Quantitative Cardiovascular Image Analysis for Routine Clinical Care:

Precision Medicine for Patient-Specific Treatment

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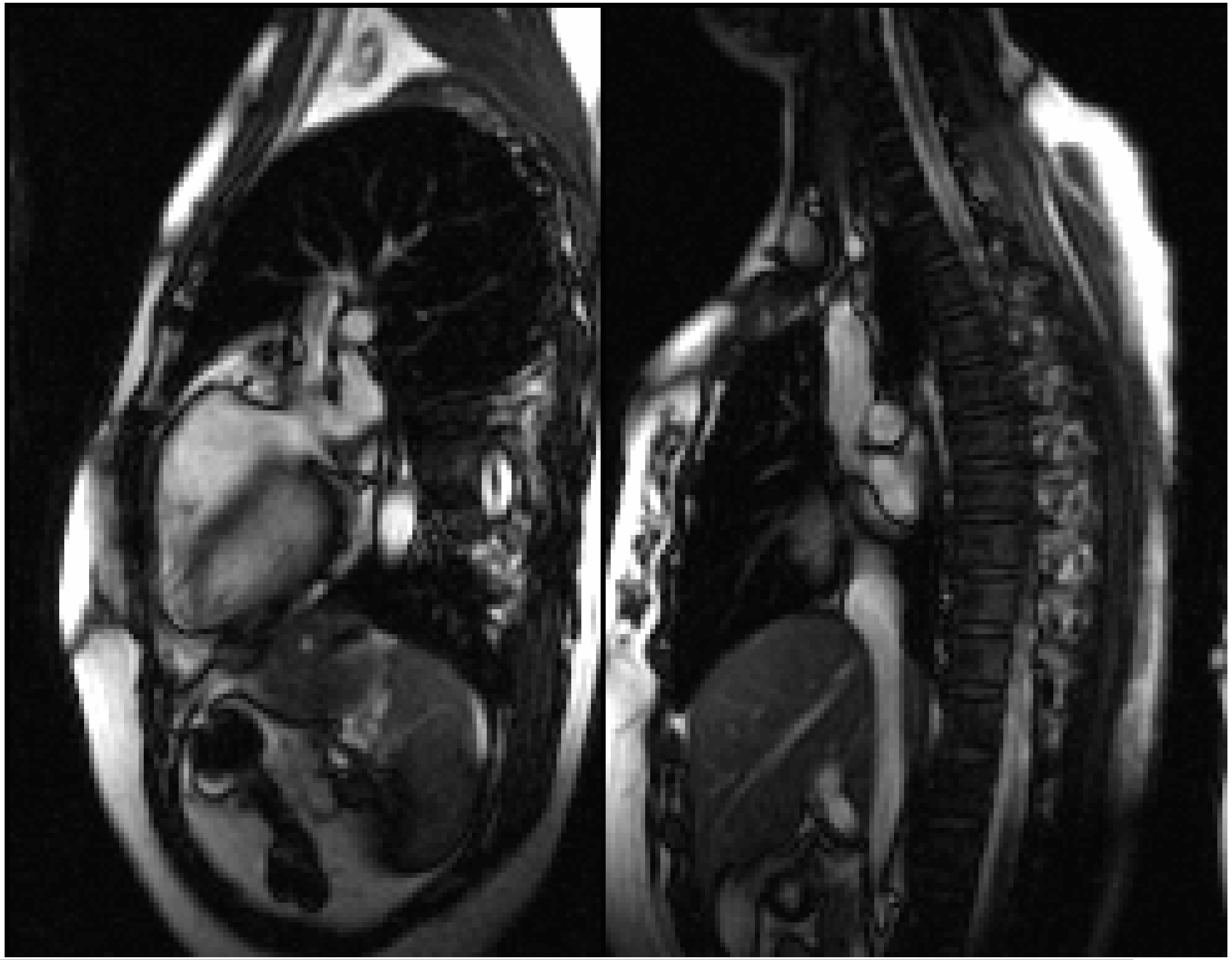
Cardiovascular Precision Medicine

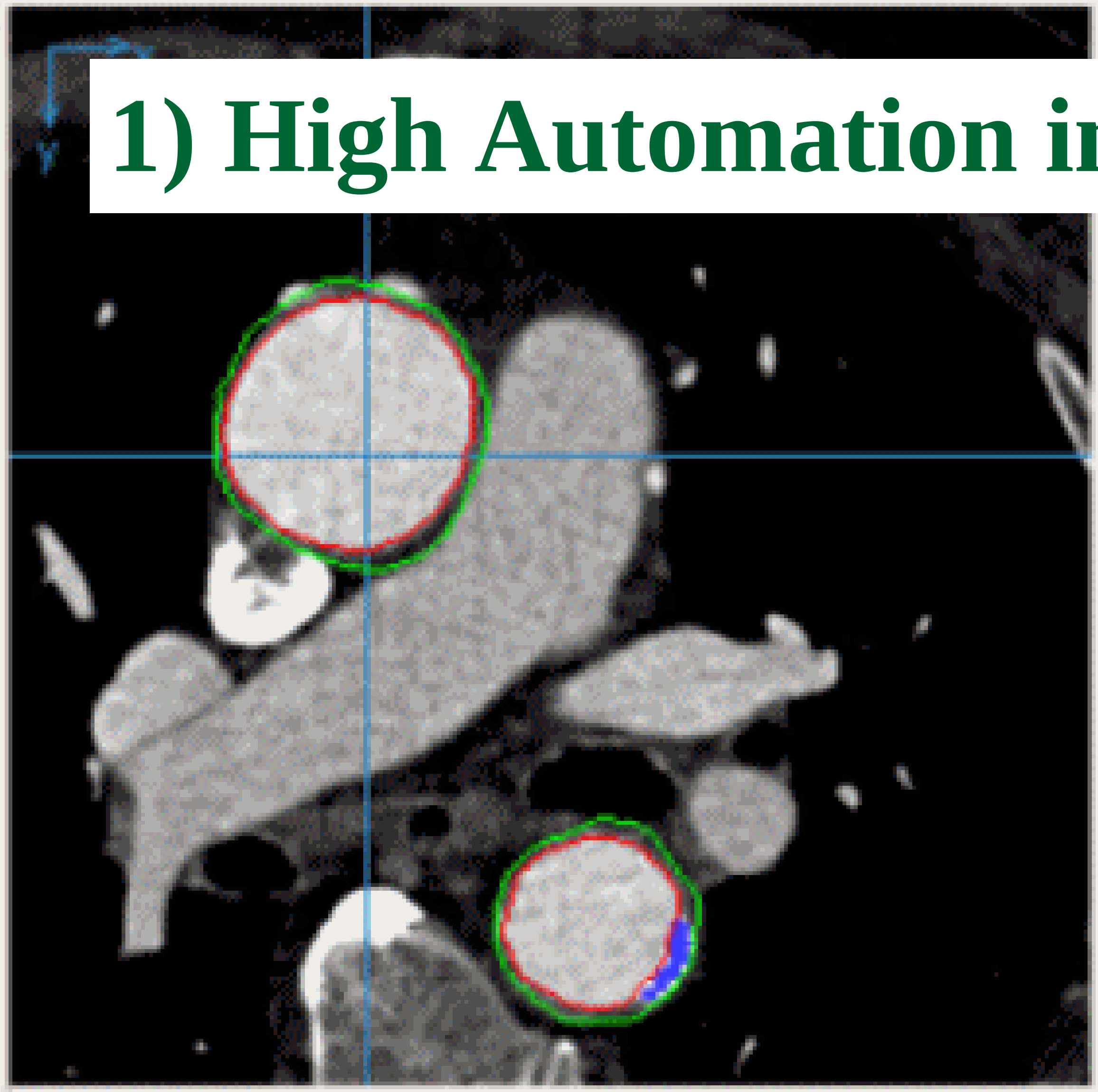
- Cardiology at forefront of quantitative analysis for decades
  - QCA – 1980's
- Cardiovascular imaging is everywhere
  - Angio, IVUS, MR, CT, SPECT, OCT, …
- Image analysis for clinical care is still mainly qualitative
- Quantification needs to be omnipresent in routine clinical care for precision medicine to reach its potential

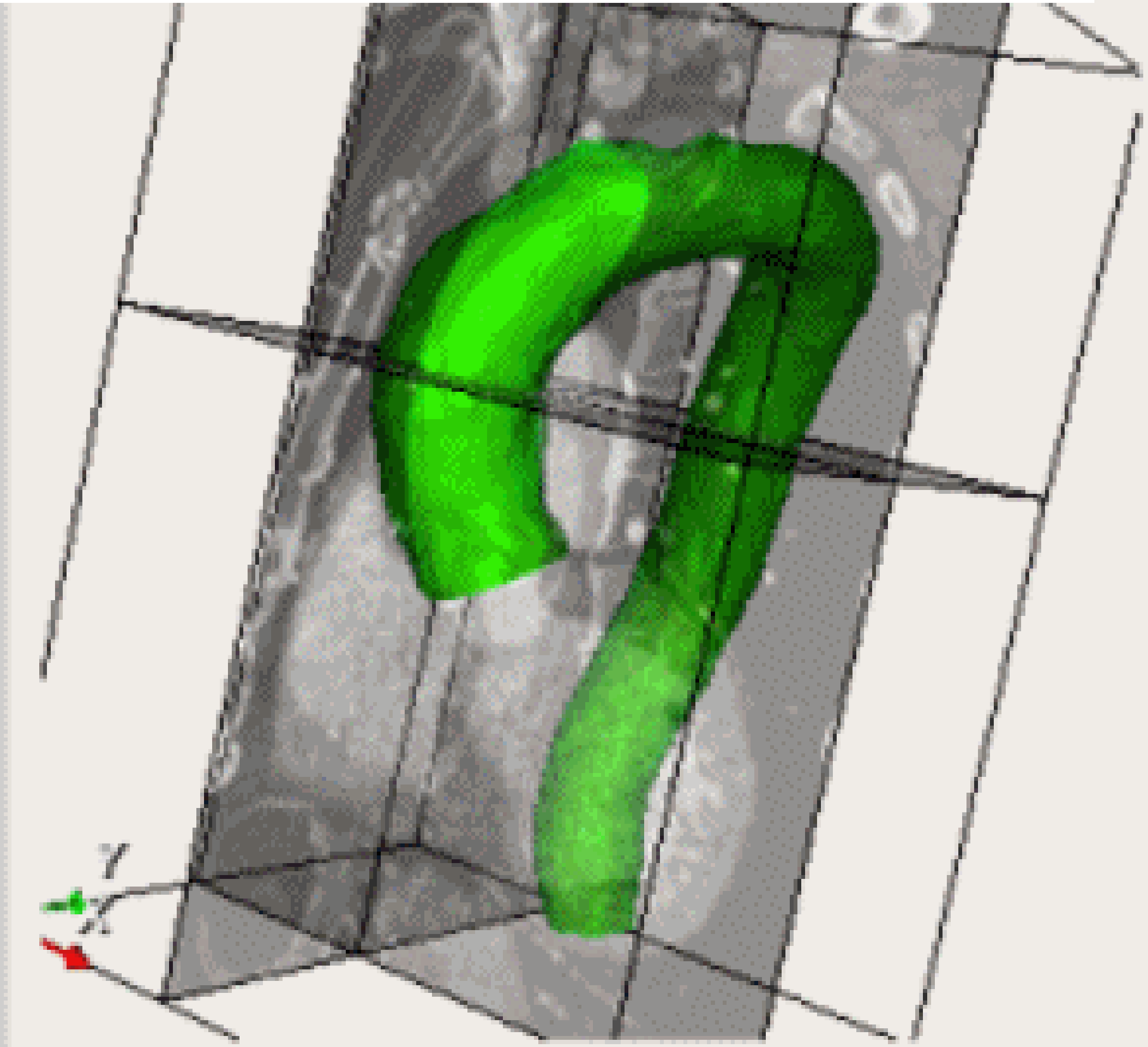
Methodology: General … Example: AORTA

- 3D and 4D analysis of aortic morphology and function
  - MR, MRA, CT, CTA
  - Lumen size valve to diaphragm
  - Atherosclerosis
    - Wall thickness
    - Percent calcium volume
  - Connective tissue disorders
    - Locations of enlarged lumen
    - Distensibility/compliance
    - Luminal eccentricity
    - Gross aortic motion



1) High Automation in 4D (Aortic CTA)





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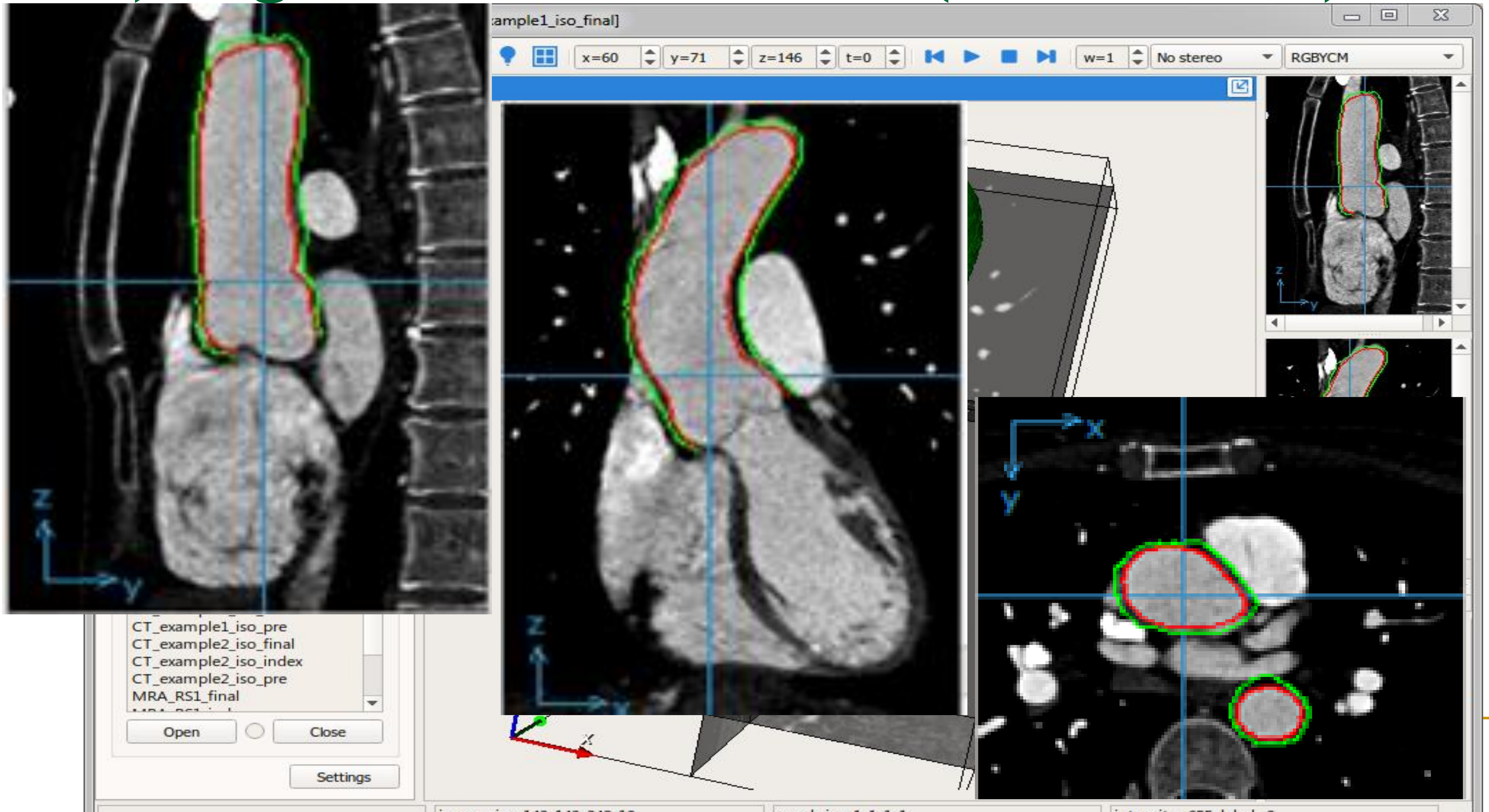
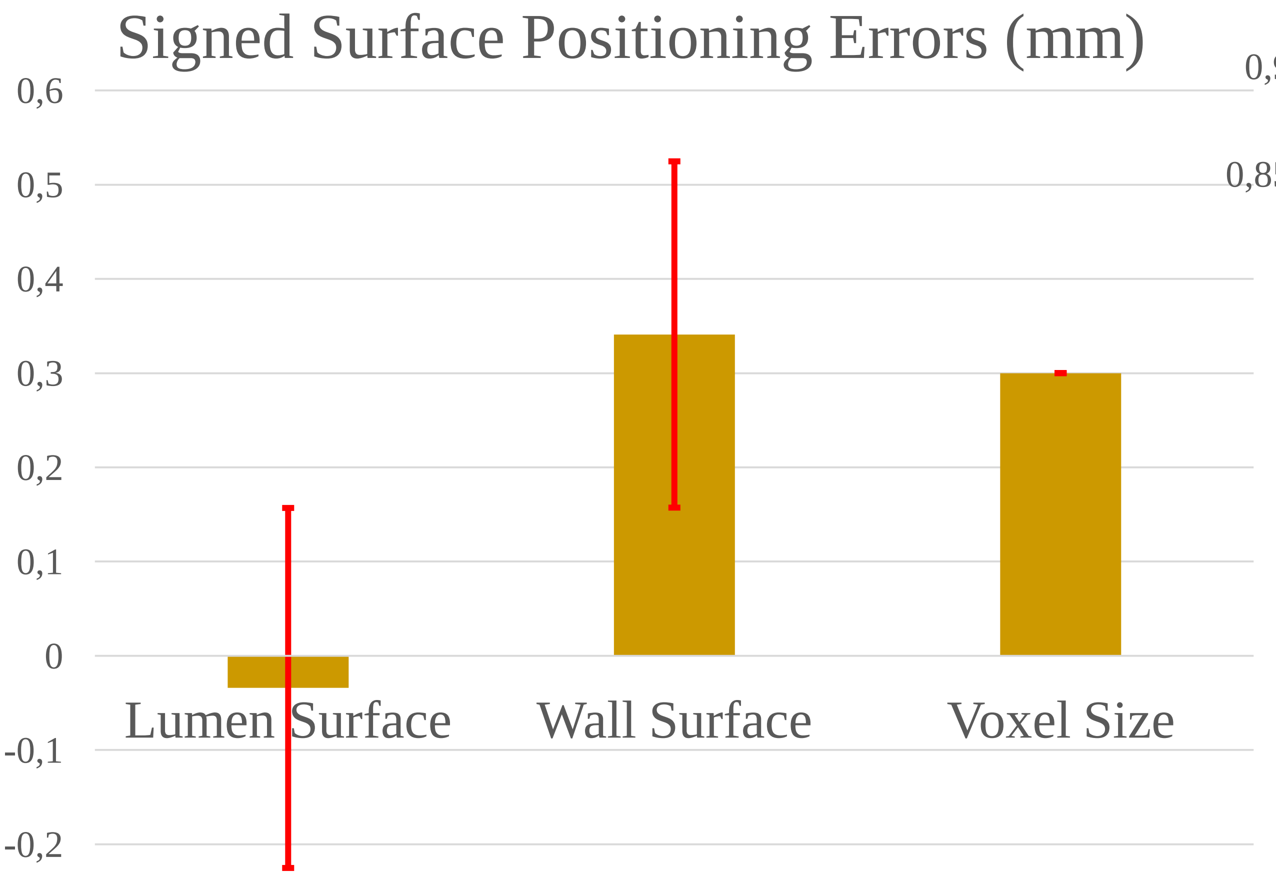
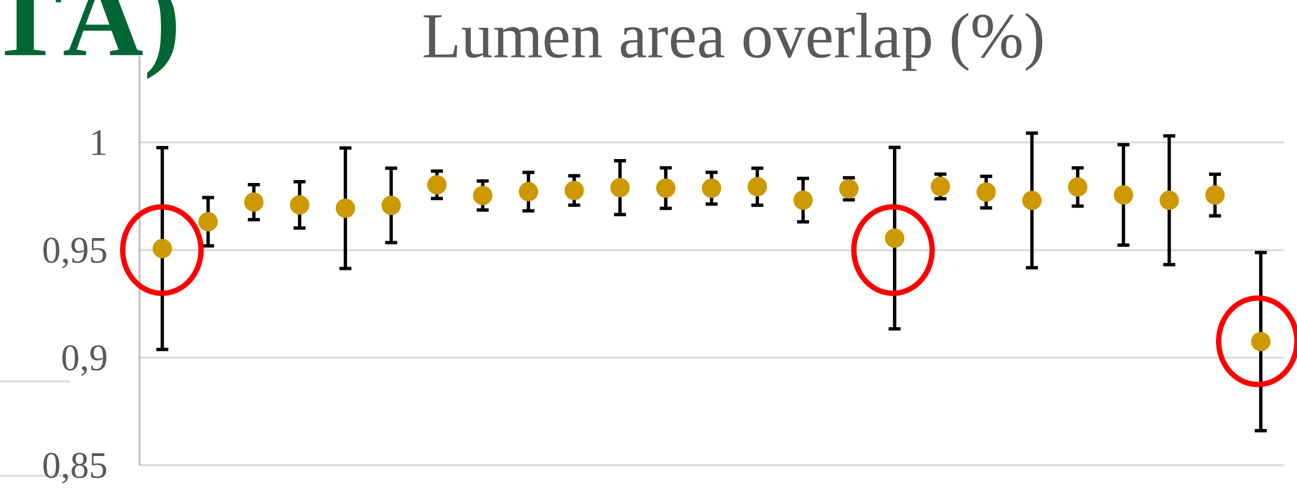
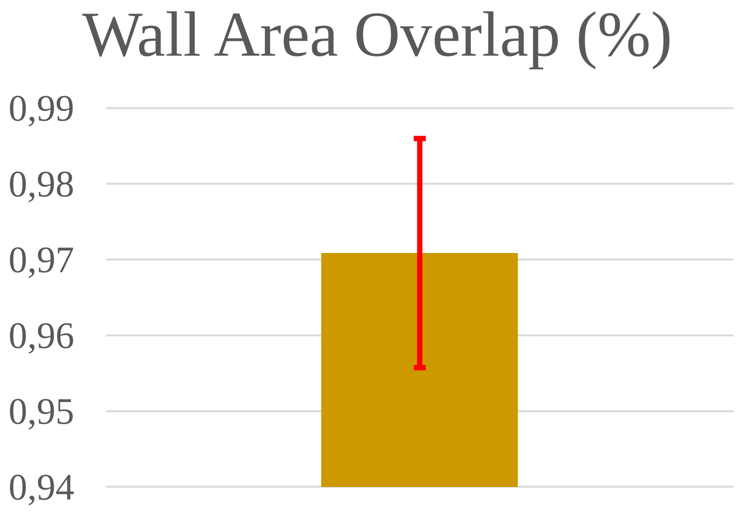


2) Validation (Aortic CTA)

- Automated 3D computer segmentation vs. manual independent standard





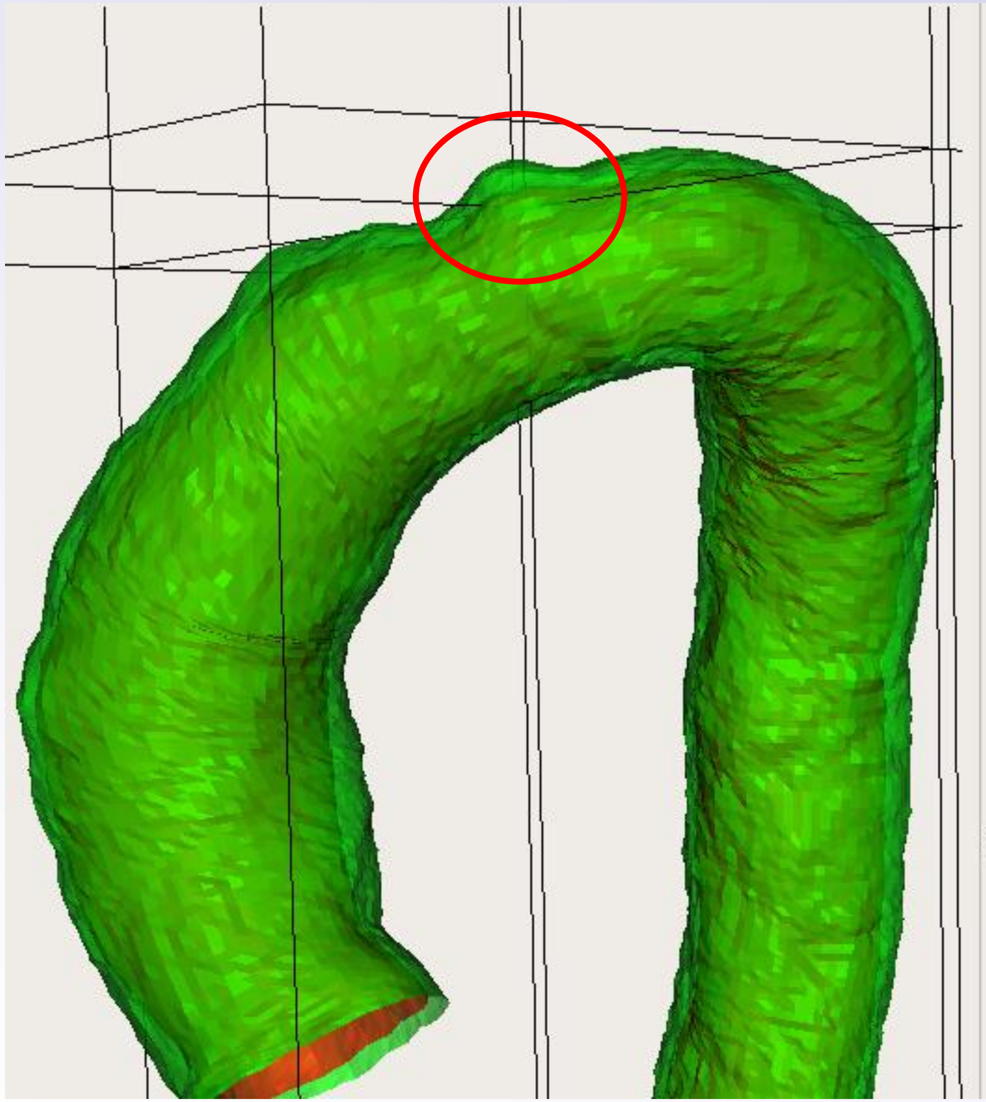


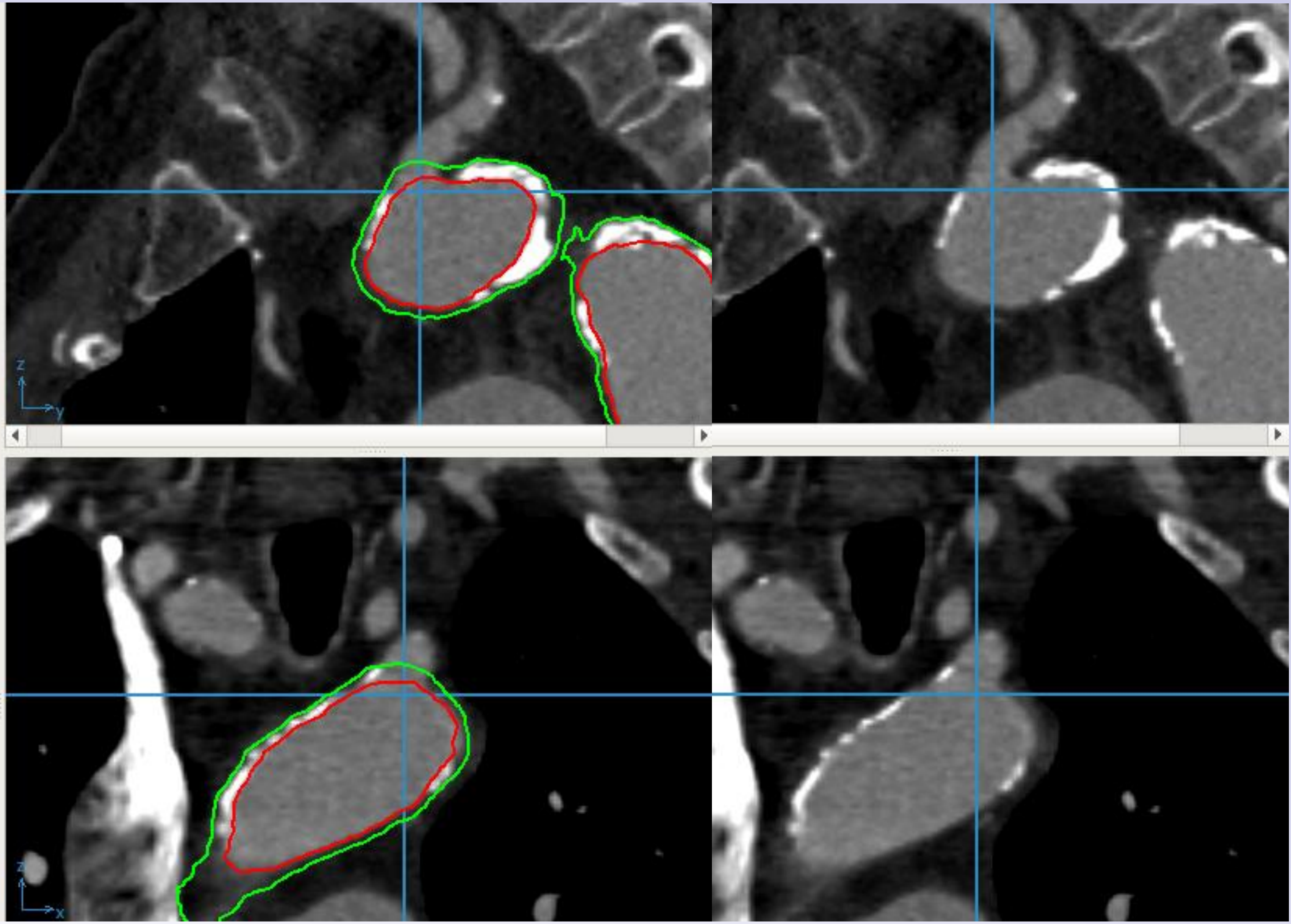
3) 100% Success in Clinical Workflow

- All analyses approved by expert

- Fully automated analysis will likely never be 100% correct
  - Currently each failure requires manual tracing slice-by-slice – impossible to expect in a busy clinical practice
  - Failed cases → disregarded … this is unacceptable

→ JUST ENOUGH INTERACTION





3D rendering helps us to quickly find small errors that may be subtle in 2D slices.
Highlighted error caused by vessel branch

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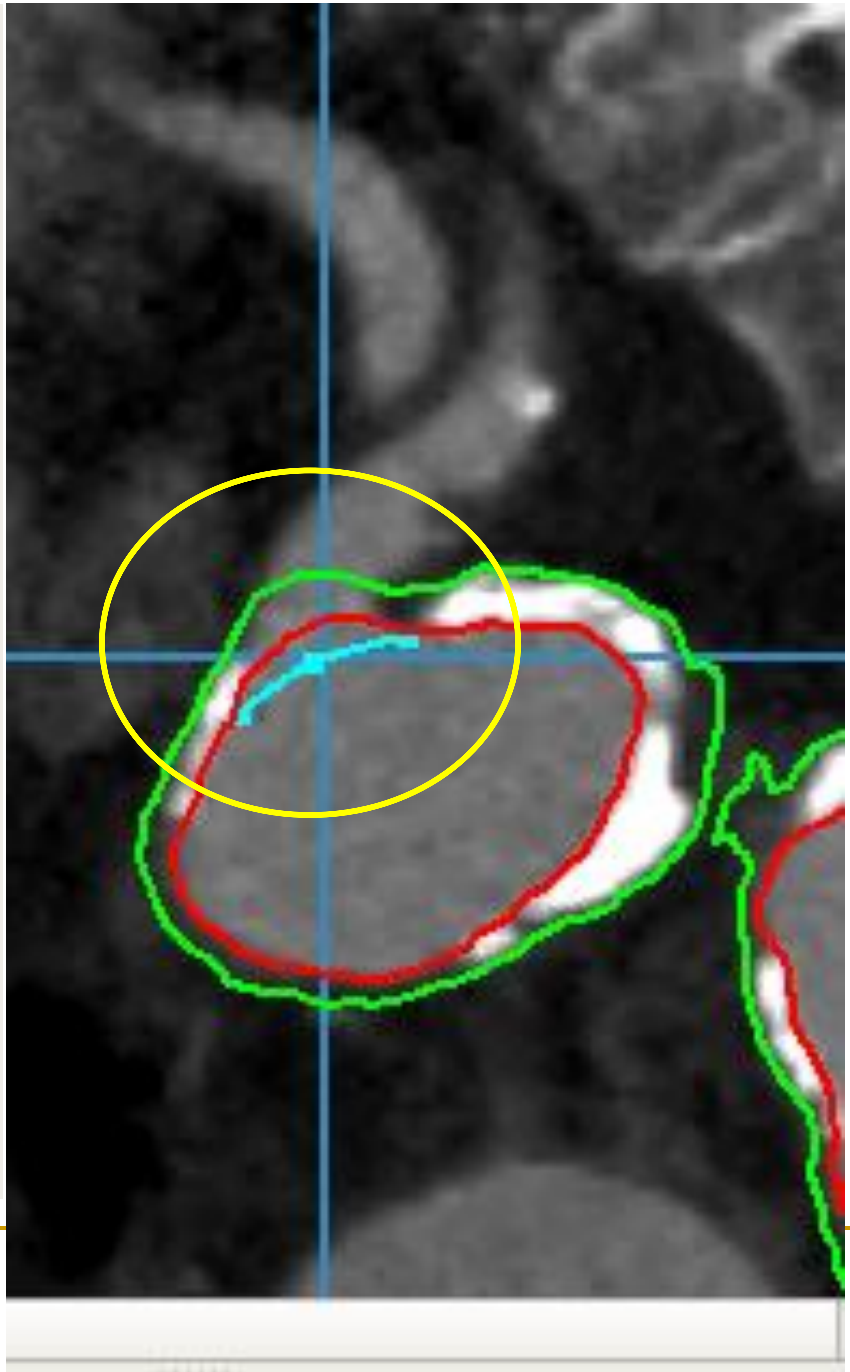

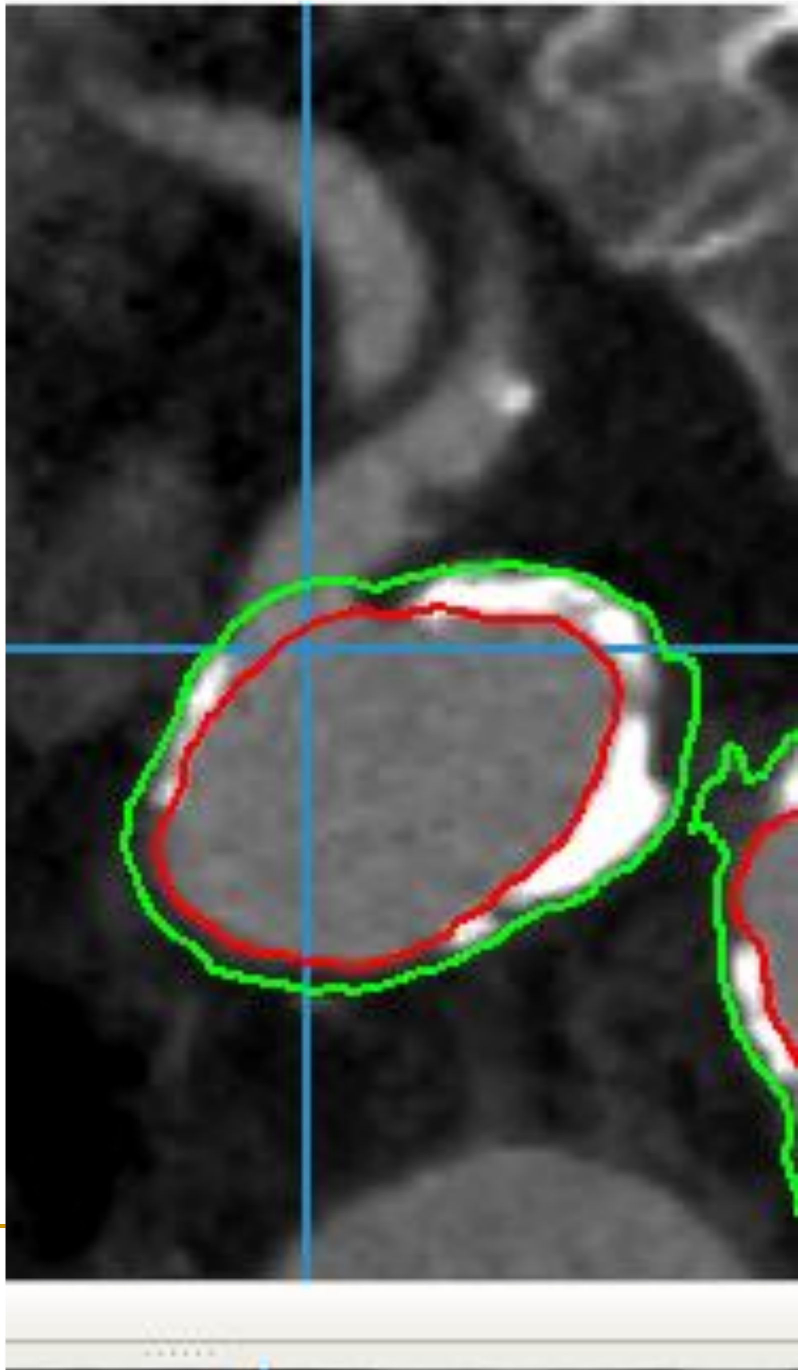

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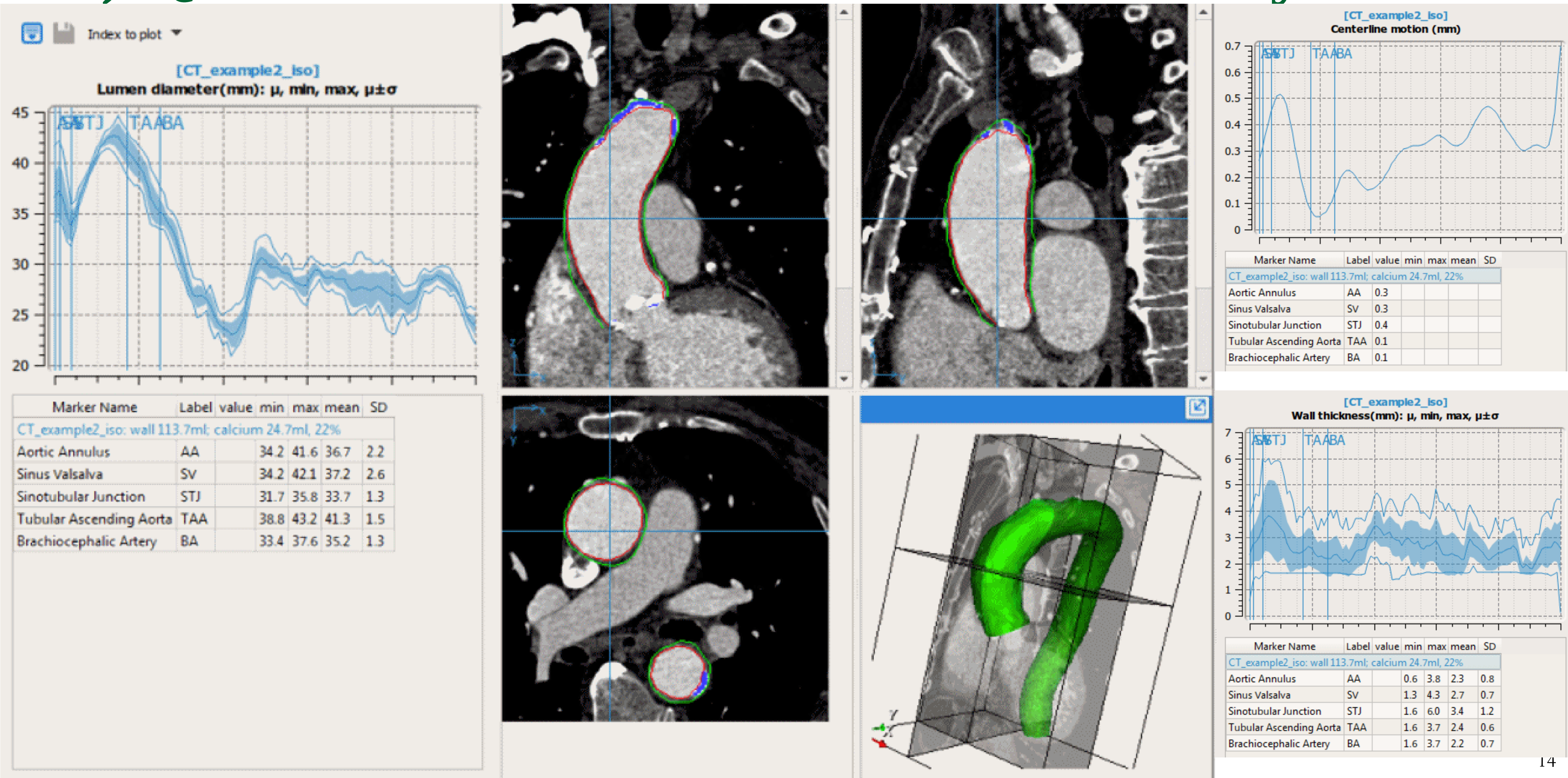
4) Quantitative Indices – 4D Aortic Analysis

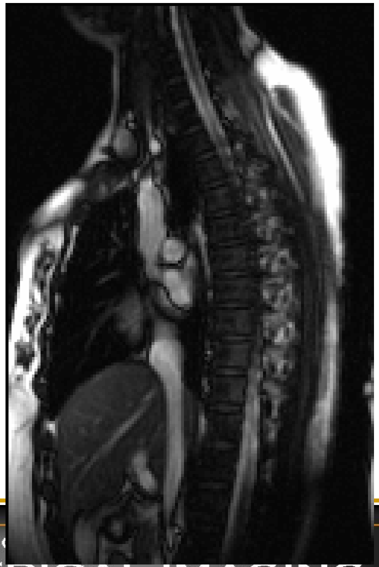


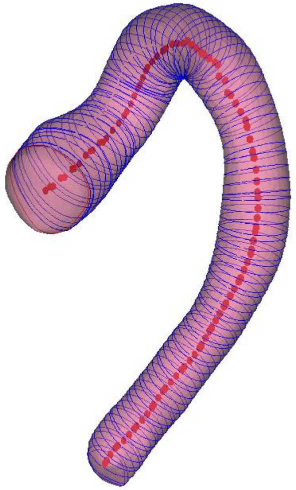
Marker Name	Label	value	min	max	mean	SD
CT_example2_iso: wall 113.7ml; calcium 24.7ml, 22%						
Aortic Annulus	AA		34.2	41.6	36.7	2.2
Sinus Valsalva	SV		34.2	42.1	37.2	2.6
Sinotubular Junction	STJ		31.7	35.8	33.7	1.3
Tubular Ascending Aorta	TAA		38.8	43.2	41.3	1.5
Brachiocephalic Artery	BA		33.4	37.6	35.2	1.3

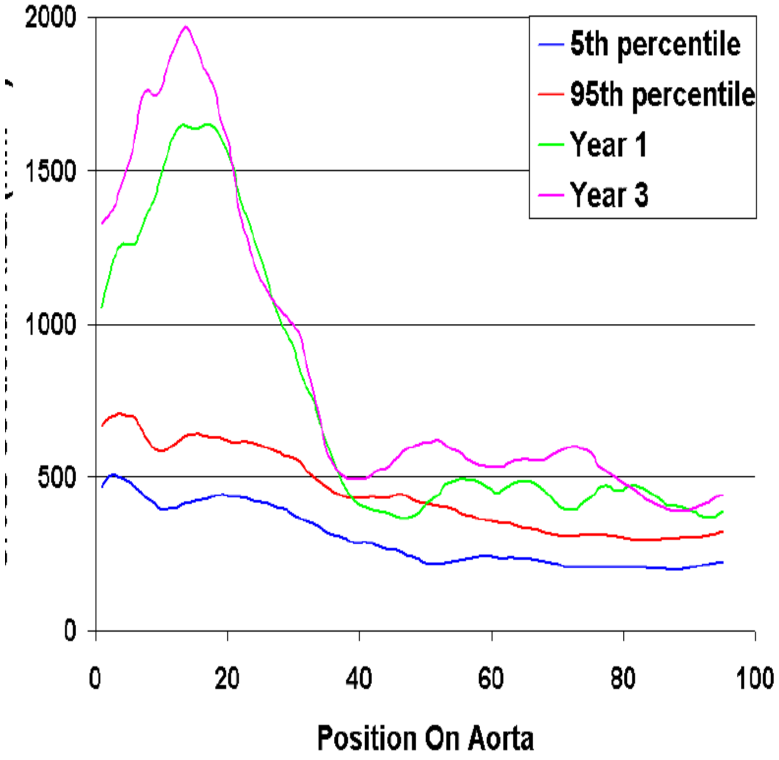
Marker Name	Label	value	min	max	mean	SD
CT_example2_iso: wall 113.7ml; calcium 24.7ml, 22%						
Aortic Annulus	AA	0.3				
Sinus Valsalva	SV	0.3				
Sinotubular Junction	STJ	0.4				
Tubular Ascending Aorta	TAA	0.1				
Brachiocephalic Artery	BA	0.1				

Marker Name	Label	value	min	max	mean	SD
CT_example2_iso: wall 113.7ml; calcium 24.7ml, 22%						
Aortic Annulus	AA		0.6	3.8	2.3	0.8
Sinus Valsalva	SV		1.3	4.3	2.7	0.7
Sinotubular Junction	STJ		1.6	6.0	3.4	1.2
Tubular Ascending Aorta	TAA		1.6	3.7	2.4	0.6
Brachiocephalic Artery	BA		1.6	3.7	2.2	0.7

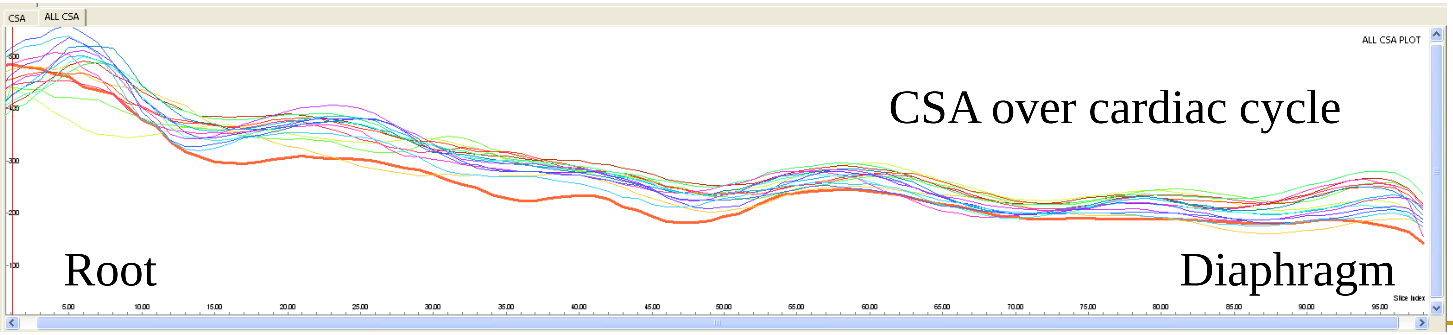
Disease Diagnosis and Progression (Marfan)







Year 3



Carotid IMT Screening

IMT

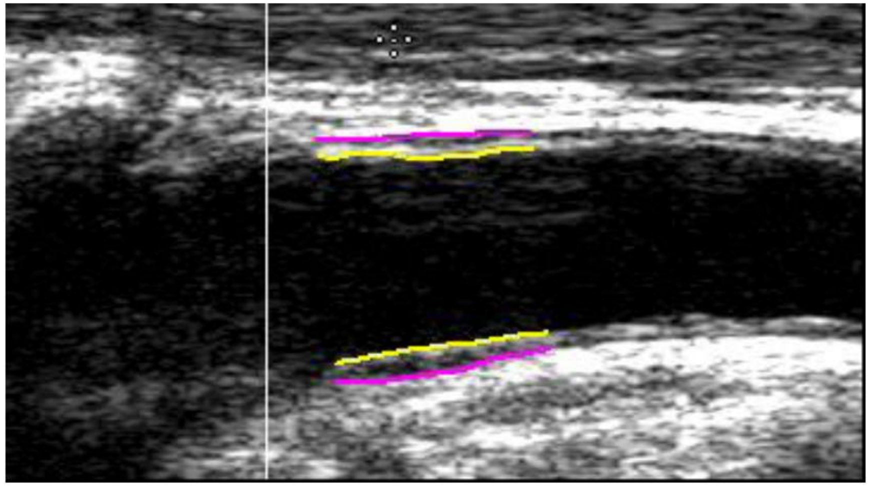
ID	002	DOB	52/1/1	Age	53	Gender	Female	Race	Caucasian
Address									

Carotid IMT

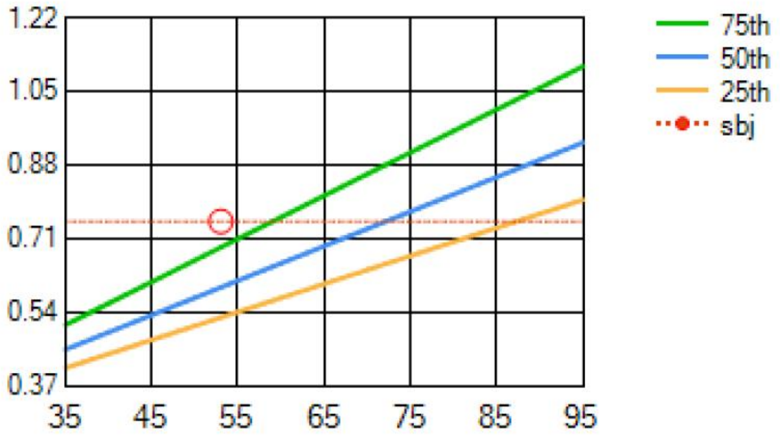
Female
53 years old
Caucasian

IMT MEASUREMENT FOR THE RIGHT SIDE CAROTID

CAROTID SEGMENT	MEAN IMT (MM)	MAXIMUM IMT (MM)	PLAQUE?	COMMENT
Common	Near: 0.72 Far: 0.75	Near: 0.94 Far: 1.06		IMT at 85th percentile of women at this age. Estimated Vascular Age: 72 yr
Bifurcation	Near: 0.74 Far: 0.89	Near: 1.02 Far: 1.12		IMT at 74th percentile of women at this age. Estimated Vascular Age: 65 yr
Internal	Near: 0.69 Far: 0.89	Near: 0.93 Far: 1.16		IMT at 83rd percentile of women at this age. Estimated Vascular Age: 88 yr



CAROTID SNAPSHOT: RIGHT BIFURCATION
Snapshot taken from study: RB-002.8, at frame 1 of 1.



FEMALE'S RIGHT COMMON FAR WALL CAROTID IMT-FOR-AGE PERCENTILE*
IMT curves top to bottom: the 75th, the 50th, and the 25th percentile in general population.

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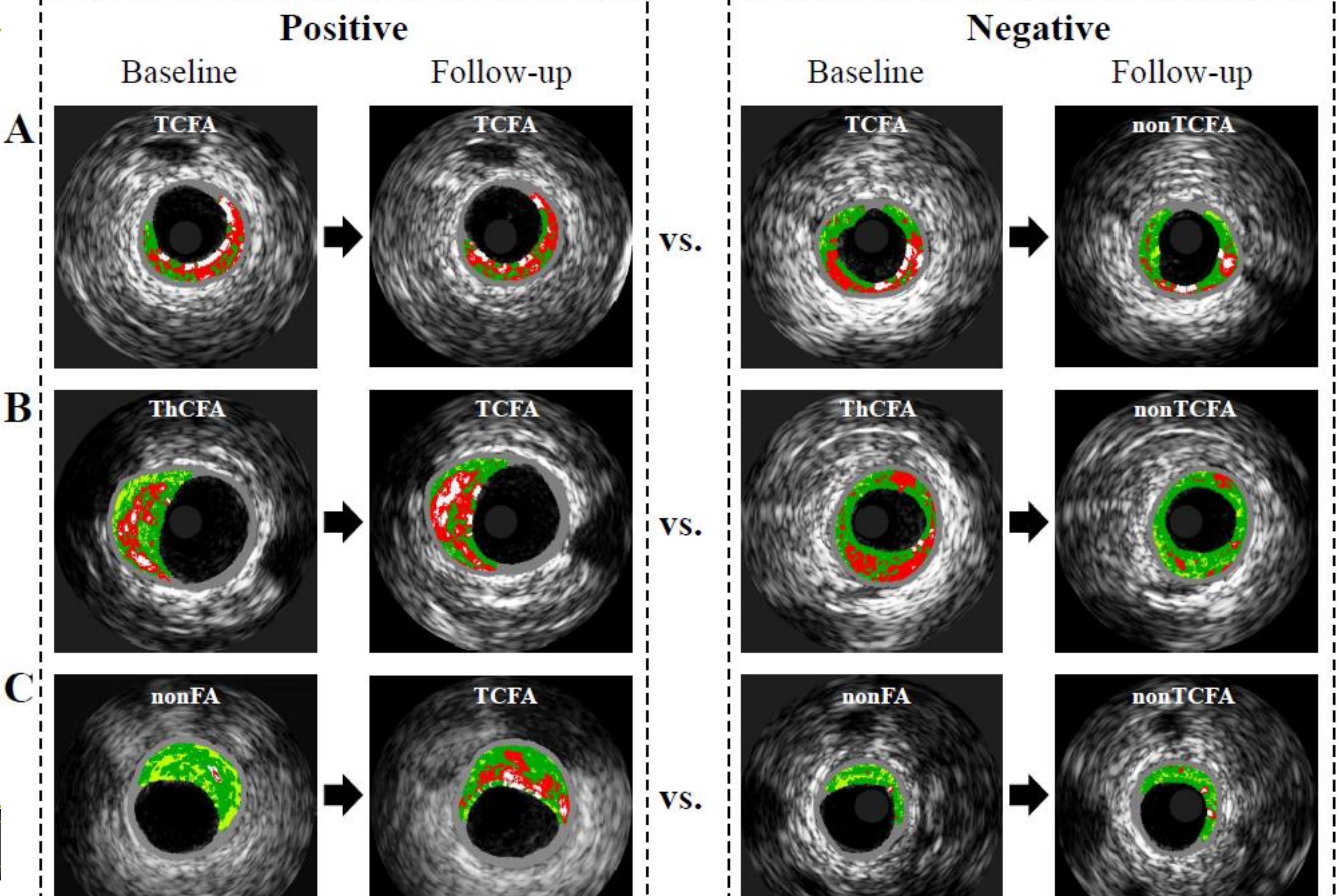
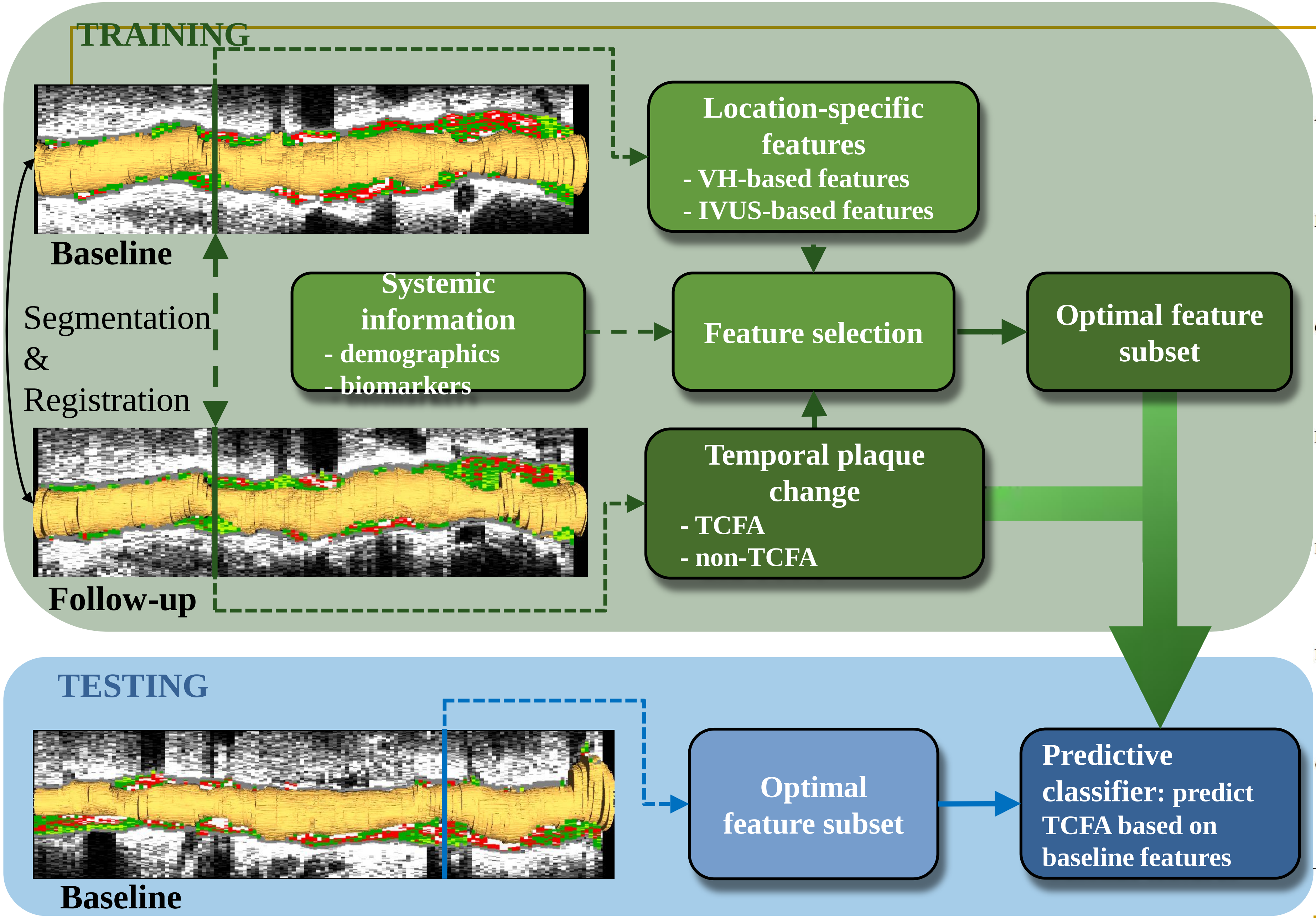
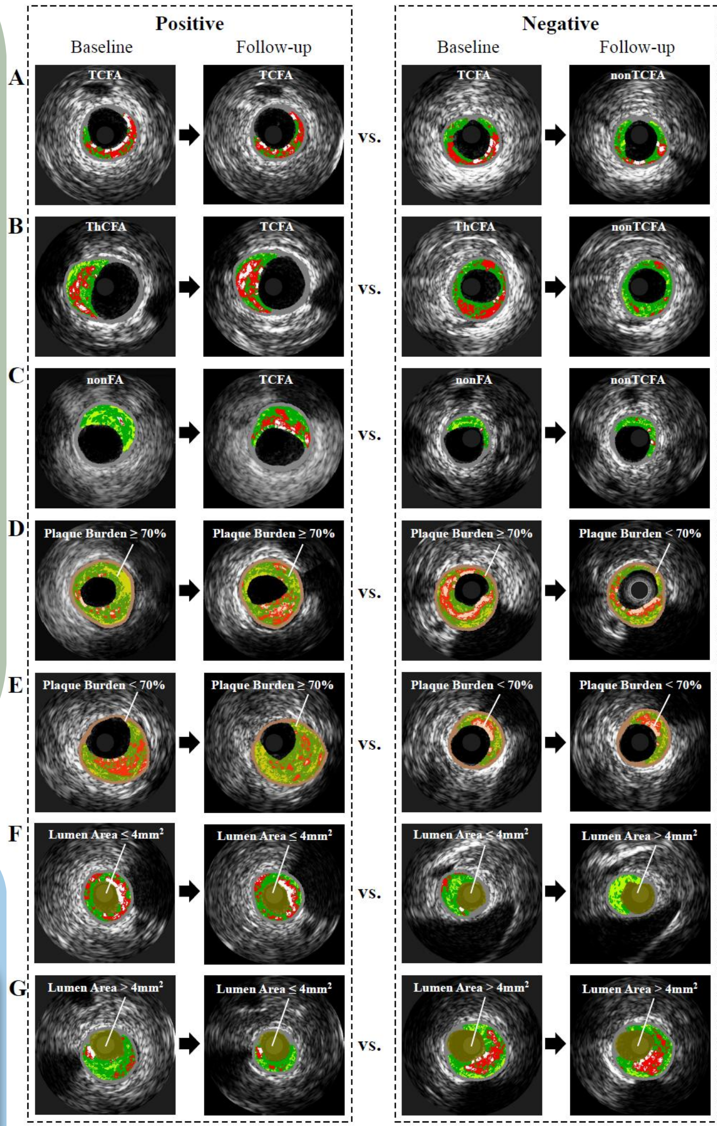
* Caucasian and African American uses ARIC Study: Bond, M.G et al.: High resolution B-mode ultrasound scanning methods in the Atherosclerosis Risk in Communities study (ARIC). J. Neuroimaging, p.68-73, 1991.
* Asian and Hispanic uses MESA Study: McClelland, R.L. et al.: Distribution of coronary artery calcium by race, gender, and age: results from the Multi-Ethnic Study of Atherosclerosis (MESA). Circulation 2006;113:30-7.

Coronary IVUS
Prediction of Future MACE

Can Future TCFA Locations be Predicted?
Can MACE be Predicted?


Positive
Baseline
Follow-up
Negative
Baseline
Follow-up
A
TCFA
TCFA
vs.
TCFA
nonTCFA
B
ThCFA
TCFA
vs.
ThCFA
nonTCFA
C
nonFA
TCFA
vs.
nonFA
nonTCFA





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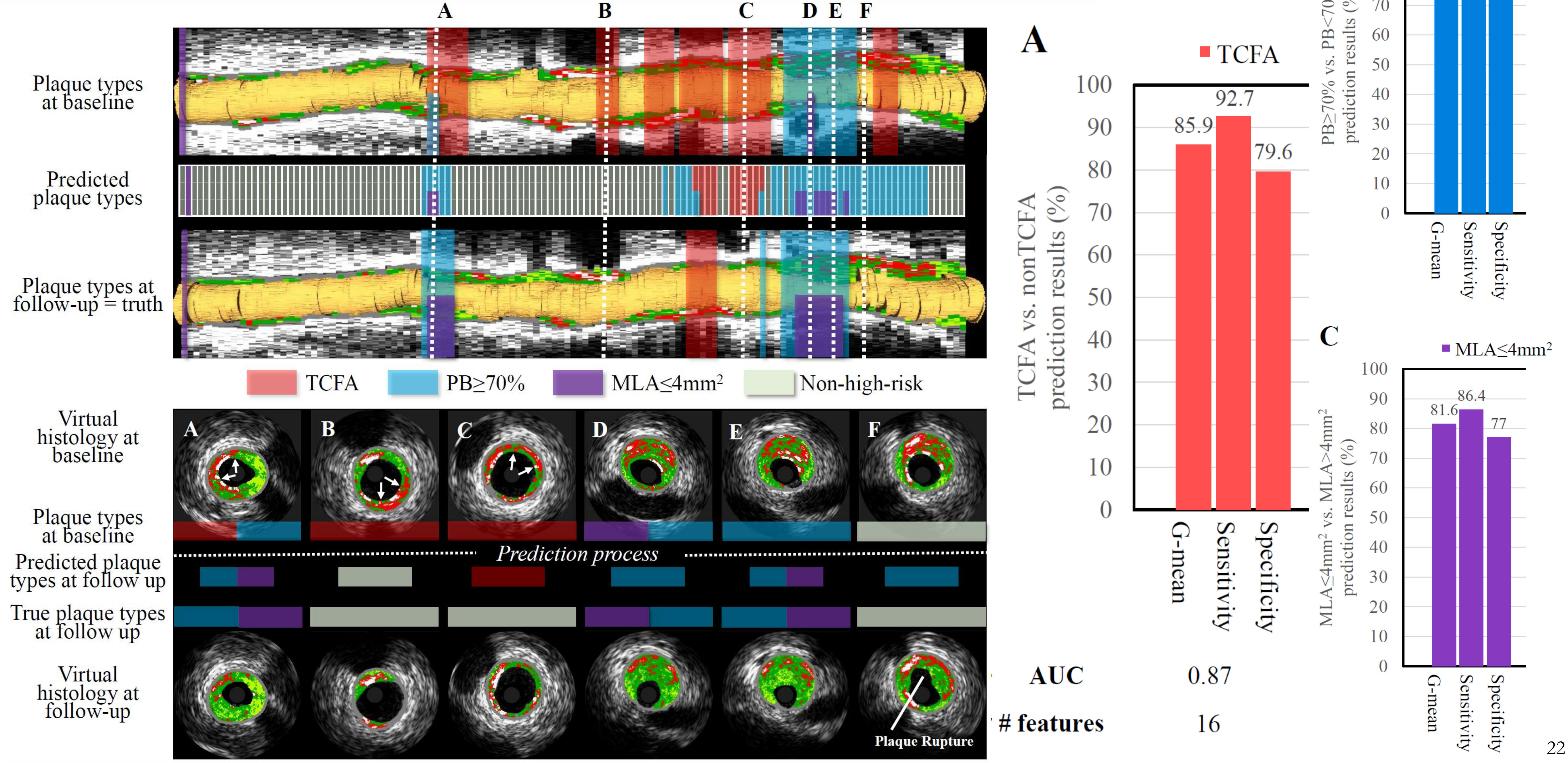
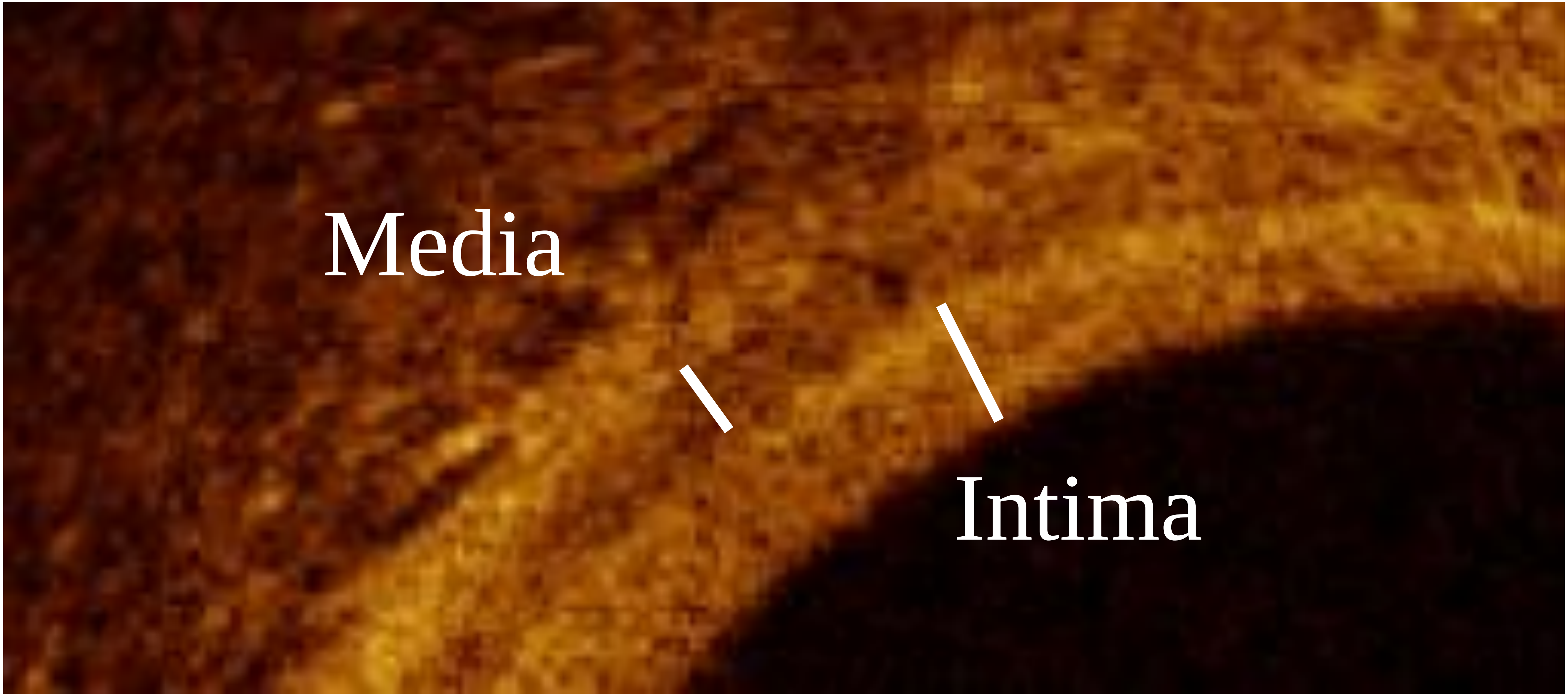
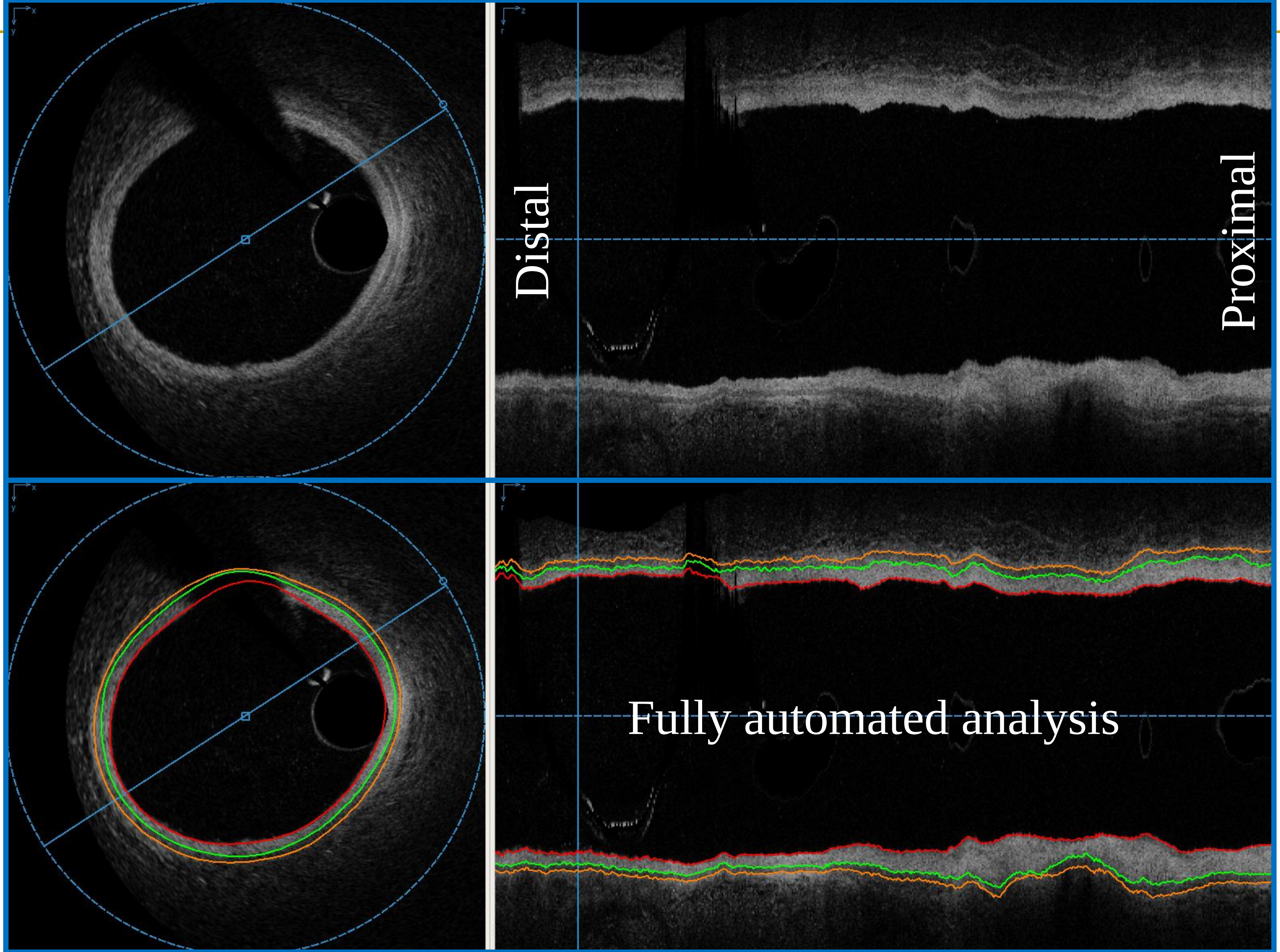
61 patients with stable angina pectoris, Charles University Prague
BL + 12M Follow-up IVUS-VH
From BL image data predicting MACE at 12M: TCFA or PB≥70% or MLA≤$4mm^2$



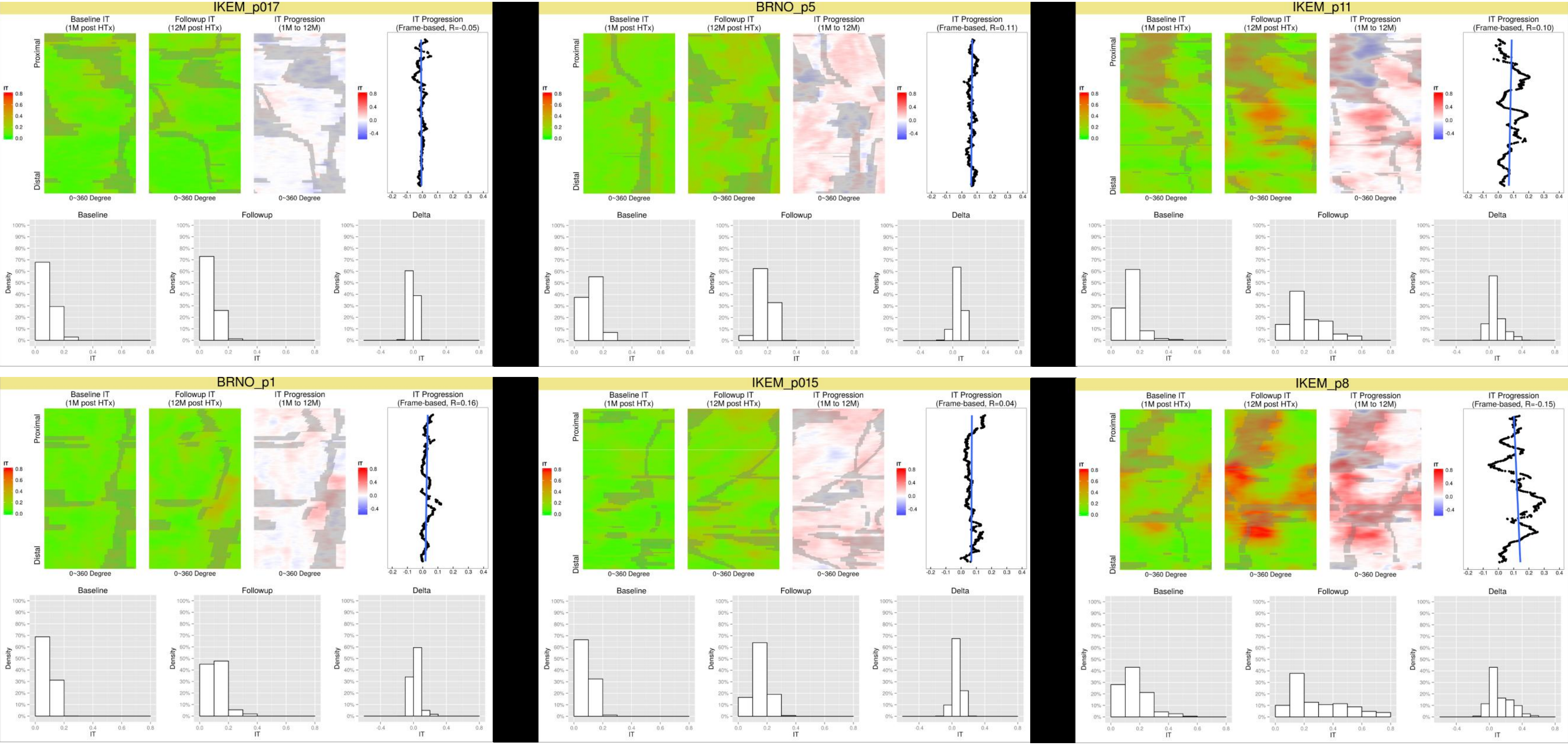
Coronary OCT
Intimal/Medial Layer Thickness Changes

3D OCT Segmentation of Coronary Wall




Distal
Proximal
Fully automated analysis

Visualization of IT Changes



Quantitative Cardiovascular Imaging at the Iowa Institute for Biomedical Imaging

- Screening
  - Carotid IMT
  - Endothelial function – Brachial FMD
- Vascular
  - Coronary IVUS
  - Coronary OCT
  - Aorta
  - AAA
  - Retinal vasculature
    - Linkages to cardiac diseases
- Cardiac
  - LV+RV
- Transplant
  - CAV quantification
- Predictions
  - Plaque type
  - CAV progression risk

Conclusion

- Quantitative image analysis is a prerequisite to precision medicine
- Challenges:
  - Large-enough datasets for machine learning
  - We need physicians' involvement to get reliable "truth" – quantification, labeling, diagnosis, …
  - Accessible databases with a wealth of patient-specific information – EMR
- Engineering knowledge and computational power are available for the first time to succeed in this task

➔ If we can have self-driving cars …

… we can have precision medicine in cardiology