Relationship between plaque development and local hemodynamics in coronary arteries

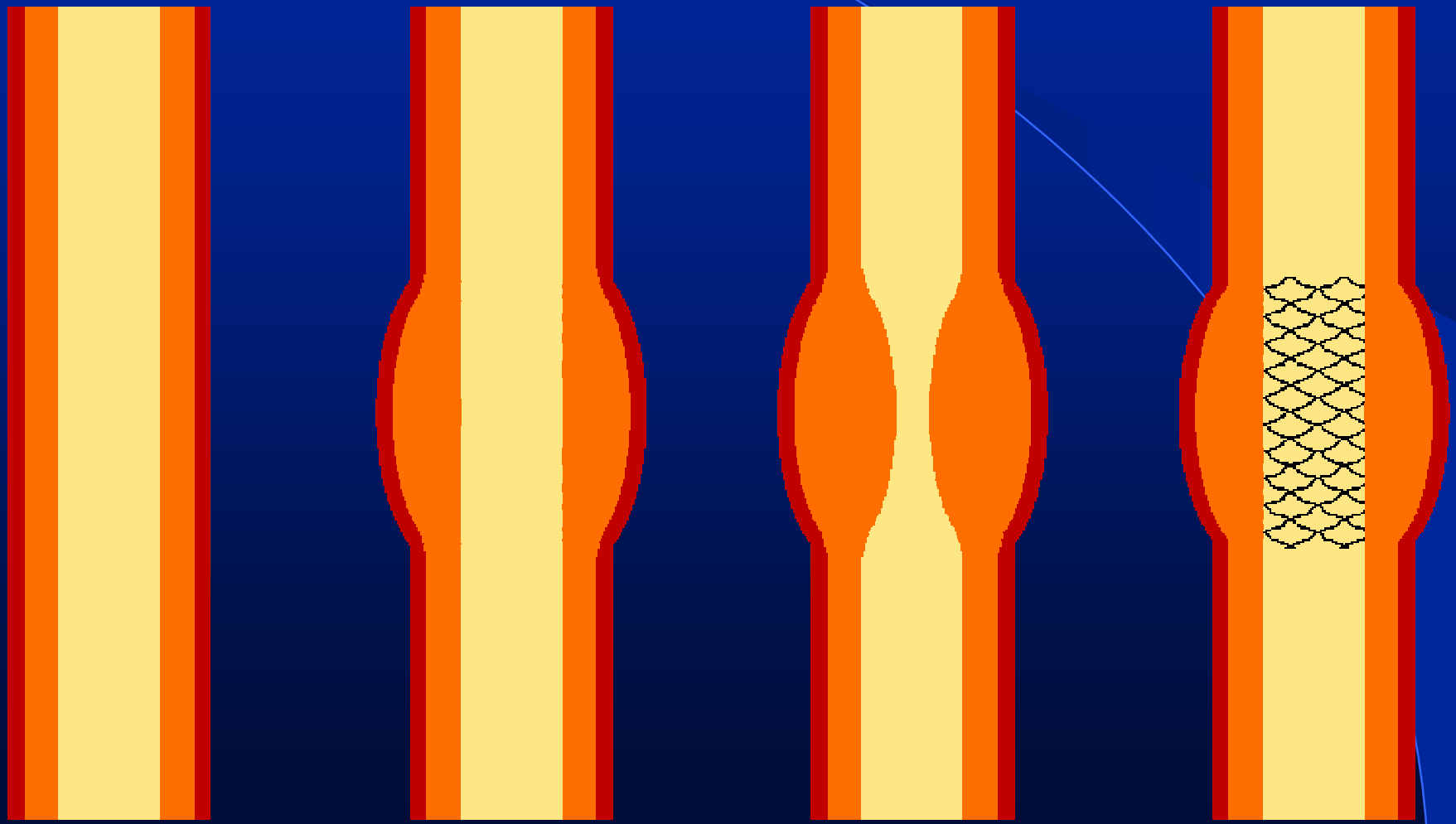
A. Wahle, J. J. Lopez,* M. E. Olszewski, S. C. Vigmostad, K. C. Braddy, T. M. H. Brennan, S. W. Bokhari,* J. G. Bennett,* E. M. Holper,* J. D. Rossen, K. B. Chandran, M. Sonka

The University of Iowa, Iowa City, Iowa (USA)
*The University of Chicago, Chicago, Illinois (USA)

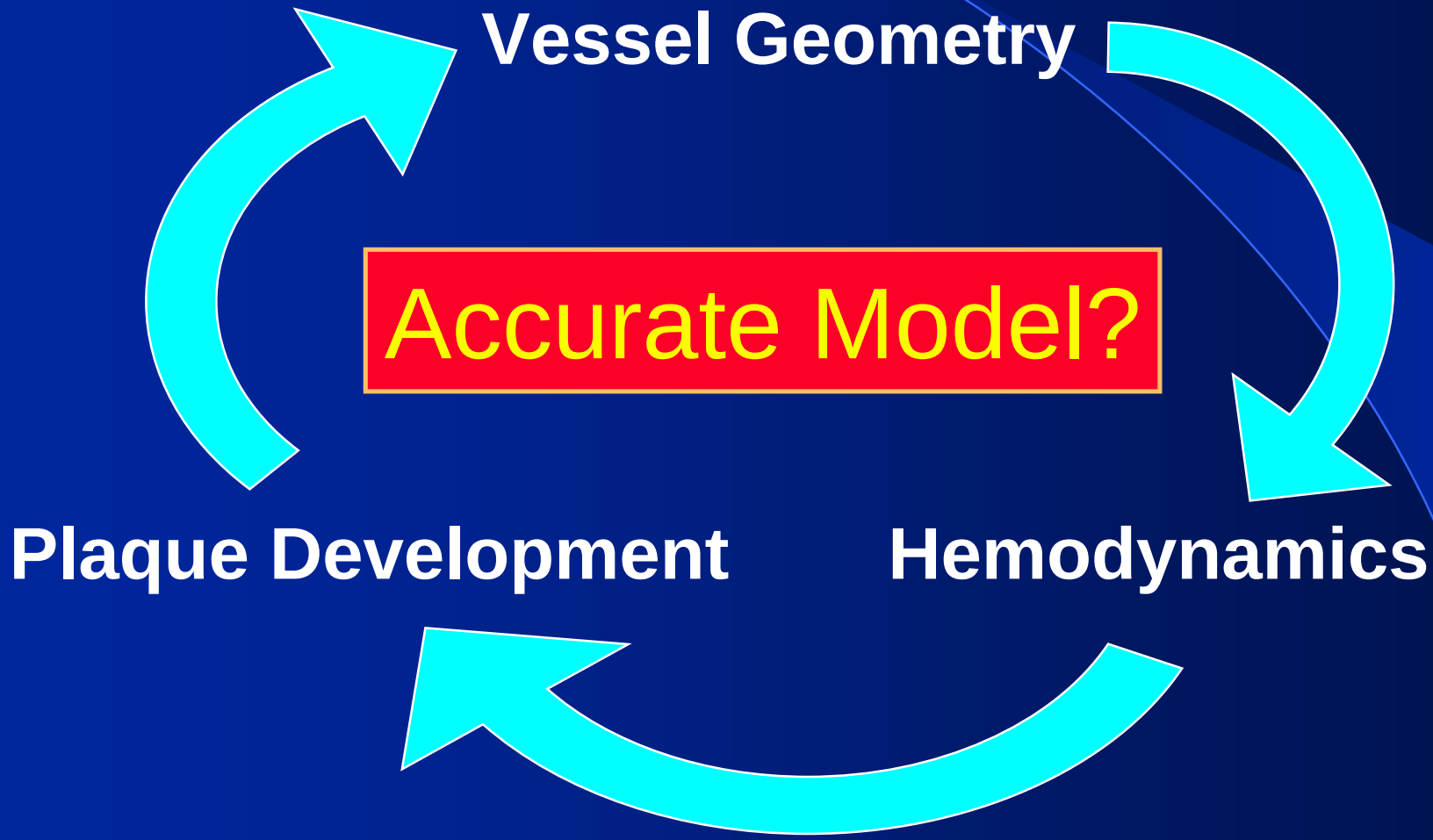
Background

- Coronary atherosclerosis major cause of death in industrialized nations
- Mechanisms of arterial plaque accumulation need to be understood
- Improvement of diagnostic methods
- Improvement of treatment (interventions)

Plaque Progression / Intervention

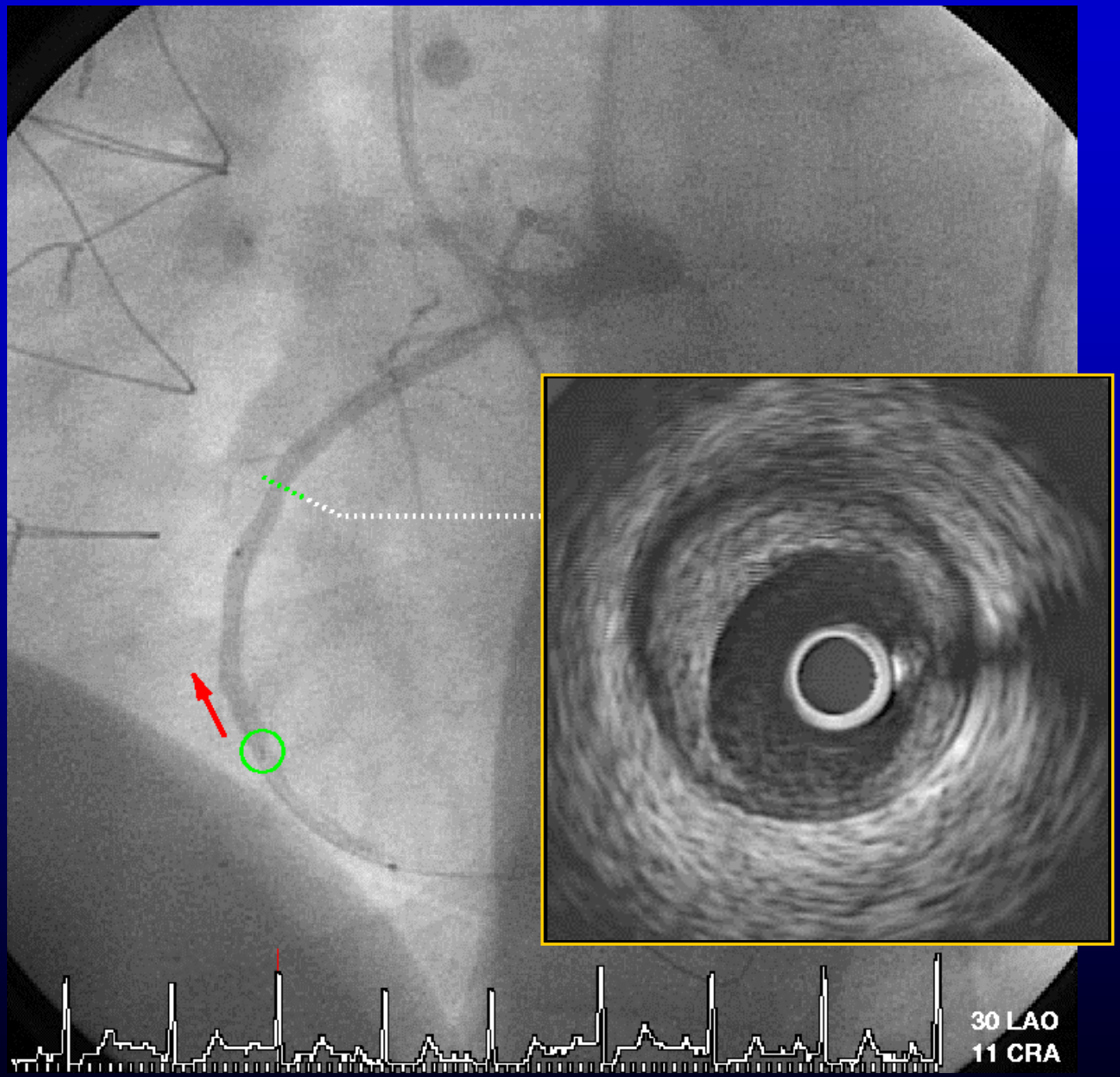


Background

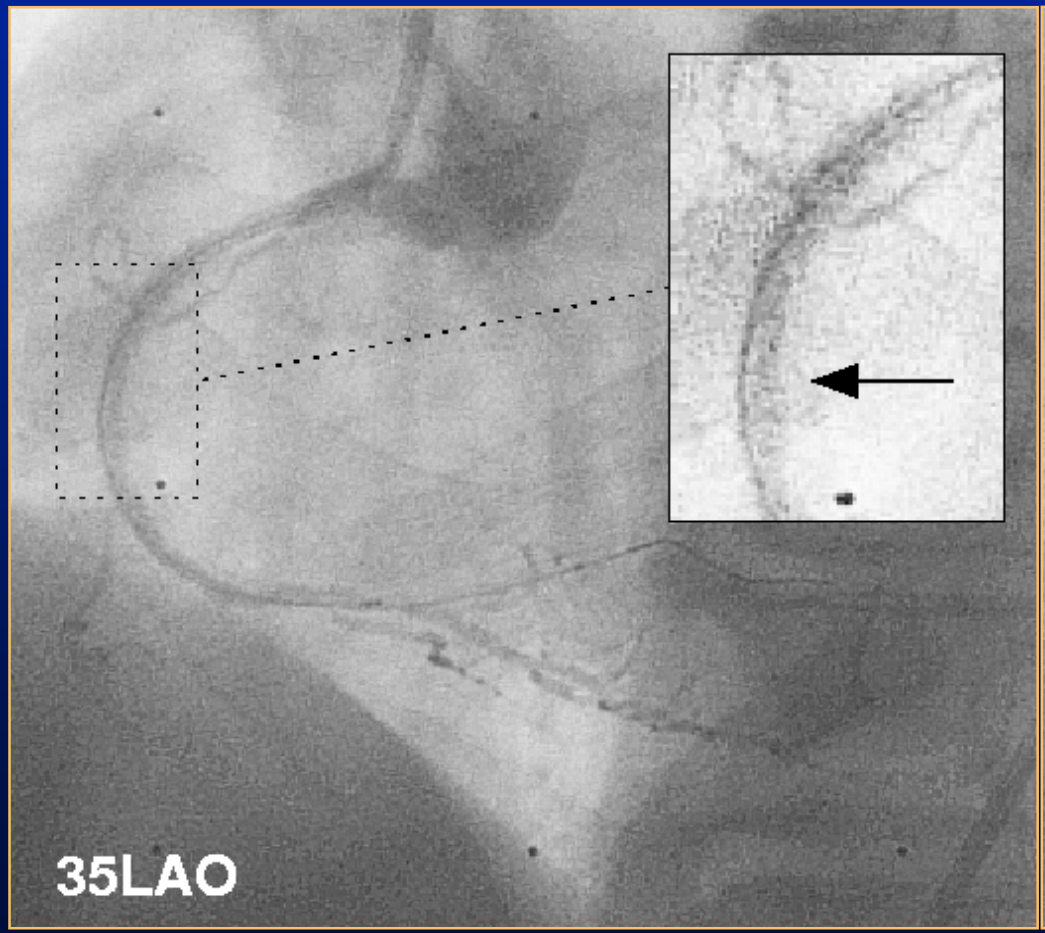

Vessel Geometry
Accurate Model?
Plaque Development
Hemodynamics

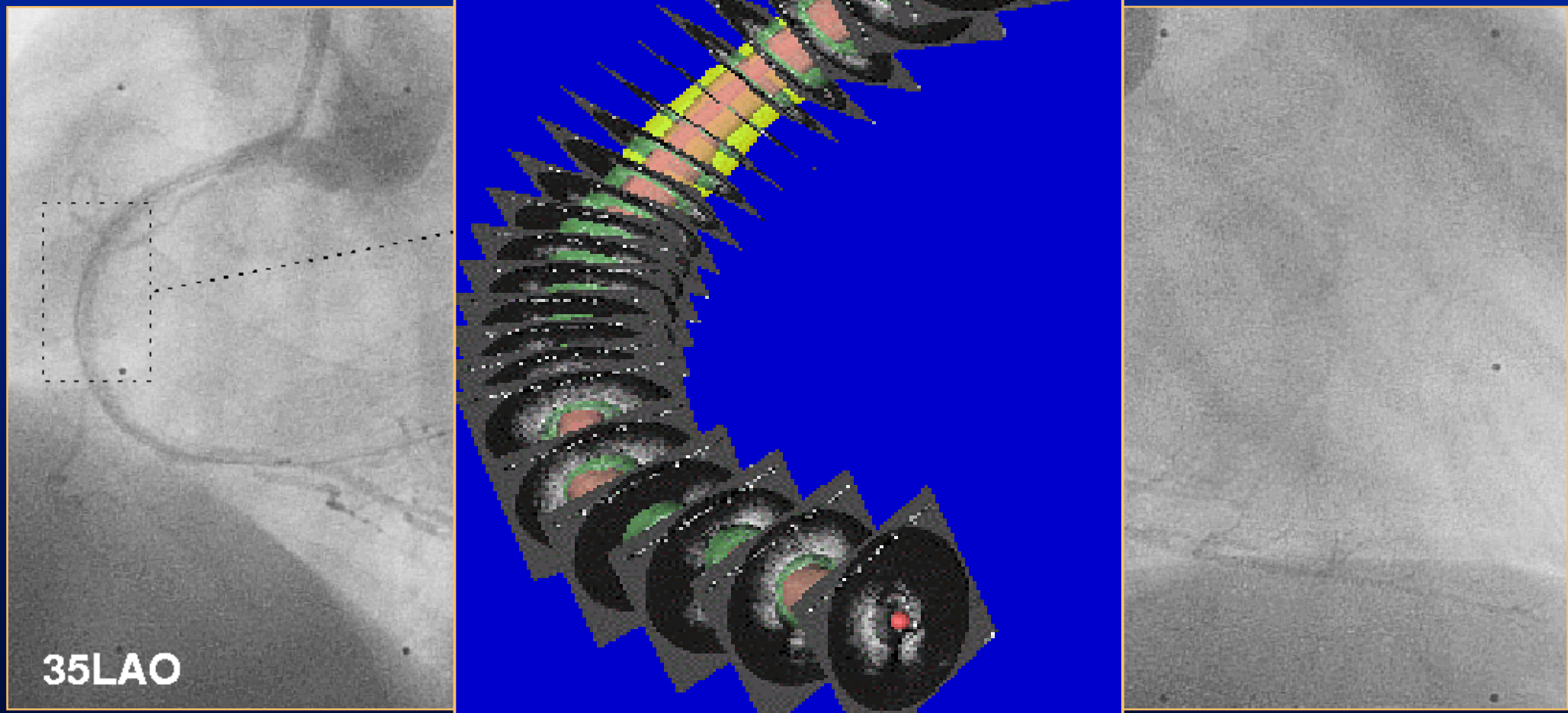
Angiography
–Lumen

Intravascular Ultrasound
–Plaque+Wall



3-D Model

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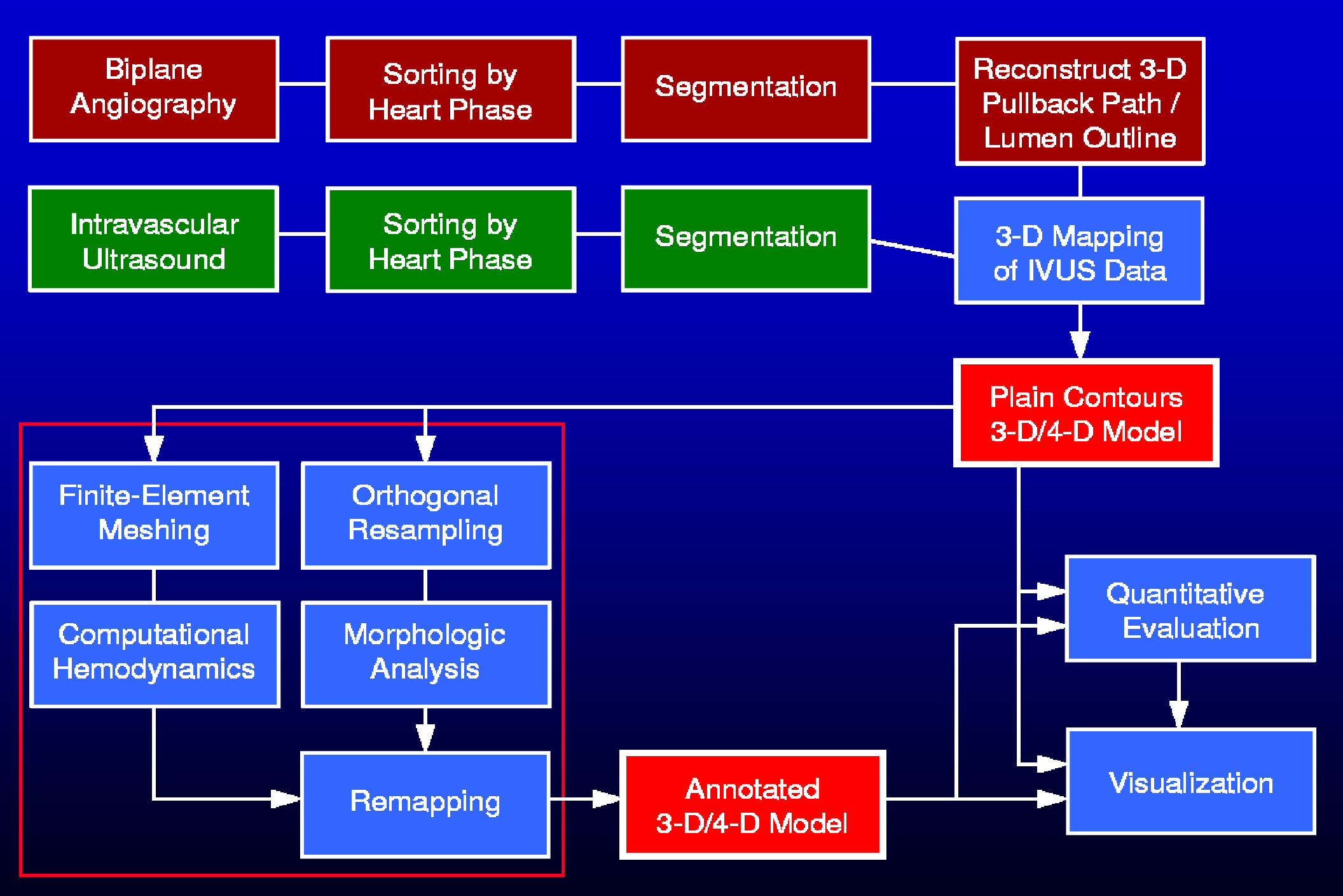
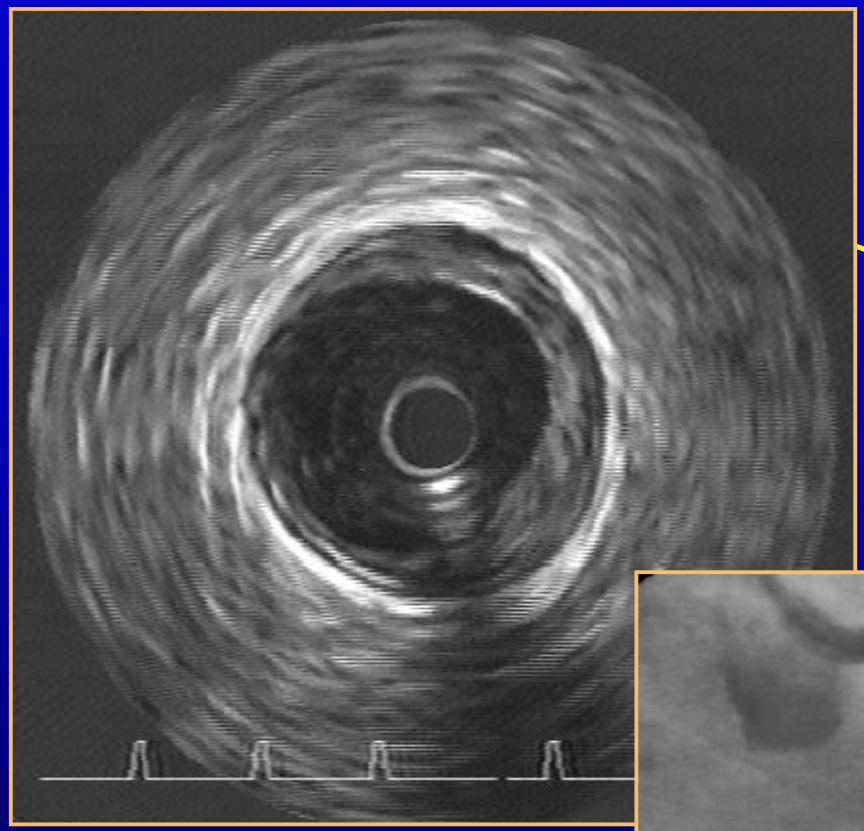
Fusion Methods

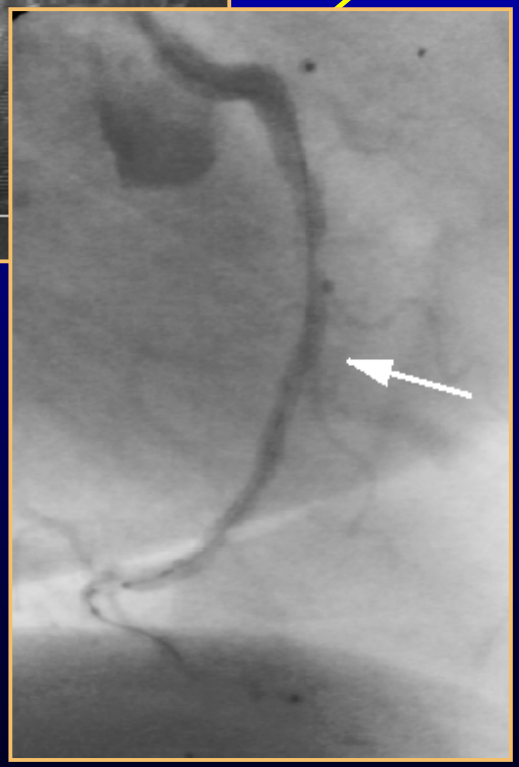
- Combines advantages of both modalities
  - Cross-sectional accuracy from IVUS
  - 3-D Geometrical accuracy from angiography
- Detailed talk on IVUS segmentation
  [5747-51, Wed. 1:20pm]

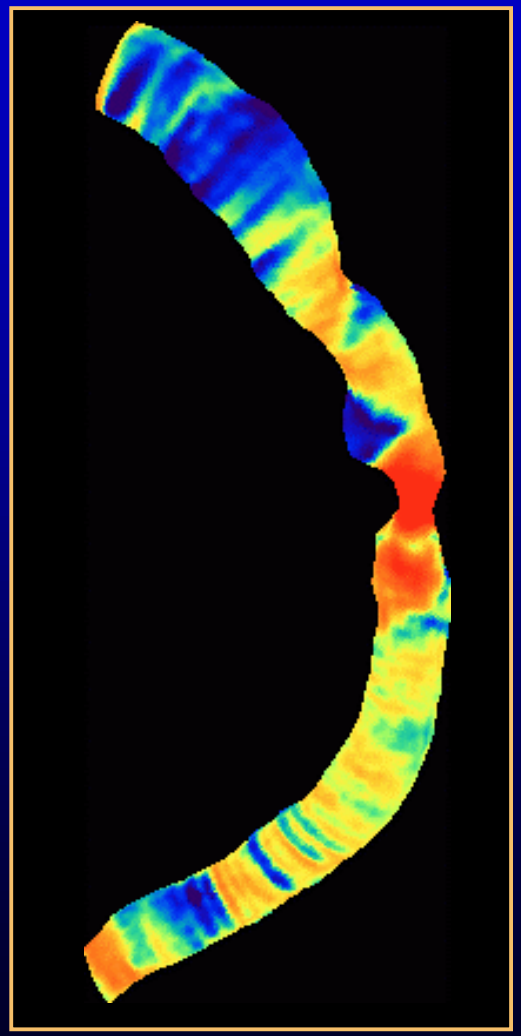

Biplane Angiography
Sorting by Heart Phase
Segmentation
Reconstruct 3-D Pullback Path / Lumen Outline
Intravascular Ultrasound
Sorting by Heart Phase
Segmentation
3-D Mapping of IVUS Data
Plain Contours 3-D/4-D Model
Finite-Element Meshing
Orthogonal Resampling
Computational Hemodynamics
Morphologic Analysis
Remapping
Annotated 3-D/4-D Model
Quantitative Evaluation
Visualization

Model “Annotation”



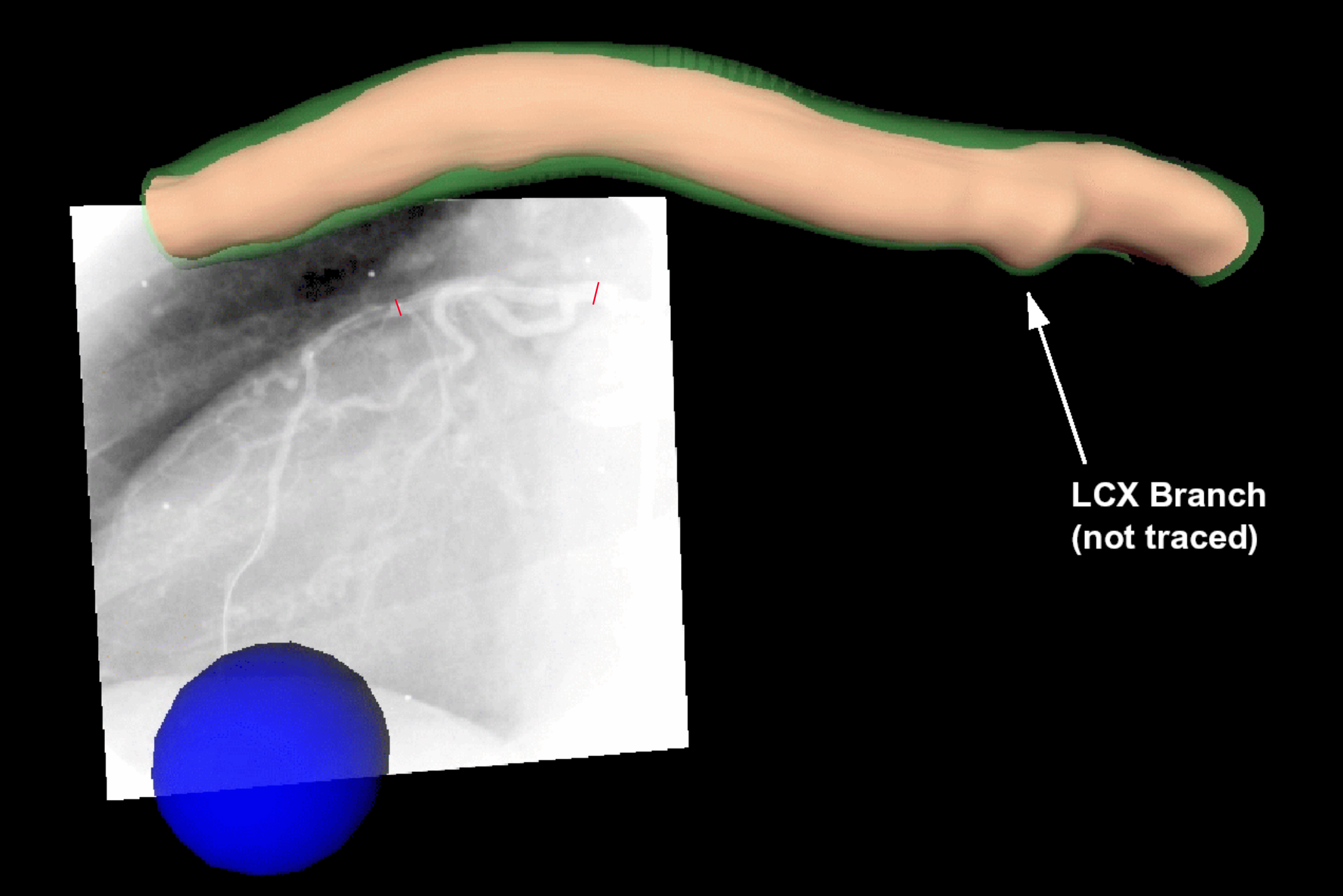
Fusion

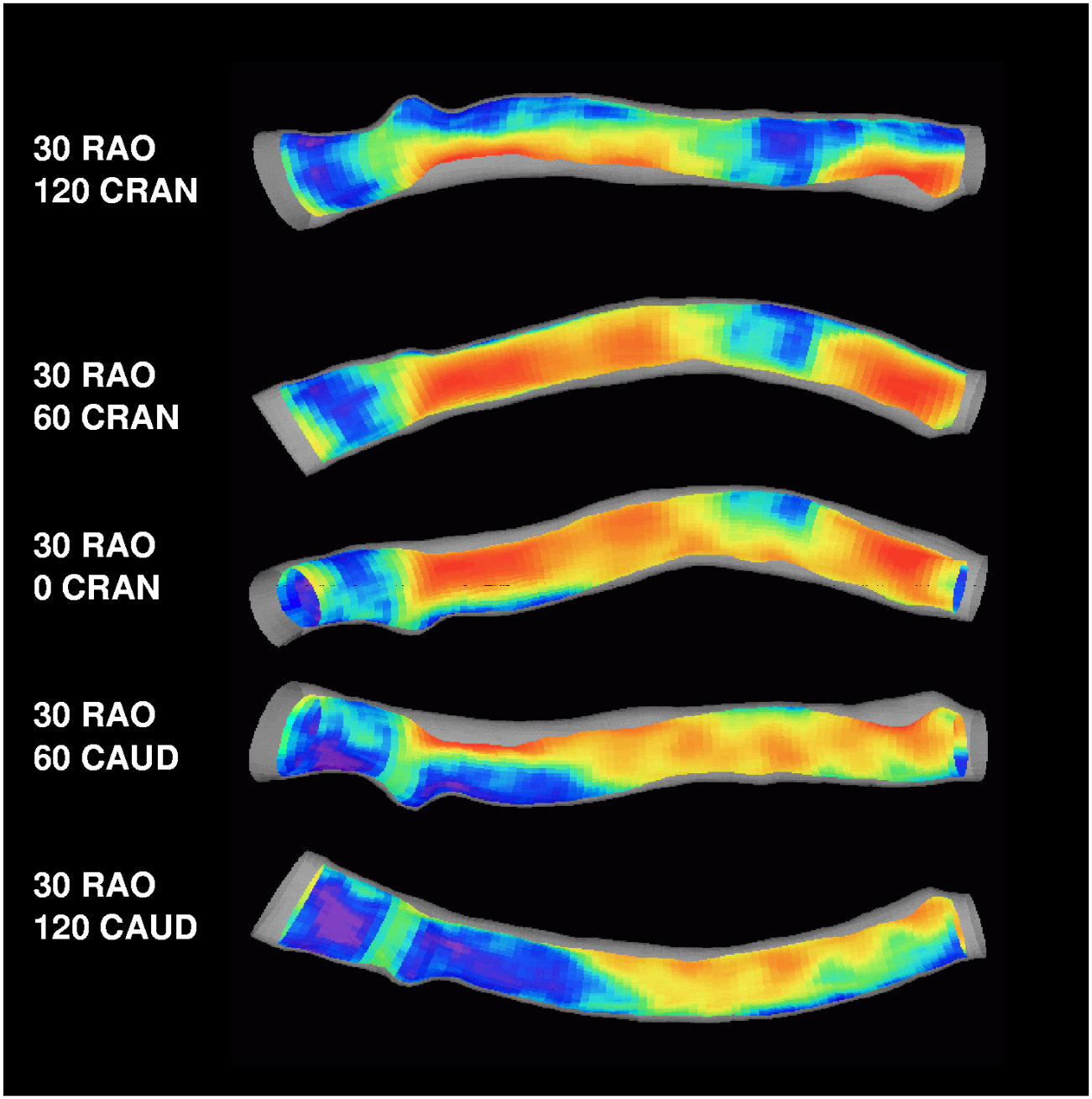


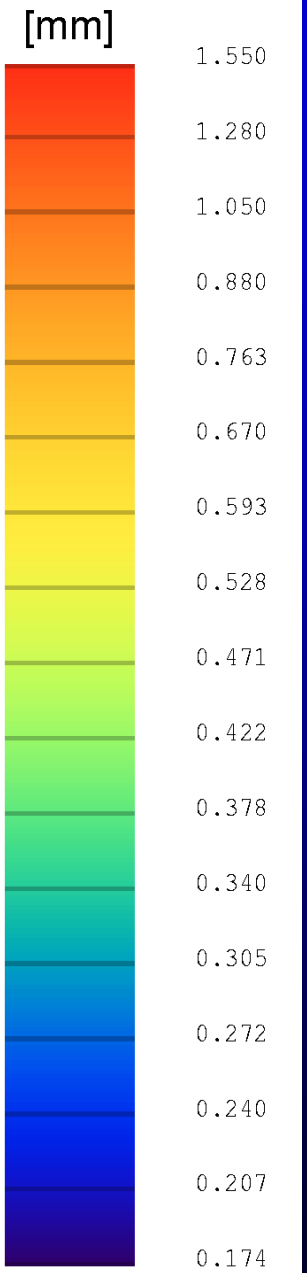


Curvature vs. Plaque Thickness

- No immediate correlation between wall shear stress and plaque thickness
- Curvature less distorted by plaque progression than shear stress
- Wall shear stress expected to be lower on ***inner*** bend of a curved vessel
  - ***Q:*** is there a direct correlation between vessel curvature and plaque distribution?


LCX Branch
(not traced)



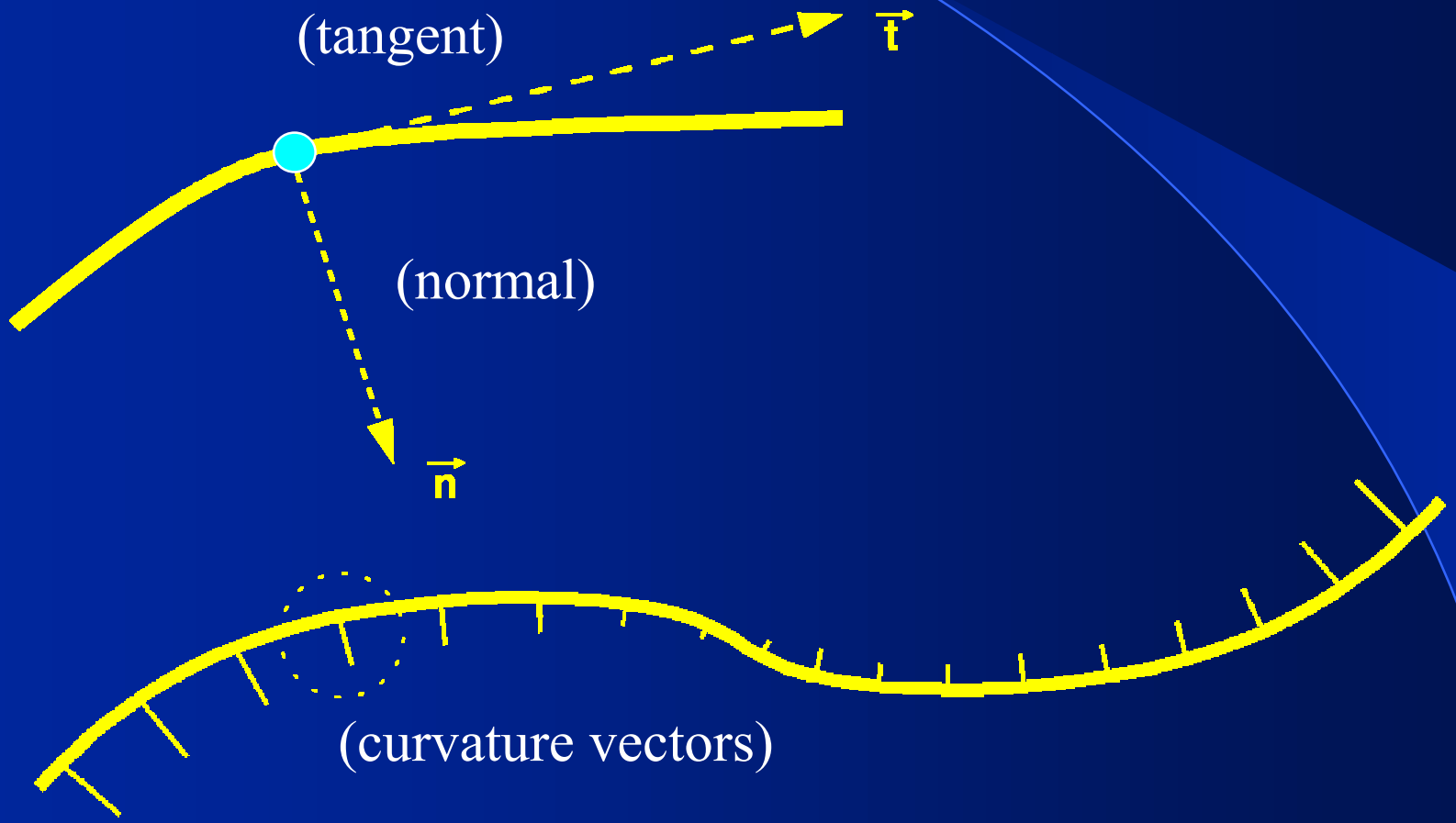


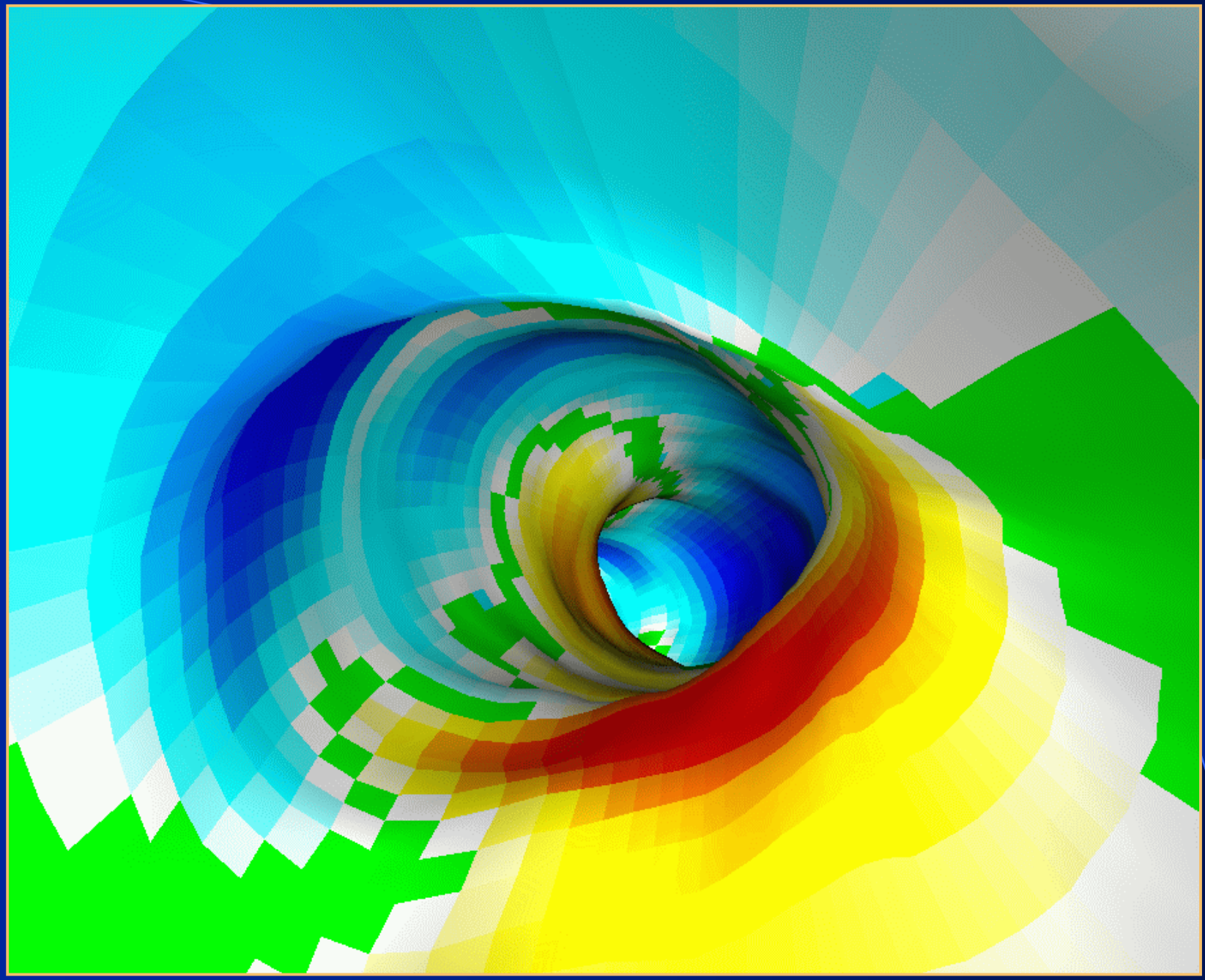
Plaque Thick-ness

Curvature Index

- Scalar value specifying:
  - Curvature ***magnitude***
  - ***inner*** and ***outer*** curvature
- Differential geometry
  - Frenet frame

Curvature Index





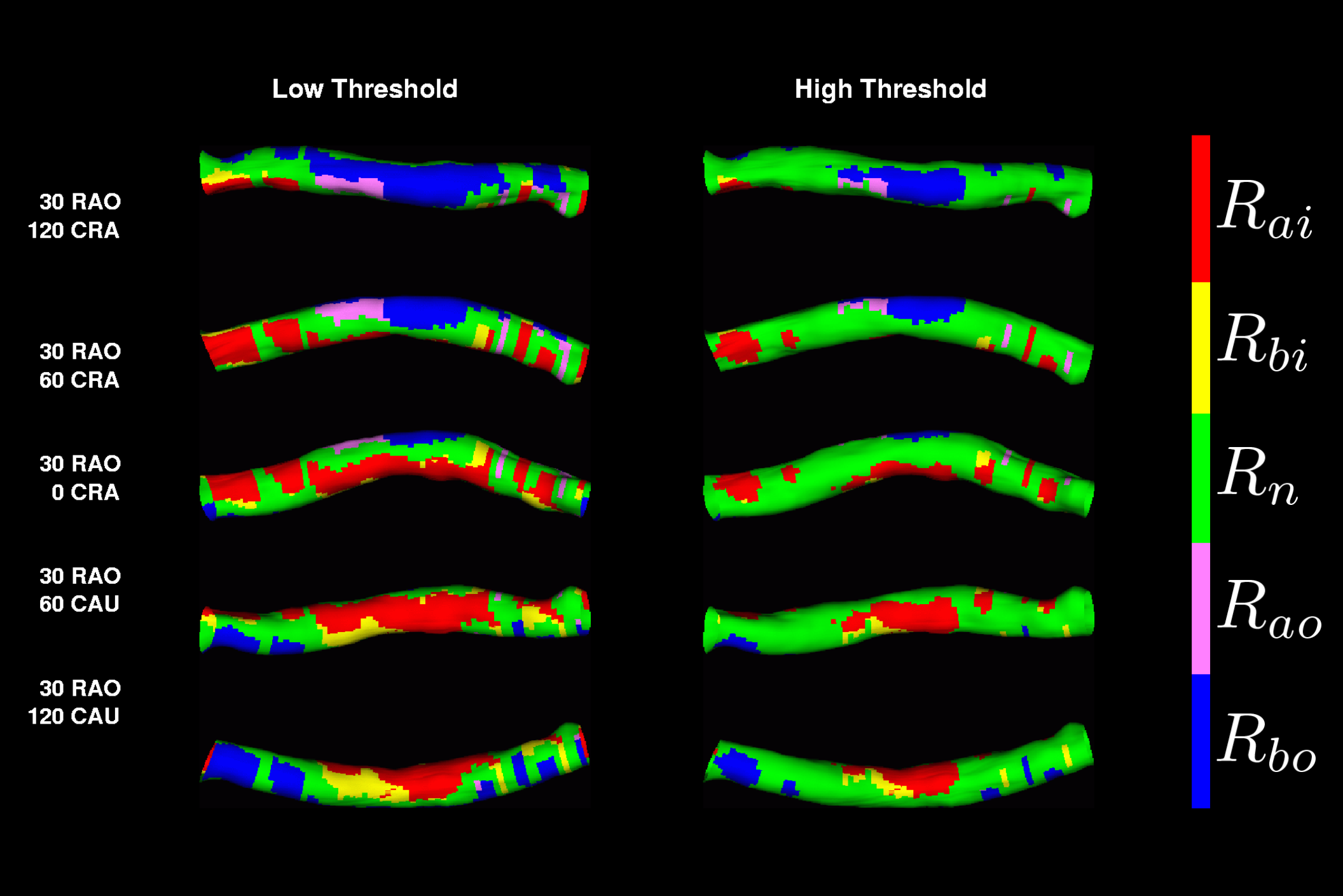
Classification Regions

	Inner curv.	Outer curv.
Above average.	R_{ai}	R_{ao}
Below average.	R_{bi}	R_{bo}

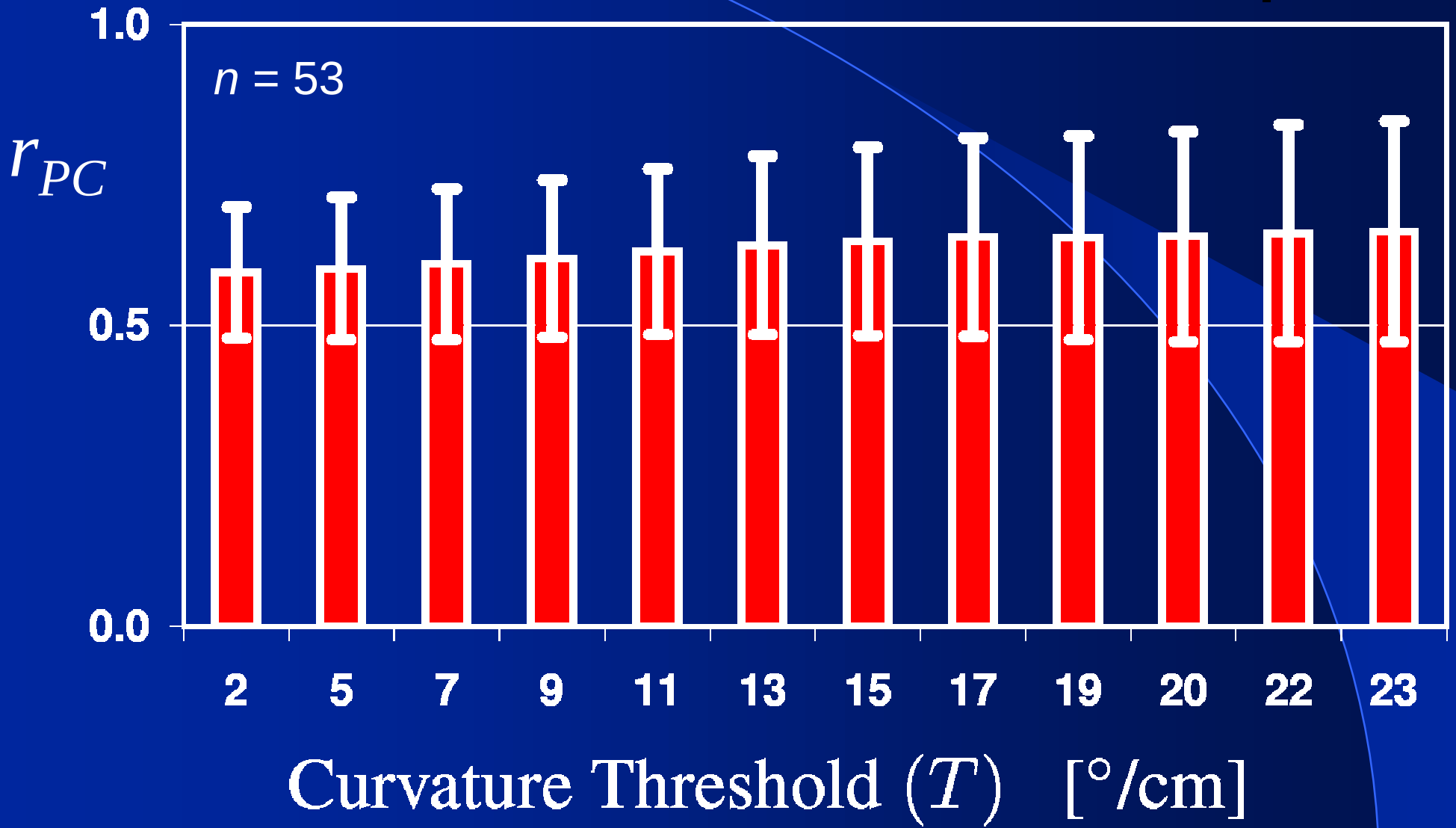
Classification Regions (1)

$$r_{PC} = \frac{\|R_{ai} + R_{bo}\|}{\|R_{ai} + R_{bo} + R_{ao} + R_{bi}\|}$$

Hypothesis test: $r_{PC} > 0.5$


Low Threshold
High Threshold
30 RAO
120 CRA
30 RAO
60 CRA
30 RAO
0 CRA
30 RAO
60 CAU
30 RAO
120 CAU
R_{ai}
R_{bi}
R_n
R_{ao}
R_{bo}

Results — Curvature/Plaque



Classification Regions (2)

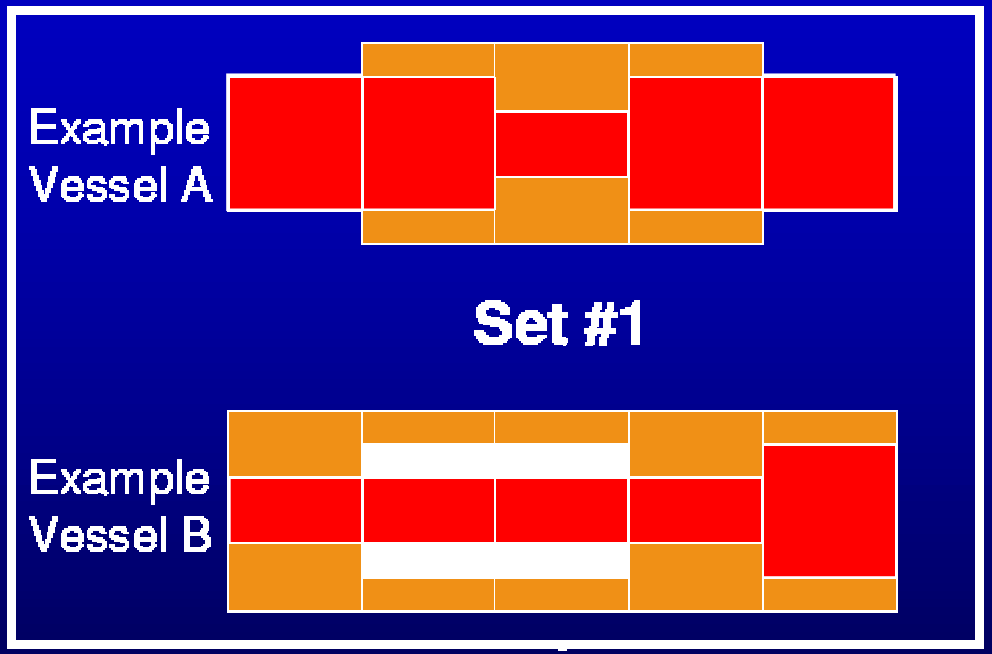
$$r_{PW} = \frac{\|R_{al} + R_{bh}\|}{\|R_{al} + R_{bh} + R_{ah} + R_{bl}\|}$$

Hypothesis test: ?

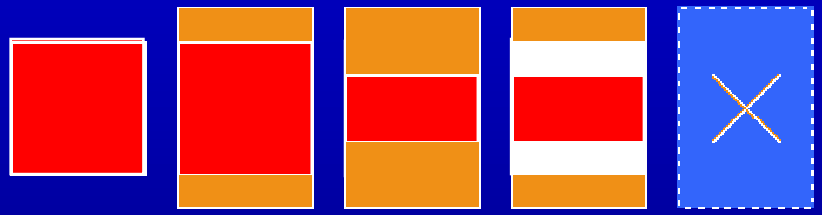
Wall Shear Stress vs. Plaque

- Correlation should be found in segments of "early disease"
  - ***Q:*** how to be defined?
- Glagov *et al.* found compensatory enlargement at <40% area stenosis
  - ***Q:*** correlation better than in >40%?

Grouping by Disease Severity



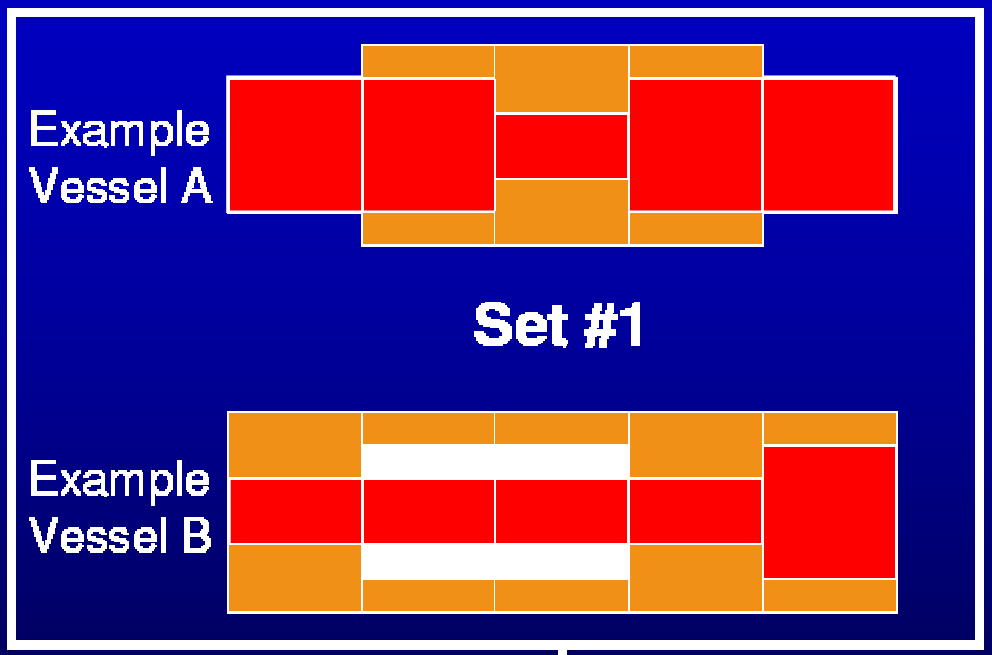
Legend:



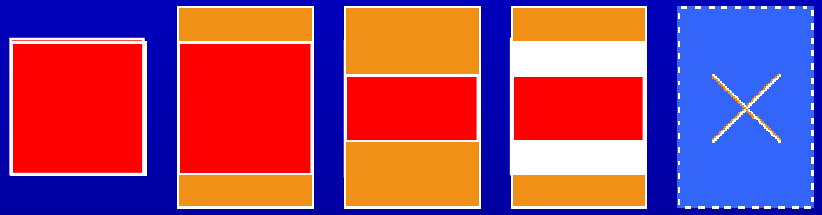
<10% <40% >40% Calc. Excl.

(area stenosis)

Grouping by Disease Severity



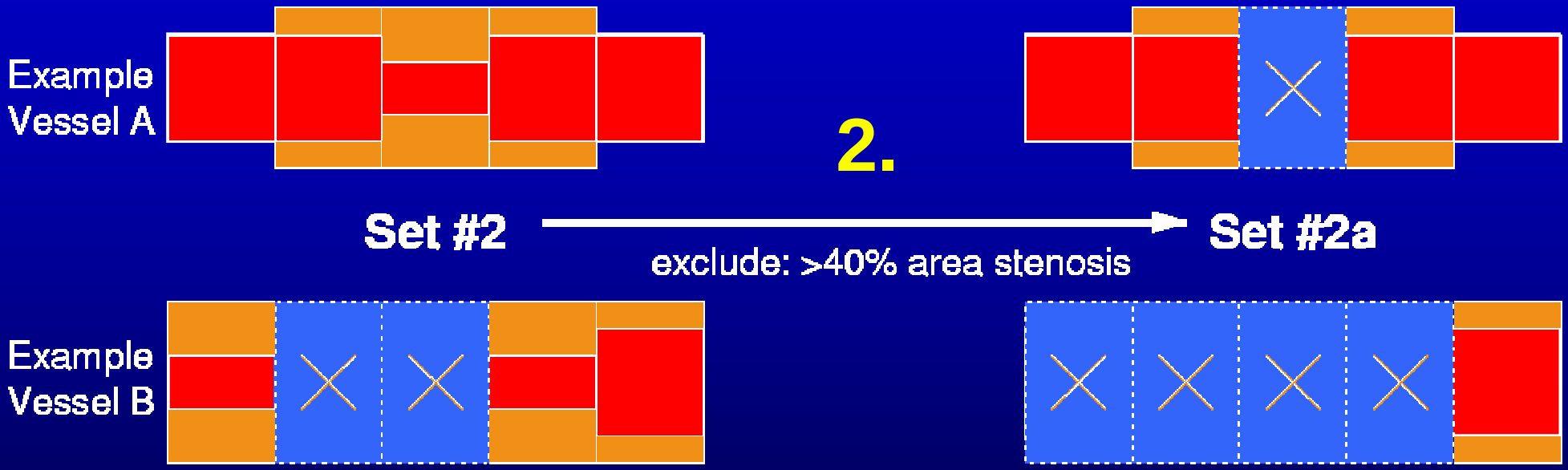
Legend:



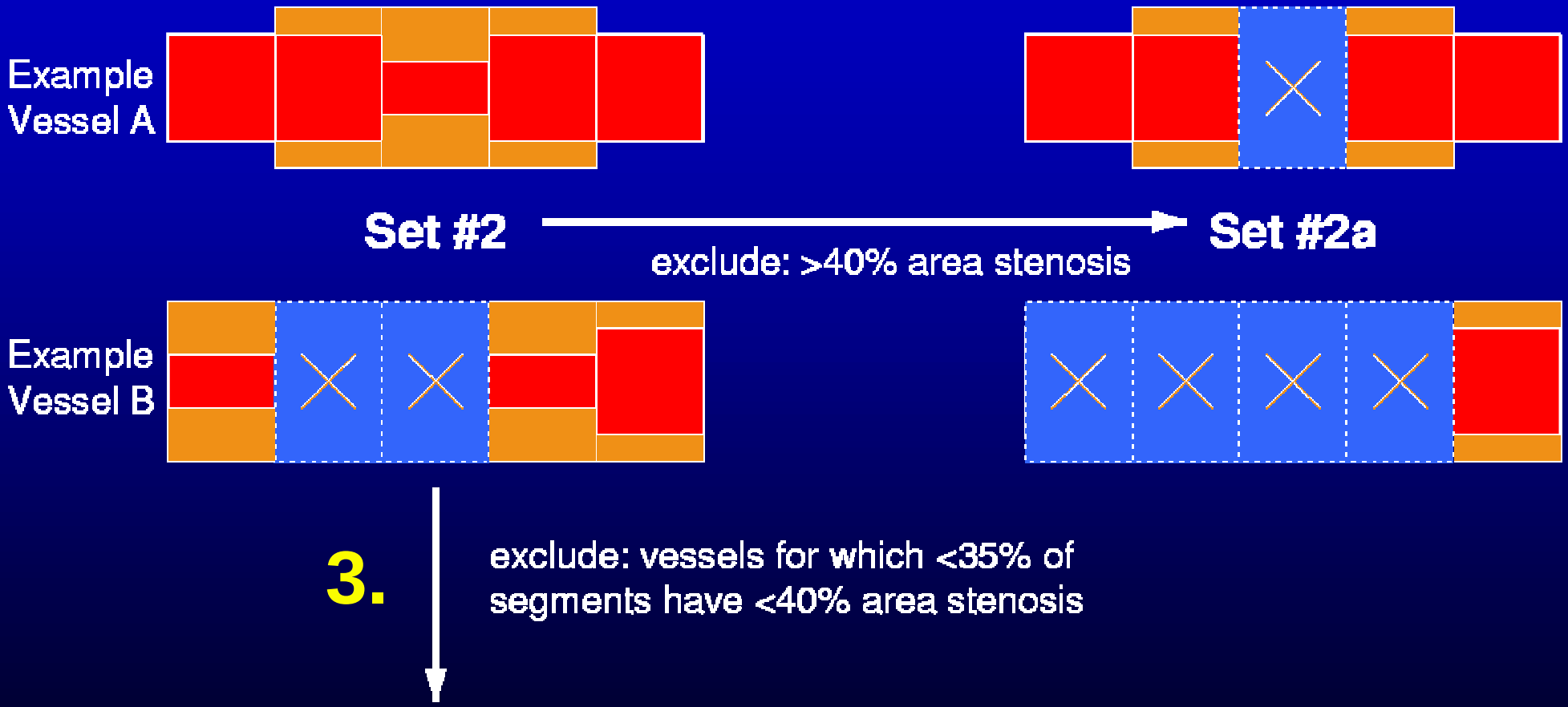
<10% <40% >40% Calc. Excl.
(area stenosis)

1. exclude: branches, stents, calcifications

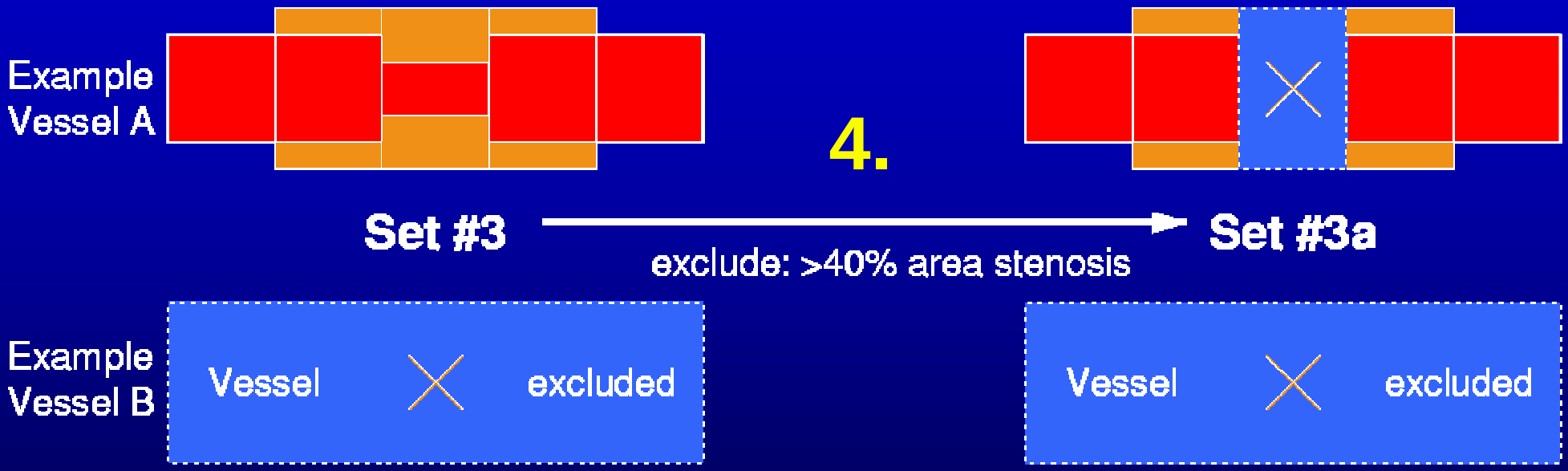
Grouping by Disease Severity



Grouping by Disease Severity



Grouping by Disease Severity

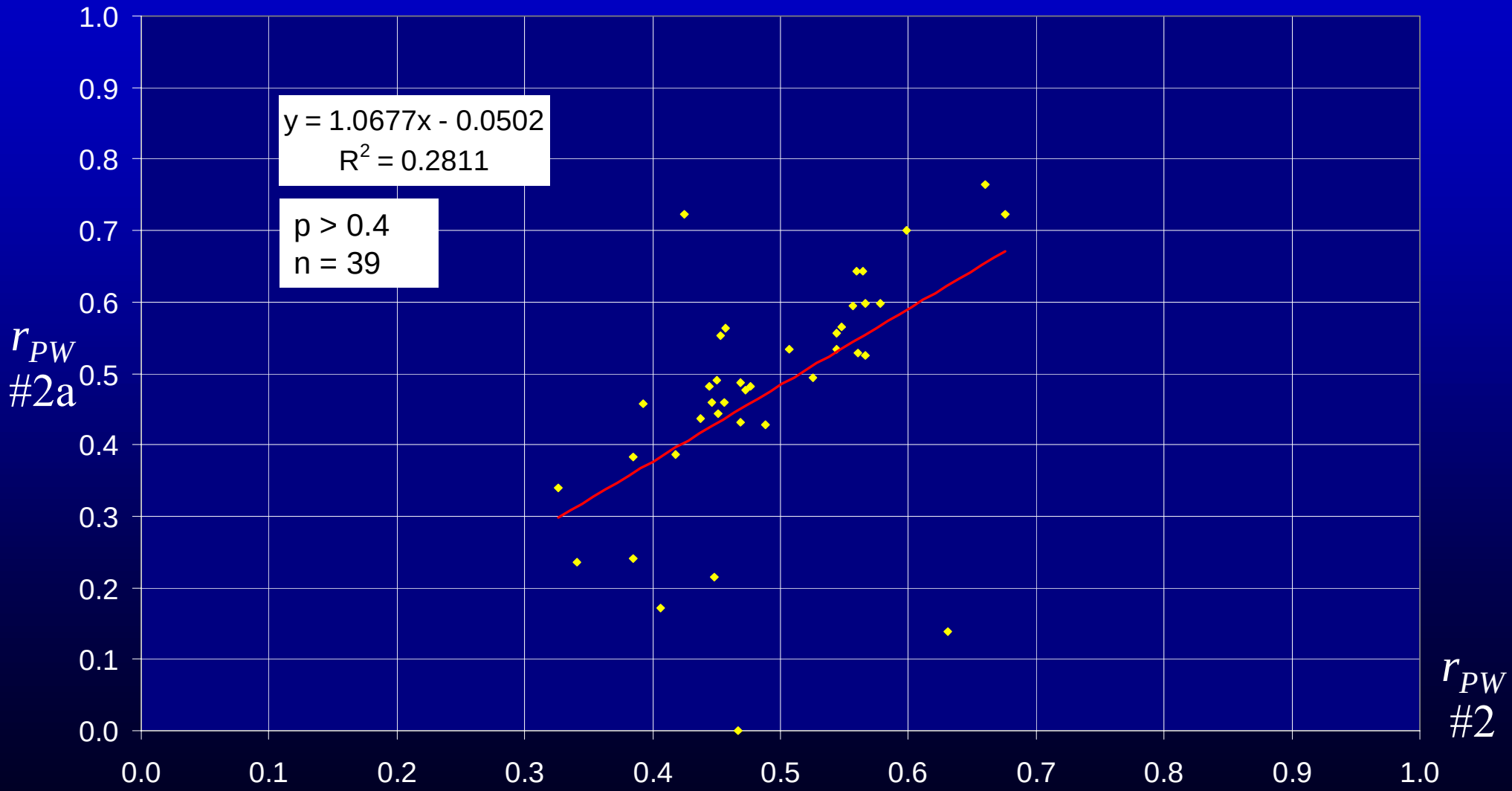


Classification Regions (2.1)

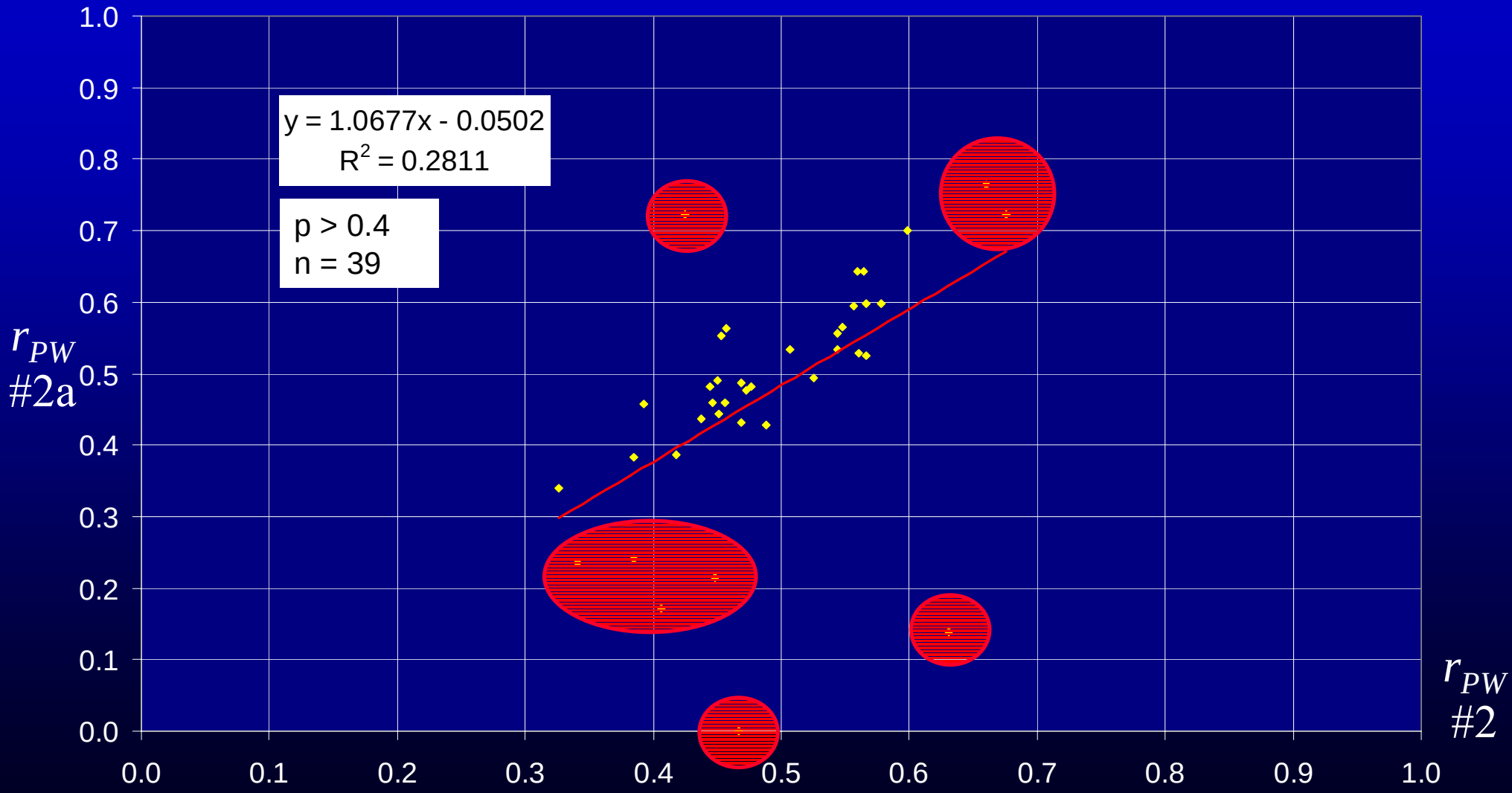
$$r_{PW} = \frac{\|R_{al} + R_{bh}\|}{\|R_{al} + R_{bh} + R_{ah} + R_{bl}\|}$$

Hypothesis: $\dfrac{r_{PW} \mid \text{10-40\% area-stenosis}}{r_{PW} \mid \text{0-100\% area-stenosis}} > 1$

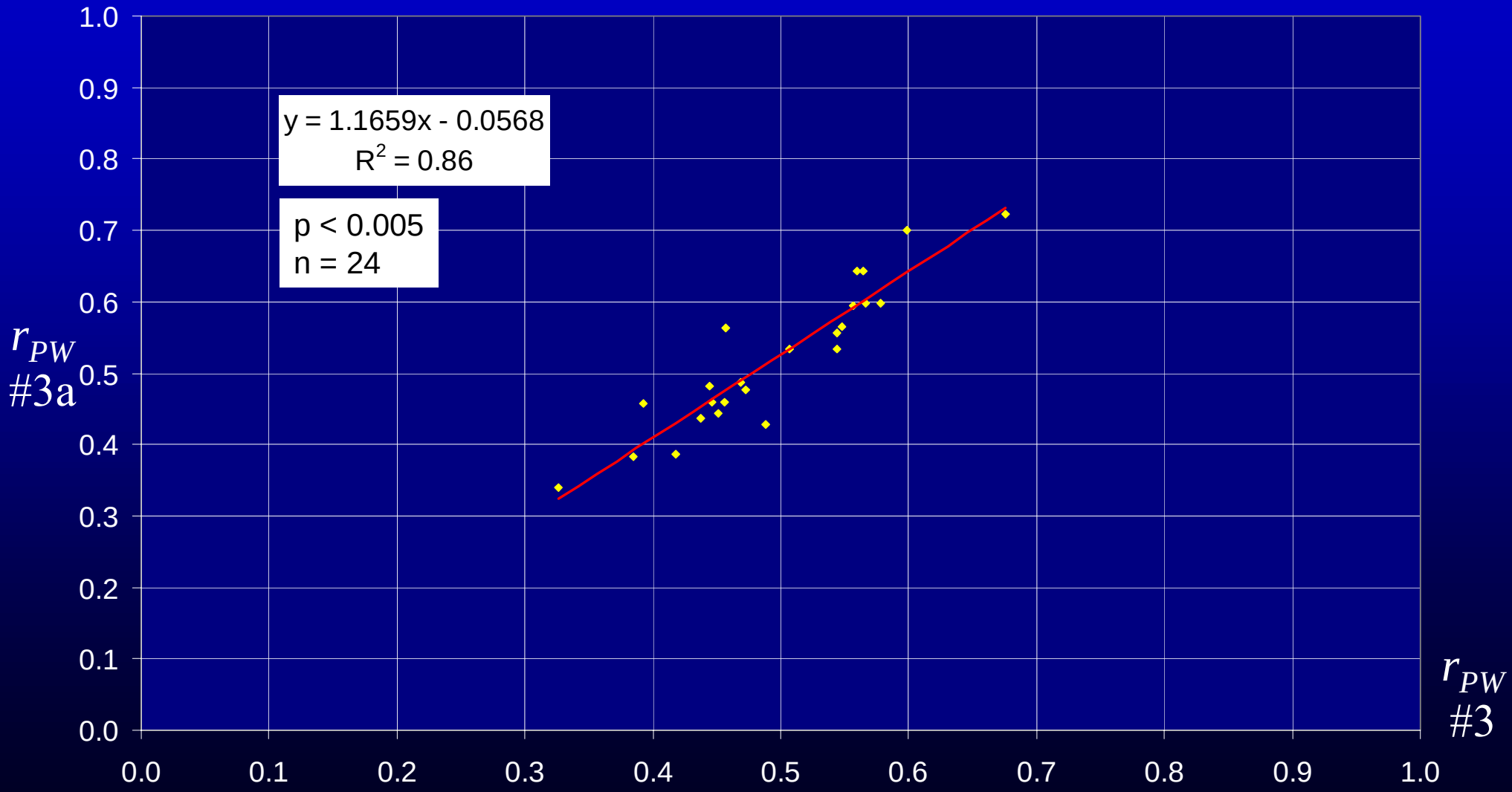
Results Sets #2 vs. #2a



Results Sets #2 vs. #2a



Results Sets #3 vs. #3a



Results – Summary

r_{PW}	Increase		Same		Decrease	
#2 / #2a	59%	(23)	5%	(2)	36%	(14)
#3 / #3a	75%	(18)	8%	(2)	17%	(4)

Conclusions

- Direct plaque-thickness/curvature correlation in majority of vessels
- No direct plaque/wall-shear-stress correlation can be determined
- Plaque/wall-shear-stress correlation predominantly in vessel segments in early stages of atherosclerosis

Acknowledgments

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Acknowledgments

Thank you!

http://www.engineering.uiowa.edu/~awahle