CT Perfusion
'One-Stop Shop' CT Imaging

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Disclosure

- Nothing to disclose related with this presentation

Ongoing Debate

How to guide coronary treatment ?

CORONARY
Clinical Research

Predicting Outcome in the COURAGE Trial (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation)

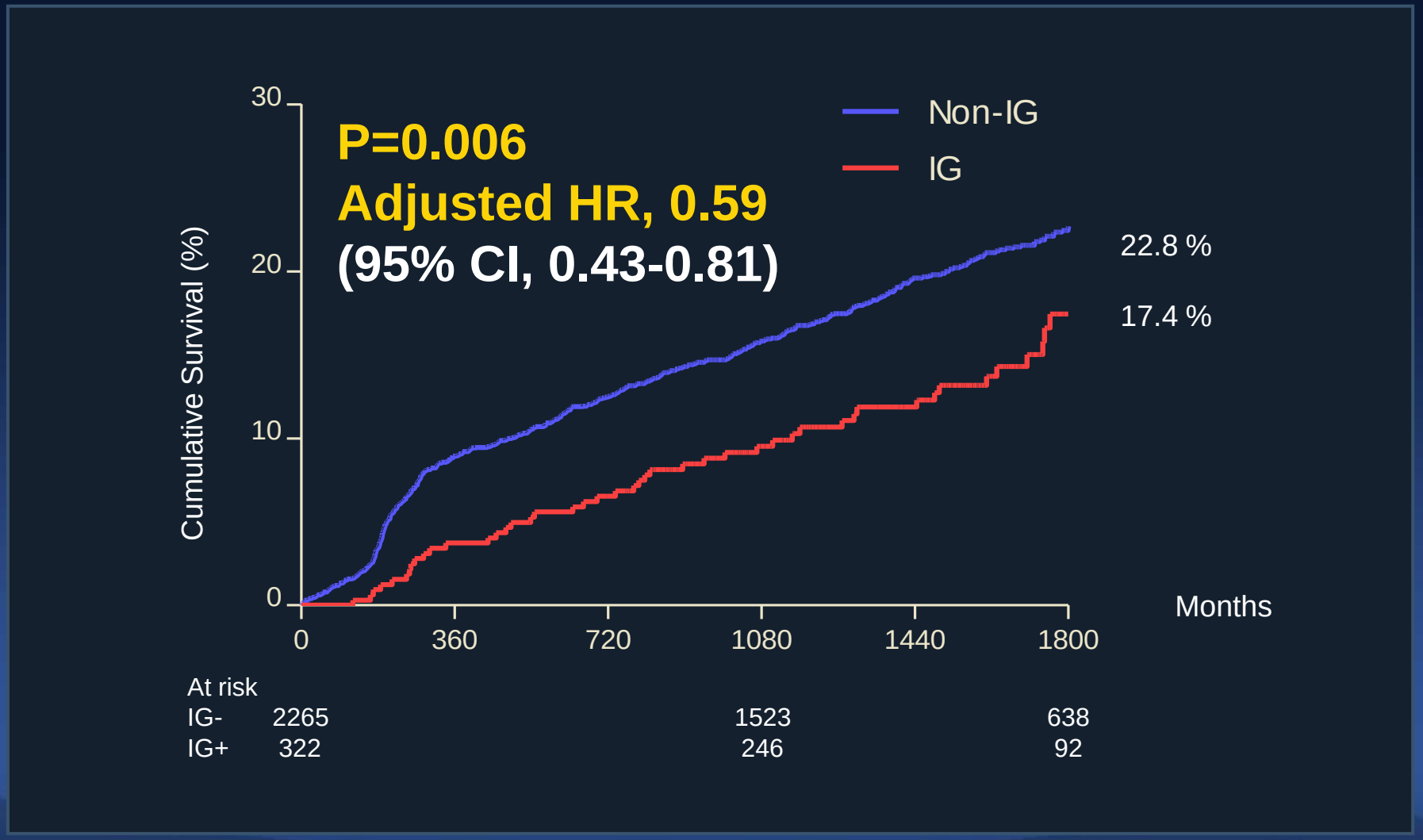
Coronary Anatomy Versus Ischemia

Conclusions In a cohort of patients treated with OMT, anatomic burden was a consistent predictor of death, MI, and NSTE-ACS, whereas ischemic burden was not. Importantly, neither determination, even in combination, identified a patient profile benefiting preferentially from an invasive therapeutic strategy. (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation [COURAGE]; NCT00007657) (J Am Coll Cardiol Intv 2014;7:195–201) © 2014 by the American College of Cardiology Foundation

Mancini GBJ et al. J Am Coll Cardiol Intv 2014;7:195

Ischemia-guided PCI using SPECT in AMC

MACCE for 5 Years

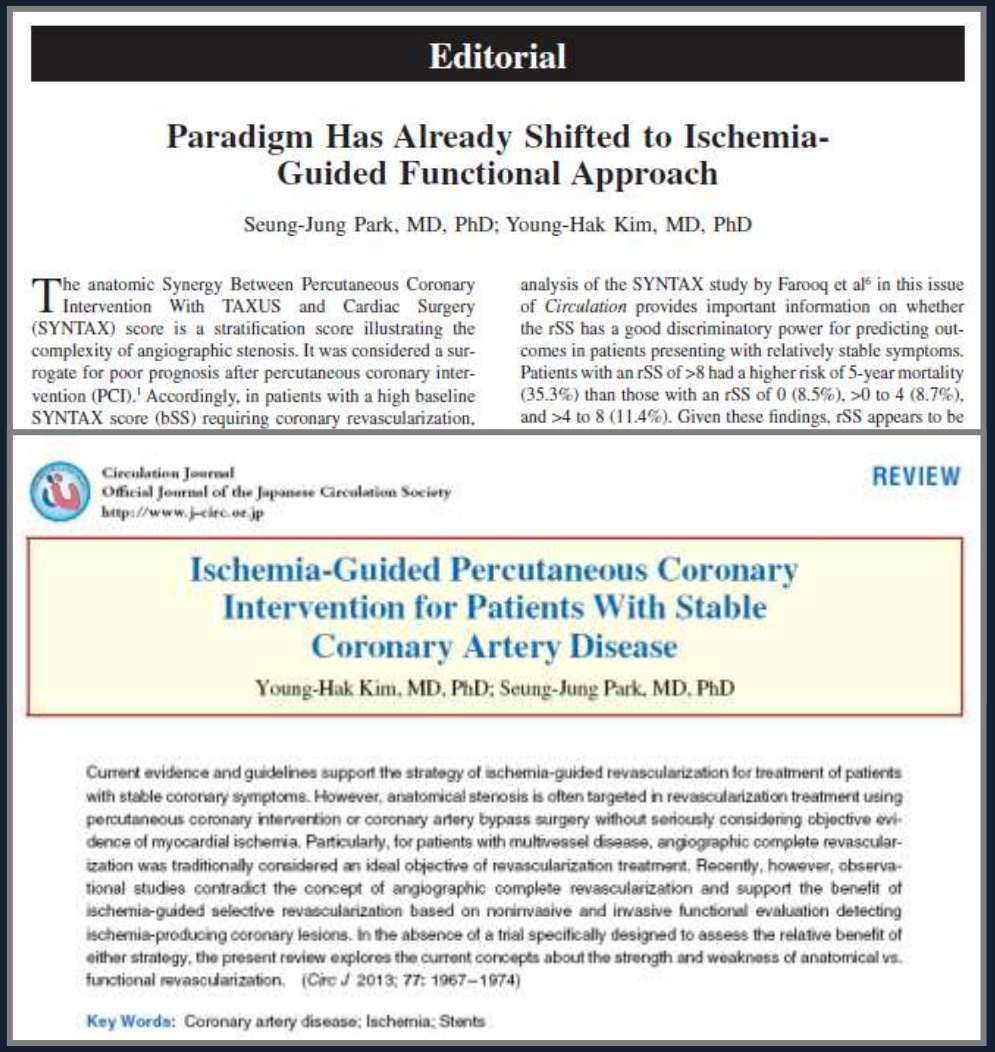


Kim YH et al. J Am Coll Cardiol 2012;60:181

Ischemia-guided Revascularization
My Belief

Kim YH, Park SJ.
Circulation. 2013;128:95-7.

Kim YH, Park SJ.
Circ J. 2013;77:1967-74.



Editorial

Paradigm Has Already Shifted to Ischemia-Guided Functional Approach

Seung-Jung Park, MD, PhD; Young-Hak Kim, MD, PhD

The anatomic Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery (SYNTAX) score is a stratification score illustrating the complexity of angiographic stenosis. It was considered a surrogate for poor prognosis after percutaneous coronary intervention (PCI).[1] Accordingly, in patients with a high baseline SYNTAX score (bSS) requiring coronary revascularization, analysis of the SYNTAX study by Farooq et al[6] in this issue of *Circulation* provides important information on whether the rSS has a good discriminatory power for predicting outcomes in patients presenting with relatively stable symptoms. Patients with an rSS of >8 had a higher risk of 5-year mortality (35.3%) than those with an rSS of 0 (8.5%), >0 to 4 (8.7%), and >4 to 8 (11.4%). Given these findings, rSS appears to be

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REVIEW

Ischemia-Guided Percutaneous Coronary Intervention for Patients With Stable Coronary Artery Disease

Young-Hak Kim, MD, PhD; Seung-Jung Park, MD, PhD

Current evidence and guidelines support the strategy of ischemia-guided revascularization for treatment of patients with stable coronary symptoms. However, anatomical stenosis is often targeted in revascularization treatment using percutaneous coronary intervention or coronary artery bypass surgery without seriously considering objective evidence of myocardial ischemia. Particularly, for patients with multivessel disease, angiographic complete revascularization was traditionally considered an ideal objective of revascularization treatment. Recently, however, observational studies contradict the concept of angiographic complete revascularization and support the benefit of ischemia-guided selective revascularization based on noninvasive and invasive functional evaluation detecting ischemia-producing coronary lesions. In the absence of a trial specifically designed to assess the relative benefit of either strategy, the present review explores the current concepts about the strength and weakness of anatomical vs. functional revascularization. (*Circ J* 2013; 77: 1967–1974)

Key Words: Coronary artery disease; Ischemia; Stents

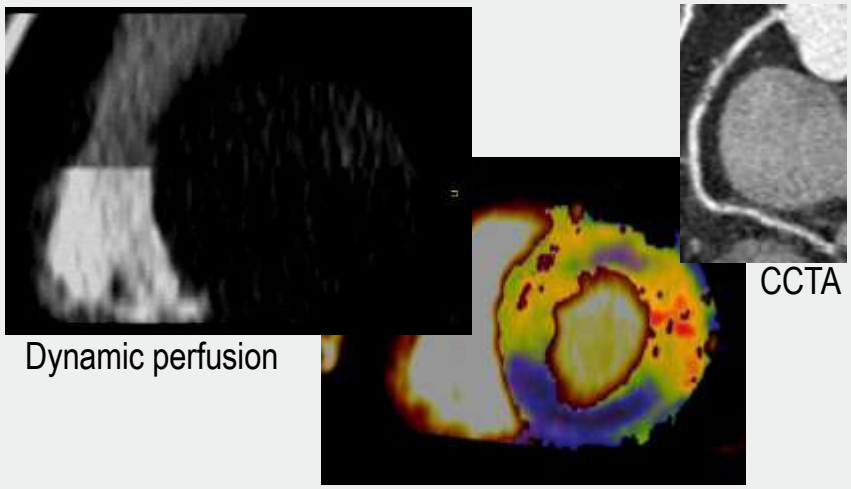
What is the best tool to detect ischemic lesion and vessel ?

- **Noninvasive method**
  - SPECT
  - PET
  - MRI
  - CT

Relatively high F(-) rate in multivessel and LM disease due to the balanced ischemia, low spatial resolution

- **Invasive method**
  - FFR

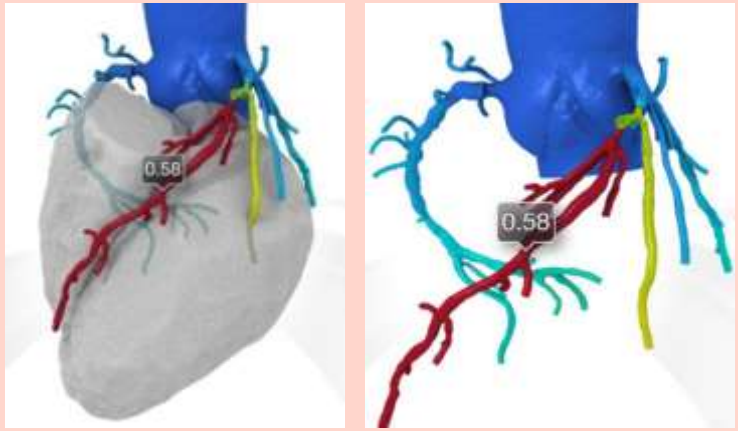
CT-based Functional Imaging



CT Perfusion (CTP)

Pros	✓ Direct view of myocardium ✓ Easy to perform ✓ No special software
Cons	✓ Radiation dose concern (two scans; stress + rest) ✓ Requirement of adenosine

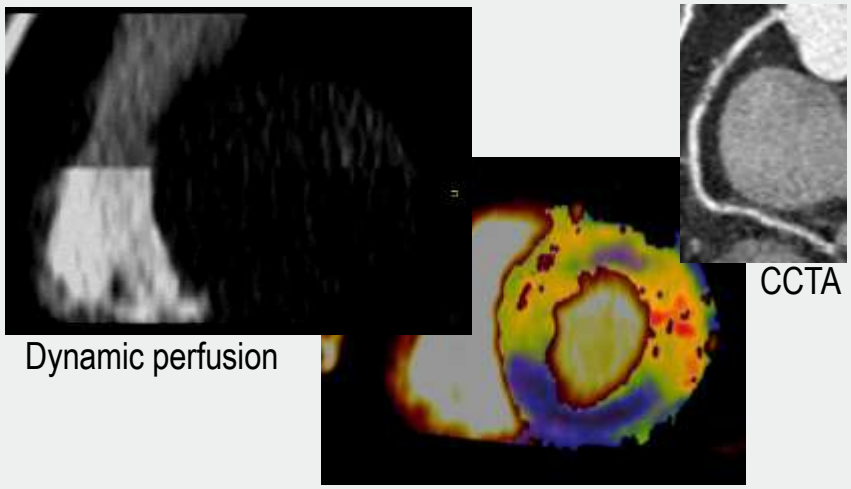
Computational fluid dynamics simulation



FFR-CT

Pros	✓ No additional scan ✓ No requirement of adenosine
Cons	✓ Indirect view of ischemia ✓ Need supercomputer ✓ No information on perfusion.

CT Perfusion Imaging



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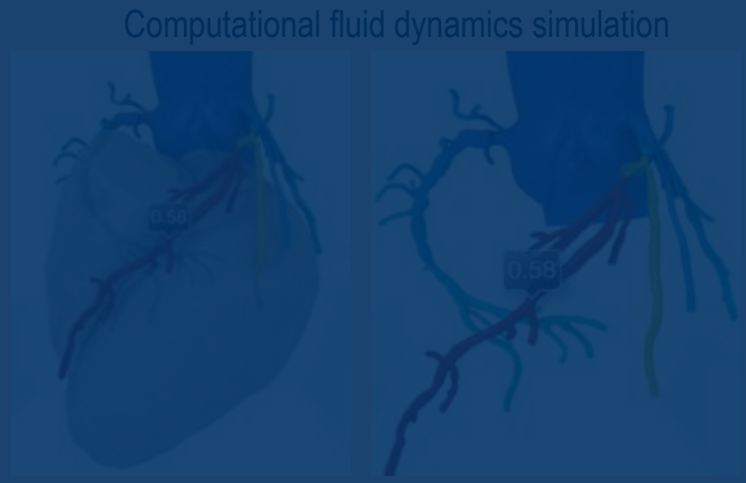

CT-FFR

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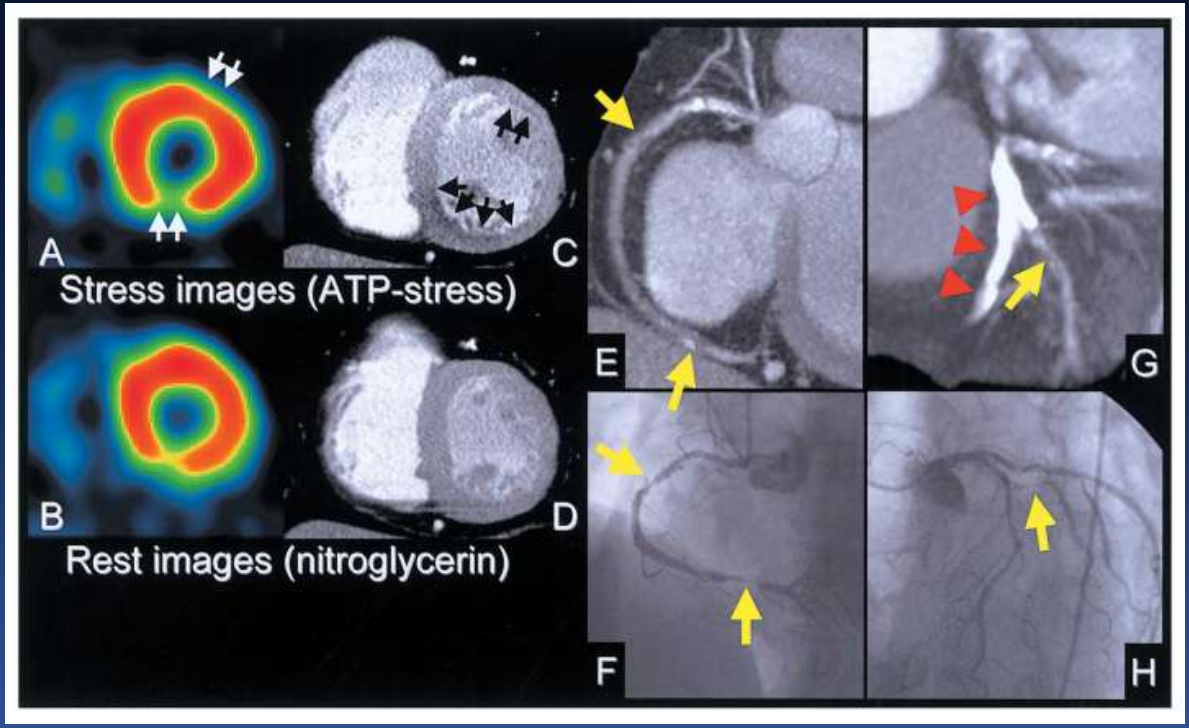
First Article of Stress CTP in 2005



Summary
16-ch CT (GE, LightSpeed 16)
12 patients
Reference: Thallium SPECT
Population: suspected CAD
Sensitivity (per-vessel): 90%
Specificity (per-vessel): 79%

Kurata A. Mochizuki T. et al . 2005 Cir J 69:550-557

Kurata A. Mochizuki T. et al . 2005 Cir J 69:550-557

Published Data about CT Perfusion

Institution	Year	Pts	Sens / Spec (%)	Ref.	CT
MGH	2009 2010	33 35	94 / 74 91 / 91	QCA/SPECT QCA	64 DSCT (Siemens), Static
Johns Hopkins	2009 2012	27 50	81 / 85 72 / 91	QCA/SPECT QCA/SPECT	64 ch, 320 ch (Toshiba), Static
Monash H (Australia)	2012 2012	42 40	91 / 72 95 / 87	FFR FFR	320 ch , Static (Toshiba)
Centro H. (Portugal)	2013	101	55 / 95 (CTP) 71 / 90 (CTP/CTA)	FFR	64 ch, single source (Siemens), Static
Grosshadern (Germany)	2012	36	93 / 87	FFR	128 DSCT, Dynamic (Siemens)
MUSC (South Carolina)	2010 2012	10 20	86 / 98 86 / 98	MRI MRI/SPECT	128 DSCT, Dynamic (Siemens)
Mount Alvernia H. (Singapore)	2011	35	83 / 78	SPECT	128 DSCT, Dynamic (Siemens)
Cedars-Sinai, LA	2010	30	92 / 86	SPECT	64 DSCT (Siemens), Static
Korea (Kunkook U.)	2011	41	91 / 72	MRI	64 DSCT-DE mode (Siemens), Static
Innsbruck (Austria)	2012	39	96 / 95	MRI/QCA	128 DSCT-FLASH mode (Siemens)

CTP Protocol in AMC

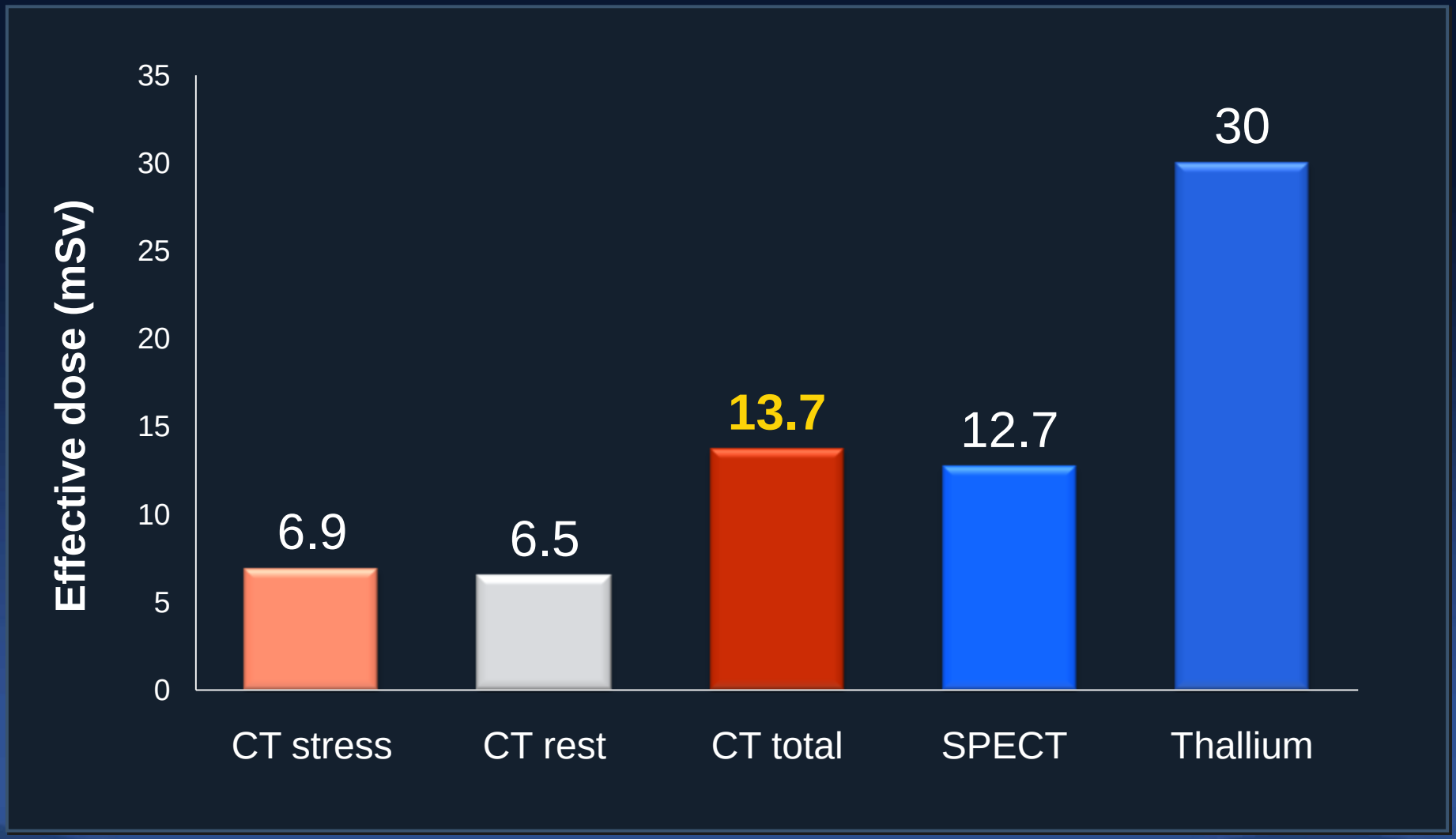
25 minutes
using dual-source 126 ch. CT (Siemens)

		10 min. interval		
Calcium scoring	**Adenosine infusion**	**Stress perfusion**	**Sublingual NTG**	**Rest perfusion (CTA)**
Scan range	4 min. 30 sec	Retrospective ECG-gating	2 min. before	Retrospective ECG-gating

Option
1. **Static perfusion**
2. Dynamic perfusion

Option
1. Retrospective mode
2. Prospective mode
3. High-pitch mode

Radiation Dose

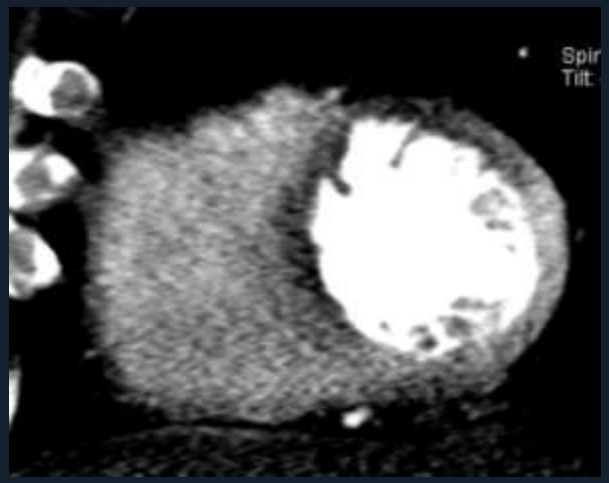
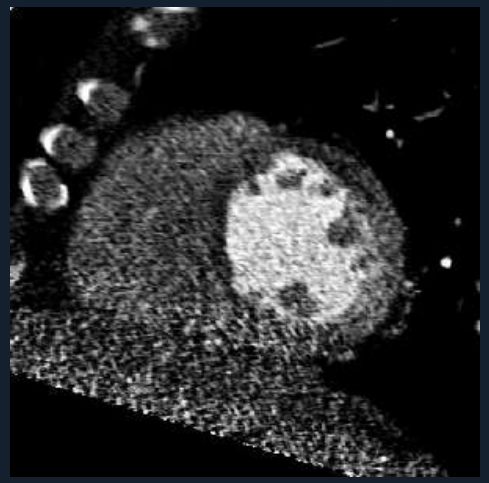


SPECT, Blankstein et al . 2009 JACC 54:1072-84

Visual Analysis of CTP

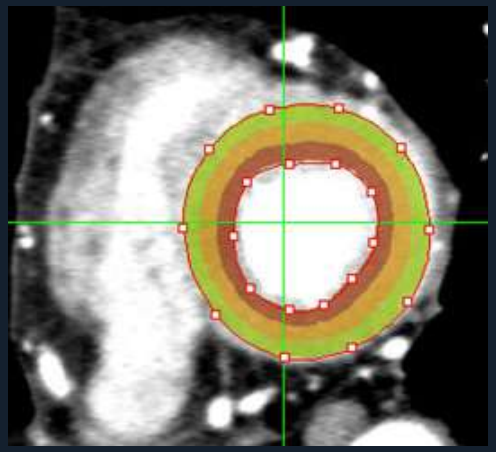
- Diagnostic indicator of myocardial ischemia
  - **Low density lesion** conforming coronary territory
  - **Persistent lesion** at systole and diastole

    DDx) Transient motion or beam-hardening artifact
  - **Wall motion abnormality (useful)**


Quantitative Analysis

- Using customized software
  - Classification of whole myocardium into 16 segments and three layers

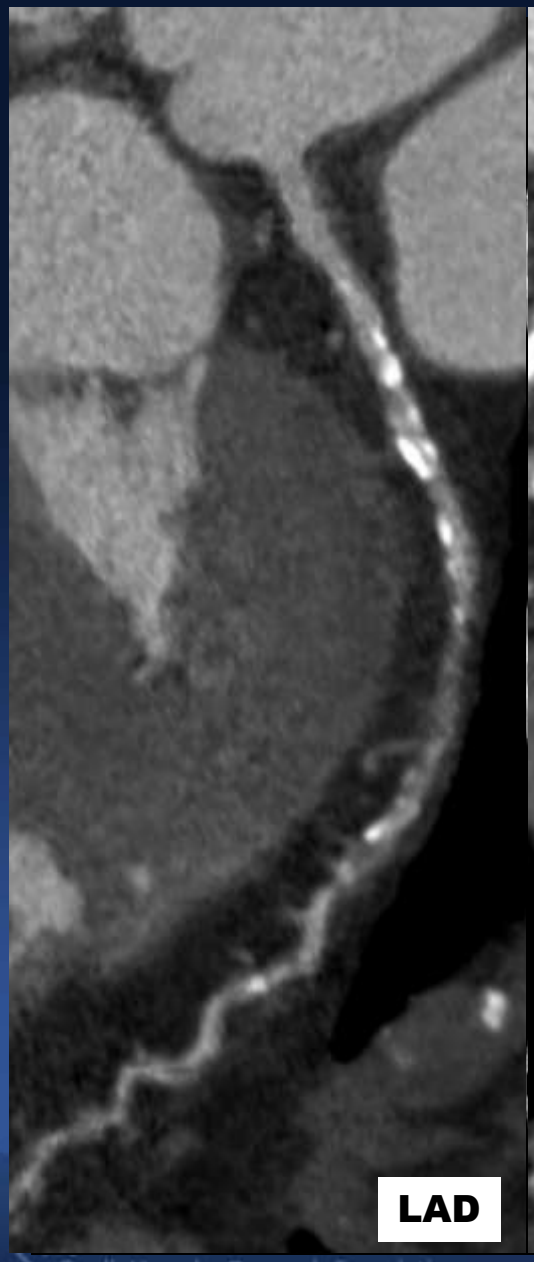


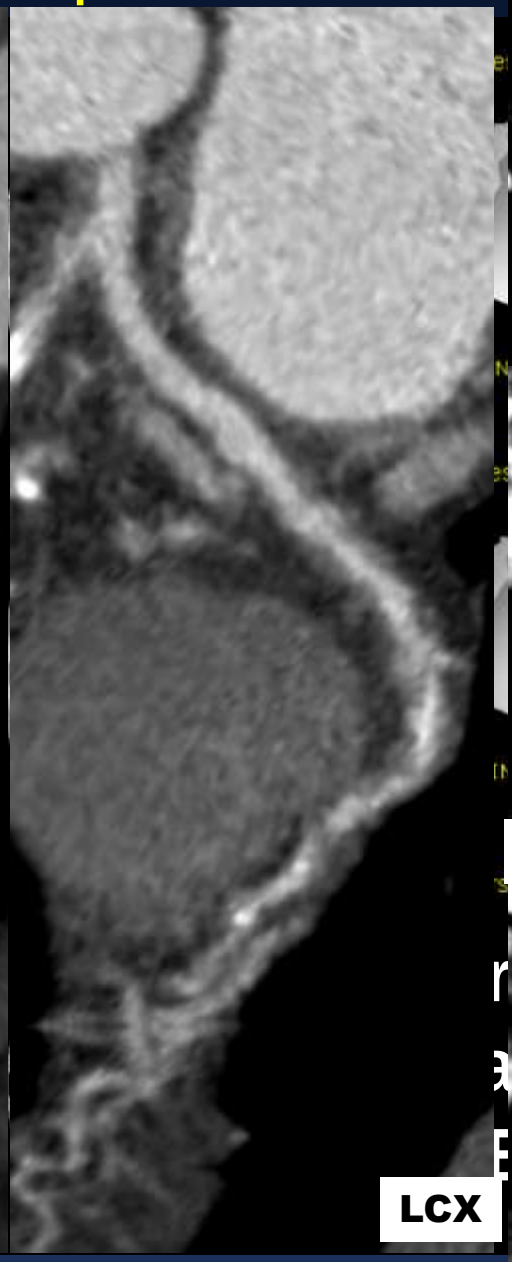
- Evaluation parameters
  - CT density on stress / rest CT
    - $Density_{stress}$ / $Density_{rest}$, HU
  - Transmural perfusion ratio (TPR)
    - $Density_{endocardial}/Density_{epicardial}$
  - Myocardial perfusion reserve index (MPRI),%
    - $(Density_{stress} – Density_{rest})/Density_{rest}$ X 100

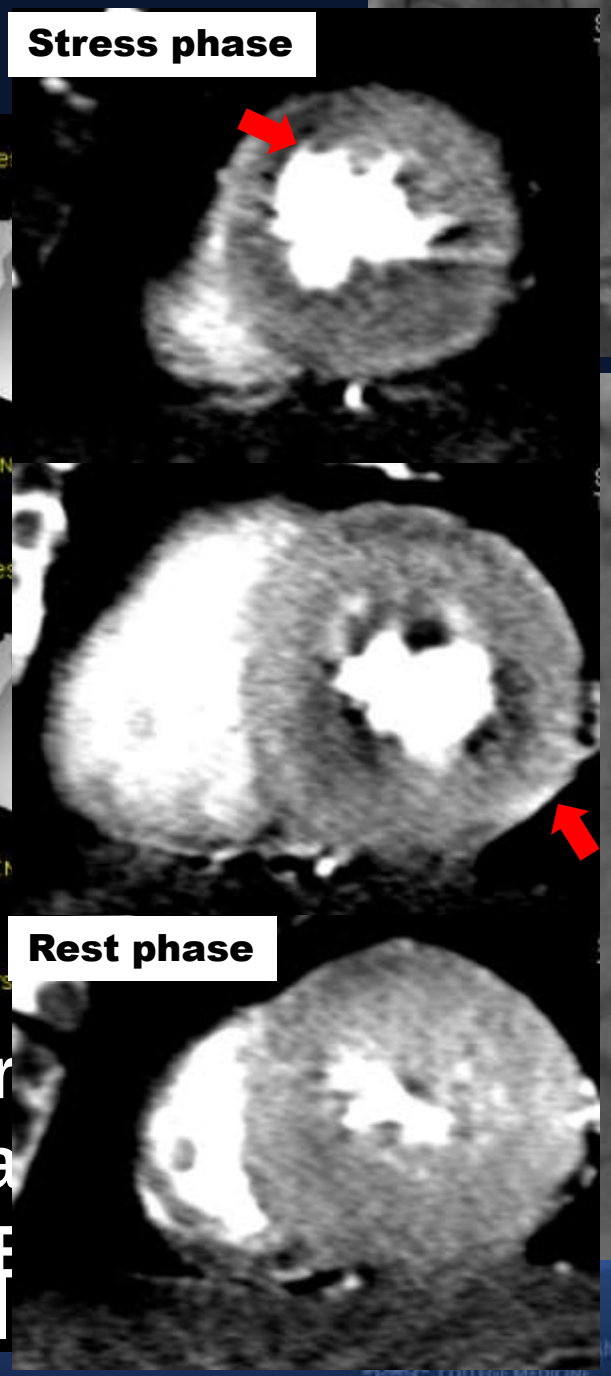
Case Examples of CTP

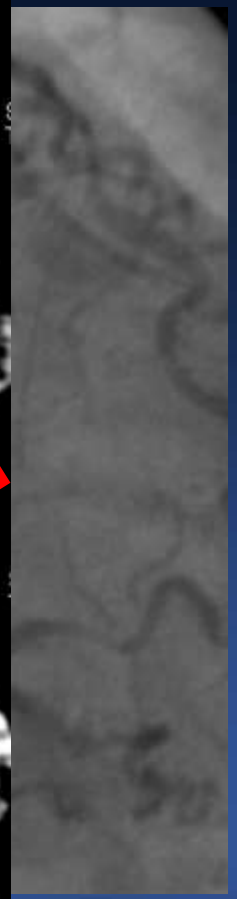
- Multivessel disease
- Calcified lesion
- In-stent restenosis
- Anatomical variant
- Old infarction and peri-ischemia

65/F, Effort chest pain

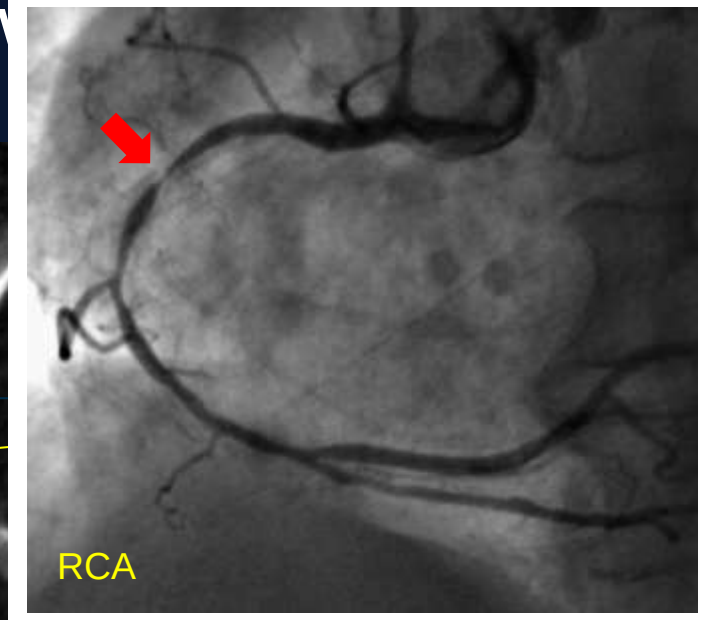


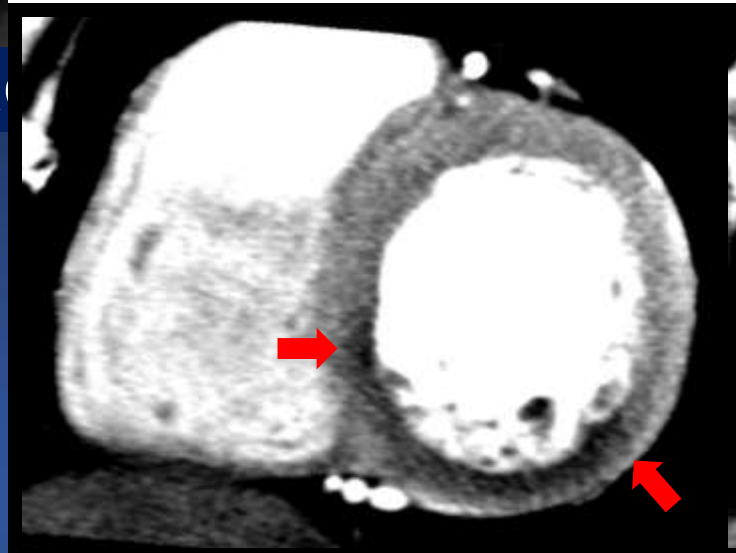


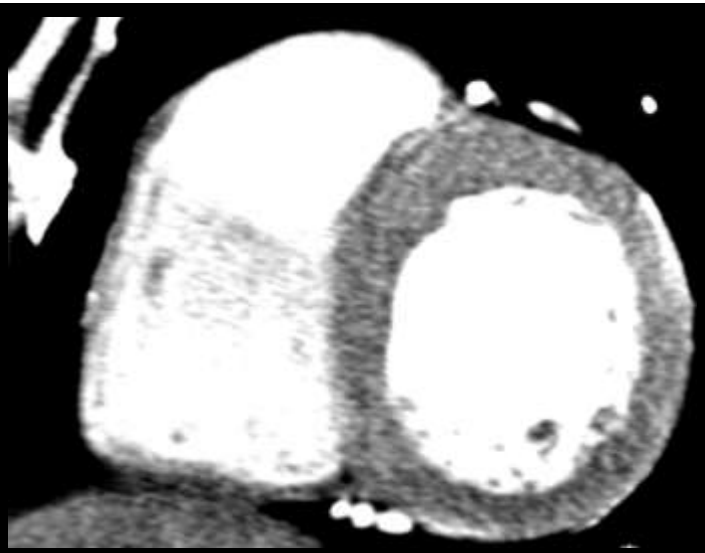




69/M, Effort chest pain



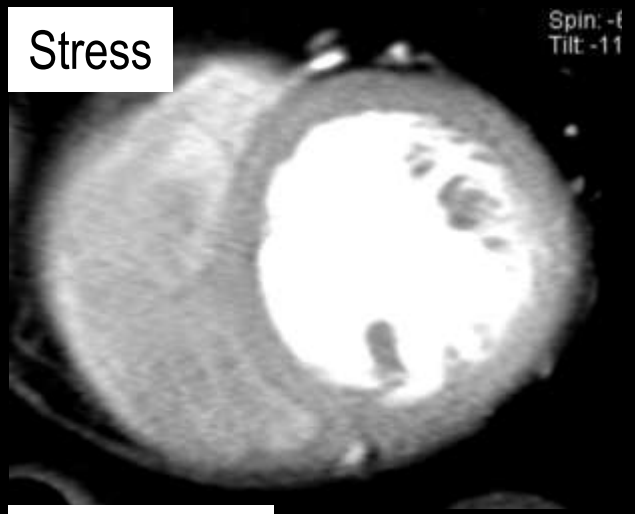




Reversible perfusion defect in RCA territory

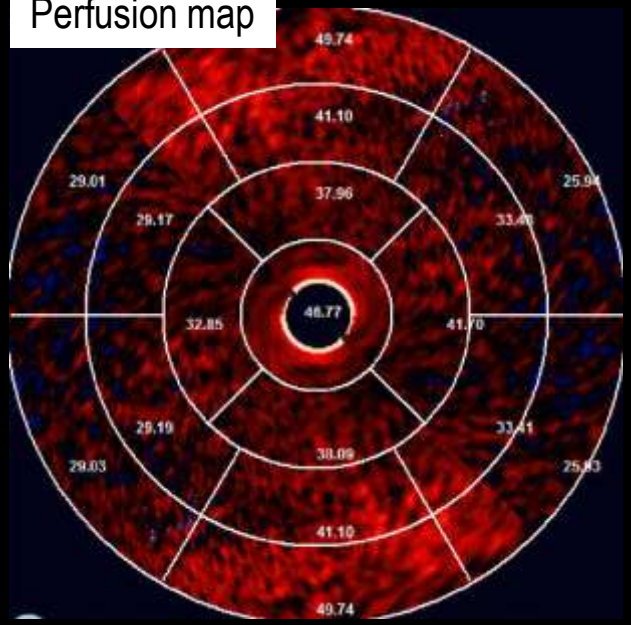
74/M, Chest pain
PCI at RCA (pRCA Taxus; mRCA/dRCA Cypher)

Stress



Rest

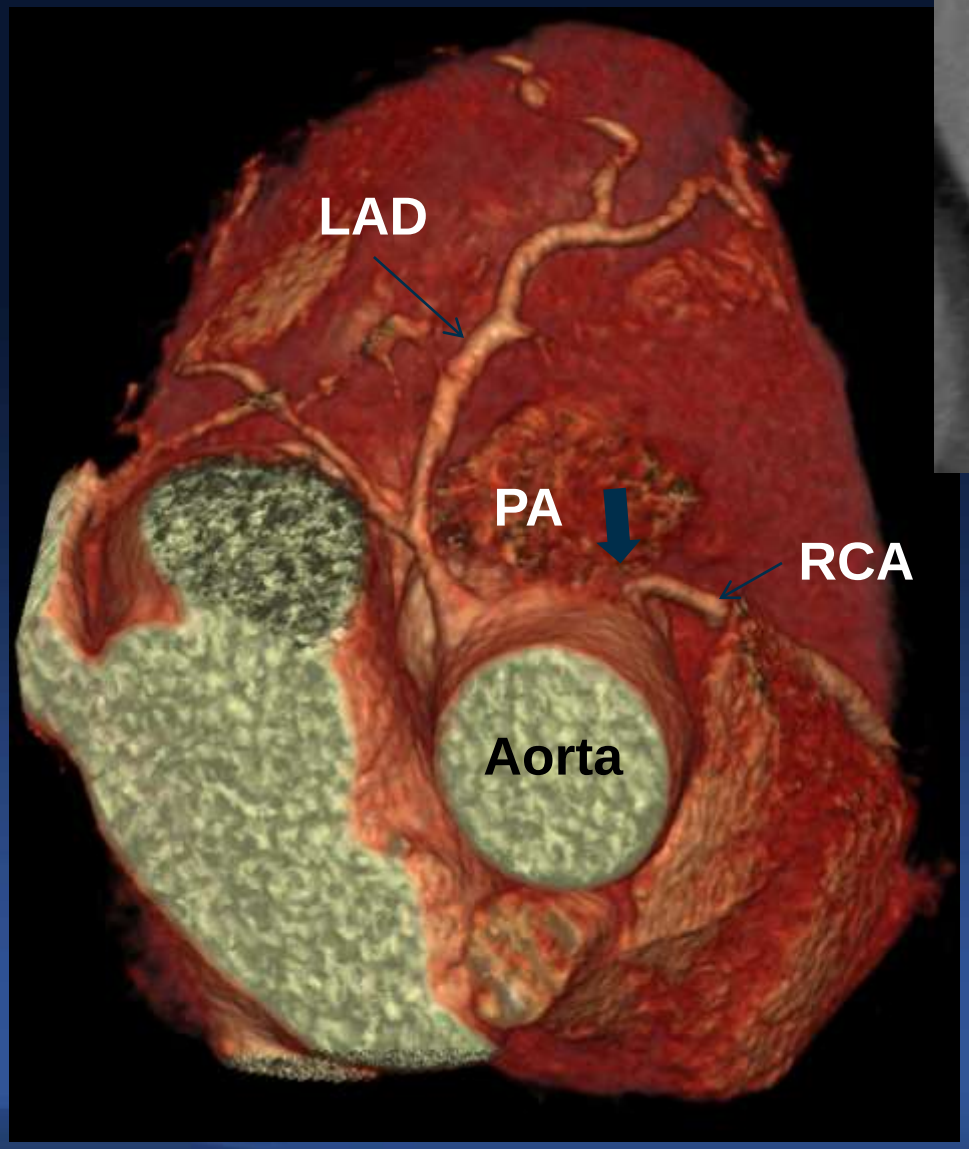
Perfusion map

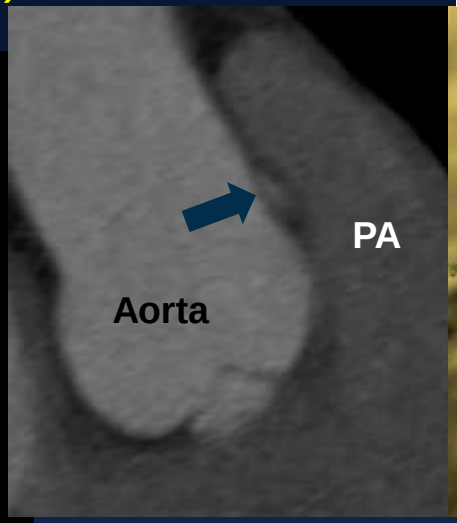


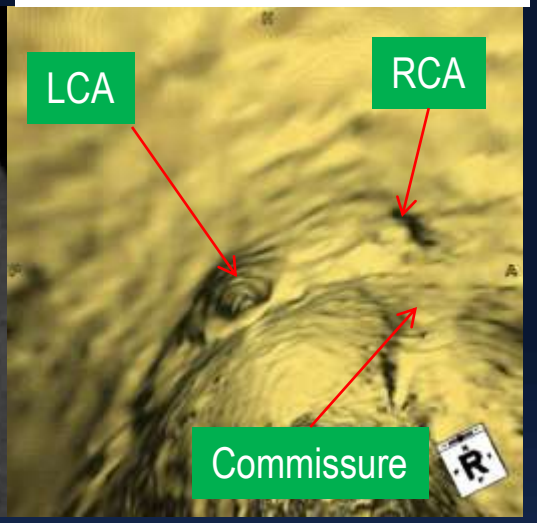
No perfusic

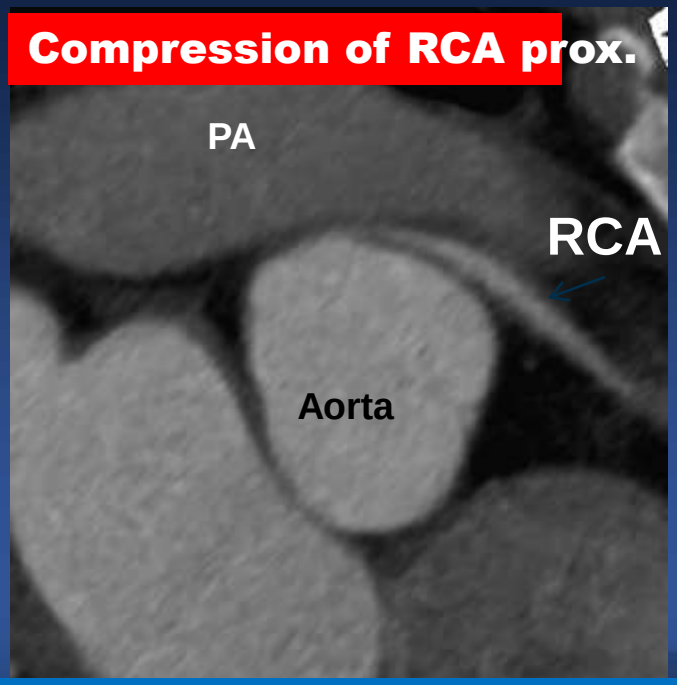
FFR = **0.83**, LAD

42/M, Effort chest pain
Positive TMT, stage 4 (II, III, aVF, V4-6)



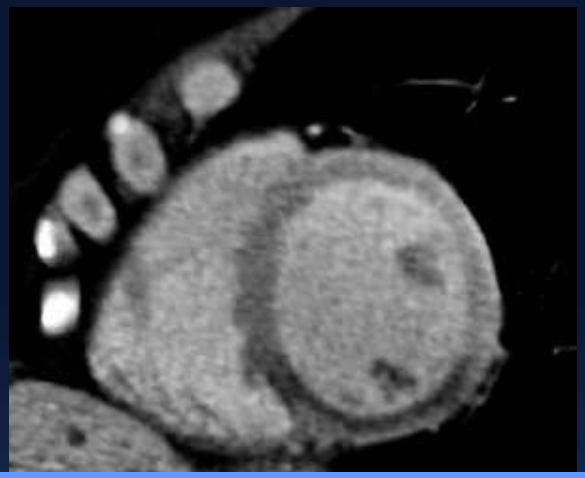


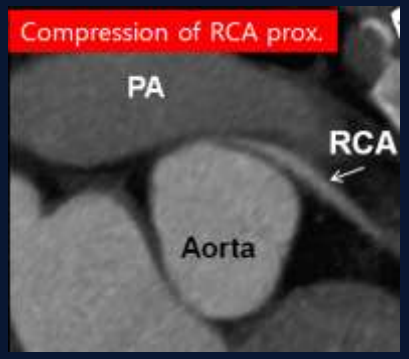




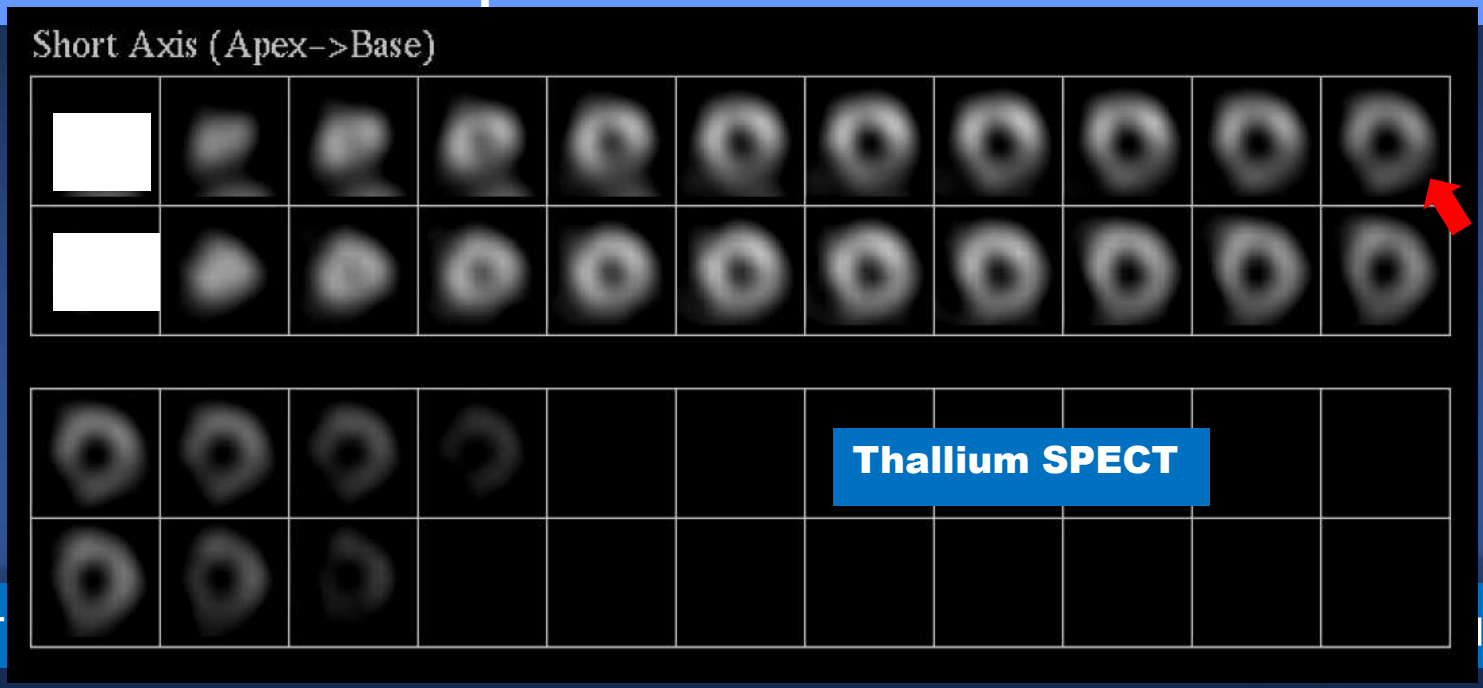
Aberrant origin of RCA from left coronary sinus with interarterial course

42/M, Effort chest pain
Positive TMT, stage 4 (II, III, aVF, V4-6)





+ Reversible perfusion defect in RCA territory

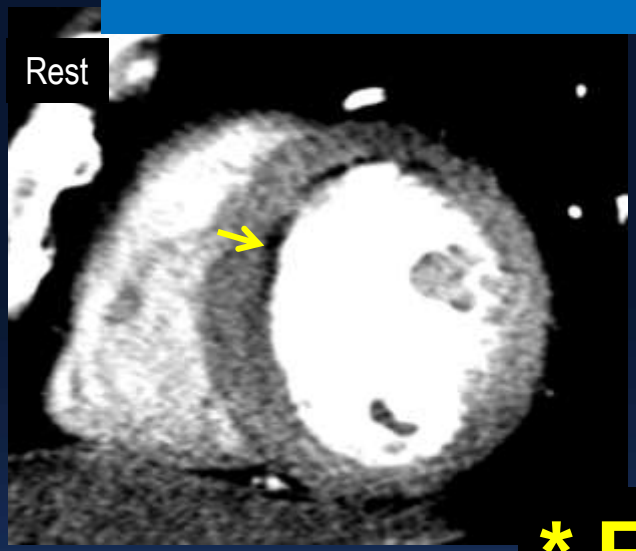


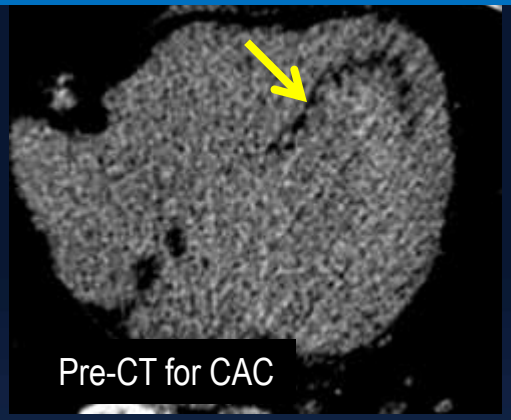
Aber

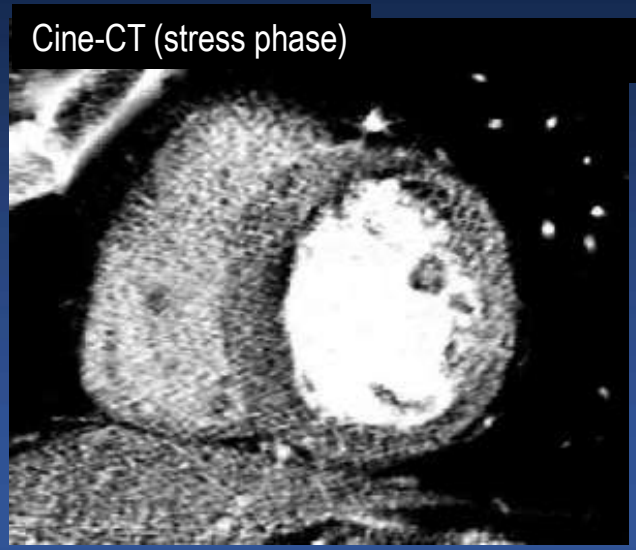
urse

53/M, recurrent chest pain
s/p PCI at LAD, RCA, LCX

Peri-infarct ischemia







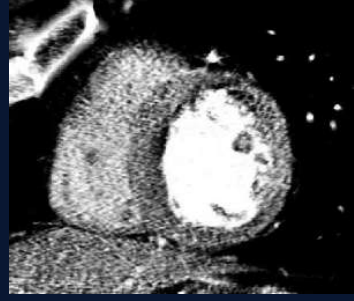
* Findings

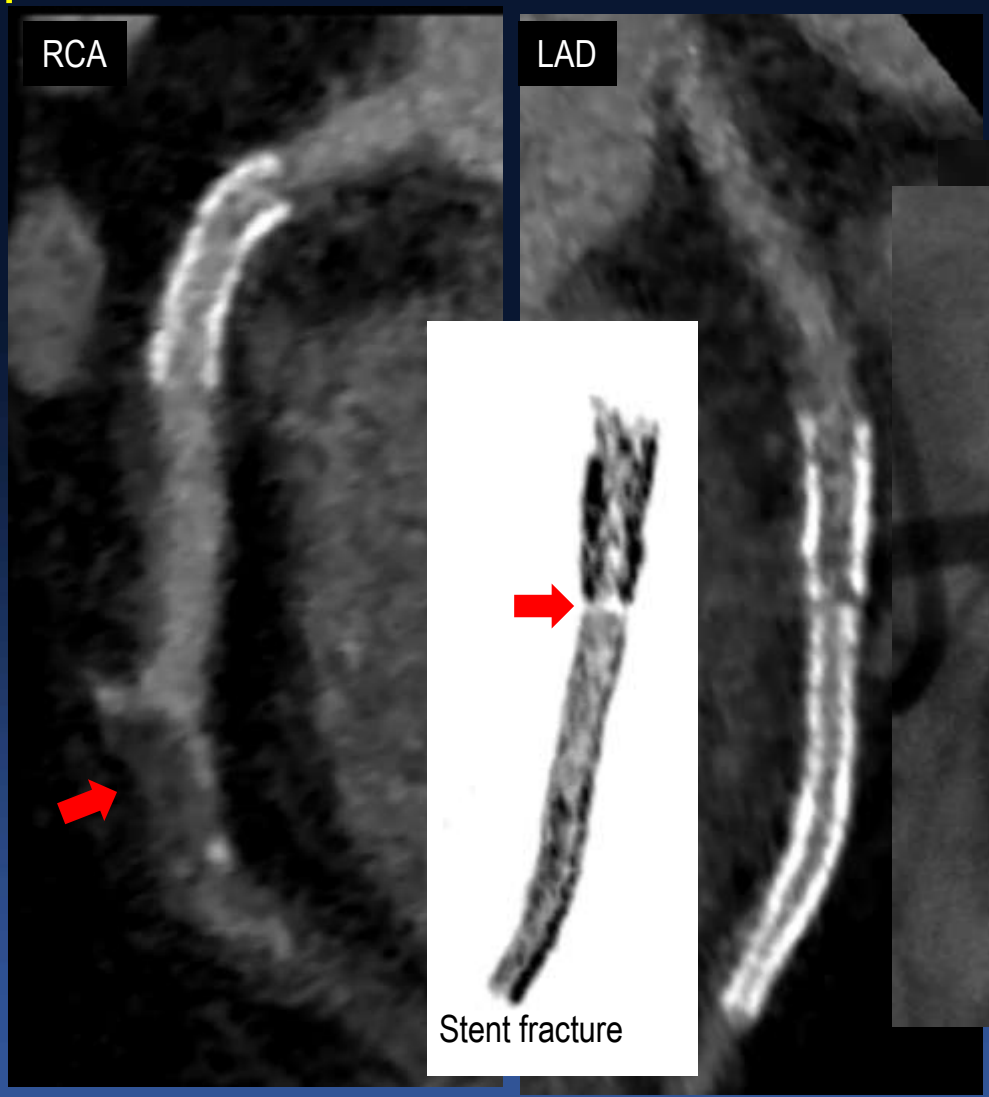
1. Reversible perfusion defect
2. Severe hypokinesia
3. Irreversible perfusion defect

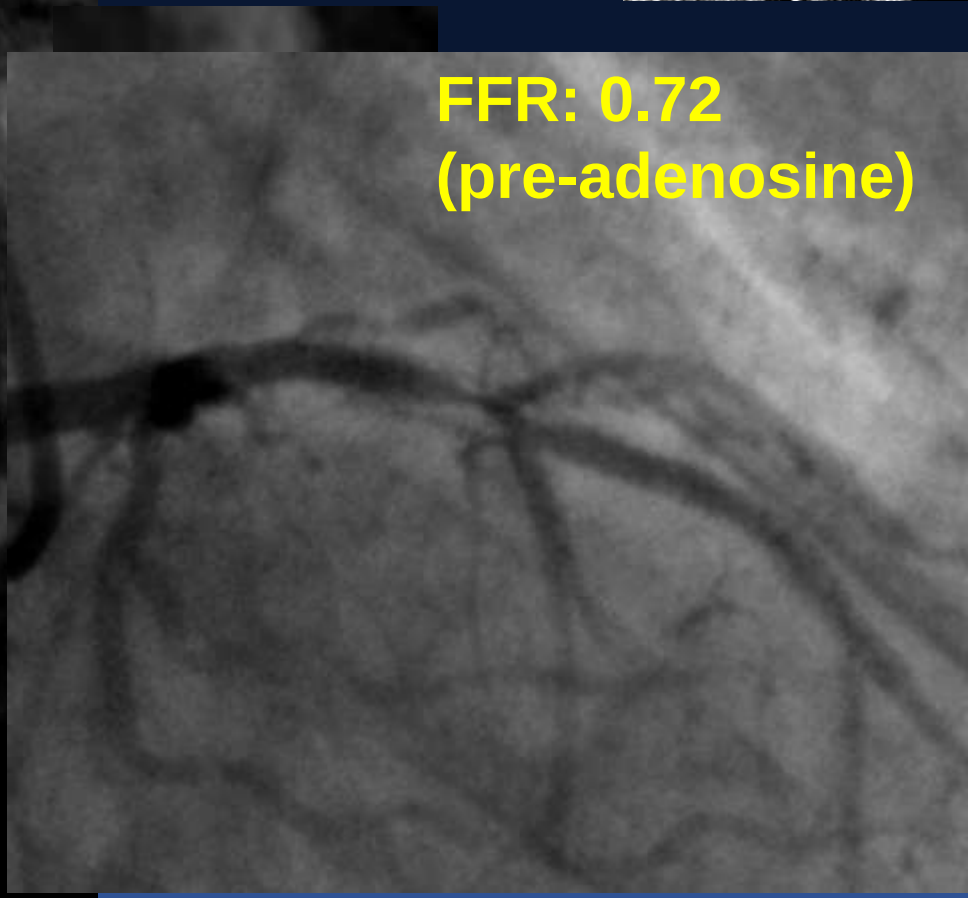
→ Subendocardial fat
(Old infarct)

Perfusion CT

53/M, recurrent chest pain
s/p PCI at LAD, RCA, LCX

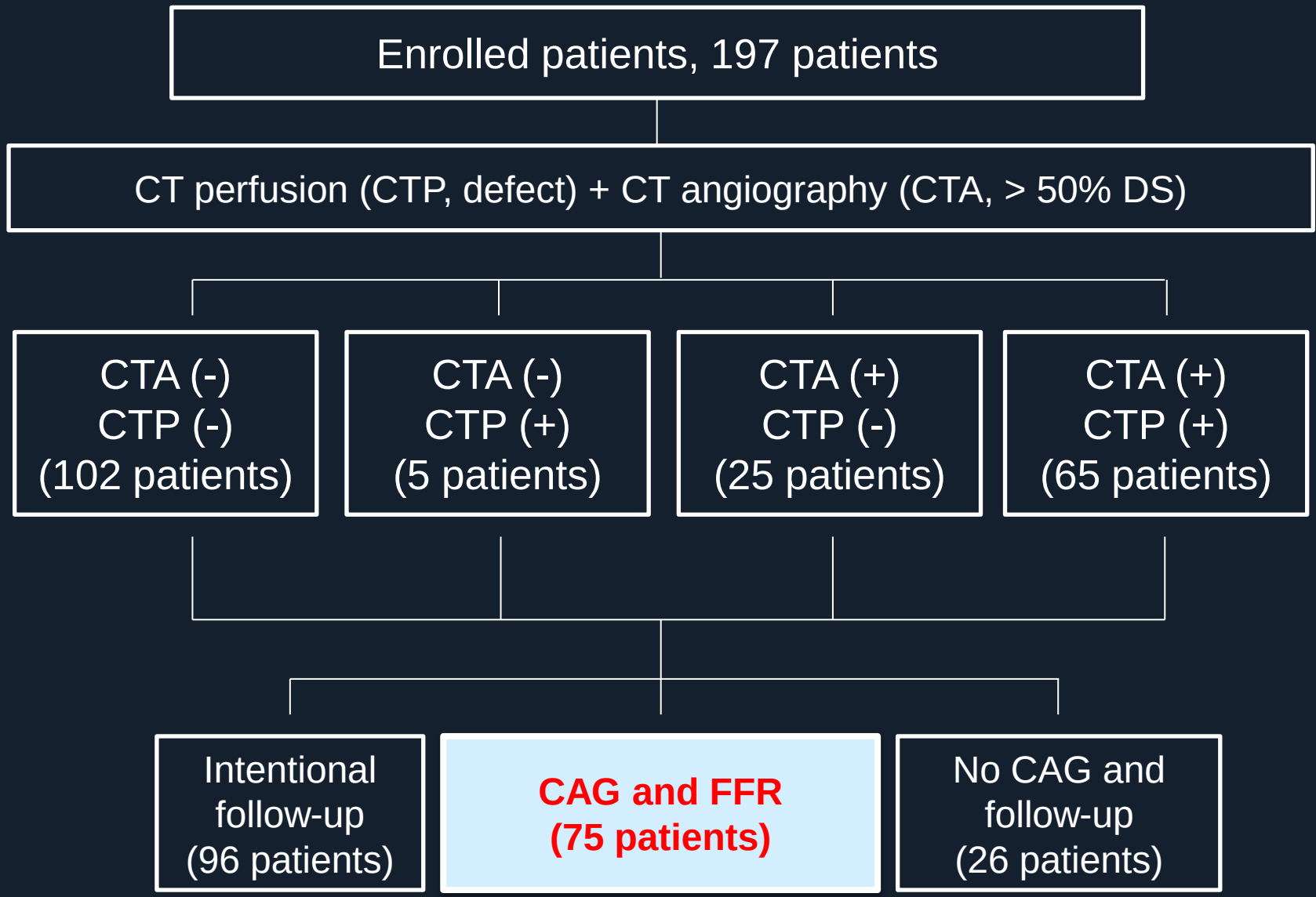






FFR: 0.72
(pre-adenosine)

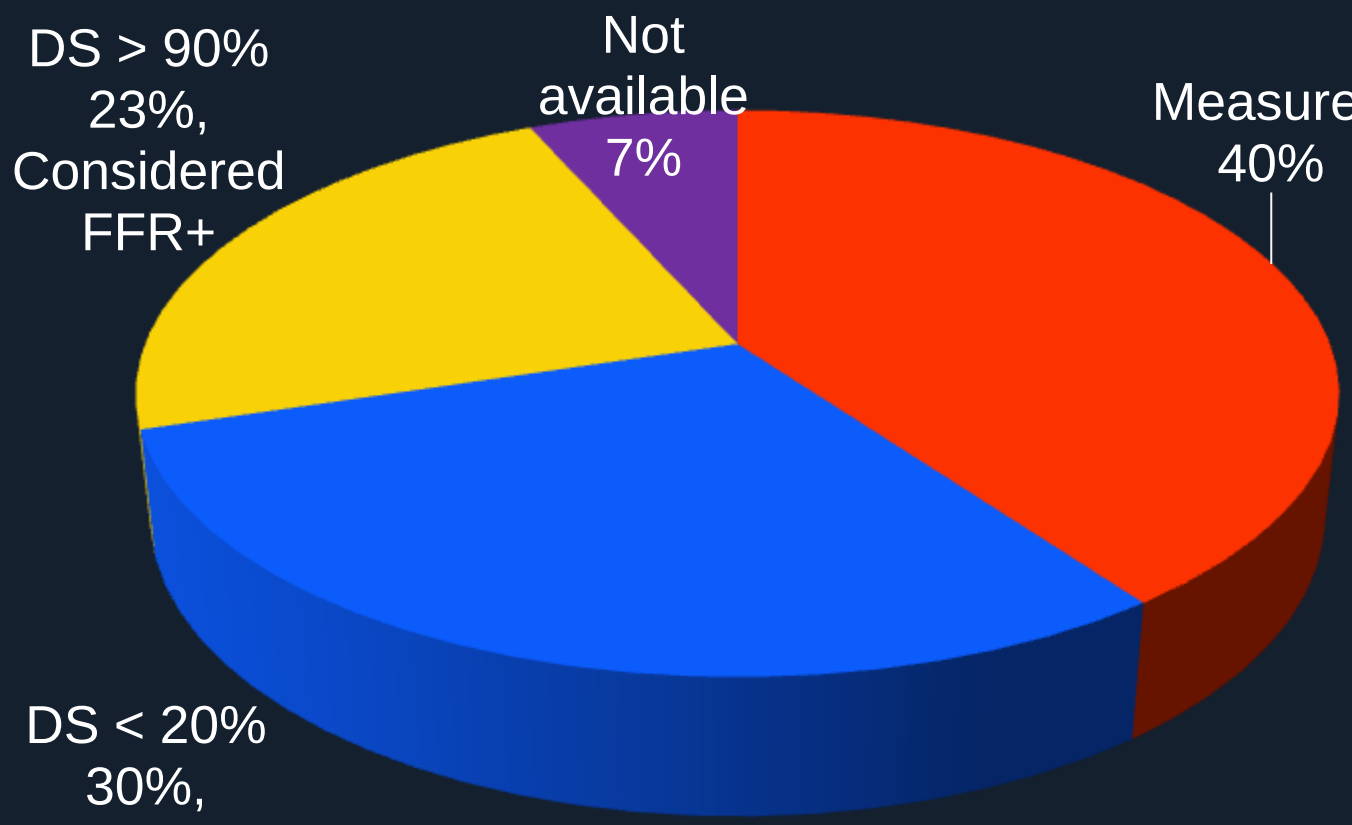
CTP Analysis in AMC



Yang DH, Kim YH et al. JACC Imaging (in revision)

Identification of Hemodynamically Significant Epicardial Artery

Of the 225 vessel territories,



FFR cutoff, 0.8

Baseline Clinical Characteristics

Patients	N=75
Age, yr	63.1±10.3
Male gender	126 (64)
BMI, kg/m^2	25.7 ± 3.1
Diabetes	44 (22)
Hyperlipidemia	31 (16)
Hypertension	98 (50)
Family history	12 (6)
Current smoking	31 (16)
Typical chest pain	94 (48)
Pre-test probability of CAD	
Low (< 10%)	3 (2)
Intermediate (10-90%)	107 (54)
High (>90%)	87 (44)

Per-vessel Visual Assessment

	CTA, DS ≥ 50%		CTP, perfusion defect		QCA, DS ≥ 50%	
	Value	95% CI	Value	95% CI	Value	95% CI
Sensitivity,%	**99**	94, 100	**80**	70, 88	**86**	76, 92
Specificity,%	**73**	65, 81	**95**	90, 98	**91**	84, 95
PPV,%	**72**	63, 80	**92**	83, 97	**87**	78, 93
NPV,%	**99**	94, 100	**87**	81, 92	**90**	83, 94
Kappa statistic	0.68	0.59, 0.78	0.77	0.68, 0.86	0.77	0.69, 0.86
Accuracy	84		89		88	

Visual Assessment: CTP or CTA

	CTP	CTA or CTP	
	Values	Value	95% CI
Sensitivity,%	**80**	**100**	96, 100
Specificity,%	**95**	**73**	64, 80
PPV,%	**92**	**71**	63, 80
NPV,%	**87**	**100**	96, 100
Kappa statistic	0.77	0.68	0.59, 0.78
Accuracy	89	83	

Subgroups

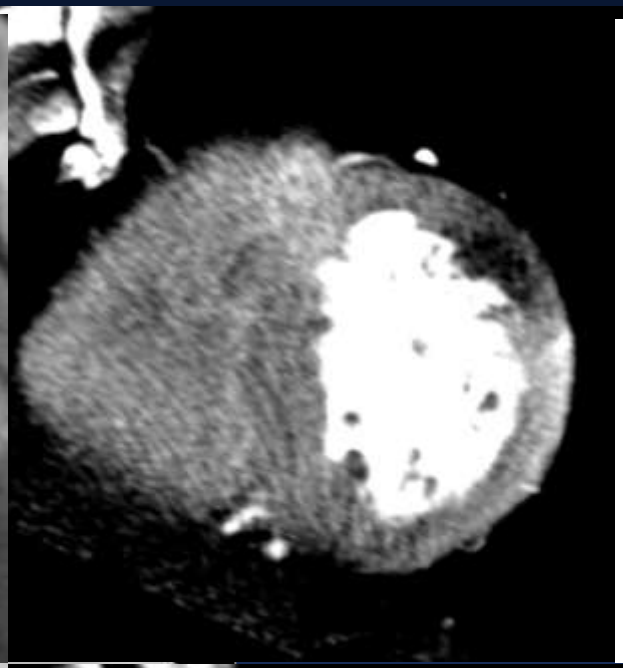
	All patients (N=210)		**High calcium** score >400 (N=63)		**Multivessel** (N=54)	
Per vessel	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
CTP	80	95	**85**	**100**	**76**	**91**
CTA	99	73	100	50	100	45
CTP or CTA	100	73	100	50	100	45
CTP and CTA	90	89	94	87	89	82
QCA	86	91	87	83	84	73

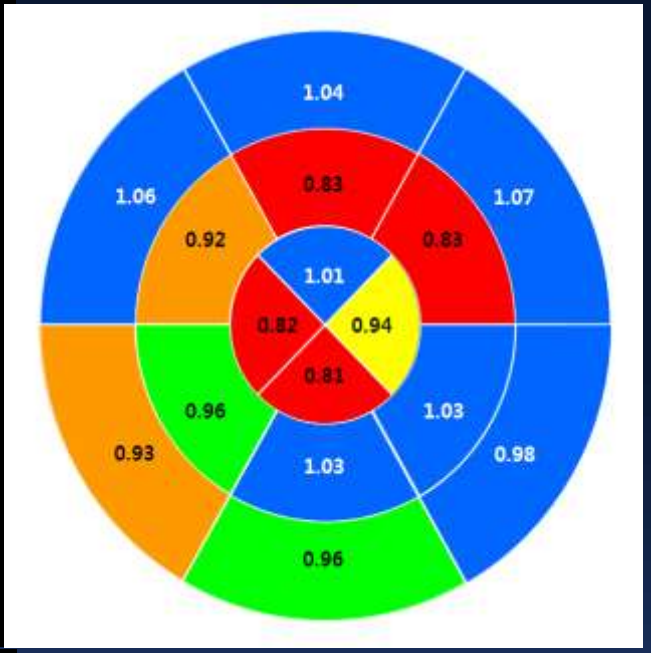
Quantitative Assessment

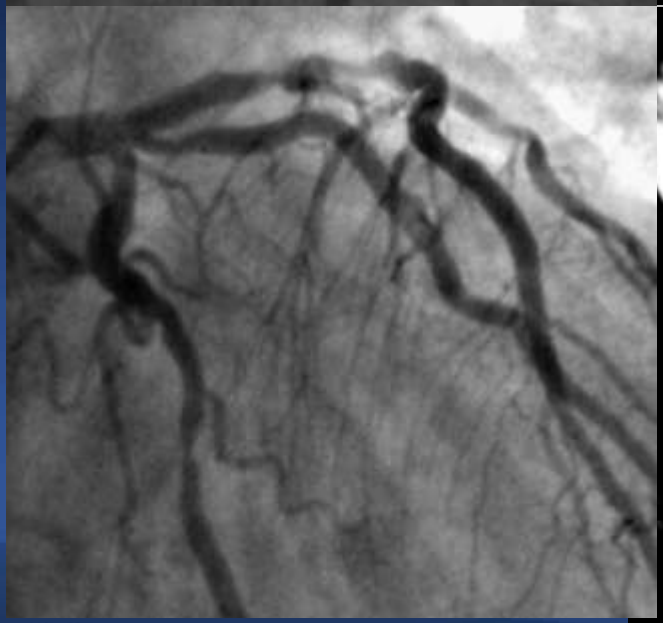
	AUC	Cut Off	Sensitivity	Specificity
TPR	**0.759**	0.98	**75**	**71**
$Density_{stress}$	0.687	102.1	**77**	**56**
$Density_{rest}$	0.559	113.9	**65**	**51**
MPRI	0.691	-4.0	**67**	**62**
Combined quantitative results (TPR, $Density_{stress}$, MPRI)	0.746	-	**63**	**75**
Integration of qualitative and quantitative results	**0.878**	-	**89**	**73**

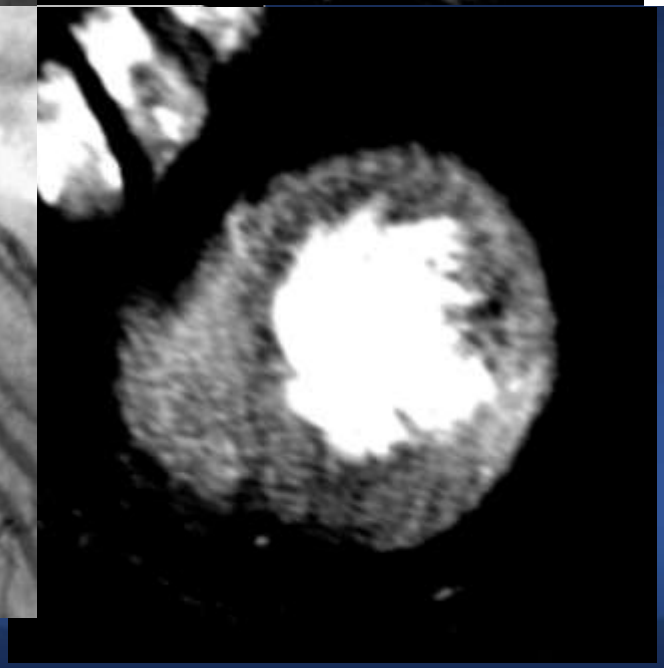
Quantitative Assessment: Multivessel

N=20	AUC	Cut Off	Sensitivity	Specificity
TPR	**0.7209**	0.97	**71**	**67**
$Density_{stress}$	0.6260	113.56	**59**	**67**
$Density_{rest}$	0.6423	109.19	**51**	**67**
MPRI	0.6243	5	**73**	**56**
Combined quantitative results (TPR, $Density_{stress}$, MPRI)	0.7433	-	**68**	**78**
Integration of qualitative and quantitative results	**0.8266**	**-**	**81**	**89**



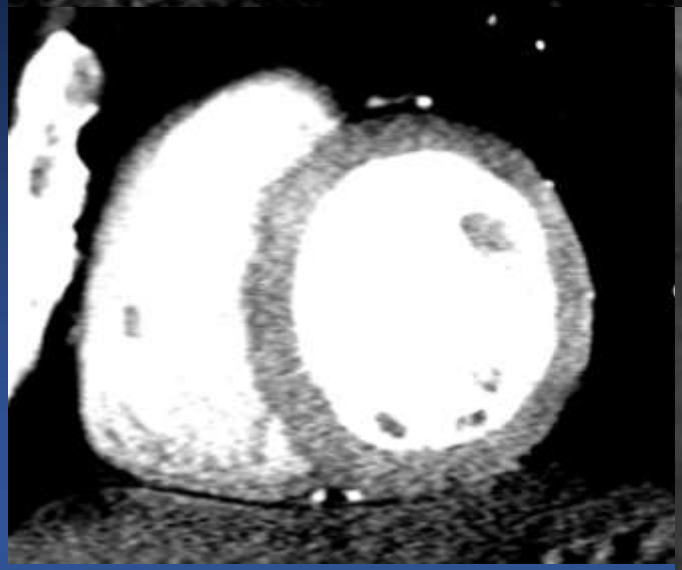


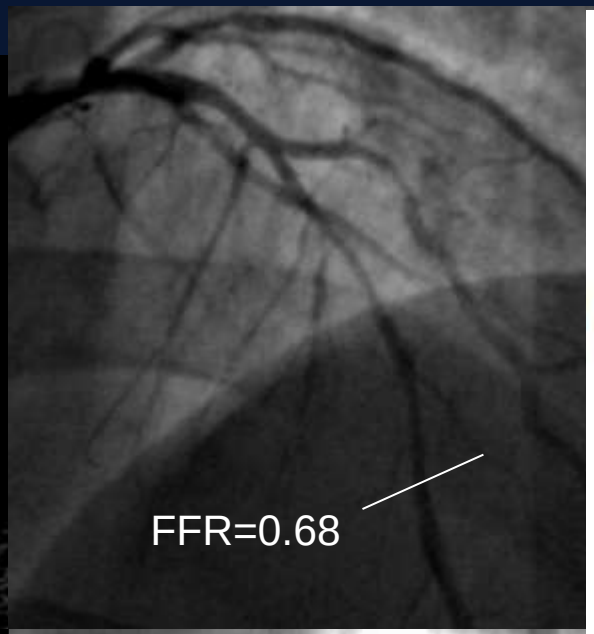


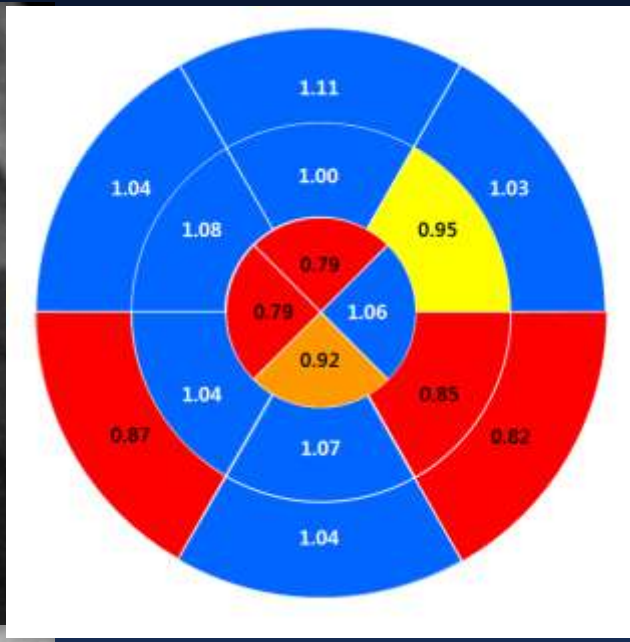


TPR map

- **LAD**
- **LCX**

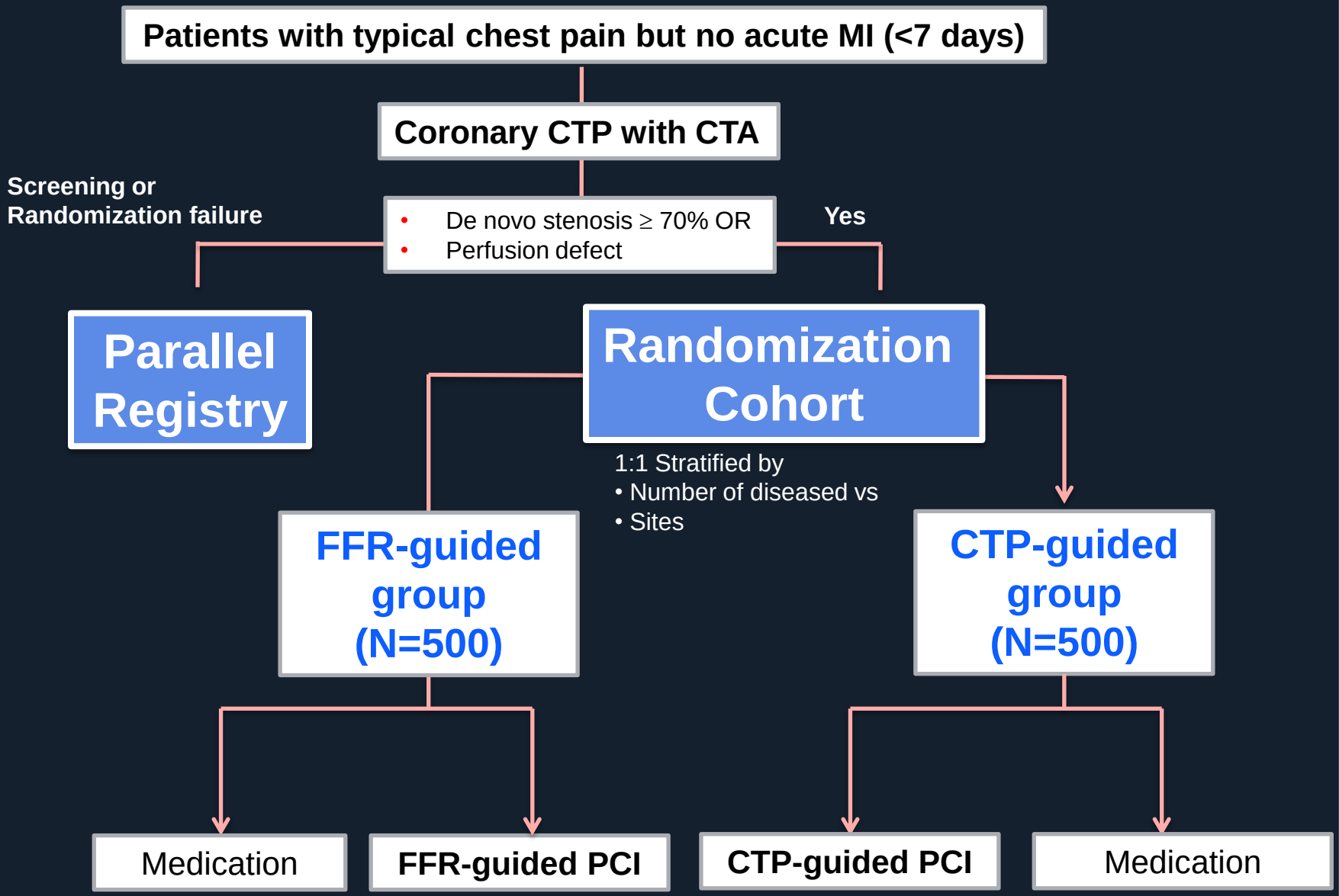



FFR=0.68


1.11
1.00
1.03
1.04
1.08
0.95
0.79
0.79
1.06
0.92
1.04
0.85
0.87
1.07
0.82
1.04

TPR map

PERFUSE RCT


Patients with typical chest pain but no acute MI (<7 days)
Coronary CTP with CTA
Screening or Randomization failure
• De novo stenosis ≥ 70% OR
• Perfusion defect
Yes
Parallel Registry
Randomization Cohort
1:1 Stratified by
• Number of diseased vs
• Sites
FFR-guided group (N=500)
CTP-guided group (N=500)
Medication
FFR-guided PCI
CTP-guided PCI
Medication

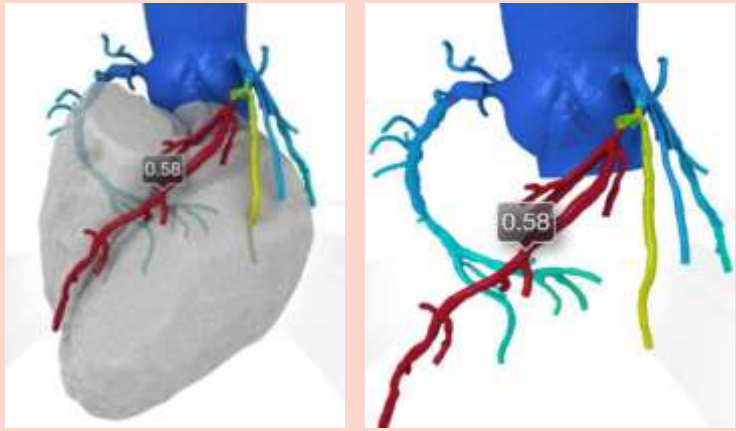
FFR_{CT} Imaging

CT Perfusion (CTP)

Pros
- ✓ Direct view of myocardium
- ✓ Easy to perform
- ✓ No special software

Cons
- ✓ Radiation dose concern (two scans; stress + rest)
- ✓ Requirement of adenosine

Computational fluid dynamics simulation

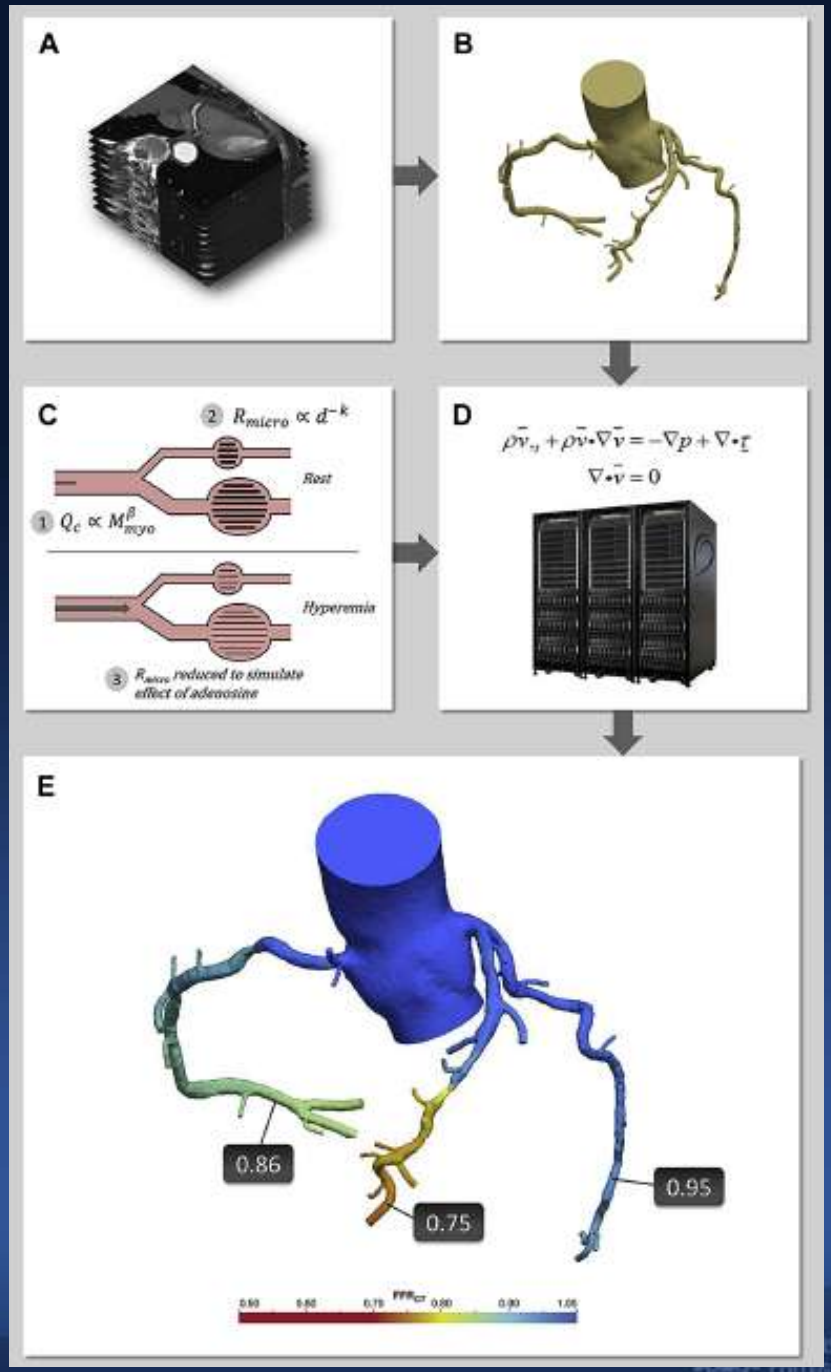


FFR-CT

Pros
- ✓ No additional scan
- ✓ No requirement of adenosine

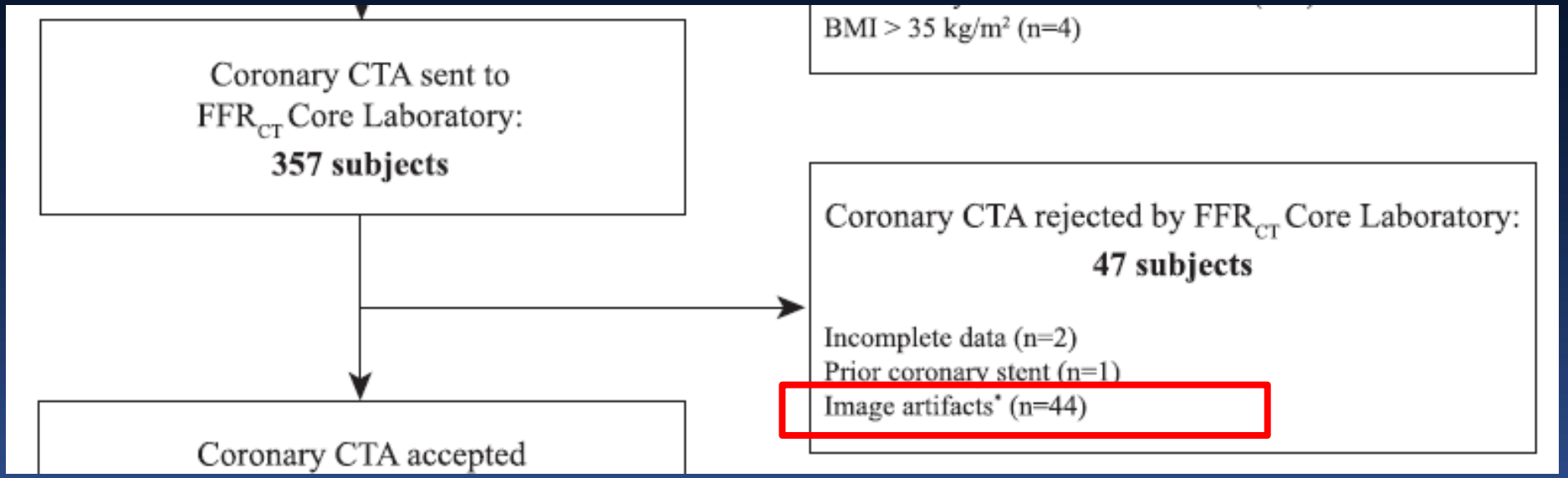
Cons
- ✓ Indirect view of ischemia
- ✓ Need supercomputer
- ✓ No information on perfusion.

HeartFlow FFT_{CT}



Nørgaard BL et al.
J Am Coll Cardiol
2014;63:1145

NXT Trial



Nørgaard BL et al. J Am Coll Cardiol 2014;63:1145

Siemens FFR-CT (cFFR) Analysis in AMC

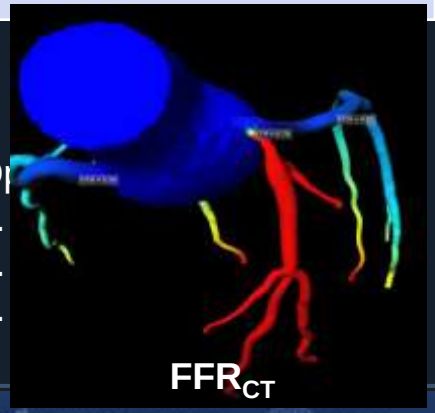
25 minutes
using dual-source 126 ch. CT (Siemens)

10 min. interval

Calcium scoring	Adenosine infusion	Stress perfusion	Sublingual NTG	Rest perfusion (CTA)
Scan range	4 min. 30 sec	Retrospective ECG-gating	2 min. before	Retr ctive EC ating

Option
1. **Static perfusion**
2. Dynamic perfusion

Op
1.
2.
3.



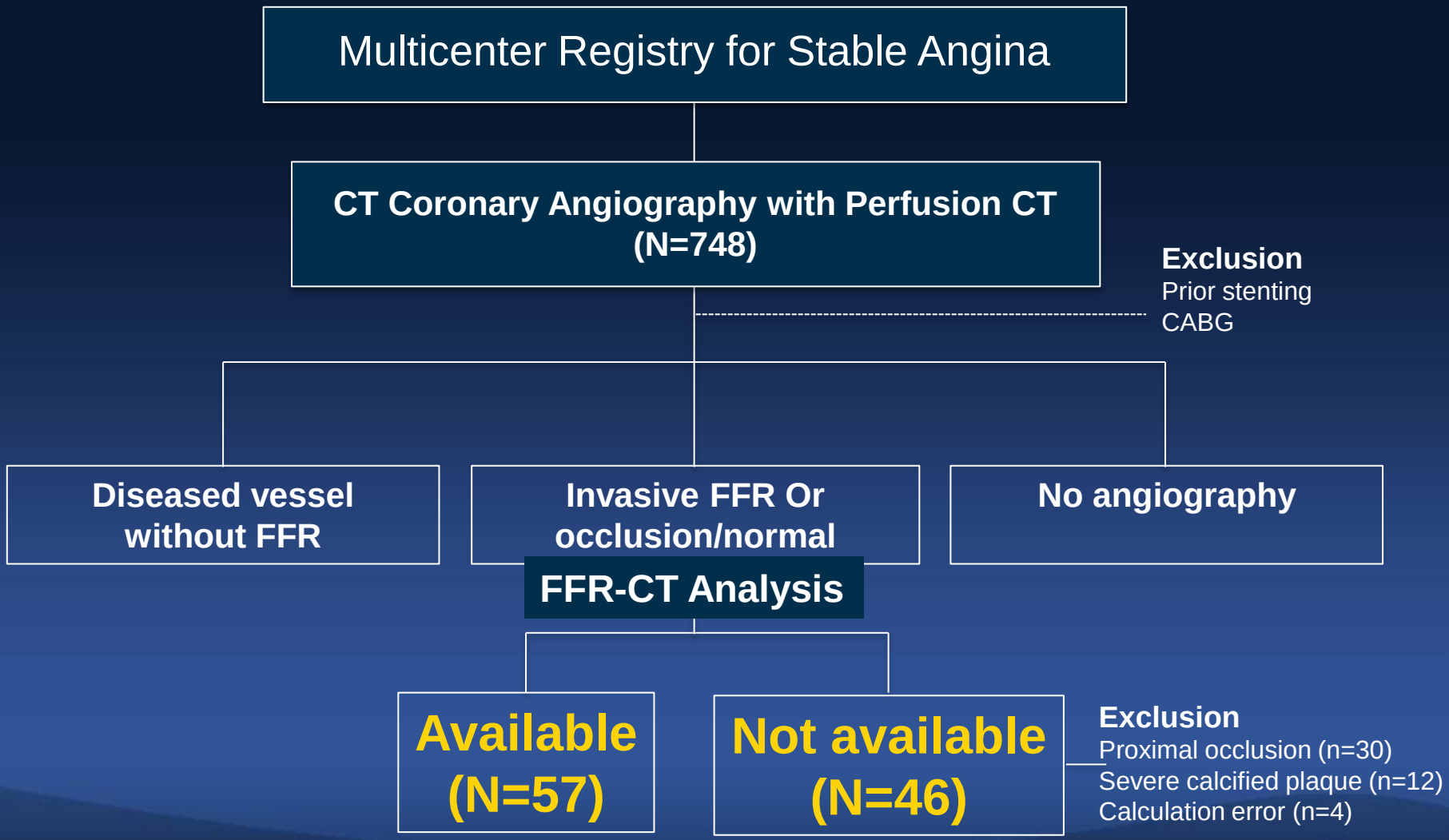
CT-Derived Fractional Flow Reserve

New Modality to Detect Ischemia

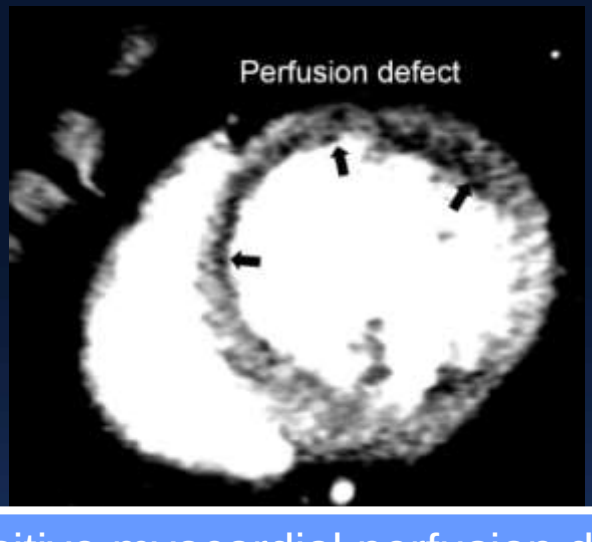
	HeartFlow	Siemens
Published Data	Yes (DISCOVER-FLOW, DeFACTO)	No
Commercial version	Available	Not available
Supercomputer requirement	Yes	No : Stand-Alone workstation
Installing at local site	Impossible	Possible
Processing time per case	6 hours*	0.5 – 1 hours

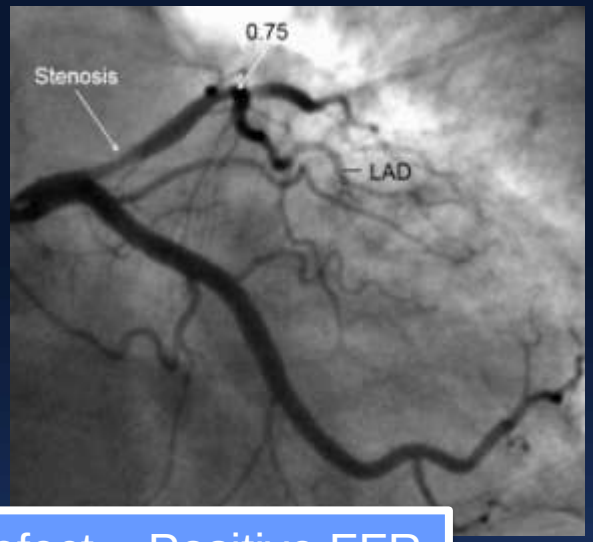
* JAMA 2012 308:1237-1245

Siemens cFFR Analysis Compared with CTP and FFR

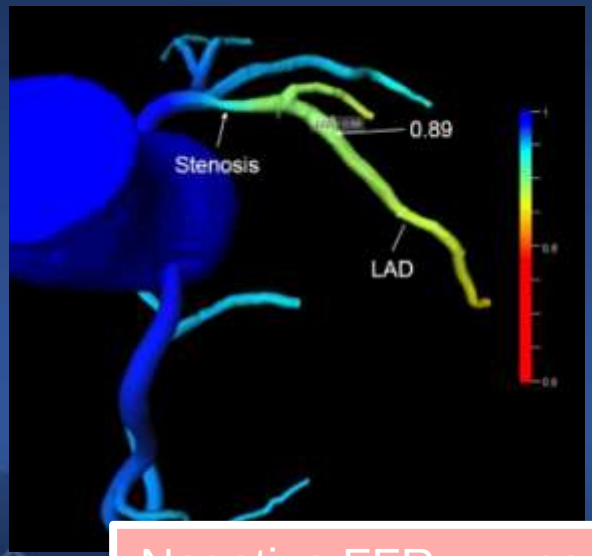


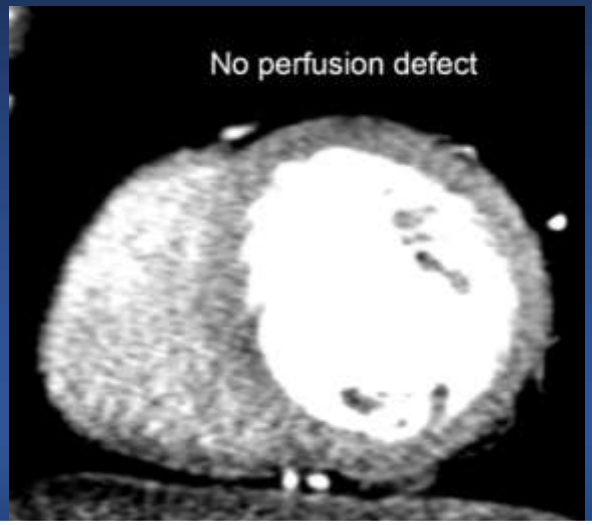
Cases

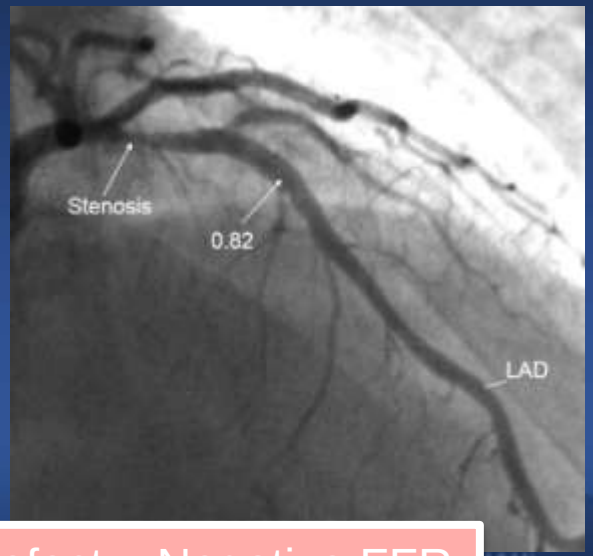




Positive FFR_{CT} – positive myocardial perfusion defect – Positive FFR

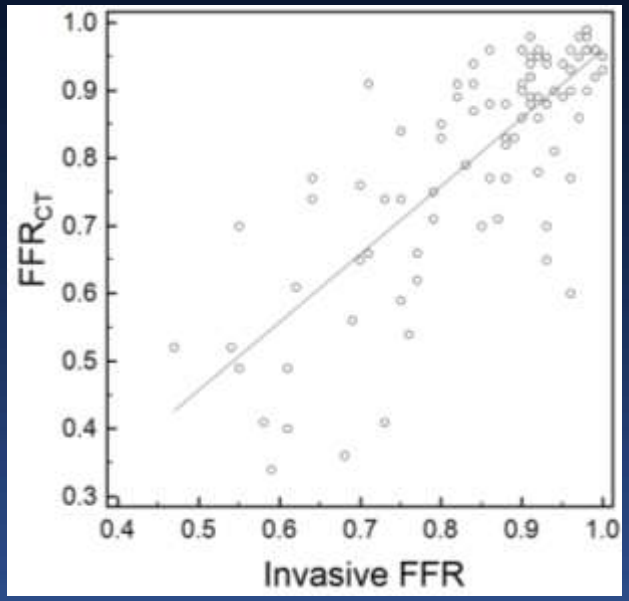


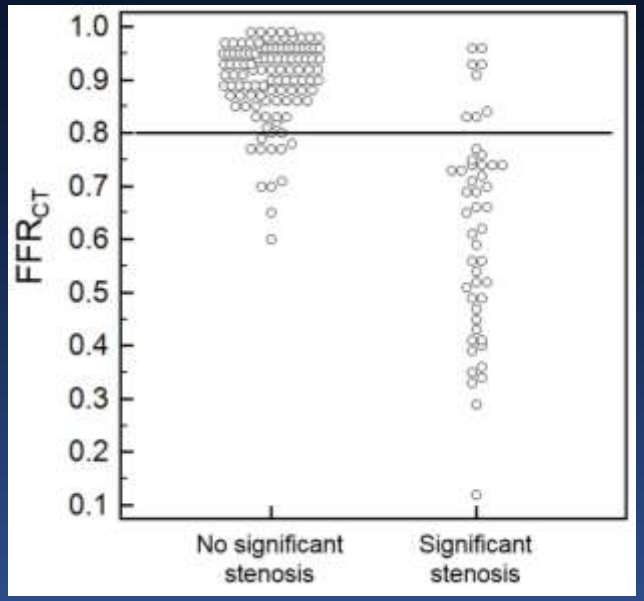


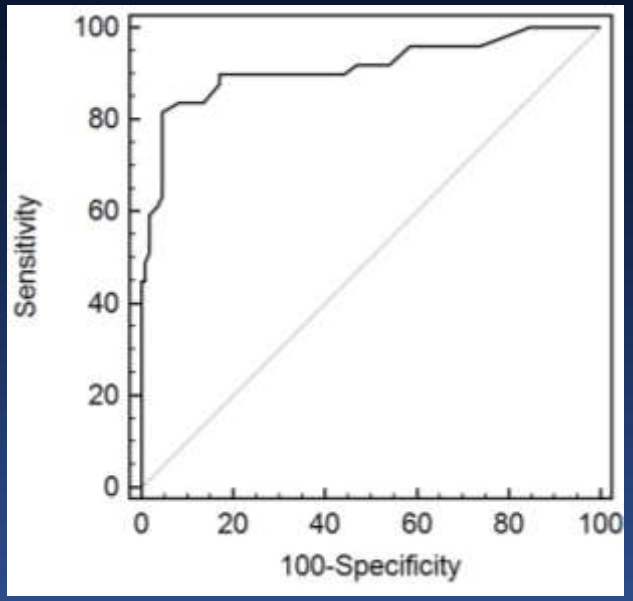


Negative FFR_{CT} – negative myocardial perfusion defect – Negative FFR

Siemens cFFR by
Compared with invasive FFR







R=0.7815
p < 0.001

Sensitivity 84%
Specificity 88%

AUC 0.913
p < 0.001

Conclusions

- With technology improvement, CT-based functional imaging become a new feasible method to detect myocardial ischemia.
- CTP showed a good diagnostic accuracy for detection of myocardial ischemia even in patients with severely calcified coronary lesions, which is hardly evaluated using CT angiography or CT-FFR.
- Further researches are required to improve the performance of CT-based ‘one-stop’ coronary imaging using CTA, CTP and CT-FFR.
- Ongoing RCT will provide the clinical relevancy of CTP in the diagnosis and treatment of stable coronary artery disease compared with invasive functional evaluation of FFR.

Thank you very much