CT-Based Myocardial Segmentation

Novel Method and Clinical Implication

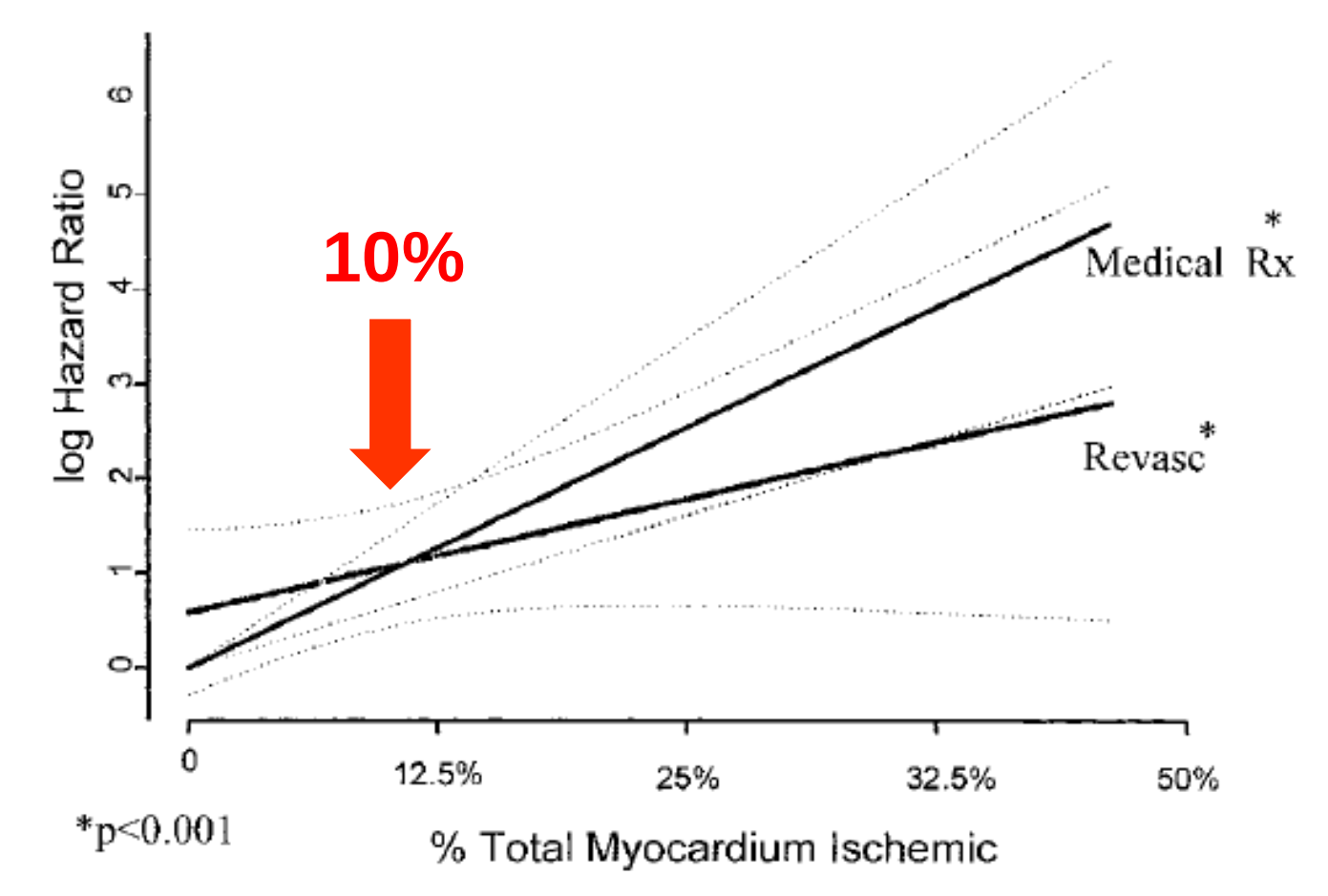
Young-Hak Kim MD. PhD.

Courtesy of SJ Kang, MD and Yang DH, MD

Division of Cardiology, University of Ulsan College of Medicine,
Asan Medical Center, Seoul, Korea

Ischemic Area Influencing Outcomes

< 10% can be managed by medication

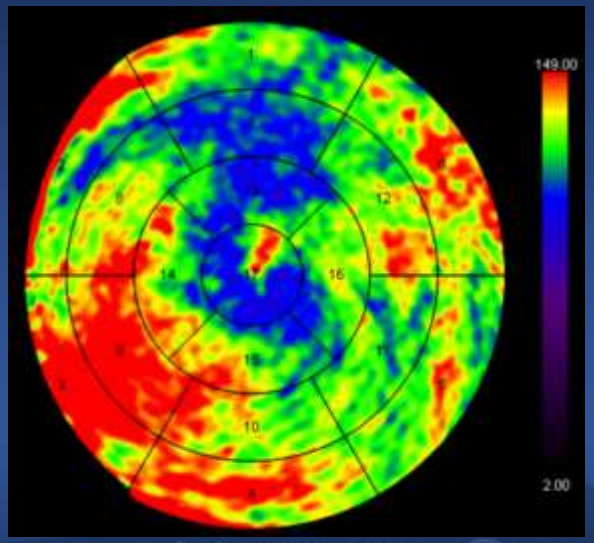


Hachamovitch et al. Circulation. 2003;107:2900

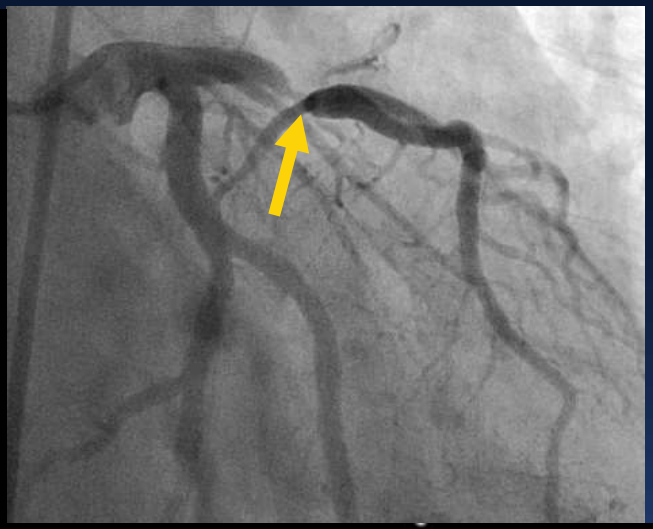
Assessment of Perfusion Area

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

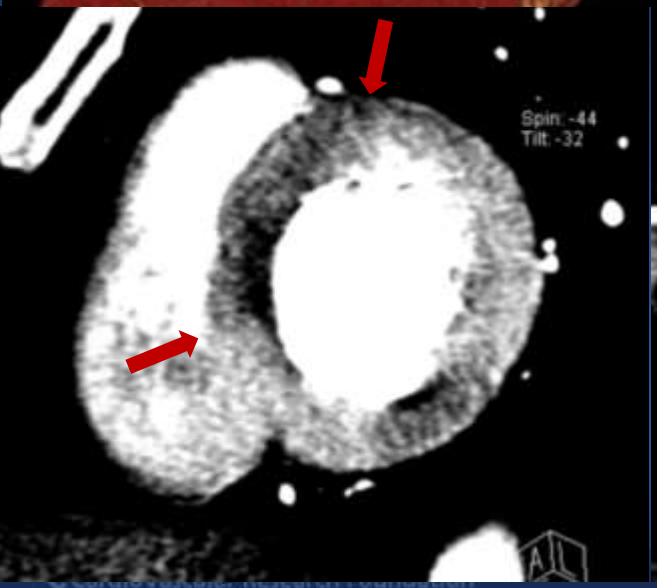
- Perfusion CT
  - Doubled radiation
  - Doubled contrast agent

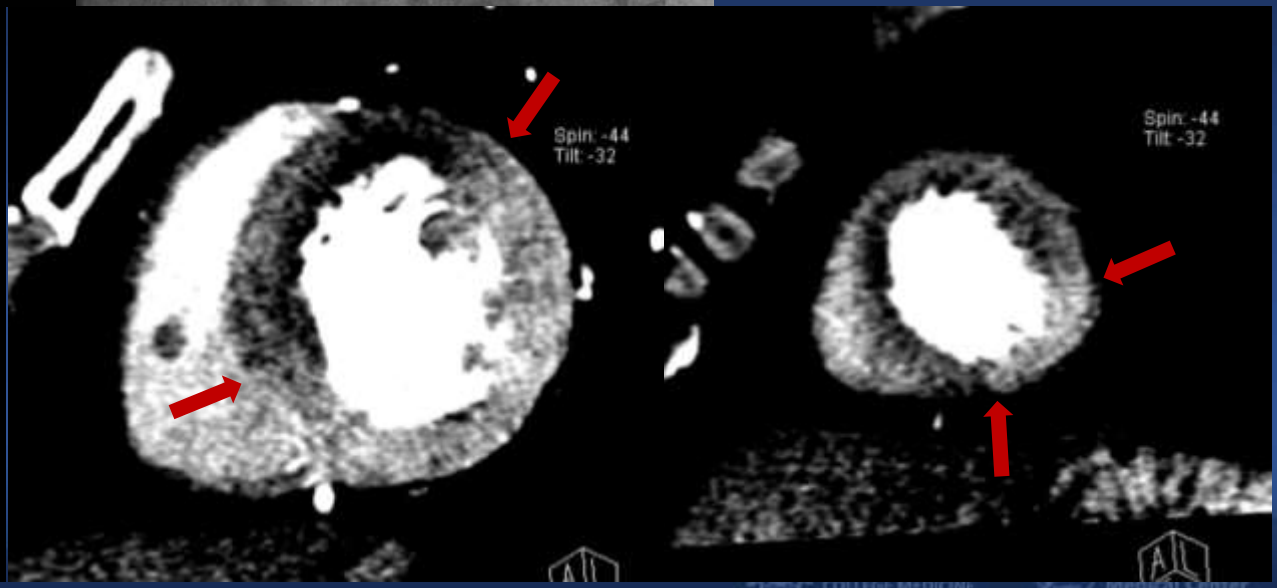


Assessment of Ischemic Area



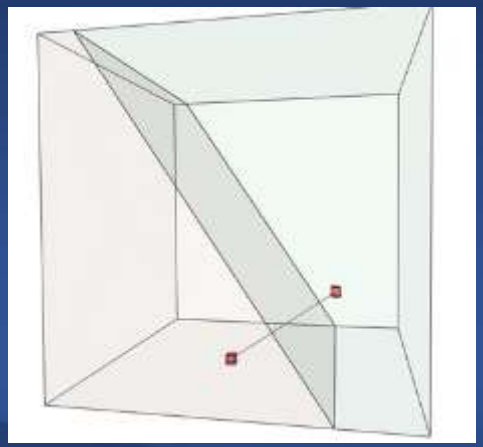
Quantitation of under-perfused area with manual or automatic tracing

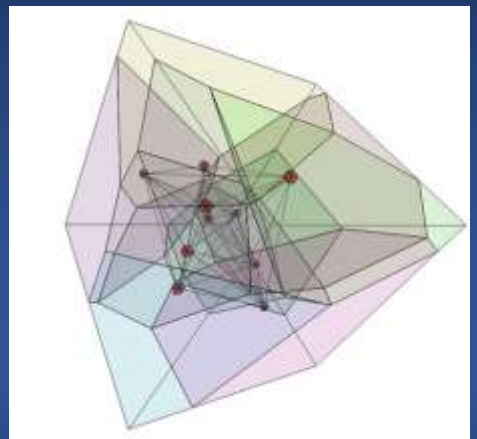


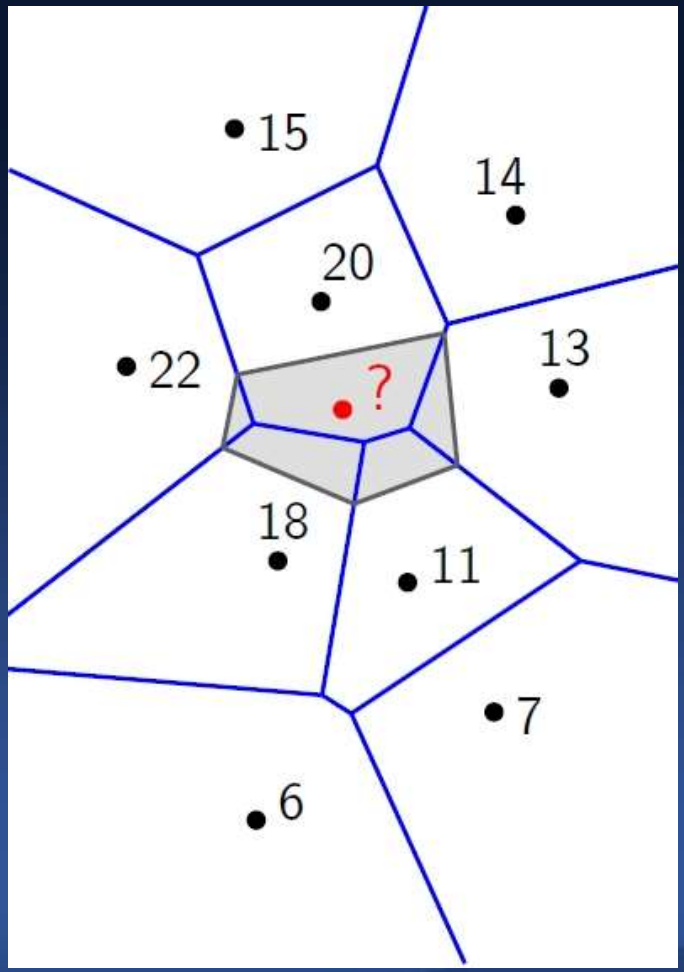


Indirect Assessment of Myocardial Segmentation according to Patient-Specific Coronary Anatomy

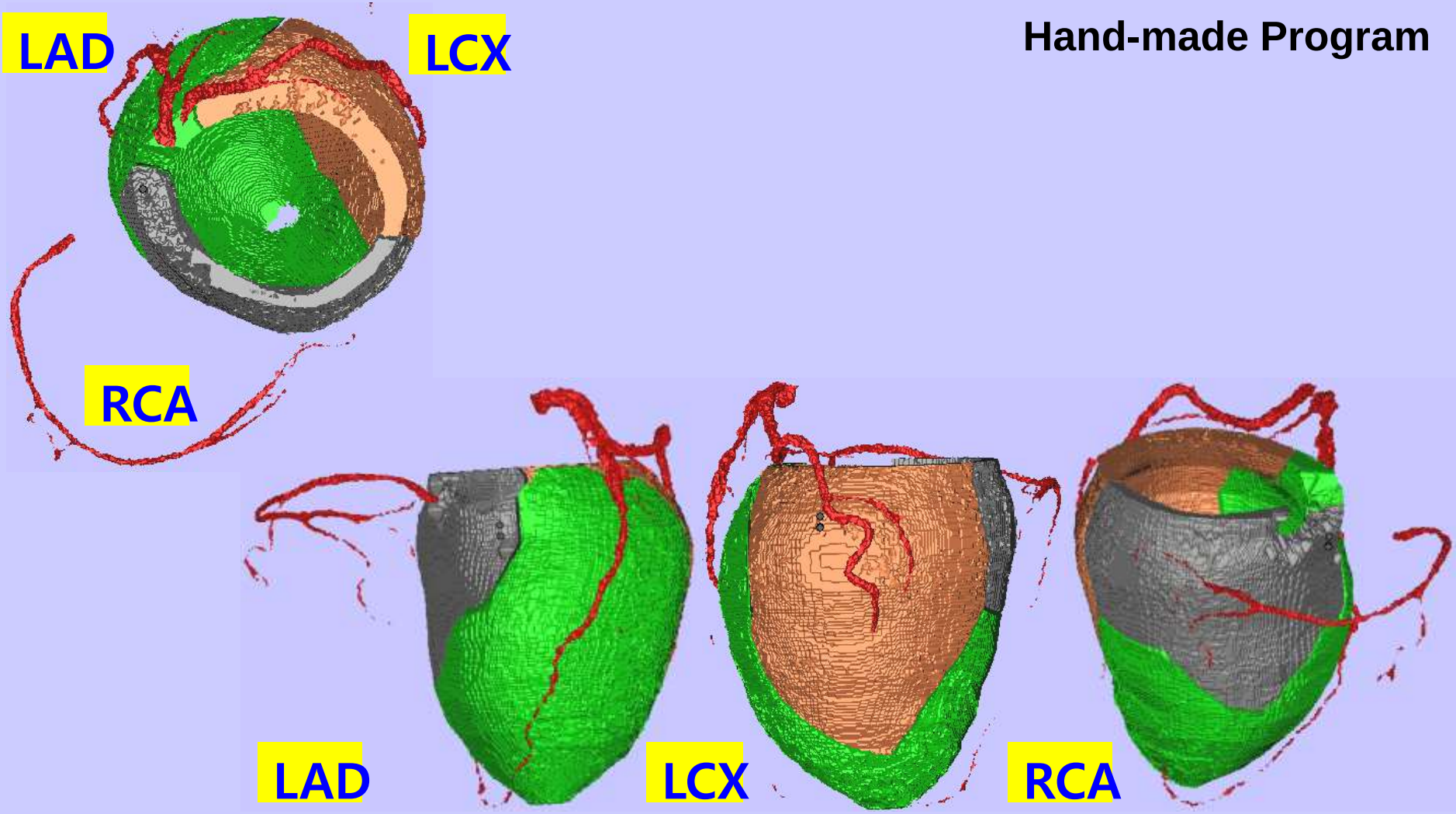
- **Voronoi diagram**
  - Seed points
  - Subdivision of the plane where the faces correspond to the regions where one site is closest
  - Border of the plane have same distance from seed points



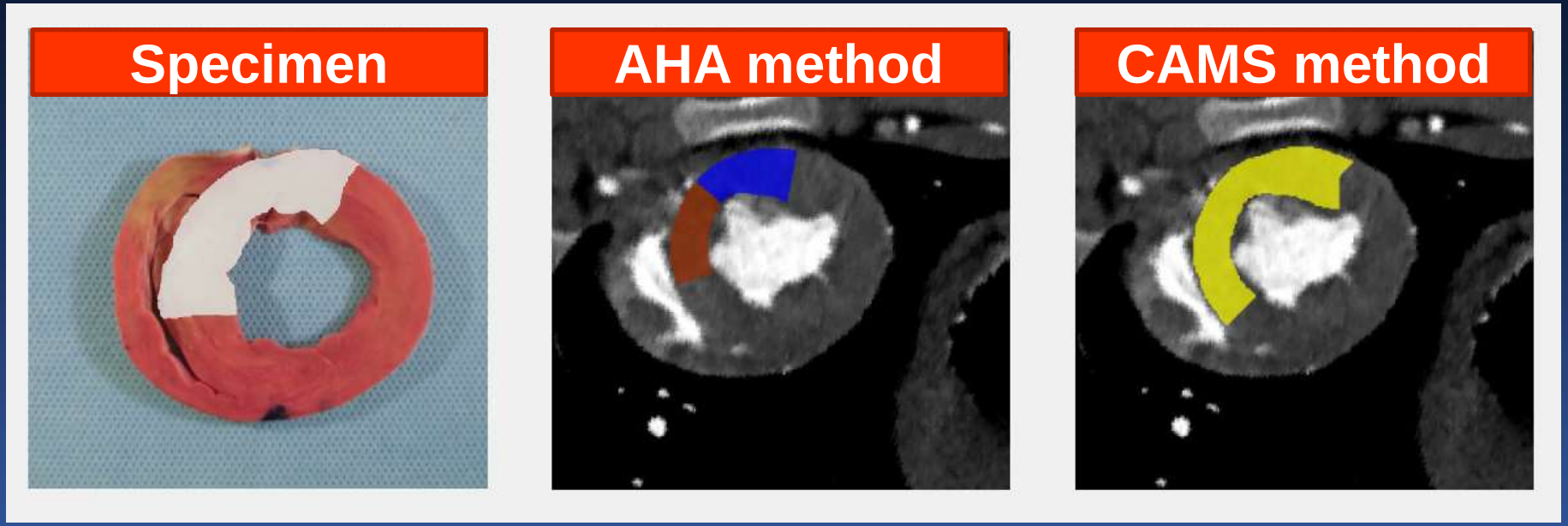




Coronary Artery-Based Myocardial Segmentation (CAMS) method

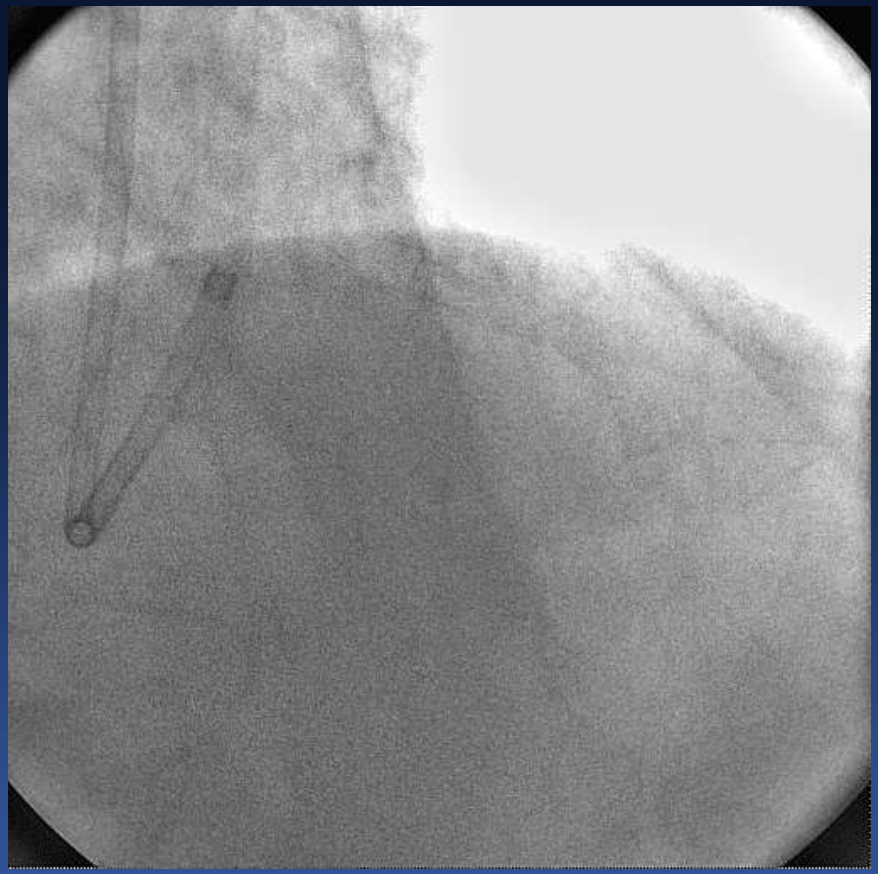


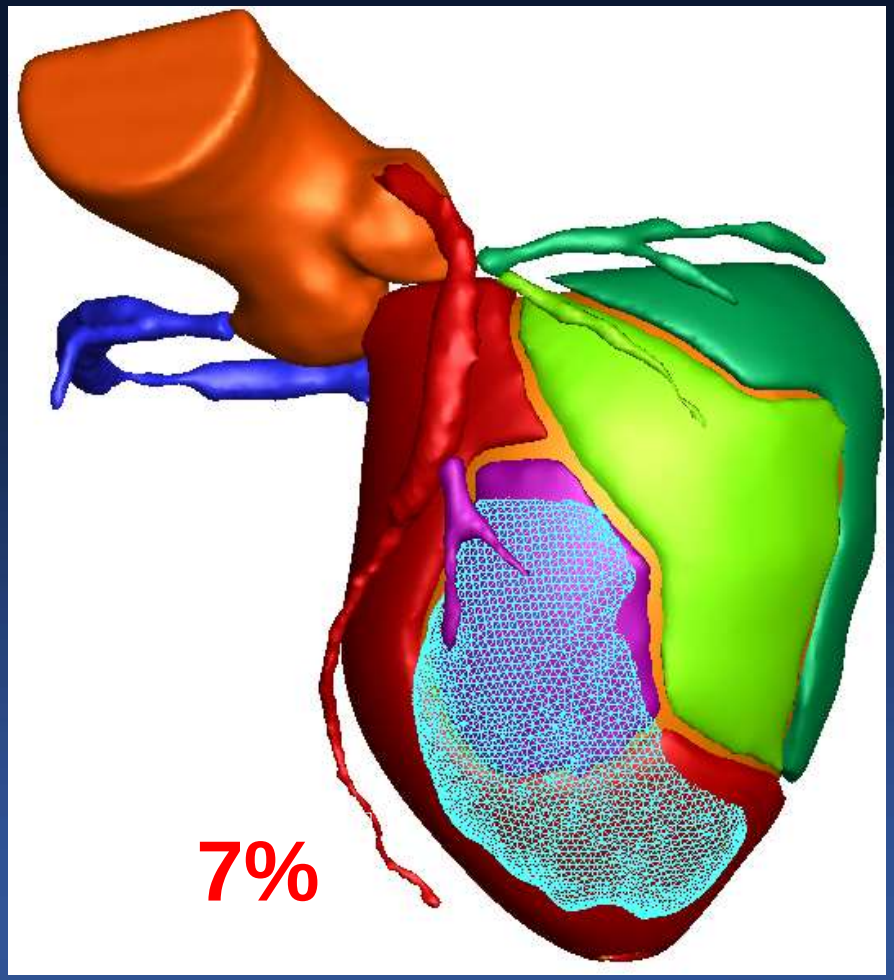
Validated with Pig Coronary Occlusion Model



Yang DH, Kim YH, et al (in submission)

Not Big Myocardial Ischemia
Ischemic Area for Diag. in Perfusion CT. < 10%

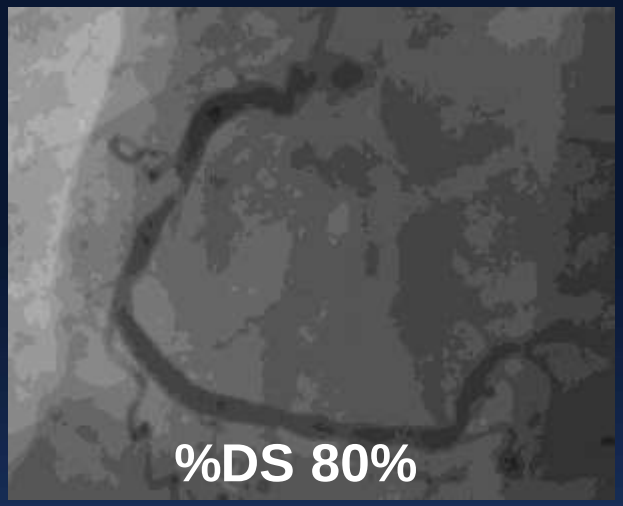


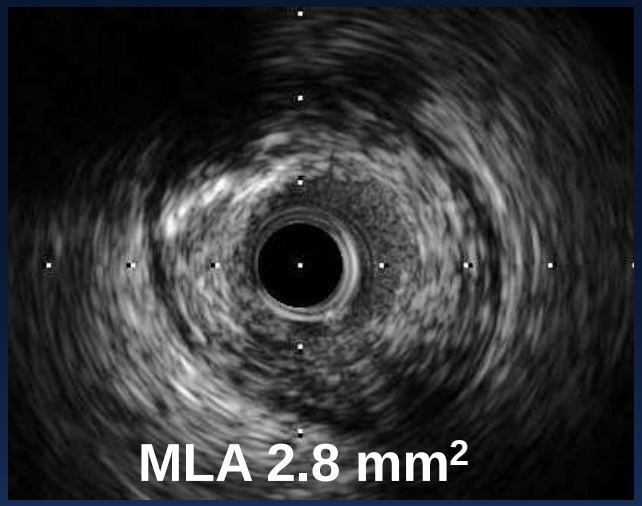


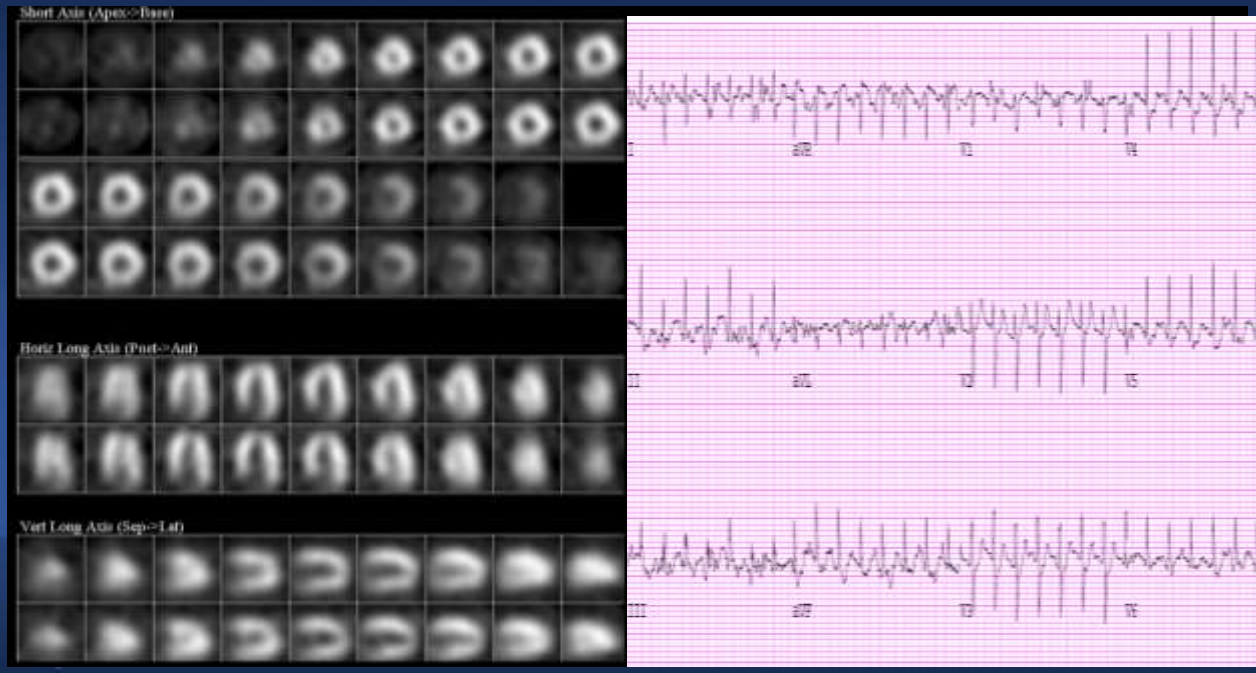
Clinical Application of CAMS Myocardial Segmentation

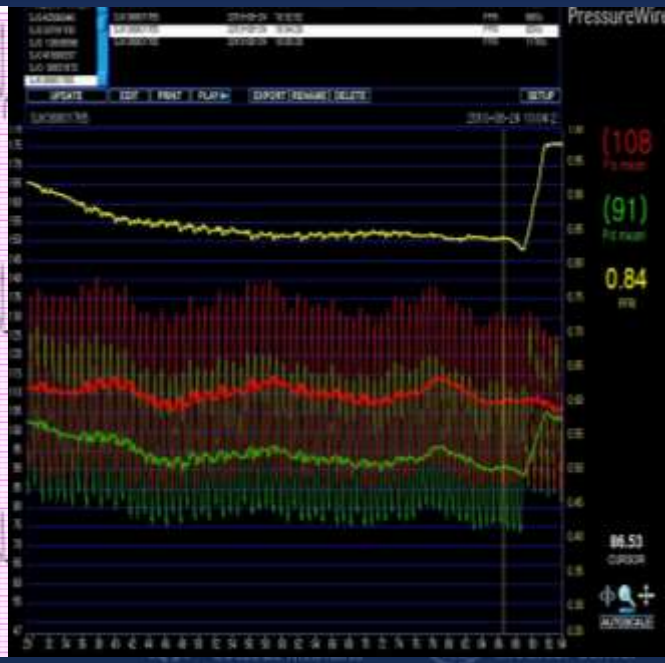
- An indirect, but simple and quick assessment for subtended myocardial perfusion area of each coronary lesion
- Combination with an invasive imaging method may improve its diagnostic performance, such as for prediction of functional ischemia

Visual-Functional Mismatch



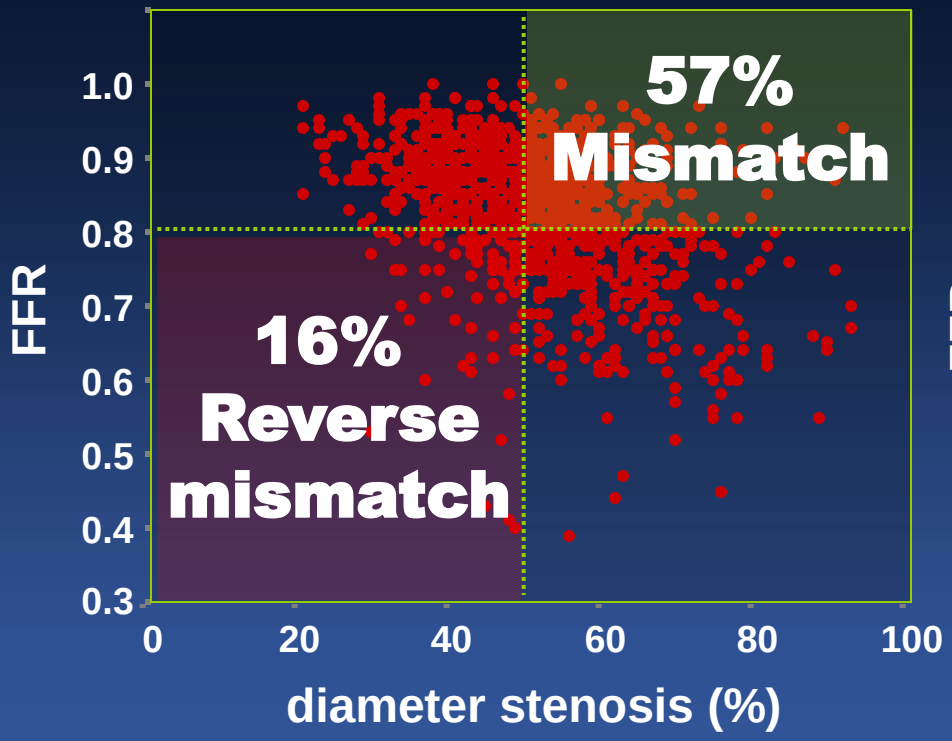




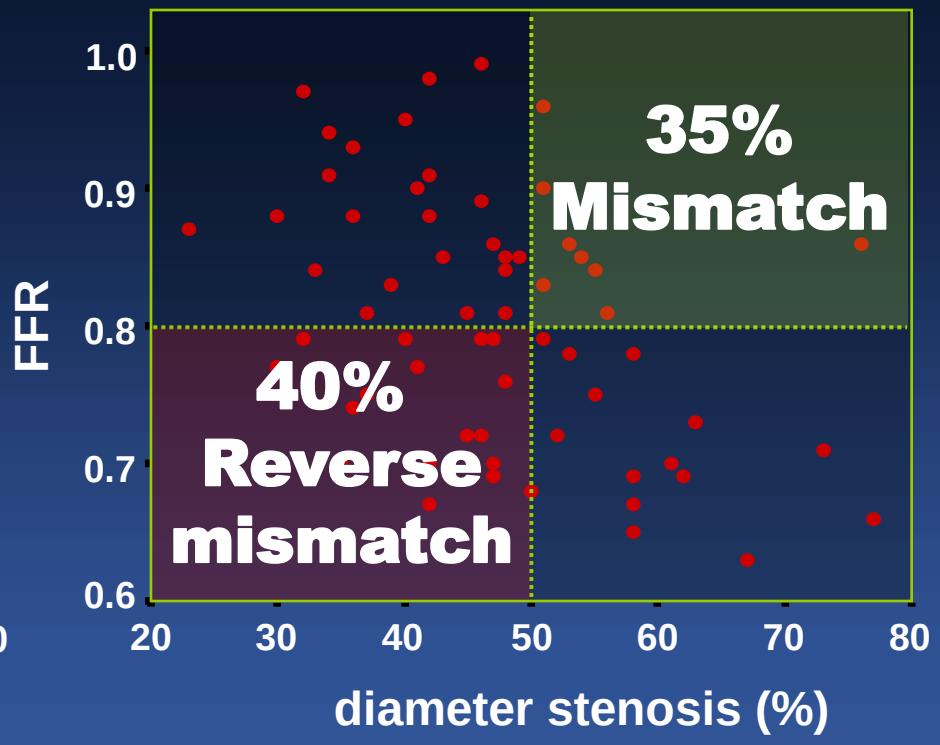


Angiography can poorly predict Functional FFR

1066 Non-LM lesions



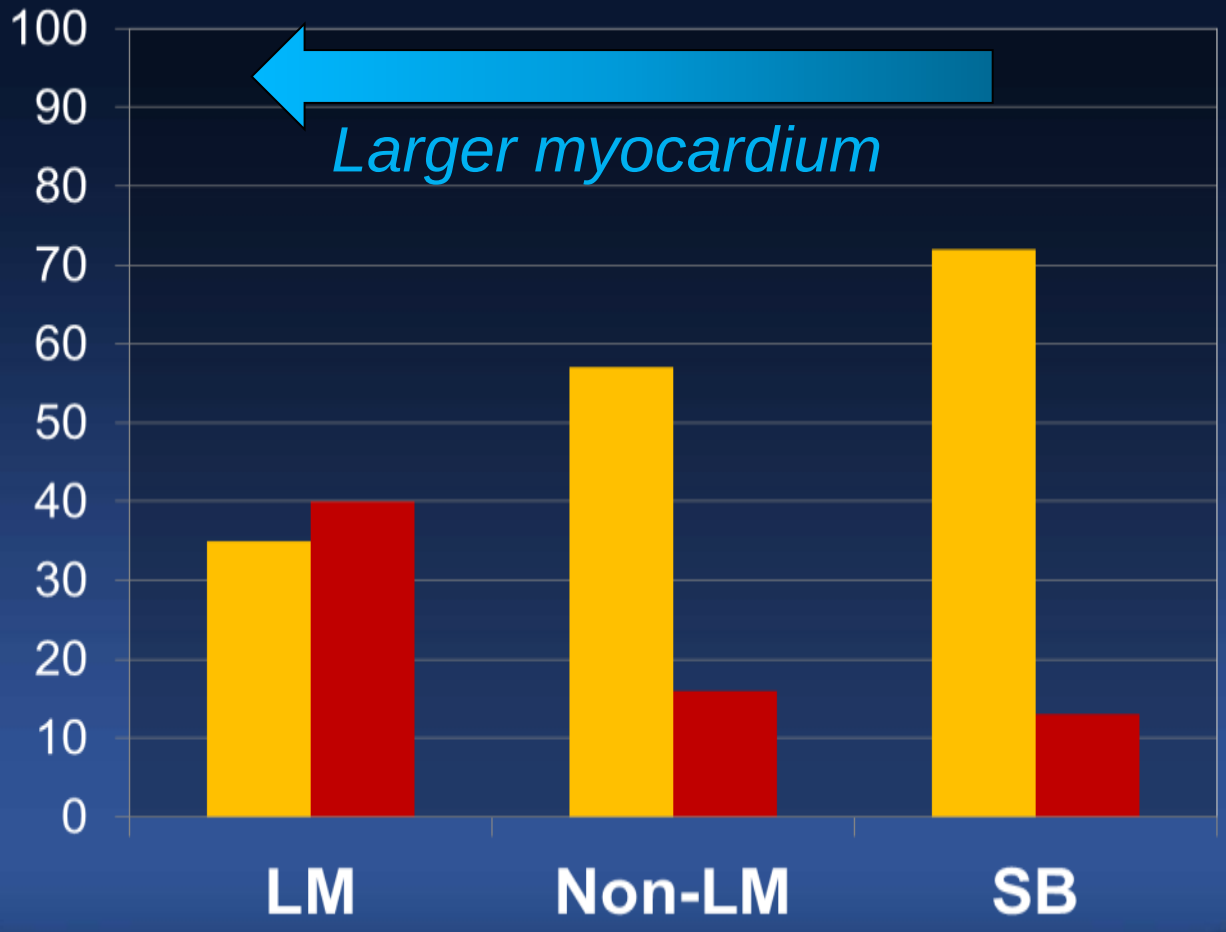
63 LM lesions



Park et al. JACC interv 2012;5:1029

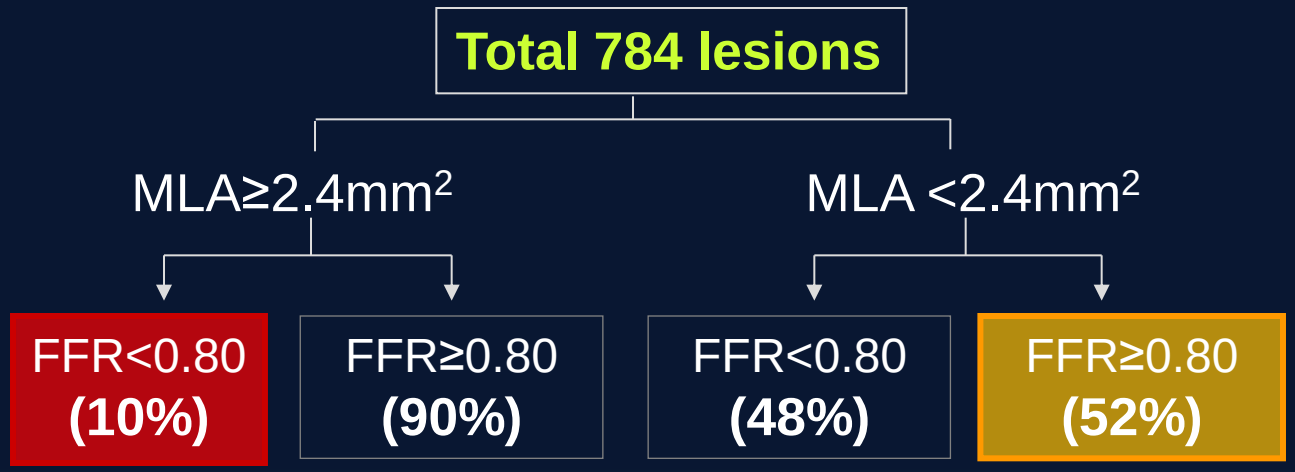
Frequency of QCA-FFR Mismatch

- Mismatch: QCA-DS>50%, FFR≥0.80
- Reverse-mismatch: QCA-DS≤50%, FFR<0.80



Mismatch btw IVUS-MLA and FFR

	N	FFR	RLA	MLA	AUC	Sens	Spec	PPV	NPV	Accu
Takaki (1999 Circ)	51	0.75	9.3	**3.0**	–	83%	92%	–	–	–
Briguori (2001 AJC)	53	0.75	7.8	**4.0**	–	92%	56%	38%	96%	**64%**
Ben-Dor (2012 *)	205	0.80	8.6	**3.09**	0.73	69%	72%	–	–	**70%**
Kang (2011 Circ int)	236	0.80	7.6	**2.4**	0.80	90%	60%	37%	96%	**68%**
Kang (2012 AJC)	784	0.80	8.2	**2.4**	0.77	84%	63%	48%	90%	**69%**
Koo (2011 JACC int)	267	0.80	6.8	**2.75**	0.81	69%	65%	27%	81%	**67%**
Gonzalo (2012 JACC)	47	0.80	7.1	**2.36** IVUS	0.63	67%	65%	67%	65%	**66%**
Gonzalo (2012 JACC)	61	0.80	7.1	**1.95** OCT	0.70	82%	63%	66%	80%	**72%**



	p-value	Adjusted OR	95% CI
MLA<2.4 *but* FFR≥0.8 *"Mismatch"*			
Women	0.048	1.450	1.003 – 2.095
LAD location	0.027	0.666	0.465 – 0.954
Reference lumen diameter	<0.001	0.298	0.204 – 0.437
Distal (vs. proximal) segment	0.002	2.021	1.293 – 3.159
MLA≥2.4 *but* FFR<0.8 *"Rev-mismatch"*			
Age	<0.001	0.940	0.909 – 0.972
LAD location	0.071	2.256	0.932 – 5.460
Plaque rupture	<0.001	11.138	4.886 – 25.39

Multivariable Analysis Predicting FFR

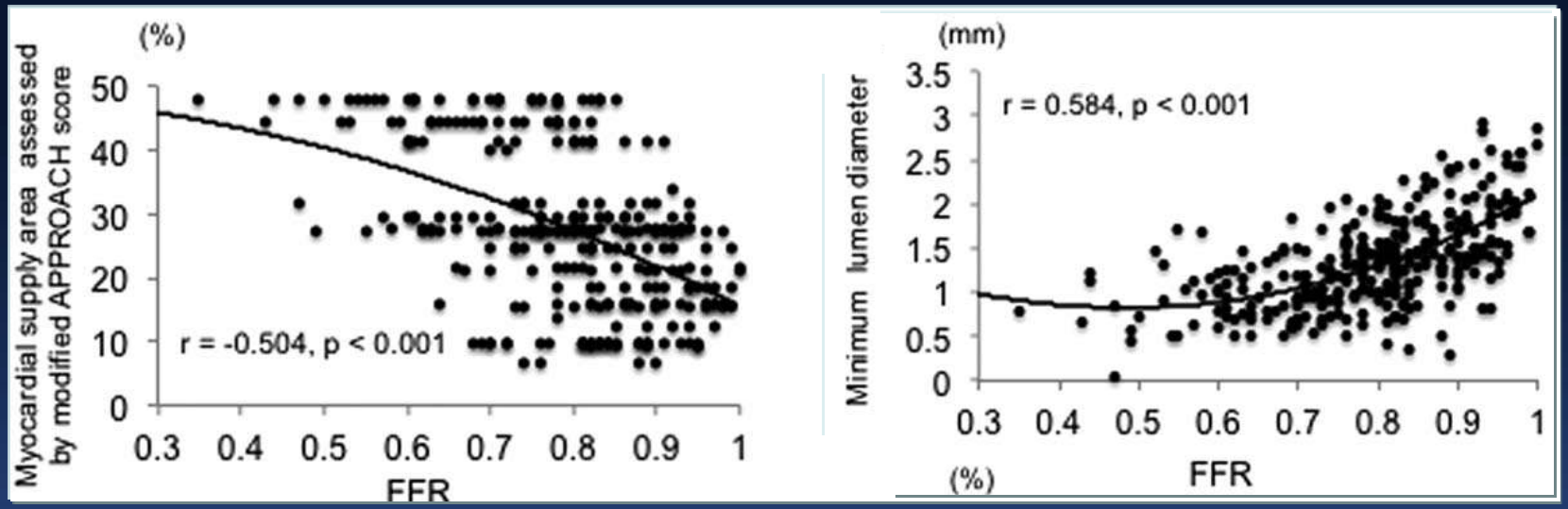
in 700 LAD lesions of 700 patients

**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†		
	ß	p value	95% CI	ß	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

Impact of Myocardial Territory on FFR

Myocardial area subtended to the artery distal to the stenosis evaluated by angiography using a modified APPROACH score



Predictors of FFR<0.80	OR	95% CI	P value
Minimum lumen diameter	0.031	0.013–0.076	< 0.001
Lesion length	1.038	1.009–1.069	0.001
Myocardial size *(modified APPROACH)*	1.113	1.079–1.147	< 0.001

Shiono et al. Catheter Cardiovasc Interv 2014;84:406

Summary

Mechanisms of Visual-Functional Mismatch

Stenosis Severity

- Angiographic DS
- IVUS-MLA
- Plaque burden
- Lesion length

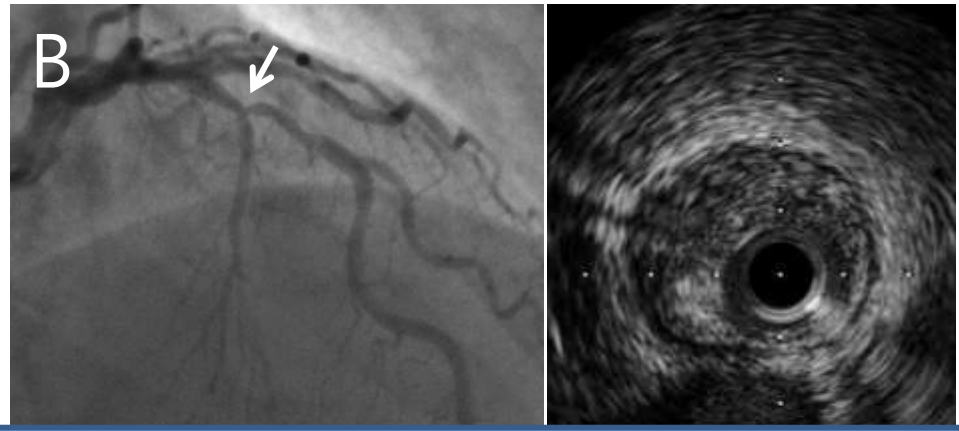
Local Factor

- Plaque rupture

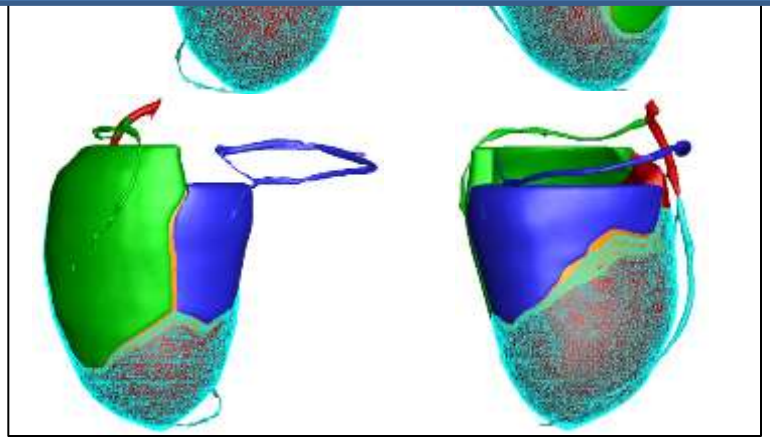
Myocardial Territory

- Age
- Gender
- LAD vs. non-LAD
- Proximal segment
- Ref vessel diameter
- Body surface area
- Body mass index
- LV mass

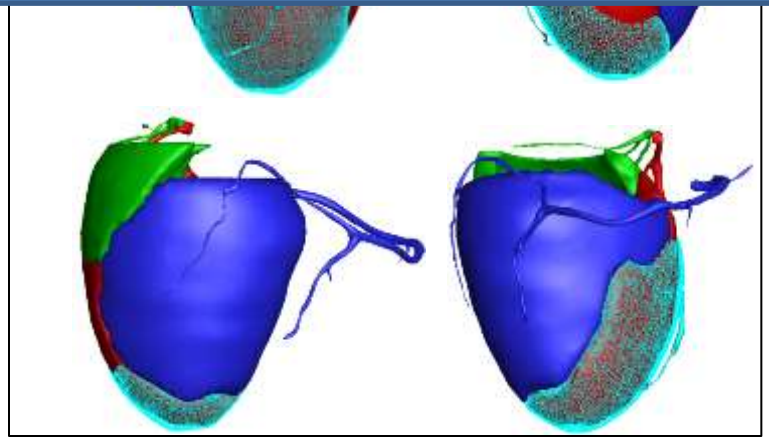
AMC data



Noninvasive CT (CAMS area) may improve the predictability for functional ischemia with the IVUS-measured parameters.



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



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

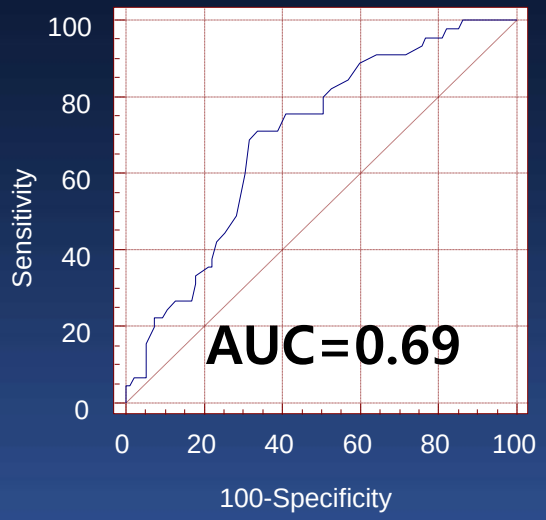
72 pts from 816 CTP registry pts in AMC

Age, years	62.5±9.2
Men	64 (89%)
Body mass index, kg/m^2	25.1±2.6
CAMS data	
Total LV myocardial volume, cc	120.3±26.1
Myocardial volume of LM territory, cc	79.4±26.9
Myocardial volume of RCA territory, cc	32.1±11.9
Myocardial volume of LAD territory, cc	52.1±14.8
Myocardial volume of LCX territory, cc	34.1±11.5
%Myocardium of RCA territory, %	27.2±8.2
%Myocardium of LAD territory, %	43.9±7.3
%Myocardium of LCX territory, %	28.8±7.9

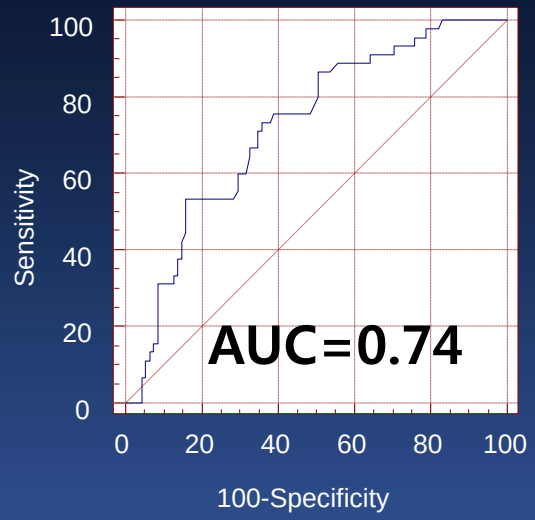
Diagnosis of Ischemia-producing Lesions by Using IVUS-MLA and CAMS

Determinants of FFR ≤0.75

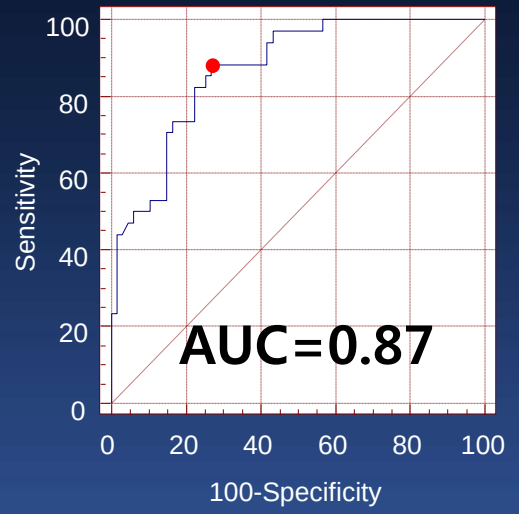
V_{sub} > 30.7cc



V_{ratio} > 25.4%



MLA ≤ 2.83mm²



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

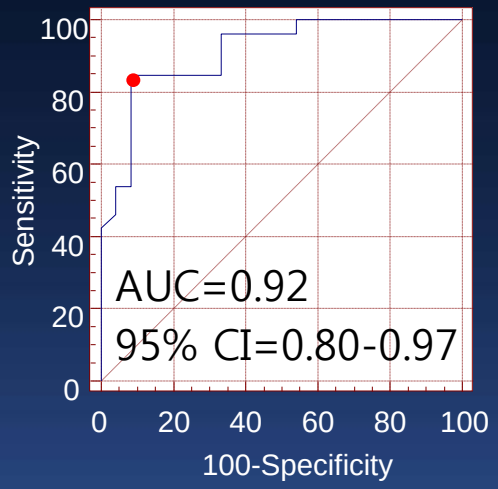
V_{sub} : myocardial volume subtended by stenotic segment
V_{ratio} : Ratio of V_{sub} to total LV myocardial volume

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

Prediction of FFR ≤0.75

V_{sub} >30.7cc

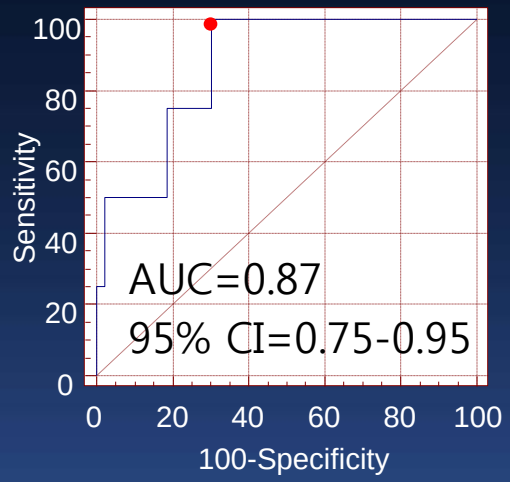
MLA cut-off ≤2.85mm²



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

V_{sub} ≤30.7cc

MLA cut-off ≤2.67mm²

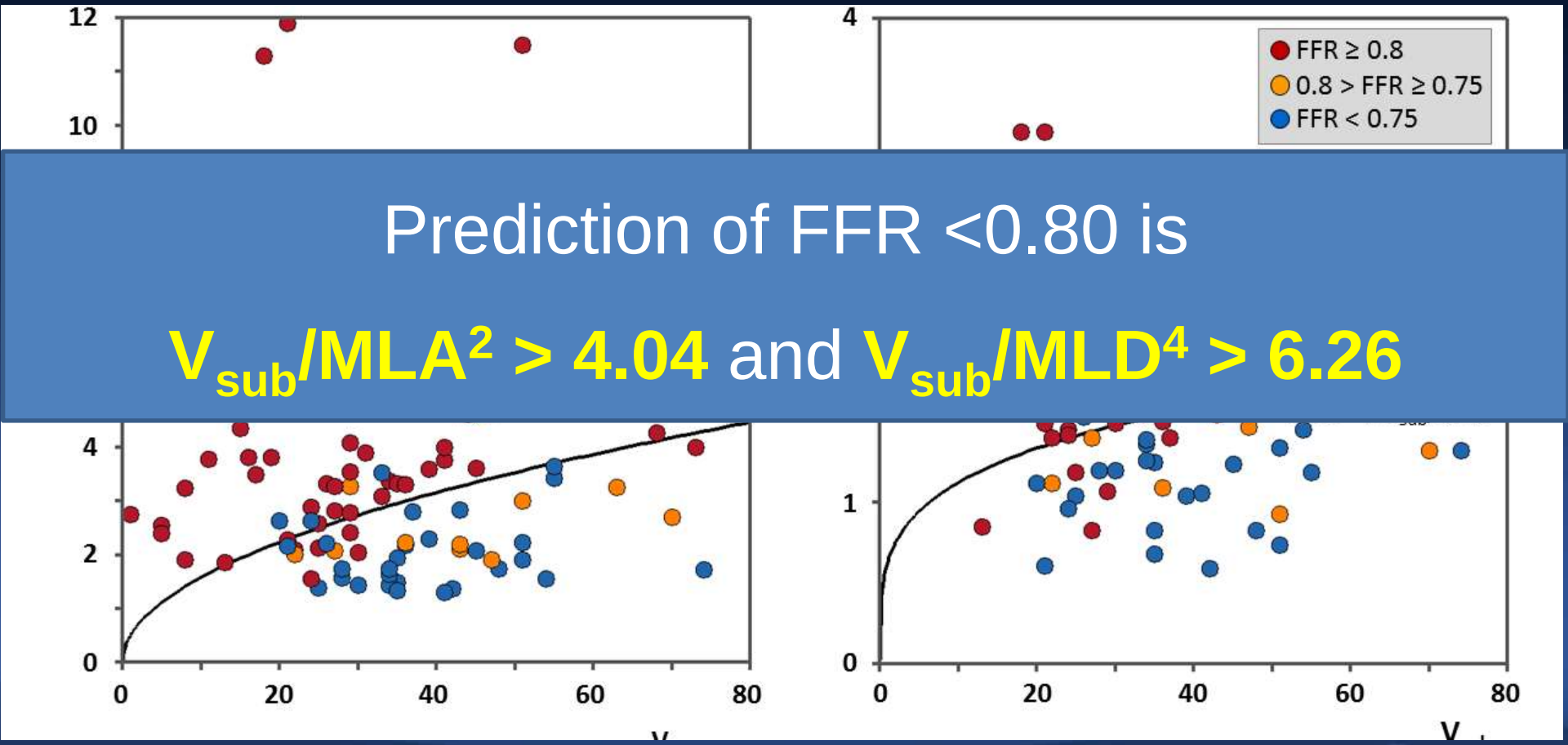


Sensitivity 100%
Specificity 69%
PPV 38%
NPV 100%

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

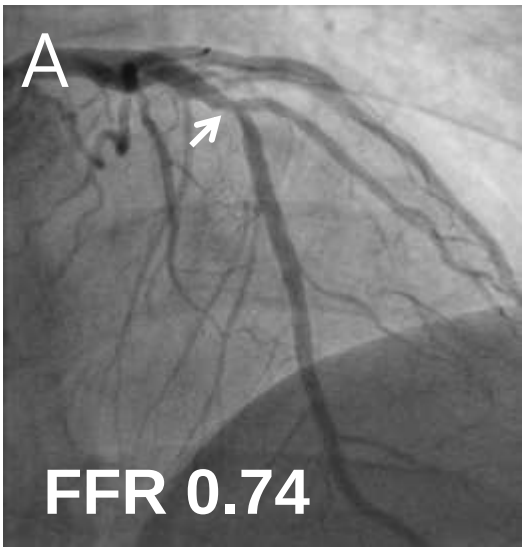
Mathematical Model Predicting FFR

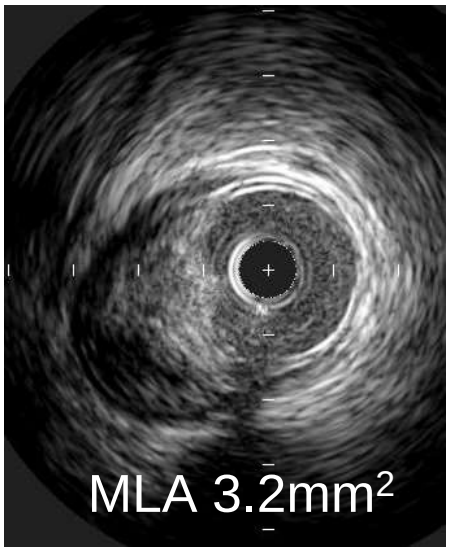
Hypothesis: Pressure drop in laminar flow (ΔP) is proportional to the flow rate divided by the square of CSA (Q/A^2) or by the diameter (Q/d^4) to the fourth power (Poiseuille's law)

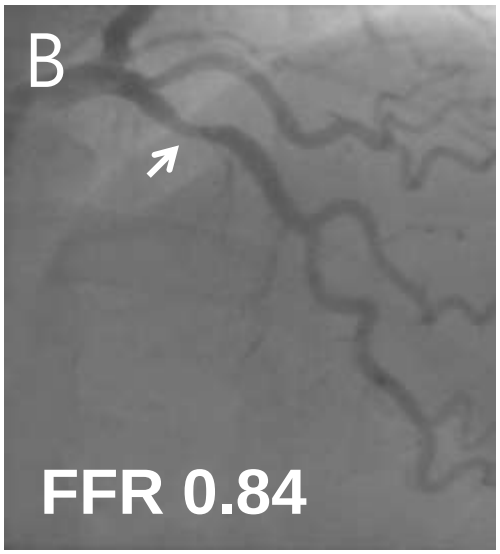


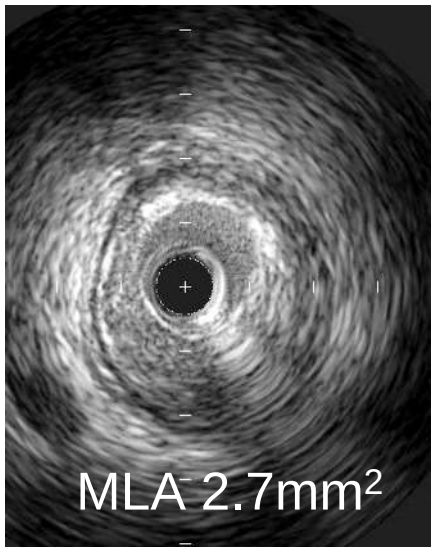
Prediction of FFR <0.80 is

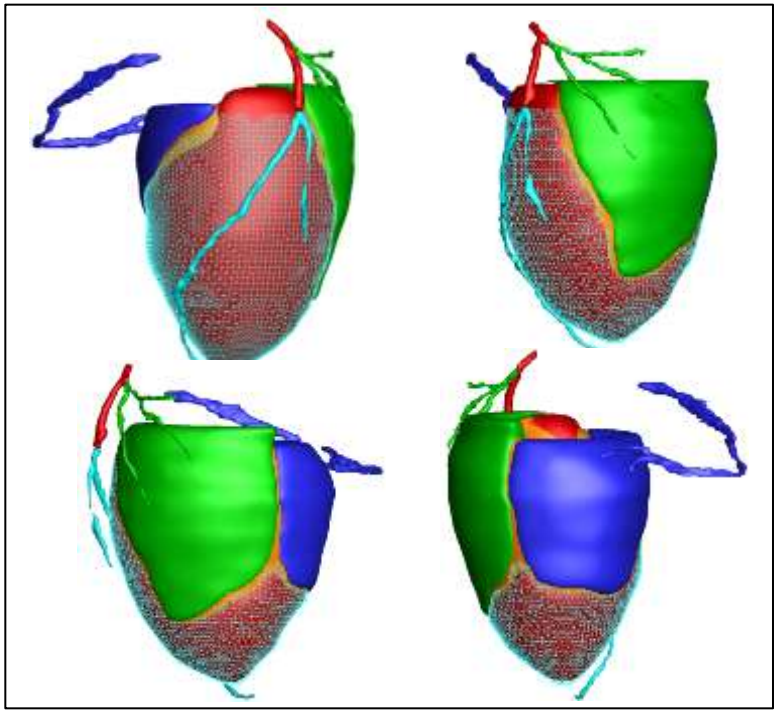
$V_{sub}/MLA^2 > 4.04$ and **$V_{sub}/MLD^4 > 6.26$**





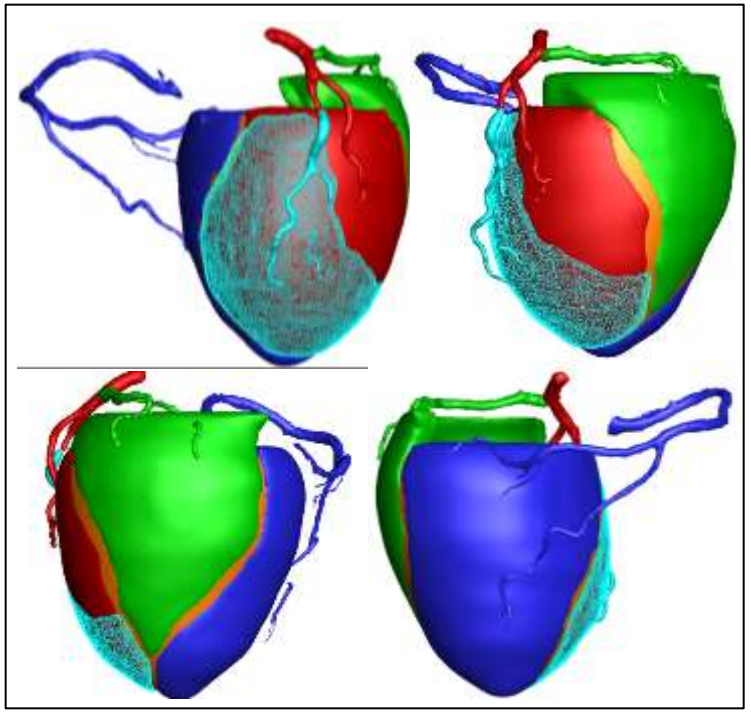






V_{sub}= 70cc, V_{ratio}= 47%

V_{sub}/MLA²= 6.84 (> 4.04)



V_{sub} = 29cc, V_{ratio}= 21%

V_{sub}/MLA²= 3.97 (< 4.04)

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%
RLD^3/MLA^2	>3.62	0.86	80%	82%	75%	86%	80%
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)

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.