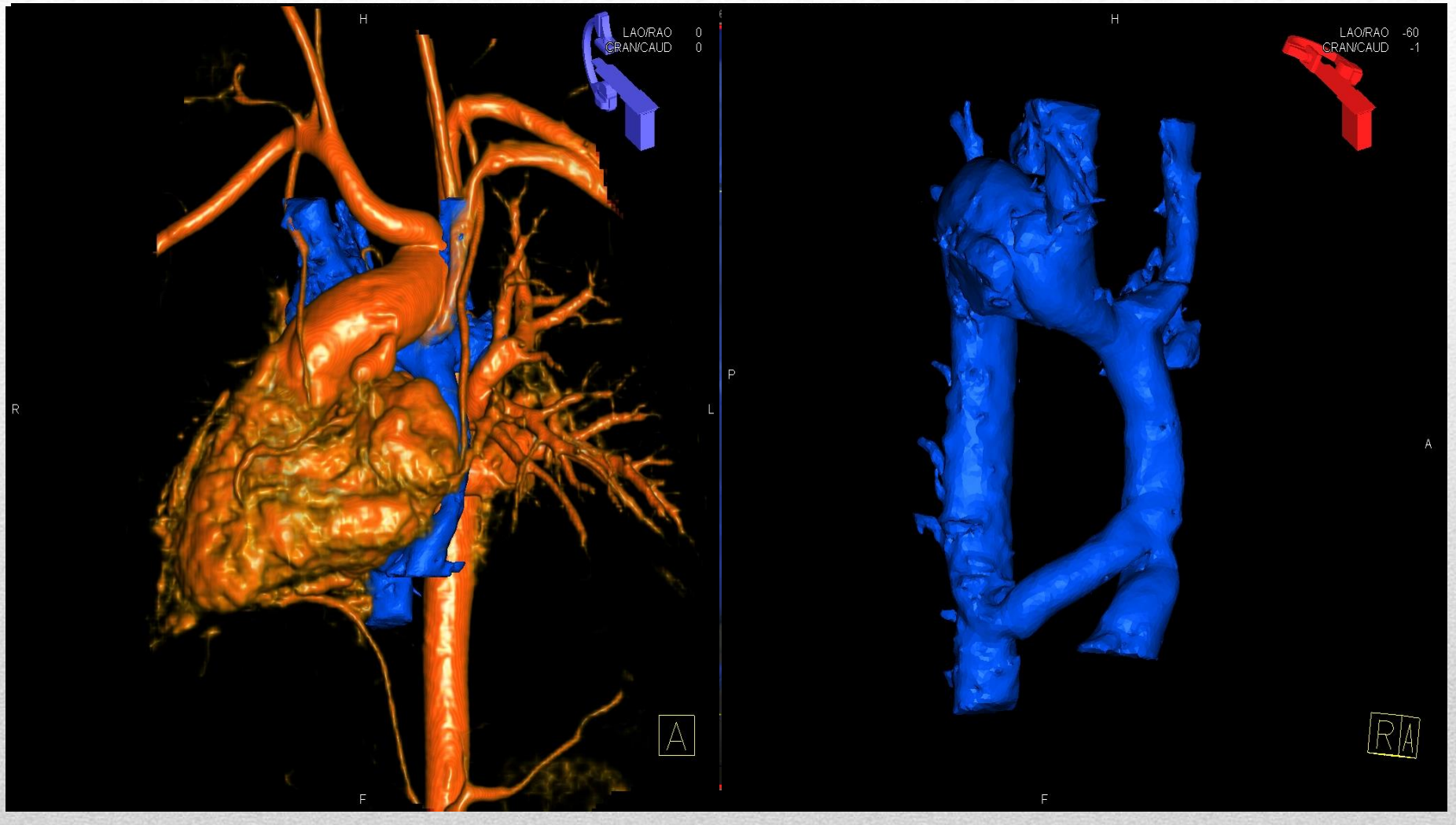


MR Fusion Utility – Camera Angle Selection

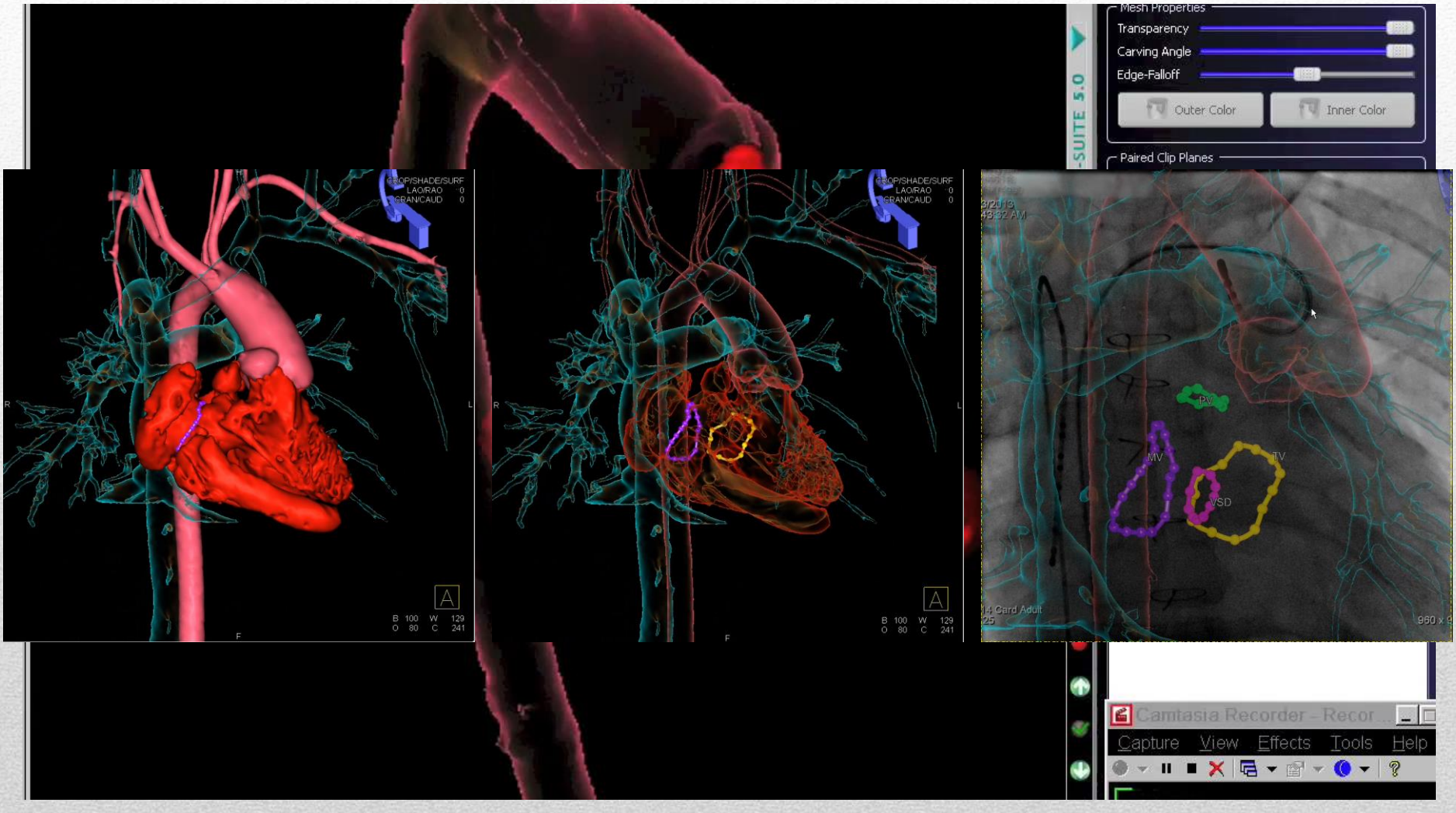


MR Fusion Utility – Device Positioning

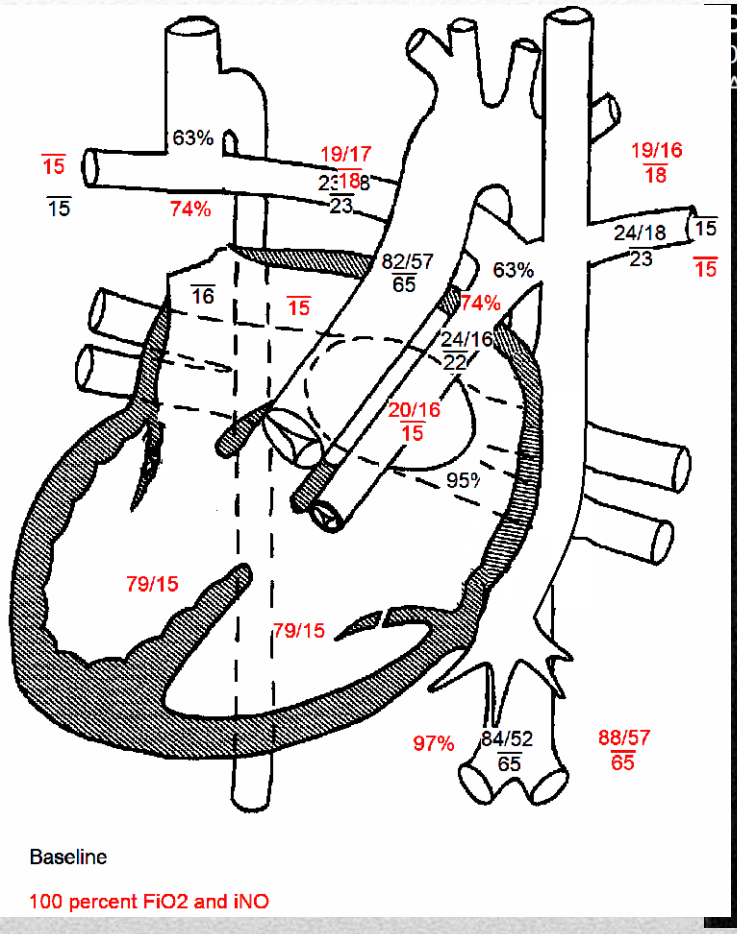
MR Fusion Utility – Device Positioning

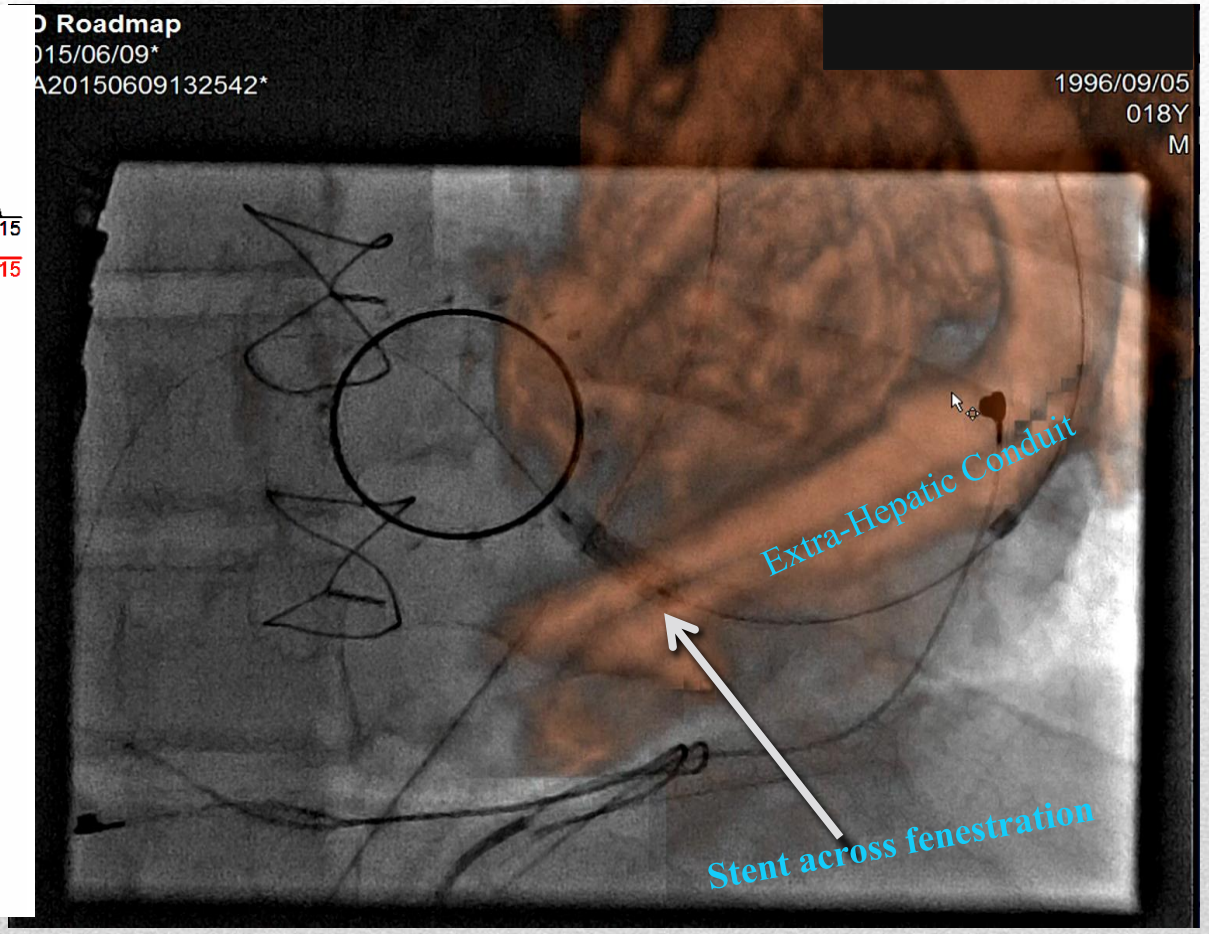


MR Fusion Utility – Trans-septal Puncture

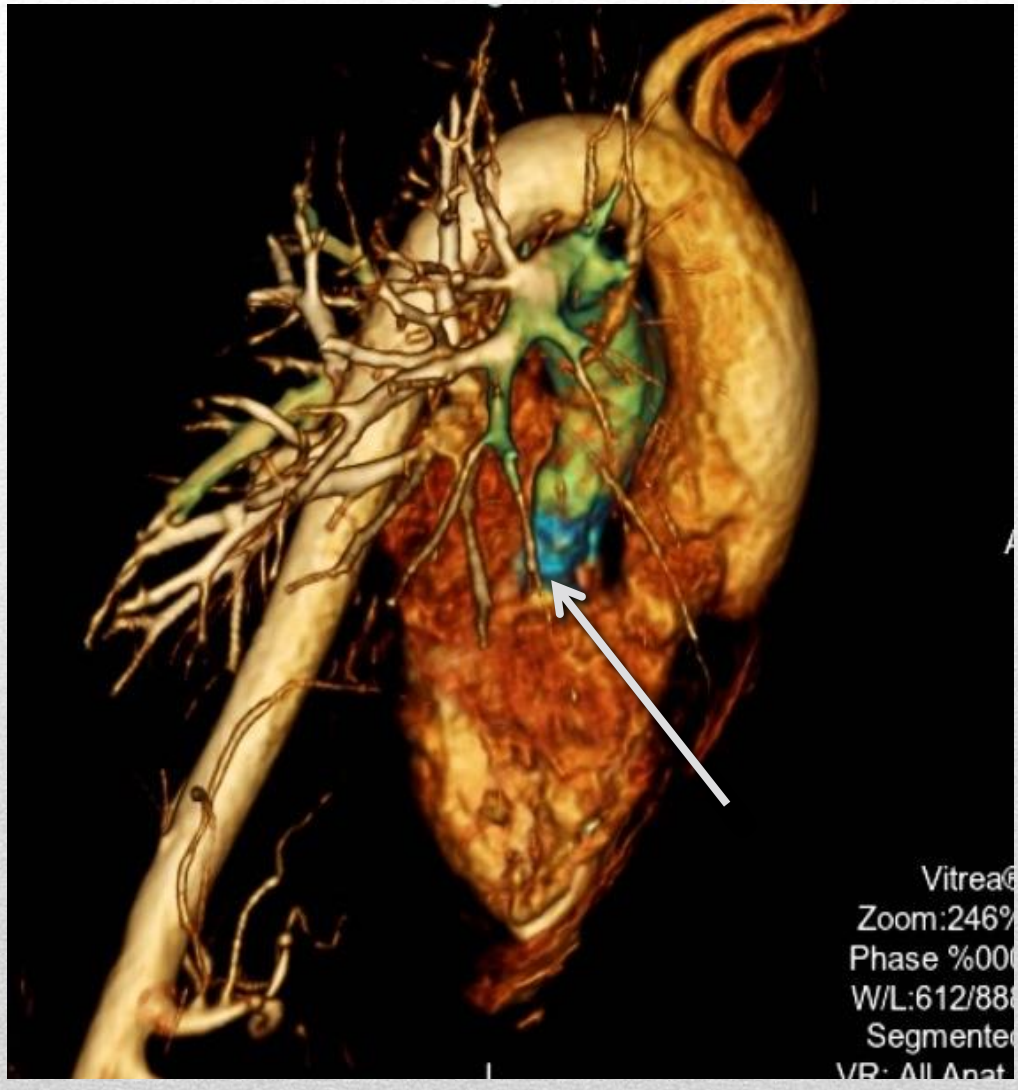


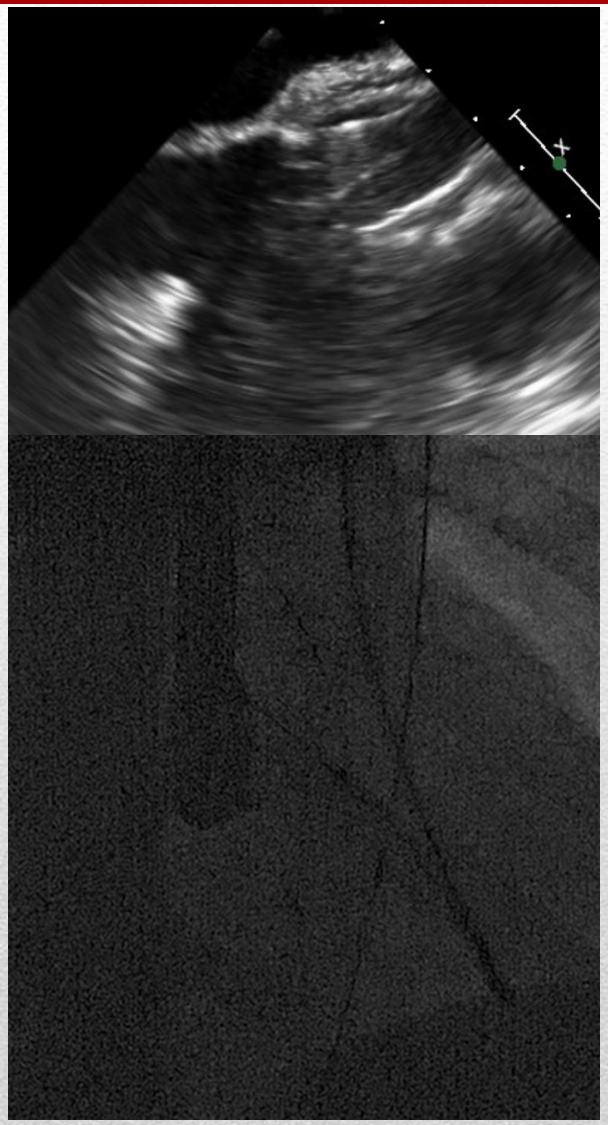
MR Fusion Utility – Fenestration Creation





MR Fusion Utility – No contrast Utilization





MR Fusion Utility – Radiation reduction

TABLE I. Baseline Demographics for Cases and Controls

	XMRF	Controls	*P* value
SCVC	15	15	–
TCVC	13	13	–
Reconstructed RVOT	16	16	–
Age (years)	4 (2.3–8.2)	3.7 (2.4–10.5)	0.98
Weight (kg)	13.9 (11.5–24.5)	14.1 (11.6–23.5)	0.7
Height (cm)	94.6 (86–119.5)	95.8 (84–122)	0.58
BSA (m^2)	0.6 (0.5–0.9)	0.6 (0.5–0.9)	0.22

TABLE II. Comparisons of Radiation Exposure, Contrast Dose, and Procedural Times Between XMRF Cases and Matched Controls

	XMRF	Controls	*P* value
Fluoroscopy time (min)	14 (11–18.7)	16.4 (12.1–23.2)	0.047
Contrast volume (cc/kg)	2 (1.2–2.8)	3.3 (2.4–3.9)	0.0006
Hand injection angiograms	1 (0–2)	1 (0–3)	0.45
Power injection angiograms	2 (1–3)	3 (2.5–4)	0.0002
Fluoro dose–area product (μGy·m^2)	513.2 (215.2–1012.9)	589.1 (296.8–1425.4)	0.042
Fluoro air kerma dose (mGy)	67.5 (33.2–118.8)	79.4 (48.7–227.6)	0.065
Total dose–area product (μGy·m^2)	625.8 (319.5–1990.7)	995.2 (597.3–1733.2)	0.027
Total air kerma dose (mGy)	94.5 (60.8–273.5)	153.8 (86.8–295)	0.017
Catheterization time (min)	48 (39–65.5)	58.5 (41–77.5)	0.06
Total anesthesia time (min)	257.5 (239.3–287.5)	155 (83–173.5)	<0.0001

(Abu Hazeem et al. CCI 2014)

MR Fusion Utility – Radiation reduction

Multi-Modality Fusion (MMF)

Patient Demographics

Comparison of 3DRA, MR and CT Fusion

Variable	3DRA-Fusion (n=25)	MR-Fusion (n=25)	CT-Fusion (n=25)	P-Value
Age (years)	9.8 ± 5.5	10.2 ± 6.3	11.1 ± 7.2	0.39
Weight (Kg)	26.6 ± 11.4	28.4 ± 12.3	30.3 ± 14.5	0.46
BSA (m^2)	1.02	1.08	1.2	0.11

MR Fusion Utility – Radiation reduction

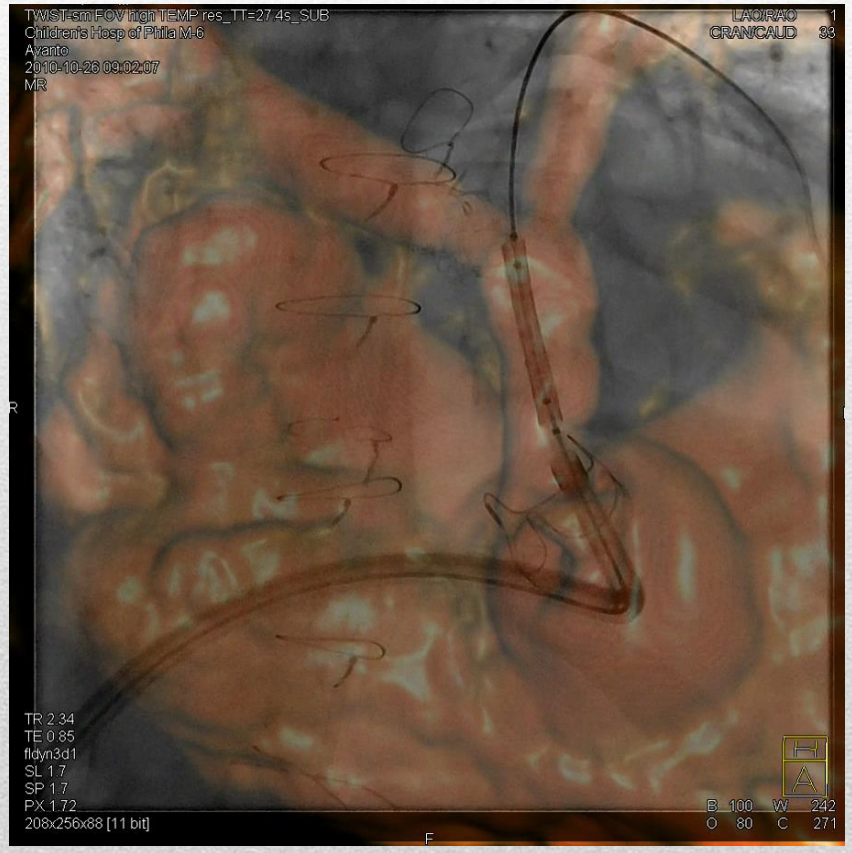
Multi-Modality Fusion (MMF)

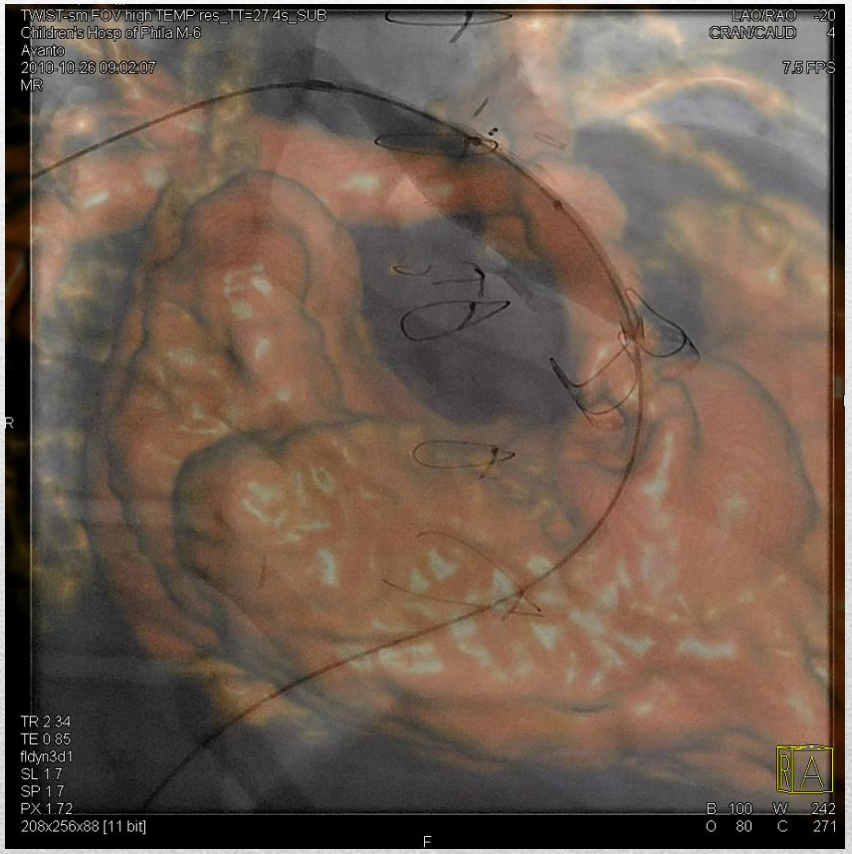
Procedure Times, Radiation and Contrast Dose

Variable	3DRA-Fusion (n=25)	MR-Fusion (n=25)	CT-Fusion (n=25)	P-Value
Radiation (min)	21.8 ± 12.2	18 ± 9.7	19.4 ± 10.4	**0.04**
# of angiography	7.2 ± 3.8	5.4 ± 4.7	6.8 ± 3.6	0.52
Dose-Area (cGy.cm^2)	4101 ± 1382	2454 ± 1113	5607 ± 2465	**0.01**
Air Kerma (mGy)	654 ± 224	499 ± 189	806 ± 328	**0.01**
Contrast (mL/Kg)	4.9 ± 3.1	2.7 ± 2.4	5.9 ± 3.8	**<0.001**
Procedure (min)	214 ± 93	163 ± 38	167 ± 42	**0.03**
Anesthesia time (min)	258 ± 112	384 ± 174	213 ± 98	**<0.001**

Limitation to Current MR Fusion technology

- Rigid registration
- Error in steep angles is larger





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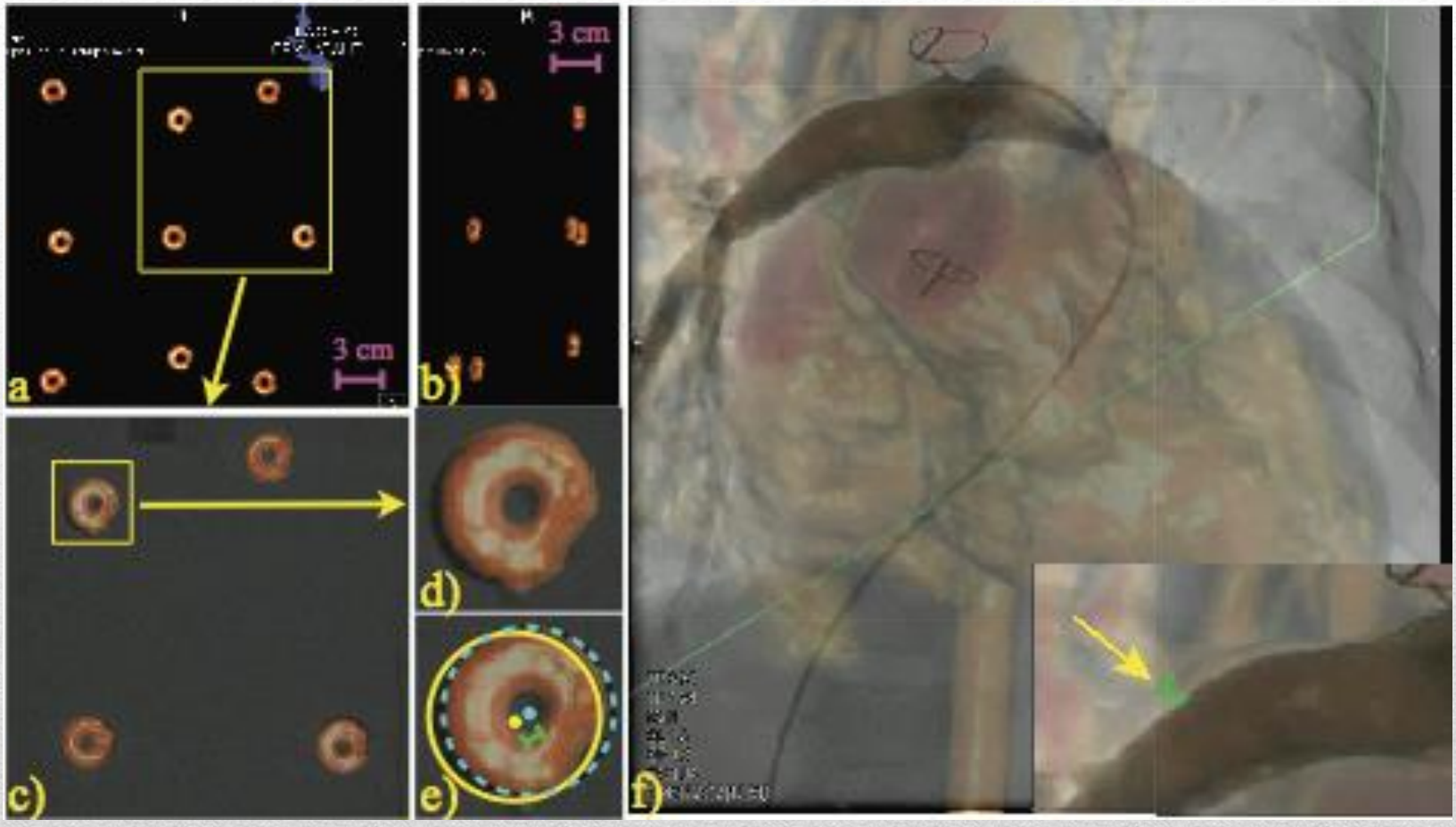

- Phantom: 1.15 mm (SD 0.73, n=8)
- Patients: 2.15 mm (IQR of 1.65-2.56 mm)

X-Ray Magnetic Resonance Fusion to Internal Markers and Utility in Congenital Heart Disease Catheterization
Dori et al. Circulation Cardiovascular Imaging 4(4):415-24 · May 2011

Registration Error

Summary

- MR Fusion:
  - Fast
  - Does not require contrast
  - Uses no radiation
  - Utilizes internal markers
  - Biplane
- Can use the planning MR for the fusion
- MR fusion can reduce radiation exposure
- This modality has the potential to improve outcomes
- Is multimodality imaging the future? Yes

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