Utilization of CT-Based Myocardial Segmentation

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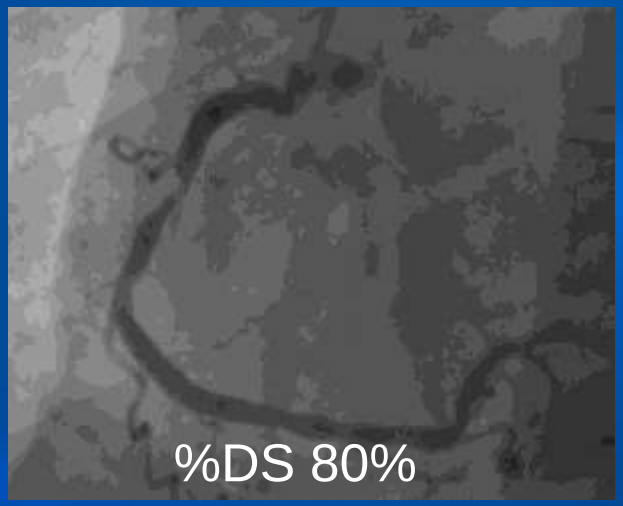
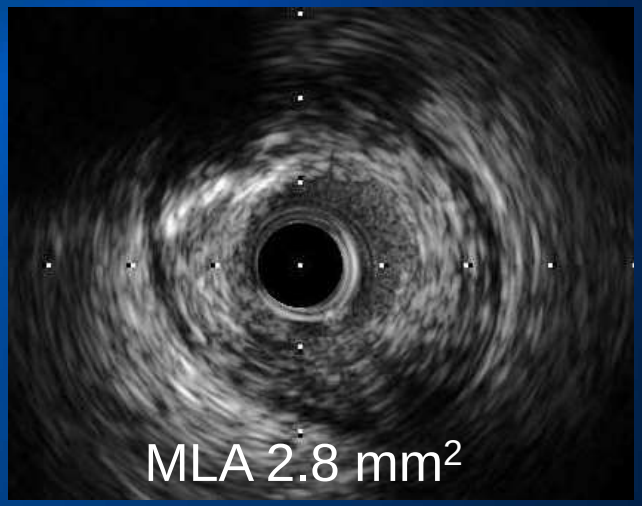
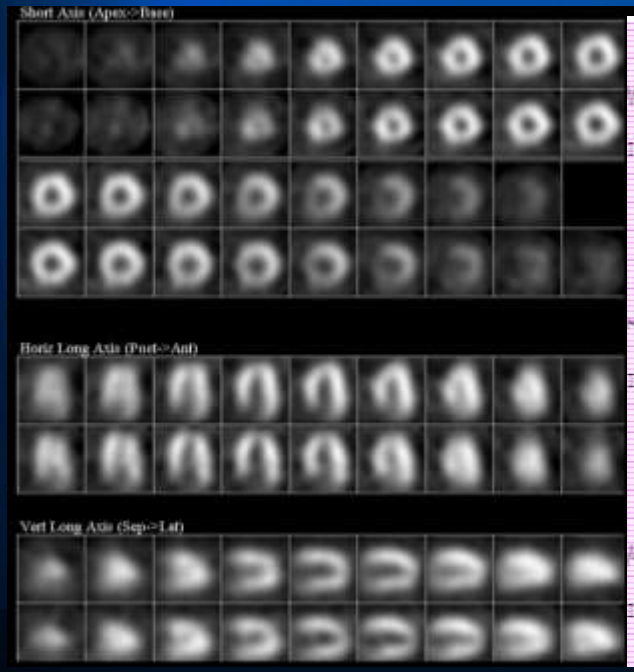
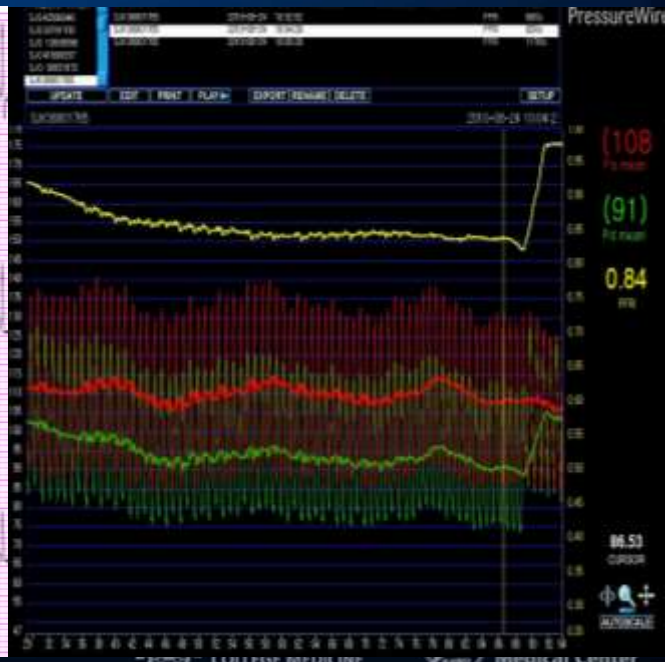
Visual-Functional Mismatch





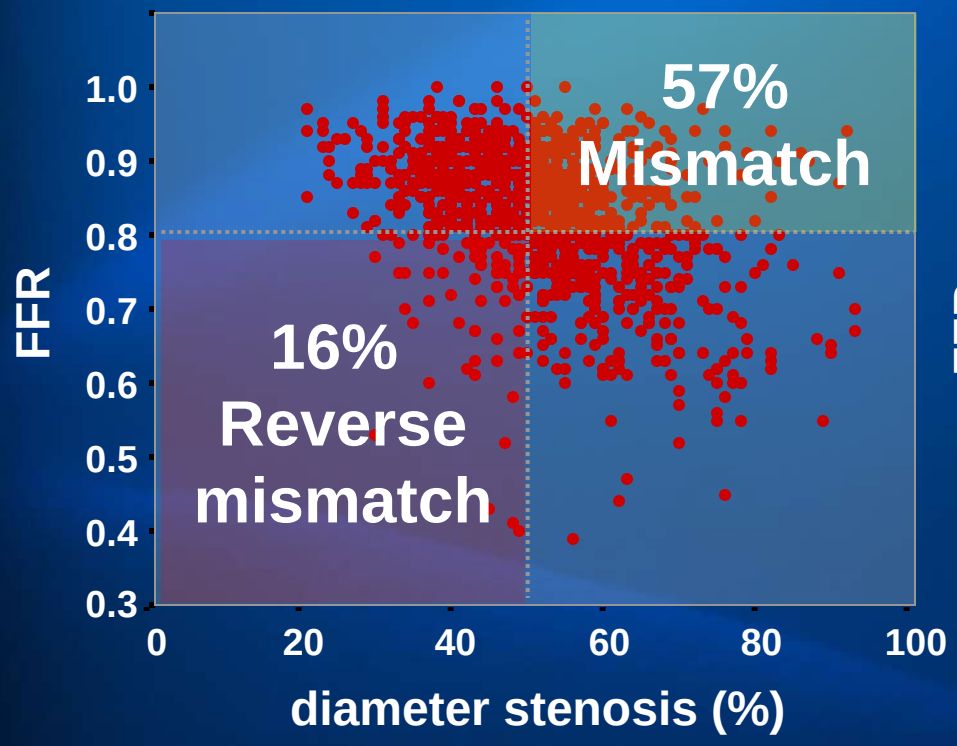




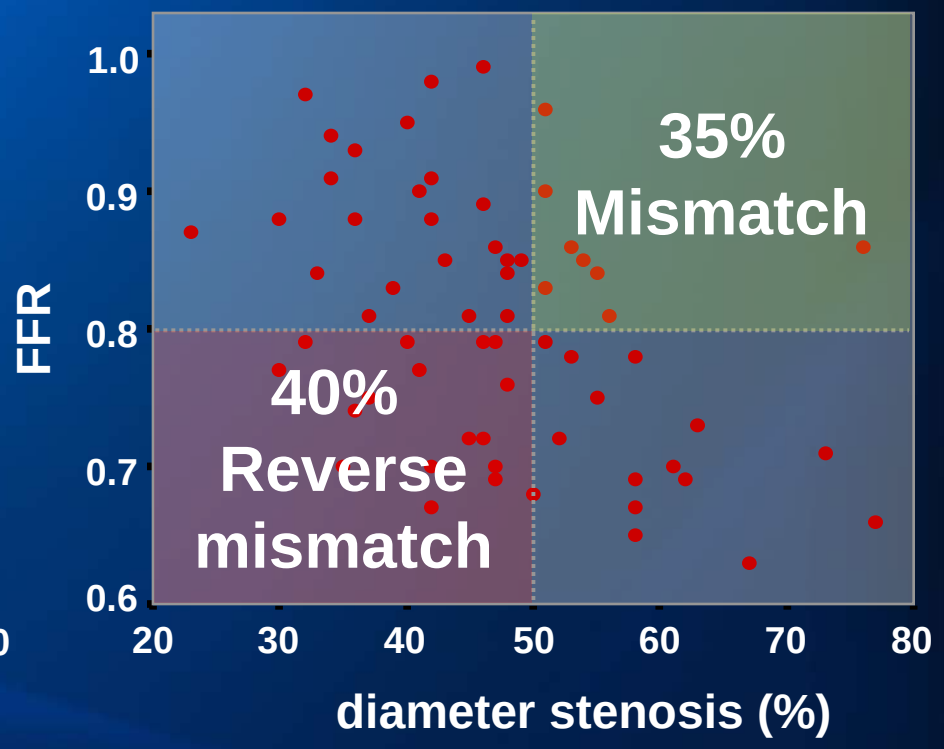
Discrepancy QCA vs. FFR in AMC

(1129 lesions with DS >30%) who underwent IVUS and FFR

1066 Non-LM lesions



63 LM lesions



Park et al. JACC interv 2012;5:1029

Multivariable Analysis Predicting FFR

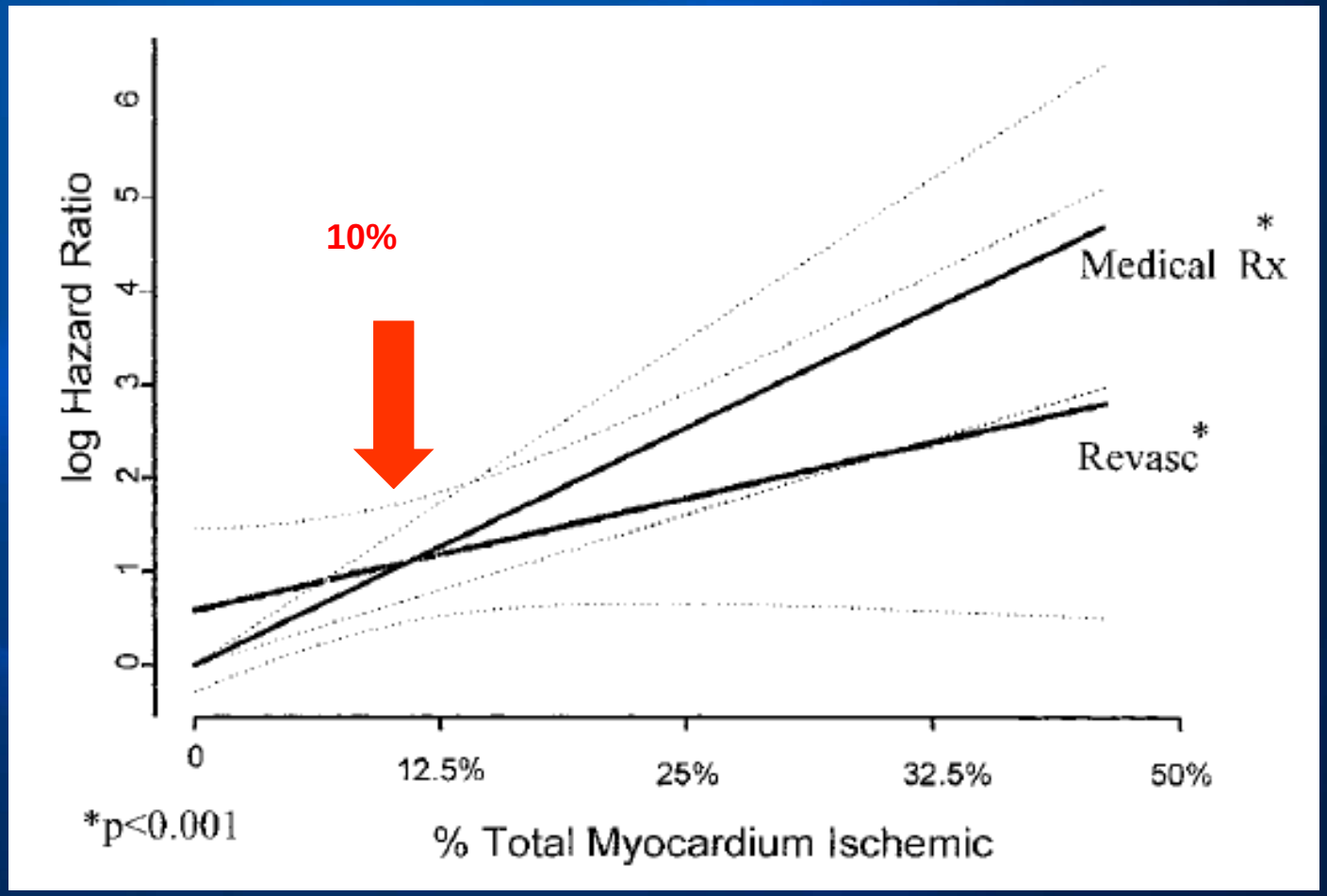
in 700 LAD lesions of 700 patients

**Including age, female, body surface area, smoking, angiographic DS, minimal lumen diameter, lesion length, IVUS-MLA, plaque burden, averaged reference EEM area and %area stenosis, †addition of left ventricular mass*

	Total (700 patients)*			608 patients with echo data†		
	β	p value	95% CI	β	p value	95% CI
Age	0.119	0.001	0.000–0.002	0.192	<0.001	0.001–0.002
BSA	**-0.111**	**0.002**	-0.101– -0.024			
LV mass				**-0.121**	**<0.001**	**-0.001 – 0.000**
Angiographic DS	-0.185	<0.001	-0.002 – -0.001	-0.190	<0.001	-0.002 – -0.002
Lesion length	-0.110	0.001	-0.001 – 0.001	-0.077	0.027	-0.001 – 0.000
IVUS-MLA	0.312	<0.001	0.022 – 0.035	0.294	<0.001	0.019 – 0.032
Plaque burden	-0.115	0.002	0.001 – 0.000	-0.157	<0.001	-0.002 – -0.001

Kang SJ et al. J Am Coll Cardiol Intv 2013;6:562

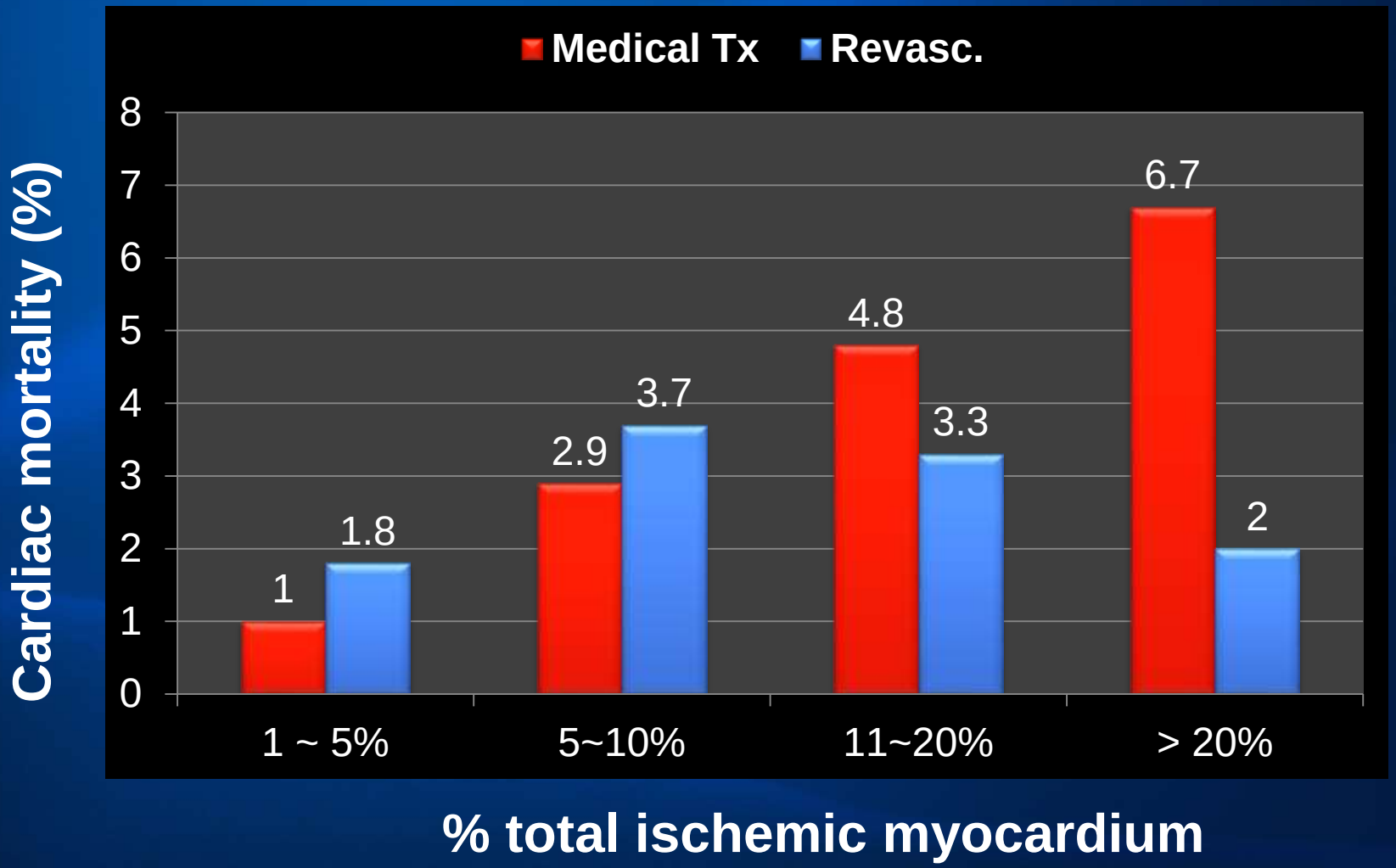
Ischemic Area Influencing Cardiac Mortality
< 10% does not need revascularization



Hachamovitch et al. Circulation. 2003;107:2900

Survival Benefit with Revascularization

at 1.9-year F/U

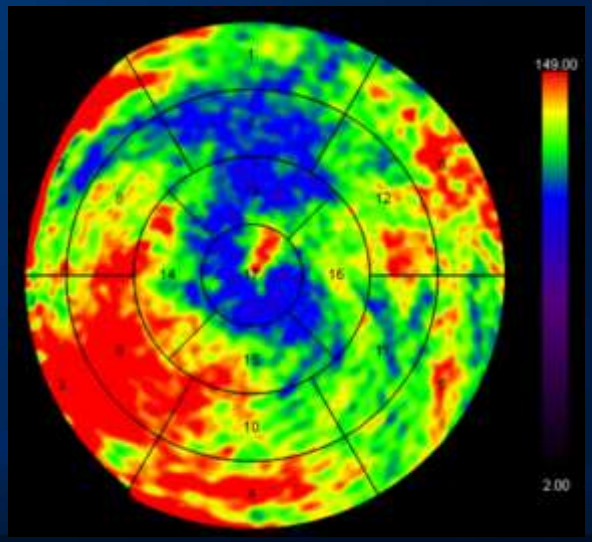


Hachamovitch et al. Circulation. 2003;107:2900

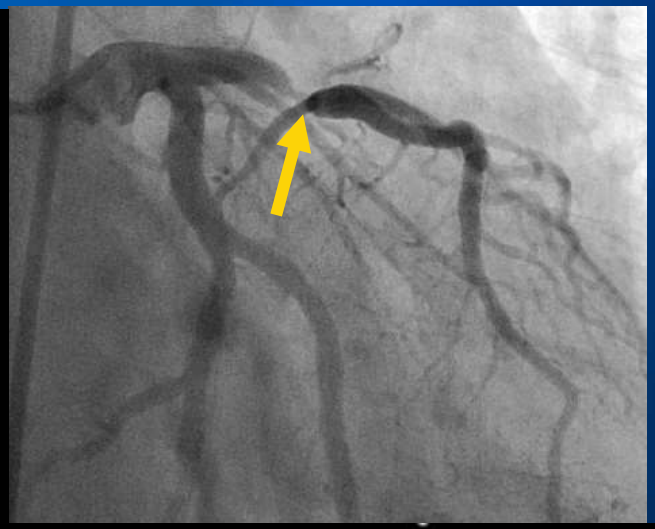
Assessment of Perfusion Area

- **SPECT**
  - Relatively low spatial resolution
  - Indirect measurement: not patient-specific
  - No anatomical imaging: limited to be correlated with coronary anatomy

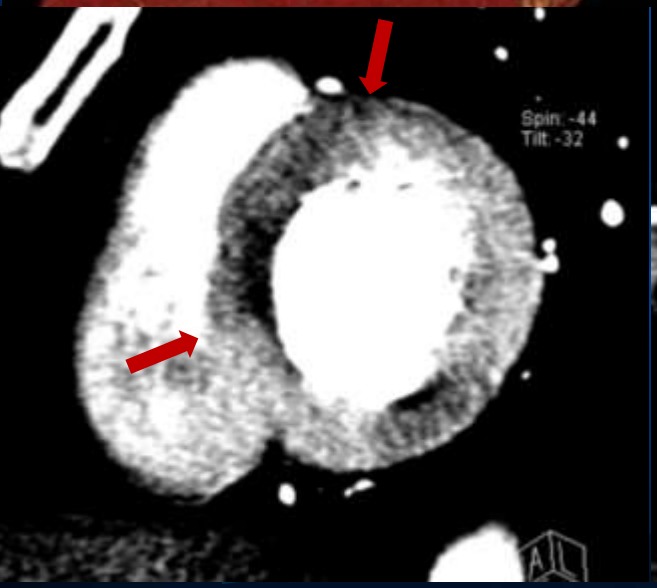
- **Perfusion CT**
  - Direct measurement
  - Doubled radiation
  - Doubled contrast agent

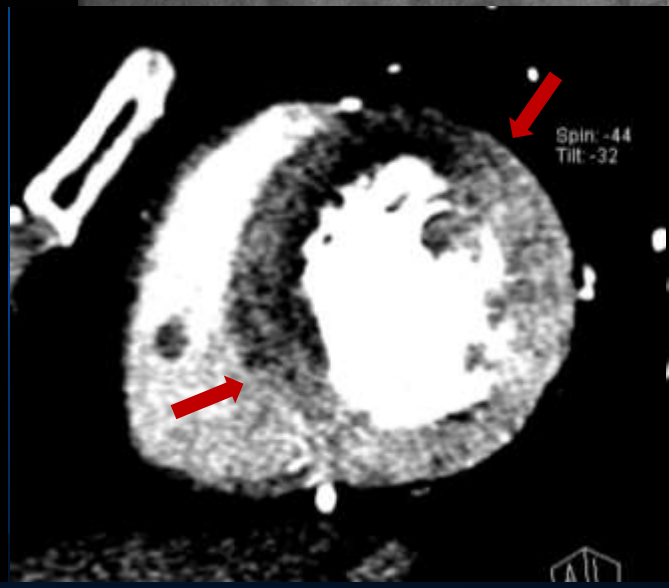


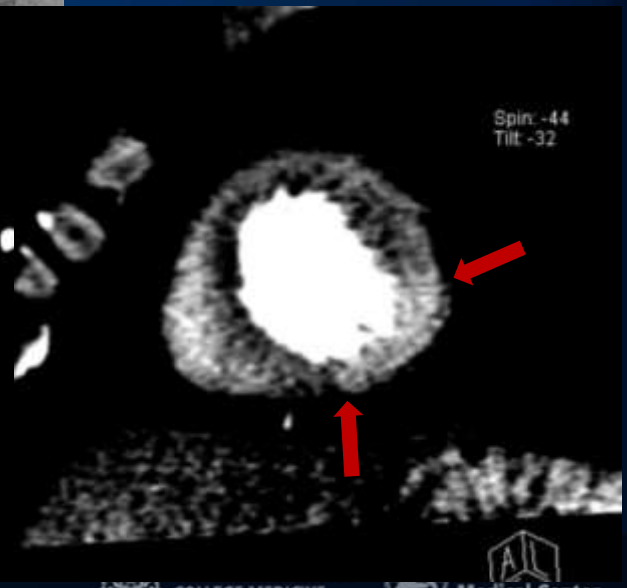
Assessment of Ischemic Area by Perfusion CT



Quantitation of under-perfused area with manual or automatic tracing

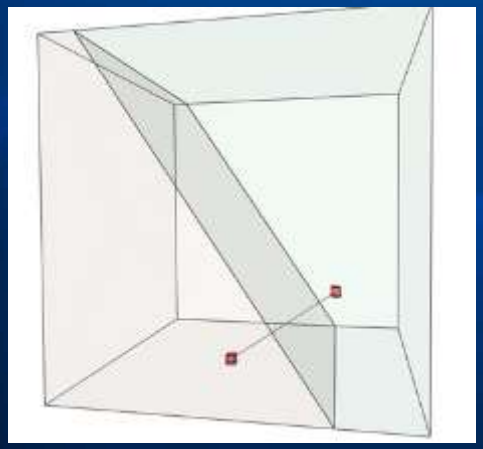


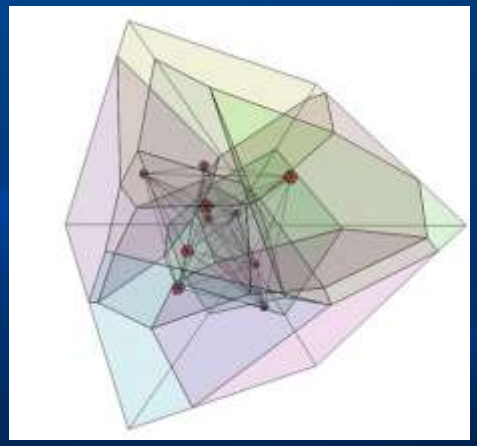


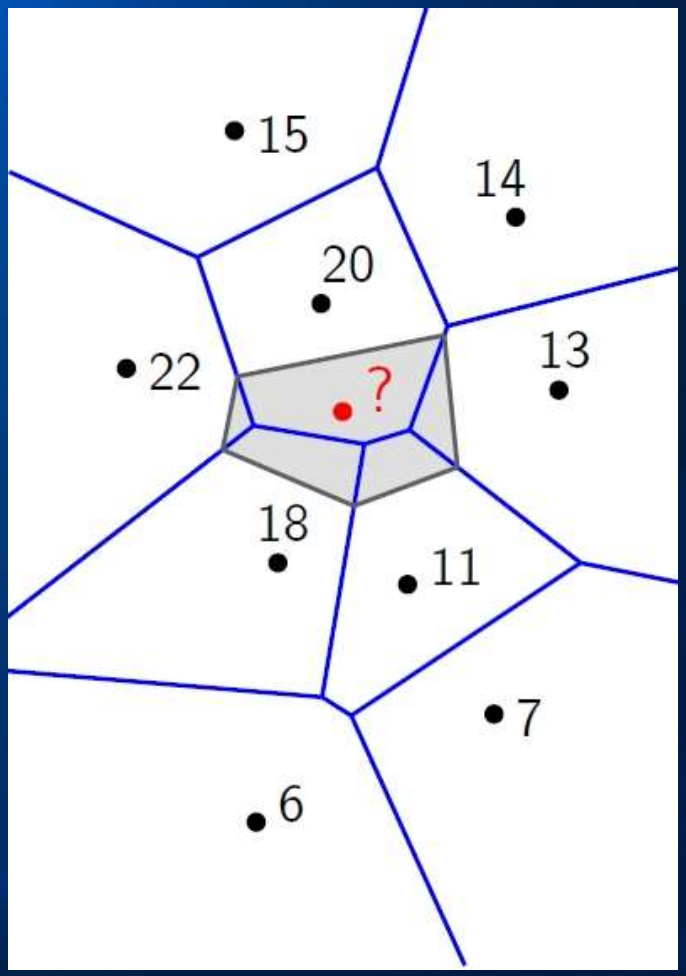


Indirect Assessment of Myocardial Segmentation according to Patient-Specific Coronary Anatomy

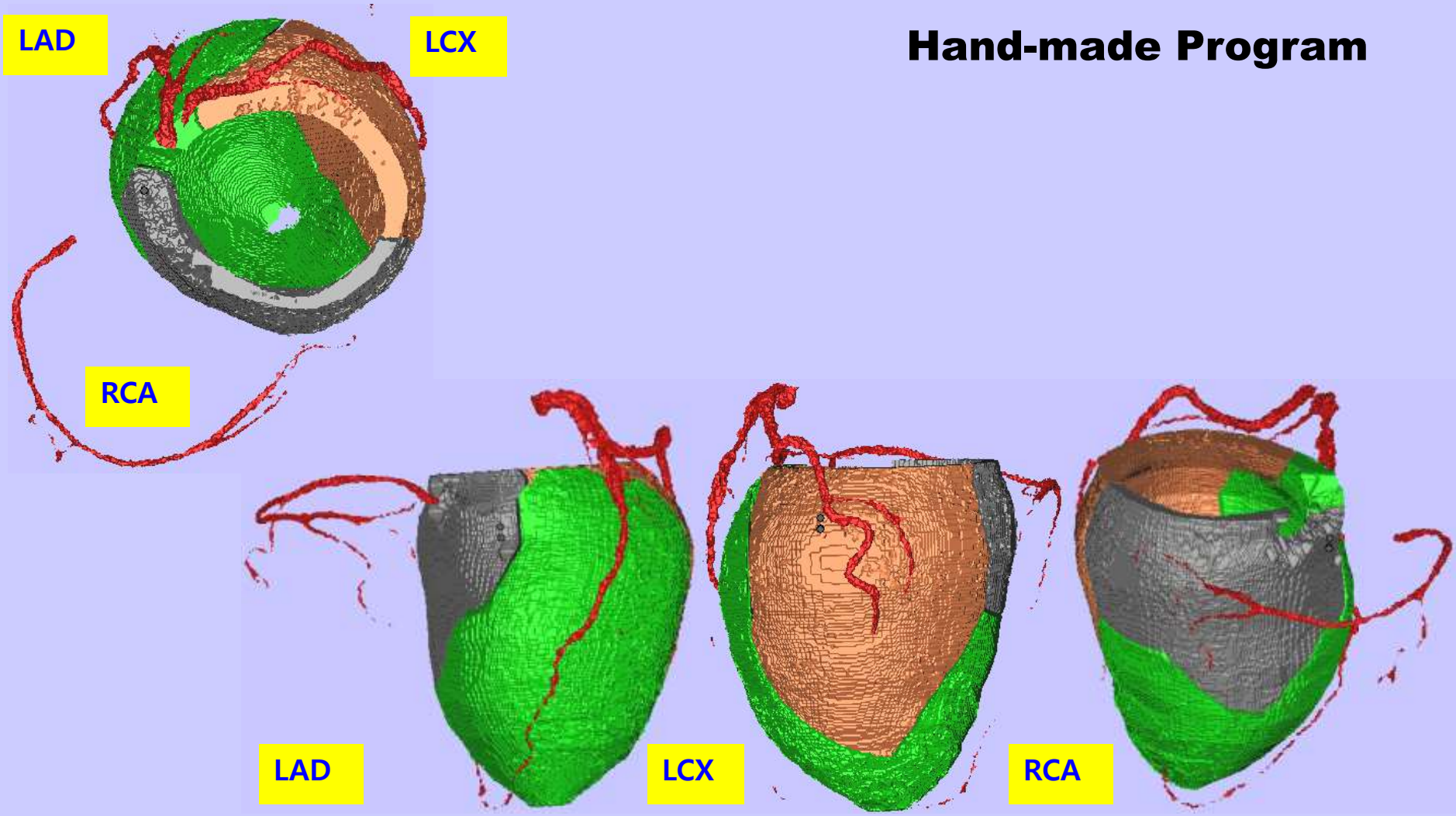
- **Voronoi diagram**
- Seed points
- Subdivision of the plane where the faces correspond to the regions where one site is closest
- Border of the plane have same distance from seed points







Coronary Artery-Based Myocardial Segmentation (CAMS) method



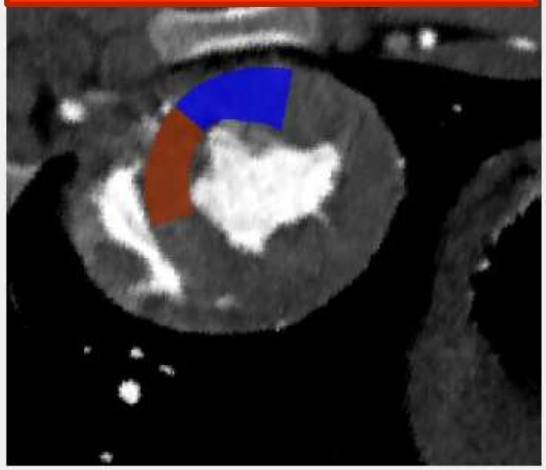
Hand-made Program

Chung JH, Yang DH, Kim NK, Kim YH, et al (in review)

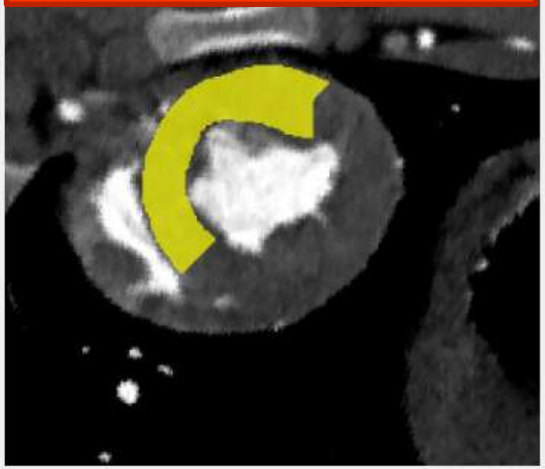
Validated
with Pig Coronary Occlusion Model

Specimen

AHA method



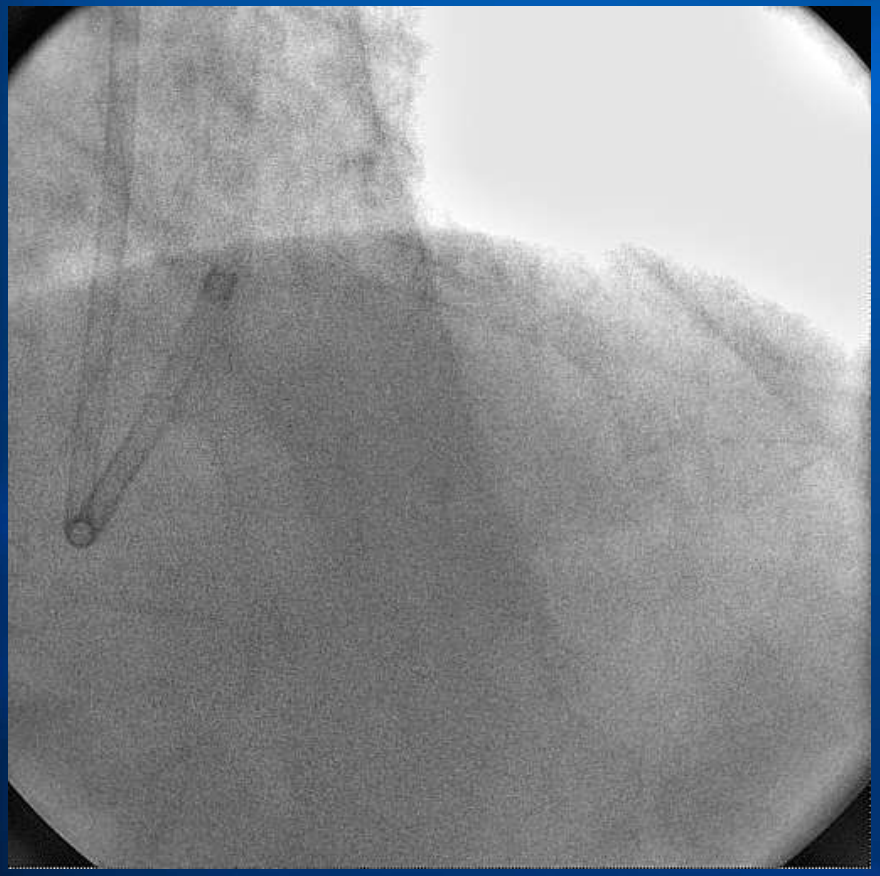
CAMS method

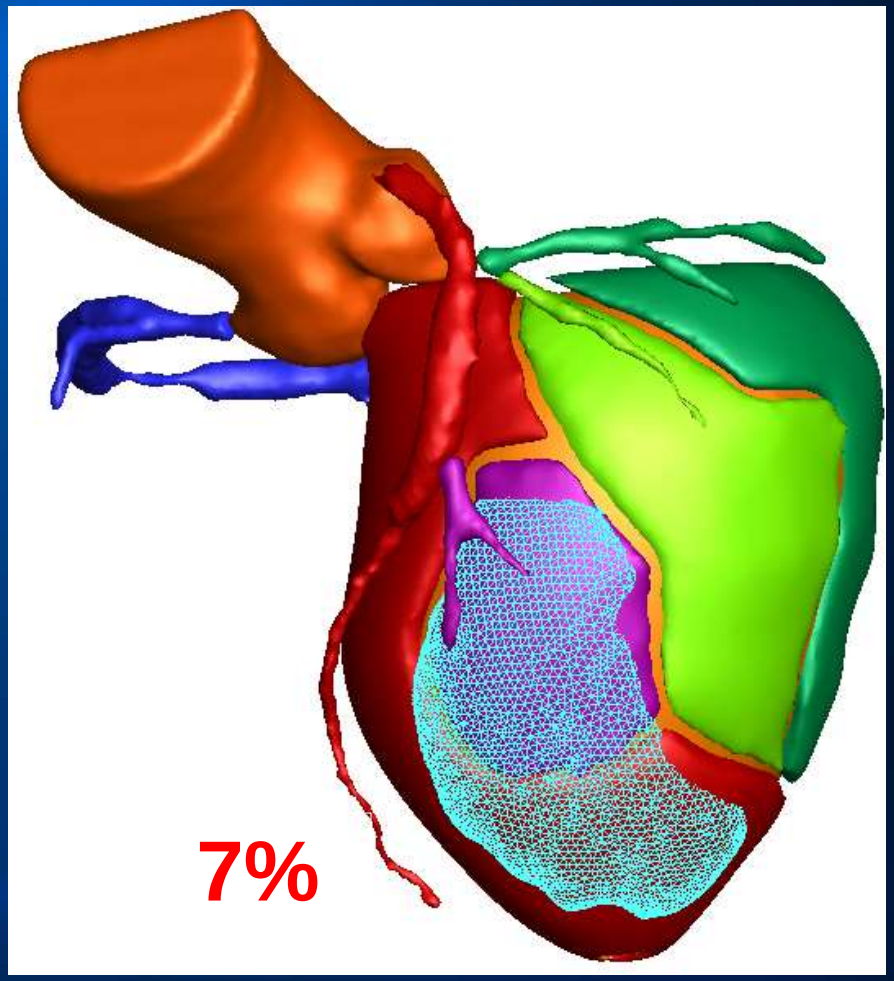


Yang DH, Kim YH, et al European Radiology (in revision)

Not Big Myocardial Ischemia

Ischemic Area for Diag. in Perfusion CT. < 10%





Engineered by Jung JH. PhD, Yang DH. MD, Kim YH. MD

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Impact of Myocardial Area at Risk with CT-CAMS

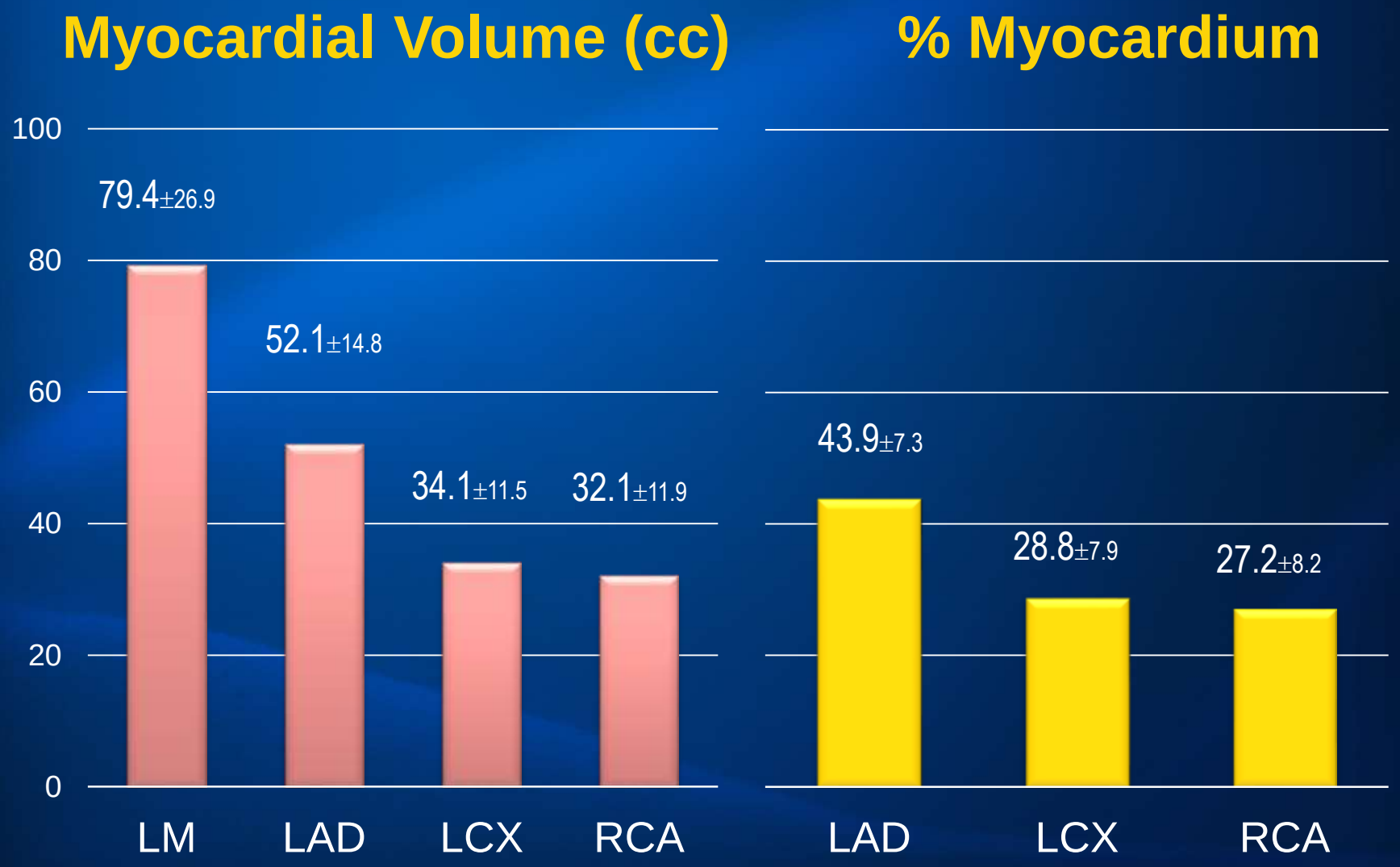
- To assess the impact and clinical utilization of a semi-automated, coronary artery-based myocardial segmentation (CAMS) using cardiac CT

- Myocardial territories was assessed with
  - ✓ **V_{sub}** subtended to each coronary lesion
    - Myocardial area at risk

  - ✓ **V_{ratio}** the ratio of the V_{sub} to total LV myocardial volume
    - Myocardial area at risk / total LV mass

Kang SJ, Yang DH, Kim YH et al. Am J Cardiol. 2016;117:1282

72 pts from 816 CTP registry pts in AMC



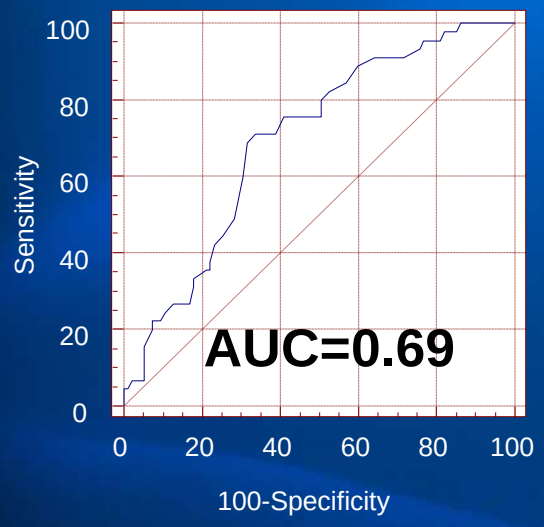
Kang SJ, Yang DH, Kim YH et al. Am J Cardiol. 2016;117:1282

Integration of CT-based CAMS Analysis and IVUS Lumen Analysis to Predict Functional Ischemia

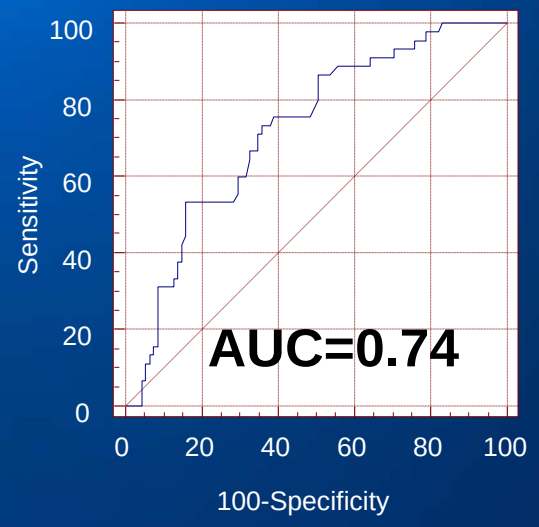
Diagnosis of Ischemia-producing Lesions by Using IVUS-MLA and CAMS

Determinants of FFR ≤0.75

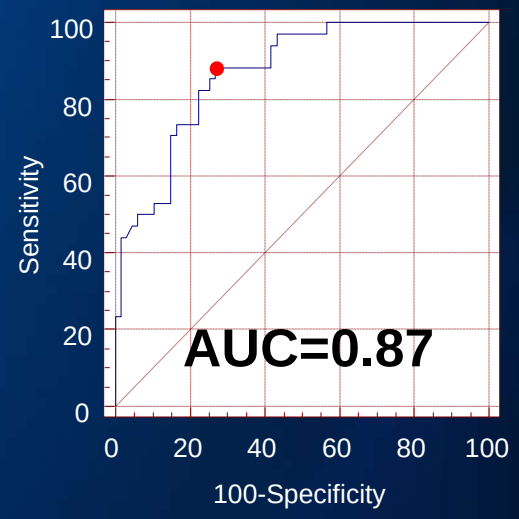
V_{sub} >30.7cc



V_{ratio} >25.4%



MLA ≤2.83mm²



Sensitivity 88%
Specificity 73%
PPV 62%
NPV 91%

V_{sub} : myocardial volume subtended by stenotic segment
V_{ratio} : Ratio of V_{sub} to total LV myocardial volume

Kang SJ, Yang DH, Kim YH et al. Am J Cardiol. 2016;117:1282

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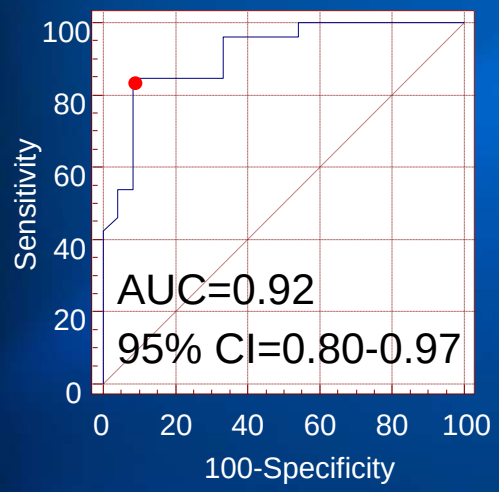
Prediction of FFR ≤ 0.75

V_{sub} > 30.7cc

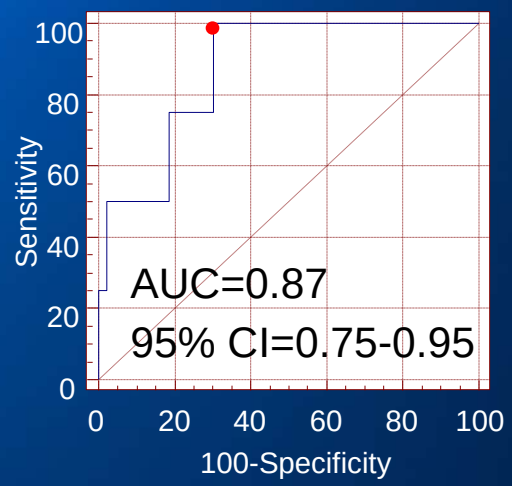
MLA cut-off ≤ 2.85mm²



Sensitivity 85%
Specificity 92%
PPV 92%
NPV 85%

V_{sub} ≤ 30.7cc

MLA cut-off ≤ 2.67mm²



Sensitivity 100%
Specificity 69%
PPV 38%
NPV 100%

In the setting of a larger myocardial territories (V_{sub}>30.7cc or V_{ratio}>25.4%), IVUS-MLA≈2.8mm² accurately predicted an FFR ≤0.75, while clinical relevance of treating lesions with a smaller myocardium may be limited

Kang SJ, Yang DH, Kim YH et al. Am J Cardiol. 2016;117:1282

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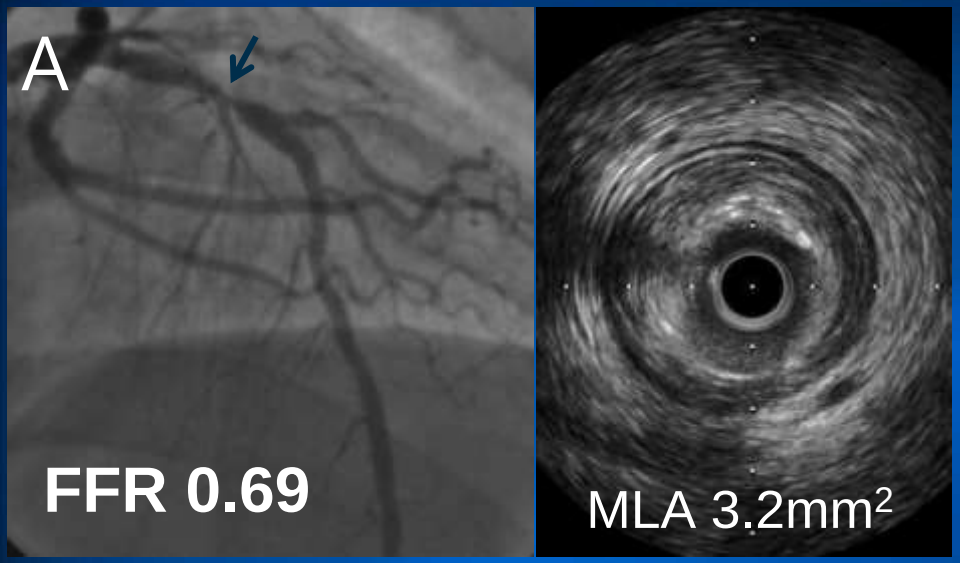
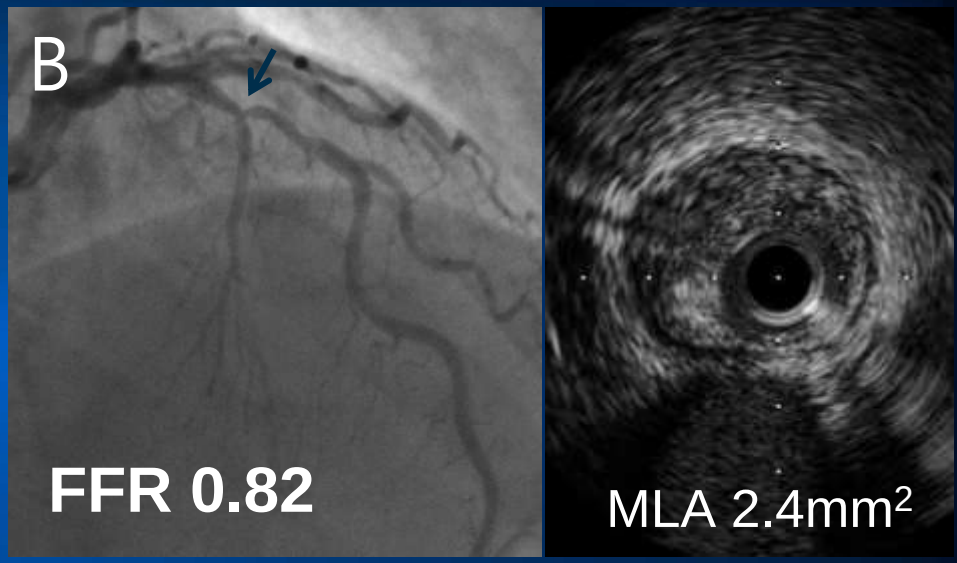
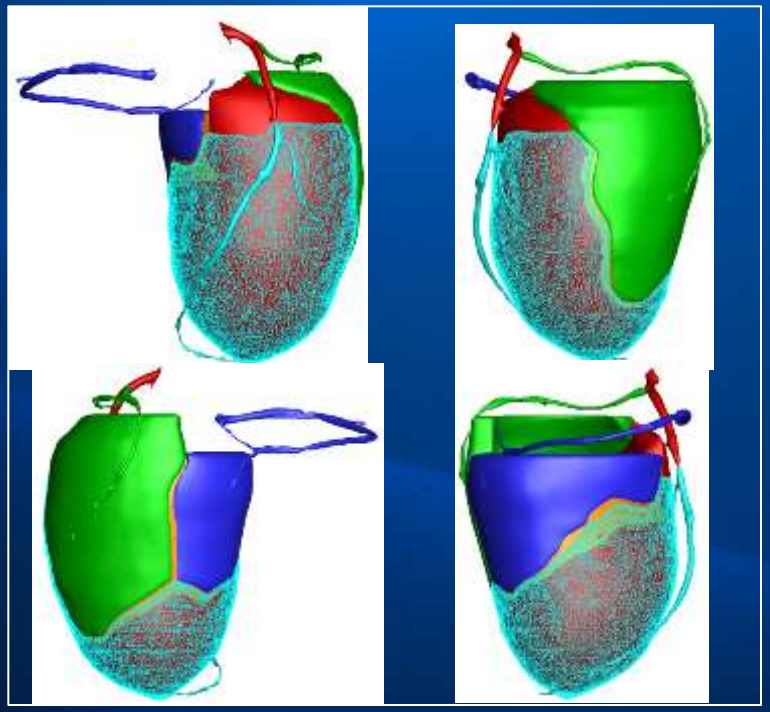
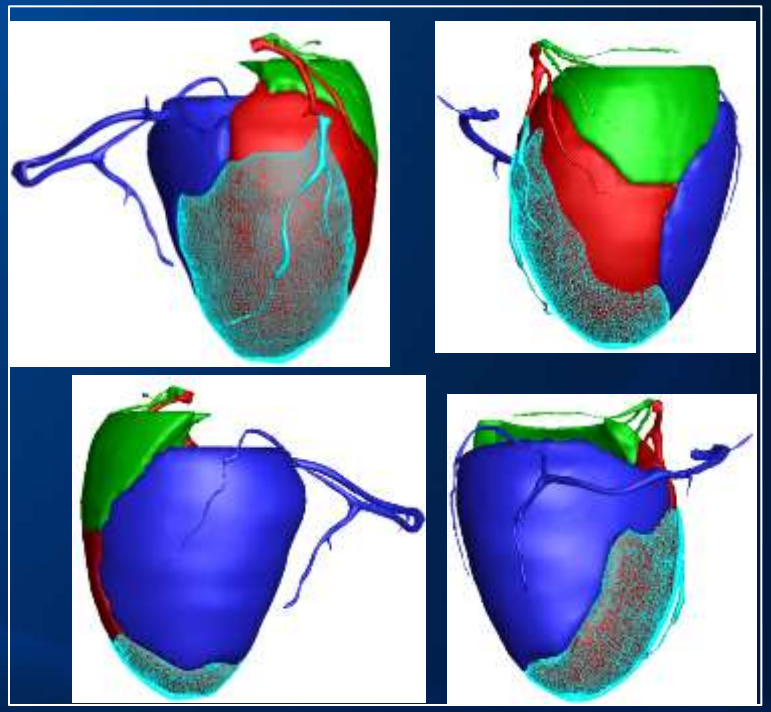






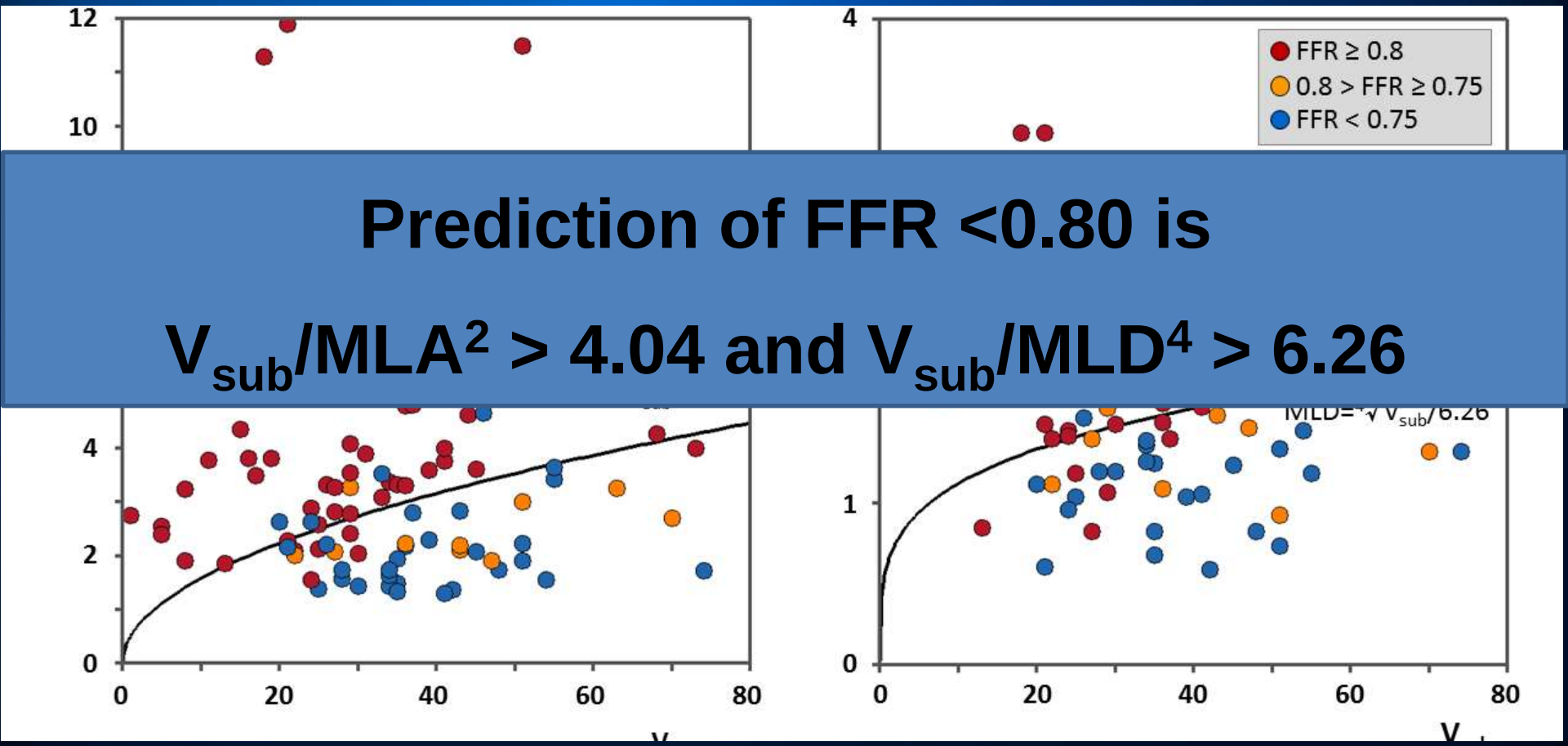
V_{sub}= 55cc, V_{ratio}= 46%



V_{sub}= 29cc, V_{ratio}= 26%

Mathematical Model Predicting FFR With Combination of IVUS and CAMS

Hypothesis: Pressure drop in laminar flow (ΔP) is proportional to the flow rate divided by the square of CSA (Q/A^2) or by the diameter (Q/d^4) to the fourth power (Poiseuille's law)



Prediction of FFR <0.80 is

$V_{sub}/MLA^2 > 4.04$ and $V_{sub}/MLD^4 > 6.26$

Kang SJ, Kweon JH, Kim YH, et al Am J Cardiol (in revision)

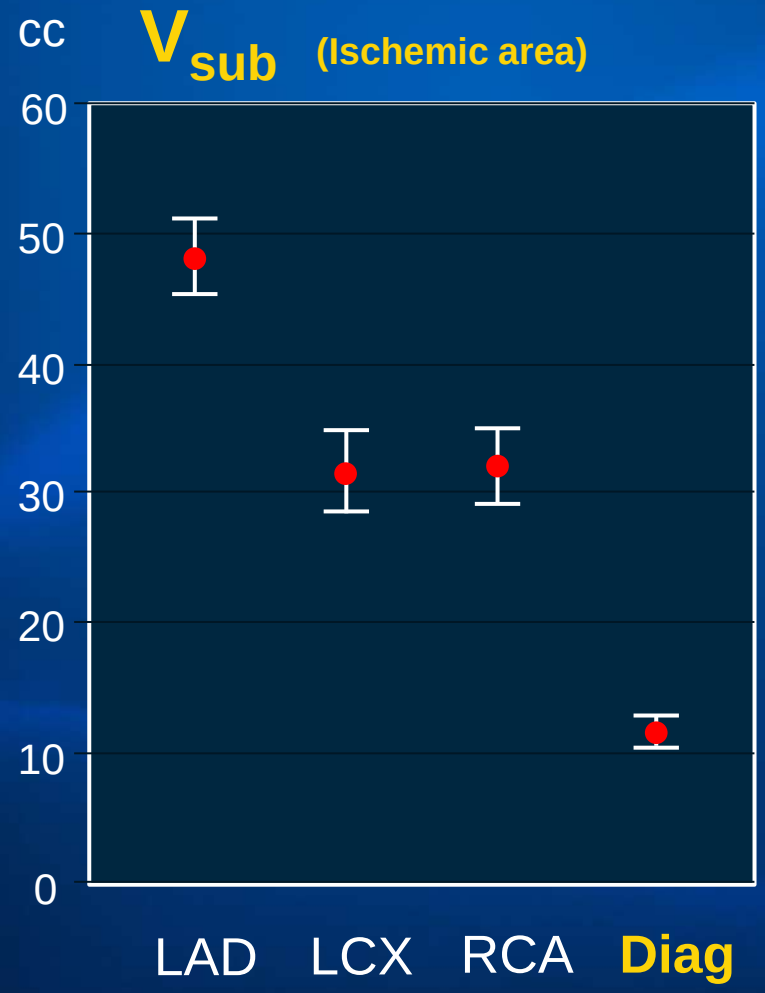
QCA- and IVUS Predictor of FFR <0.80

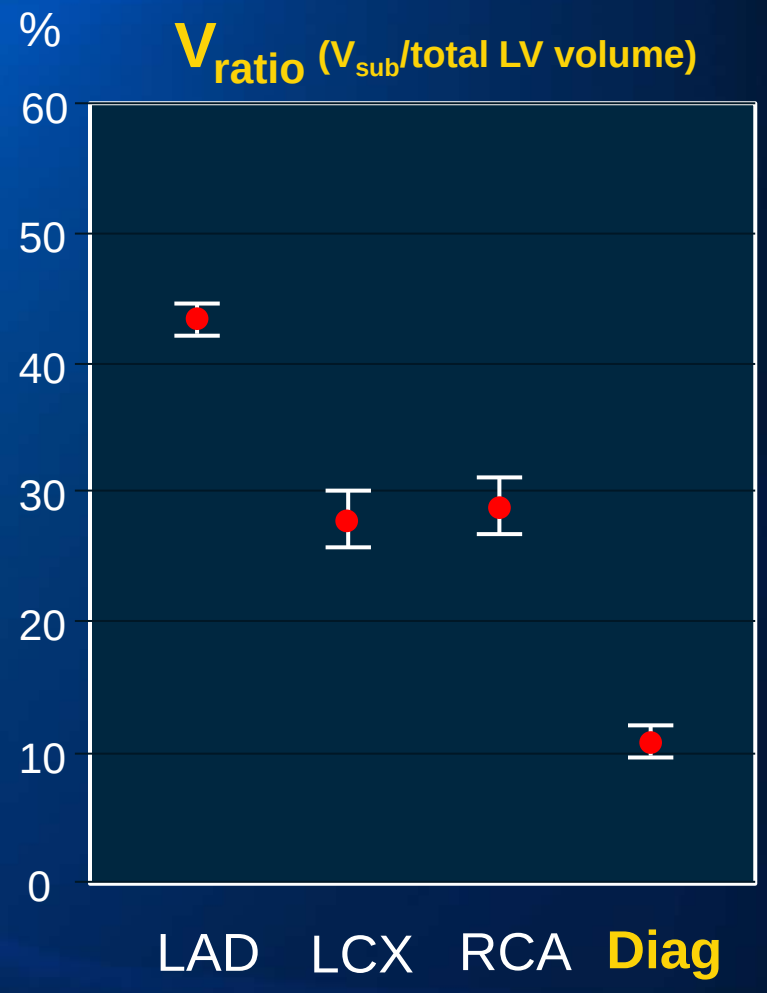
	Criterion	AUC	Sensitivity	Specificity	PPV	NPV	Accur
QCA-DS	>52	0.83	69%	87%	78%	80%	79%
MLD	<1.59	0.82	73%	82%	73%	82%	77%
IVUS-MLA	**<2.72**	**0.87**	**76%**	**82%**	**74%**	**83%**	**79%**
BSA/MLA^2	>0.22	0.89	80%	82%	75%	86%	79%
V_{sub}/MLA^2	**>4.04**	**0.94**	**88%**	**90%**	**86%**	**92%**	**90%**
V_{sub}/MLD^4	>6.26	0.87	71%	90%	83%	82%	82%

Significant difference in AUCs between IVUS-MLA vs. V_{sub}/MLA^2 (Diff=0.068, p=0.005)

CAMS for Prediction of Side Branch Functional Ischemia

Diagonal Branches Compared with Epicardial Vessels

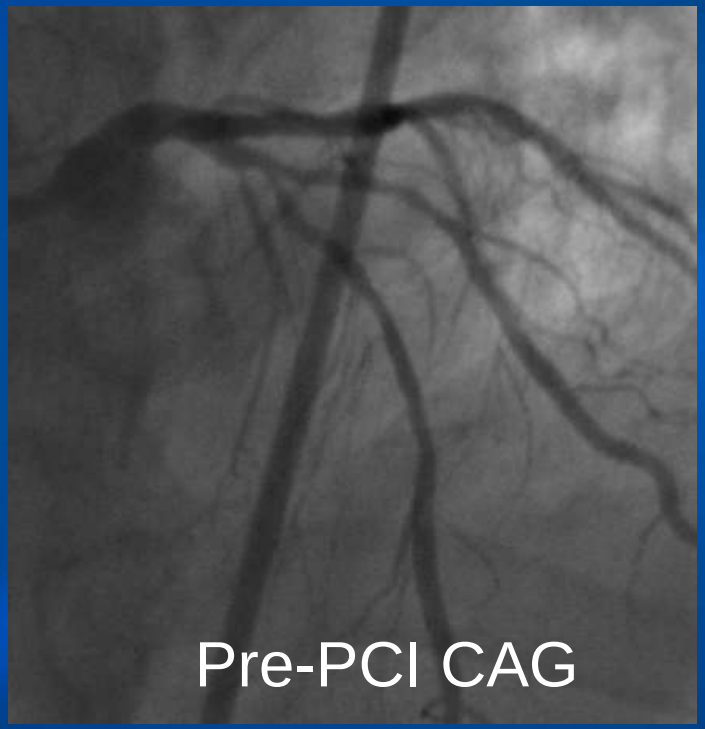


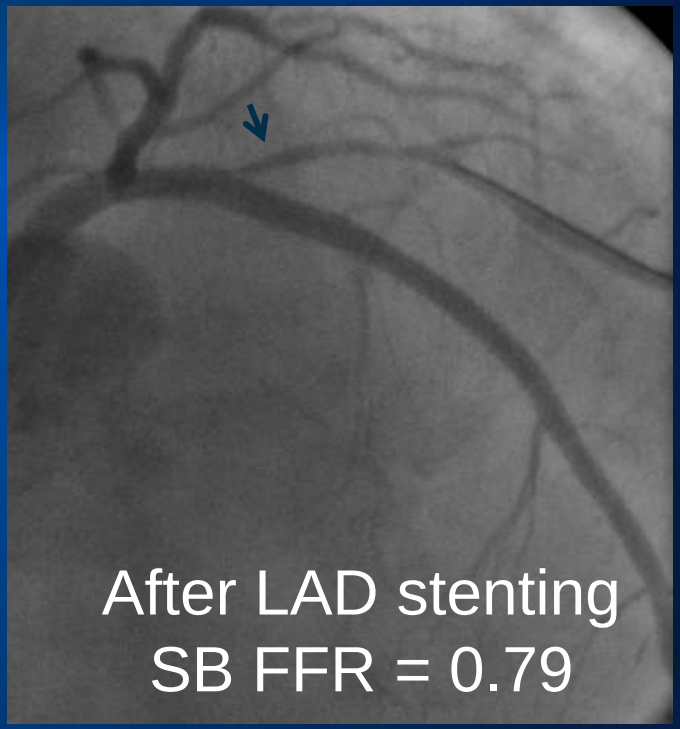


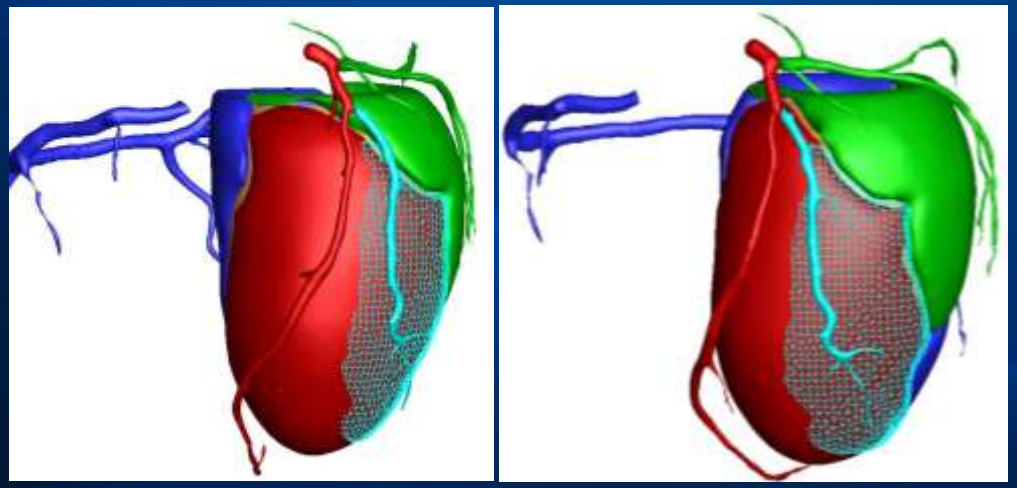
Only 2 (2%) of diagonal branches had a V_{ratio} of >20%

Kang SJ, Yang DH, Kim YH et al. (in submission)

Case 1. 70-year old male



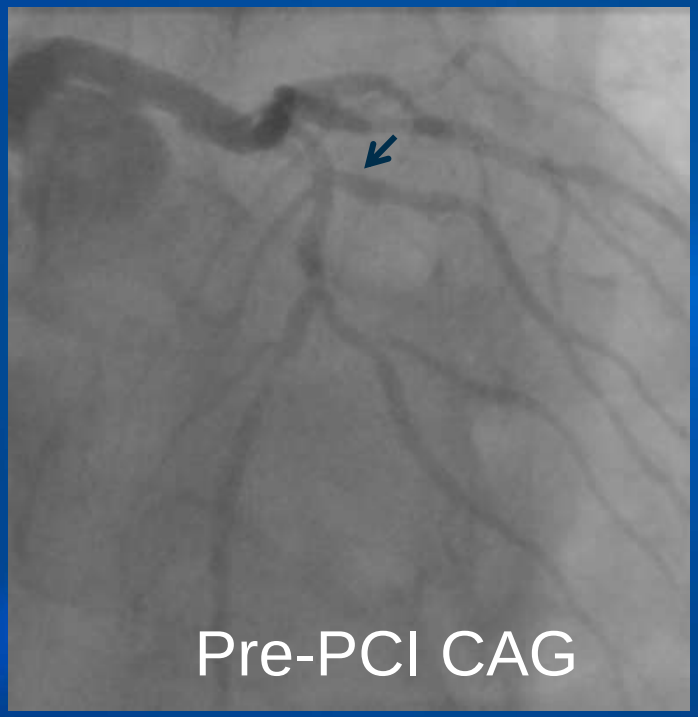


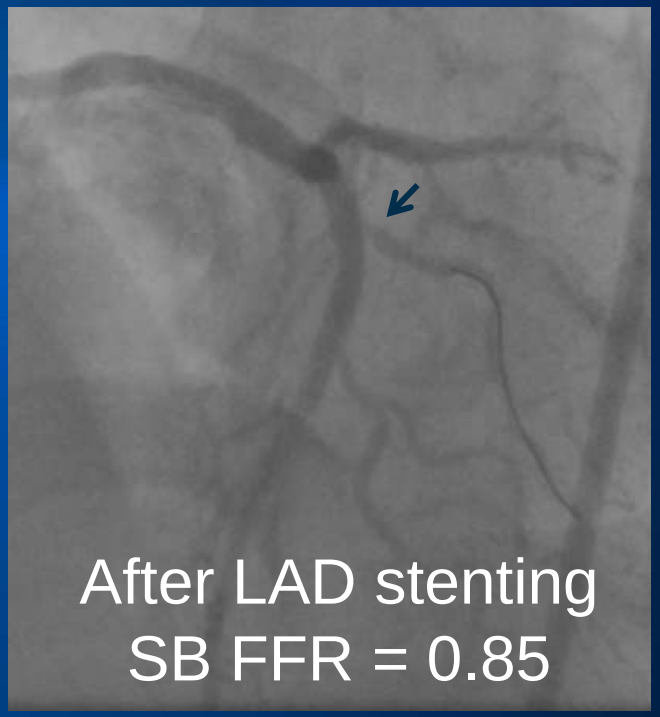


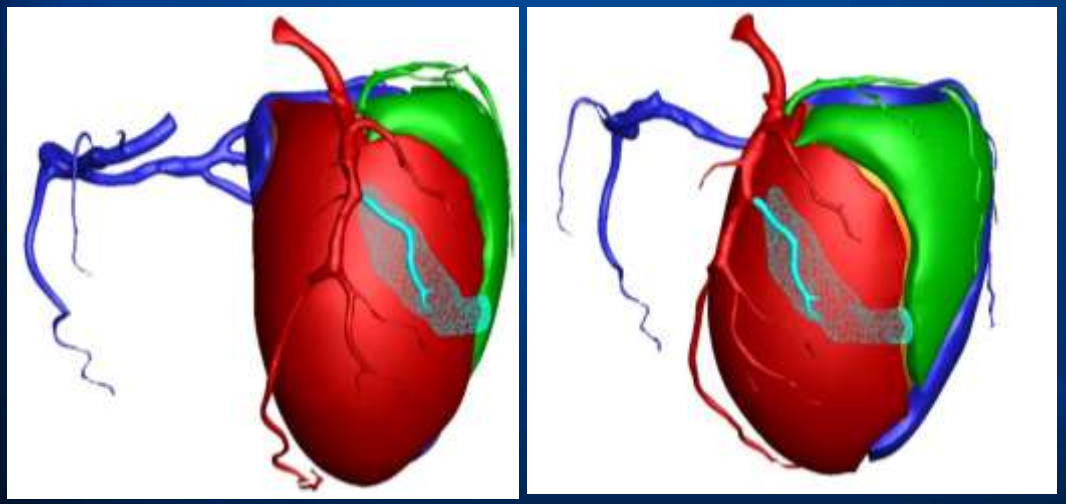
LAD LCX RCA Diagonal

	V_{sub}	V_{ratio}
LAD	36cc	41%
LCX	17cc	19%
RCA	37cc	40%
Diagonal	**14cc**	**15%**

Case 2. 56-year old male



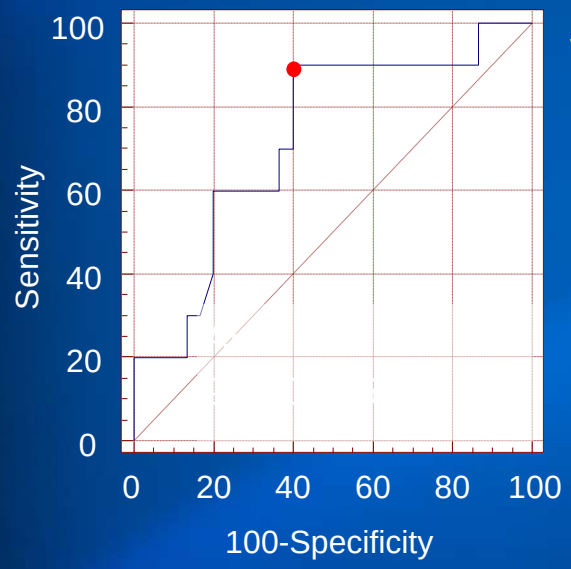




LAD LCX RCA Diagonal

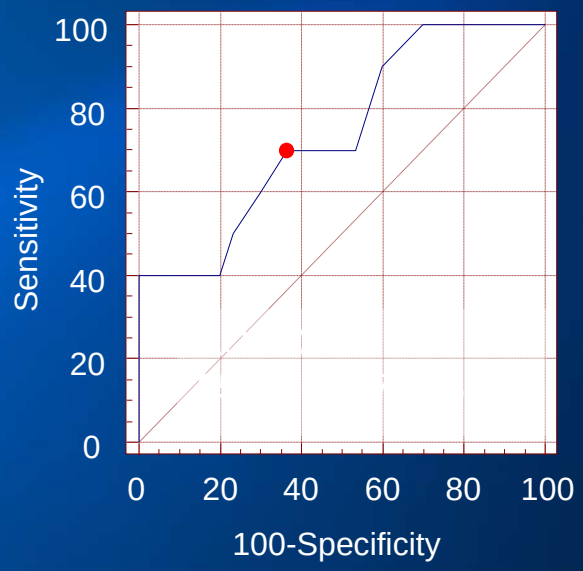
	V_{sub}	V_{ratio}
LAD	48cc	45%
LCX	17cc	16%
RCA	43cc	39%
Diagonal	**4cc**	**4%**

Prediction of SB FFR ≤0.80 After MB Stenting



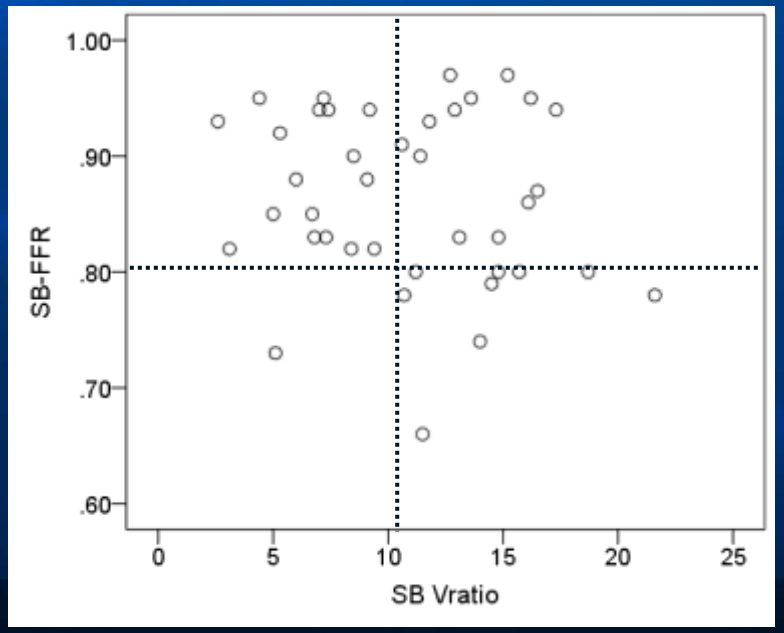
V_{ratio} ≥10.6%

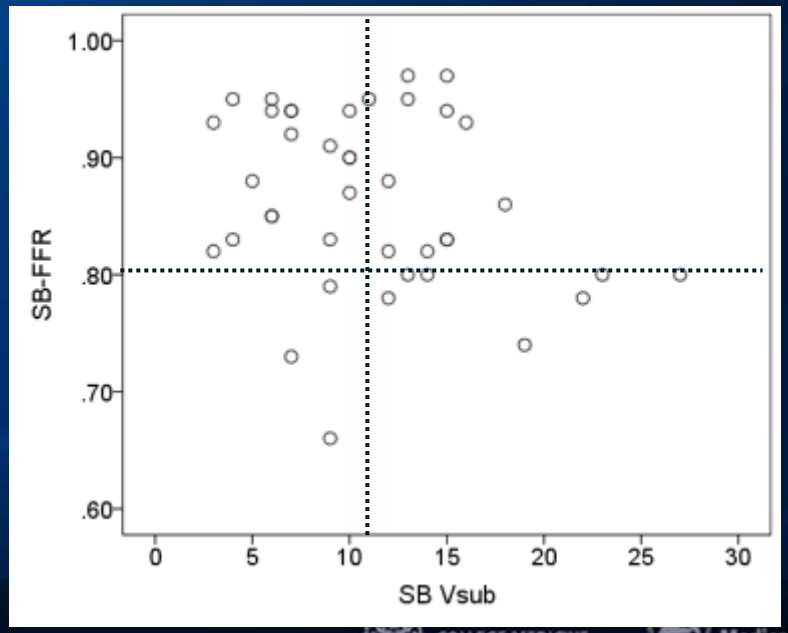
Sensitivity 90%
Specificity 60%
PPV 43%
NPV 95%



V_{sub} ≥11.0cc

Sensitivity 70%
Specificity 63%
PPV 39%
NPV 86%





Conclusion

- Ischemia area, represented by CAMS-estimated subtended myocardium, was an important determinant of functional ischemia of a coronary lesion.
- CT-based myocardial segmentation using CAMS method appears to be useful to improve the performance of IVUS-based ischemia prediction and decision making for revascularization.