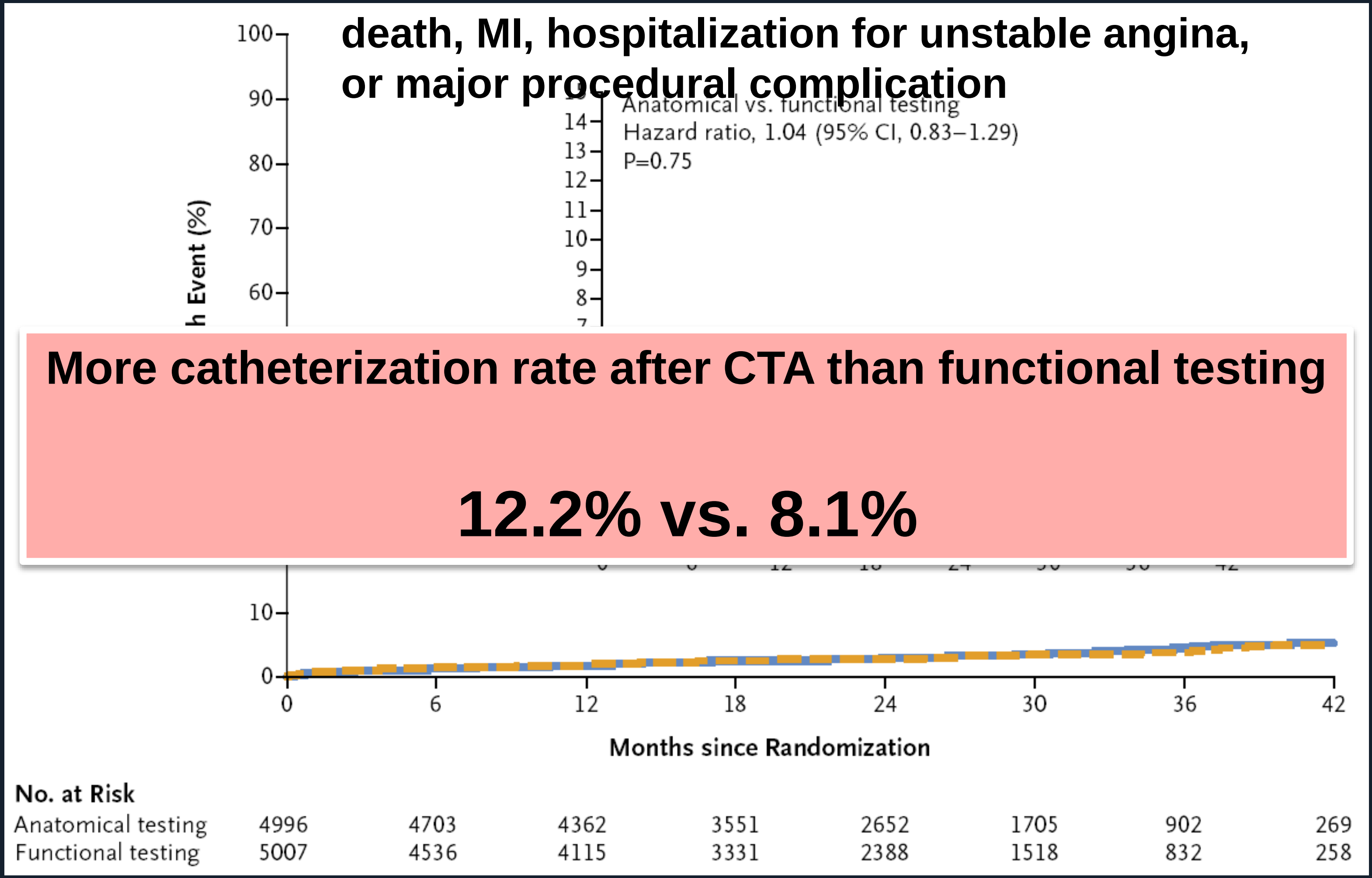
CT-based
Functional Coronary Imaging

Young-Hak Kim, MD, PhD

Heart Institute, University of Ulsan College of Medicine,
Asan Medical Center, Seoul, Korea

PROMISE Trial
Initial CTA vs. Functional Test

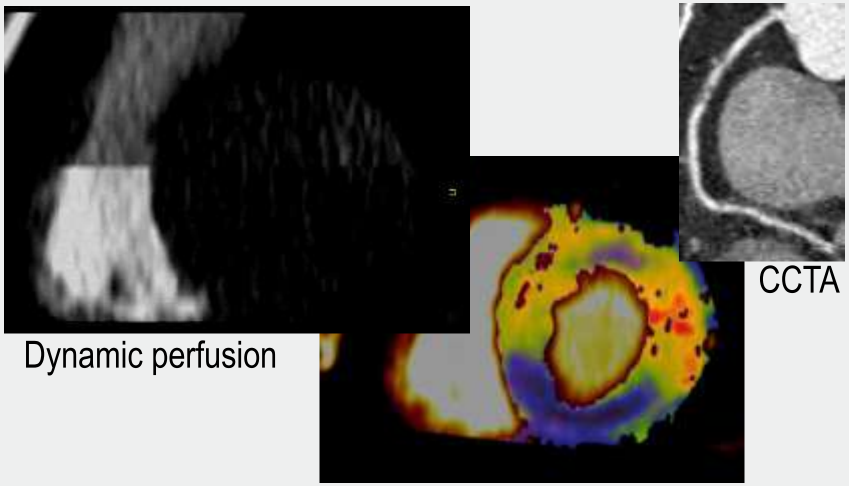


More catheterization rate after CTA than functional testing

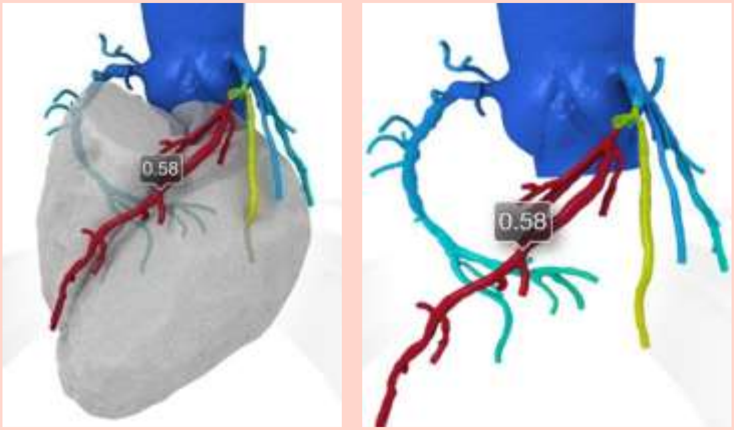
12.2% vs. 8.1%

Douglas PS et al. NEJM 2015, ACC 2015

CT-based Functional Imaging



Computational fluid dynamics simulation



CT Perfusion (CTP)

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

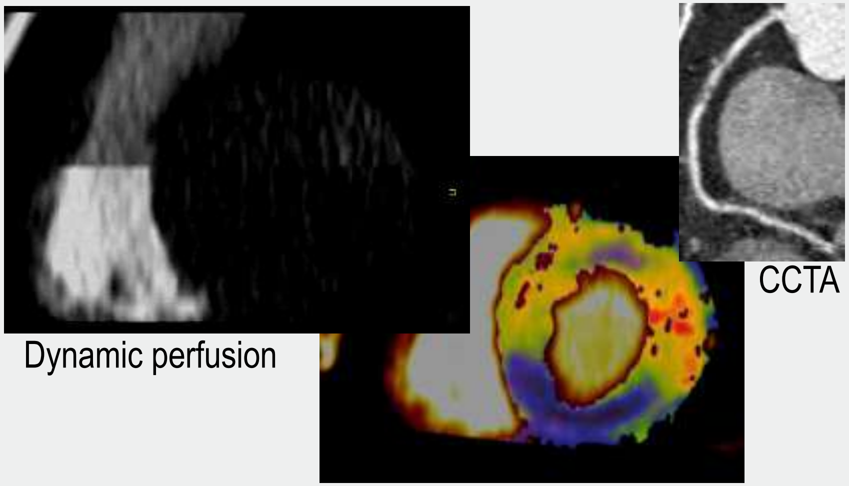
Cons
- ✓ Radiation dose concern (two scans; stress + rest)
- ✓ Requirement of adenosine

FFR-CT

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

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

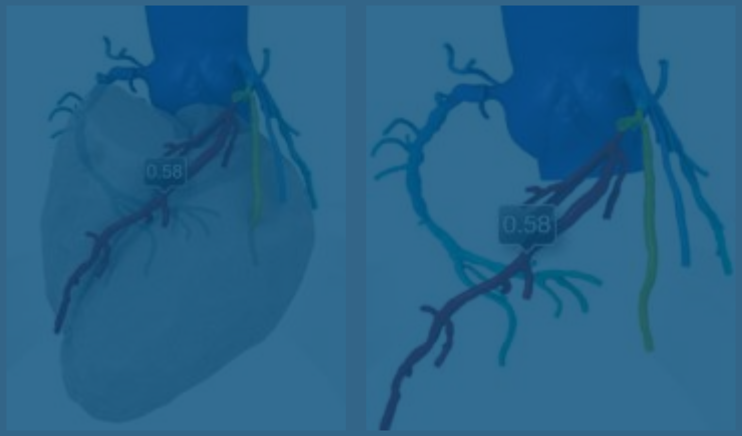
CT-based Functional Imaging



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.

CTP Protocol in AMC

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

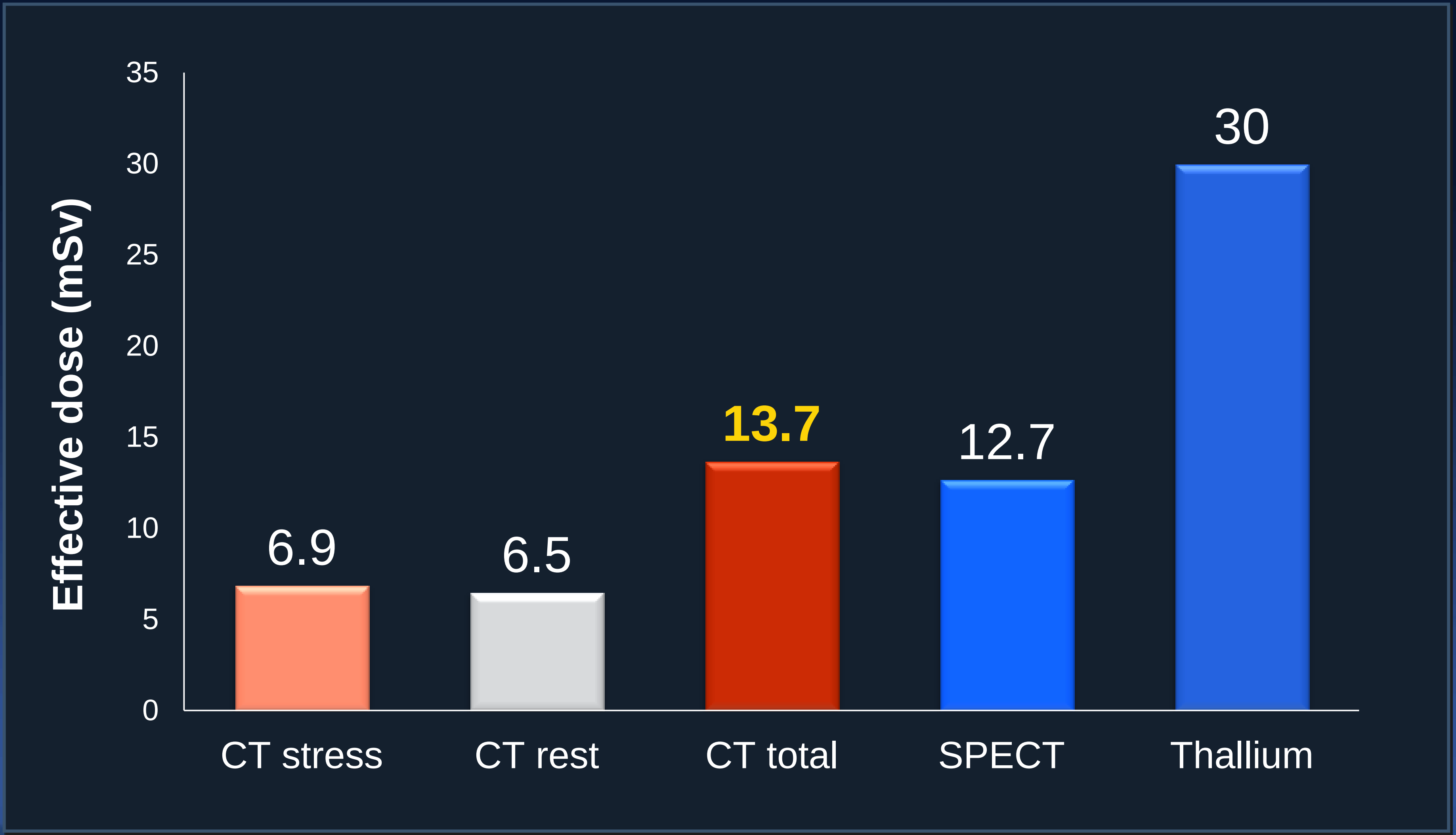
10 min. interval

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

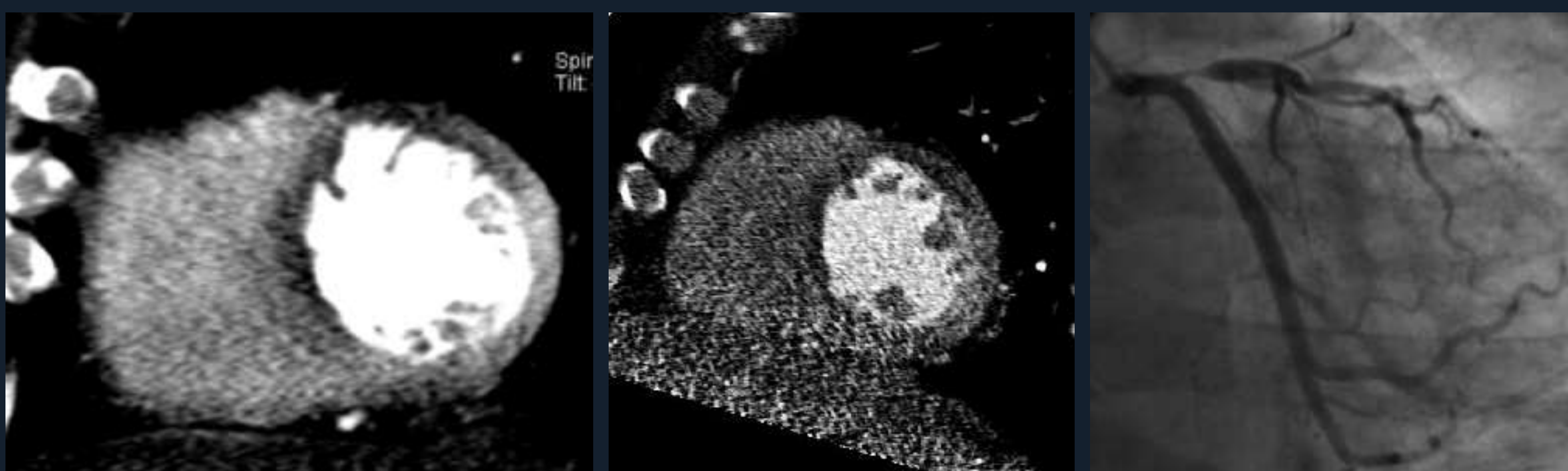


SPECT, Blankstein et al . 2009 JACC 54:1072-84

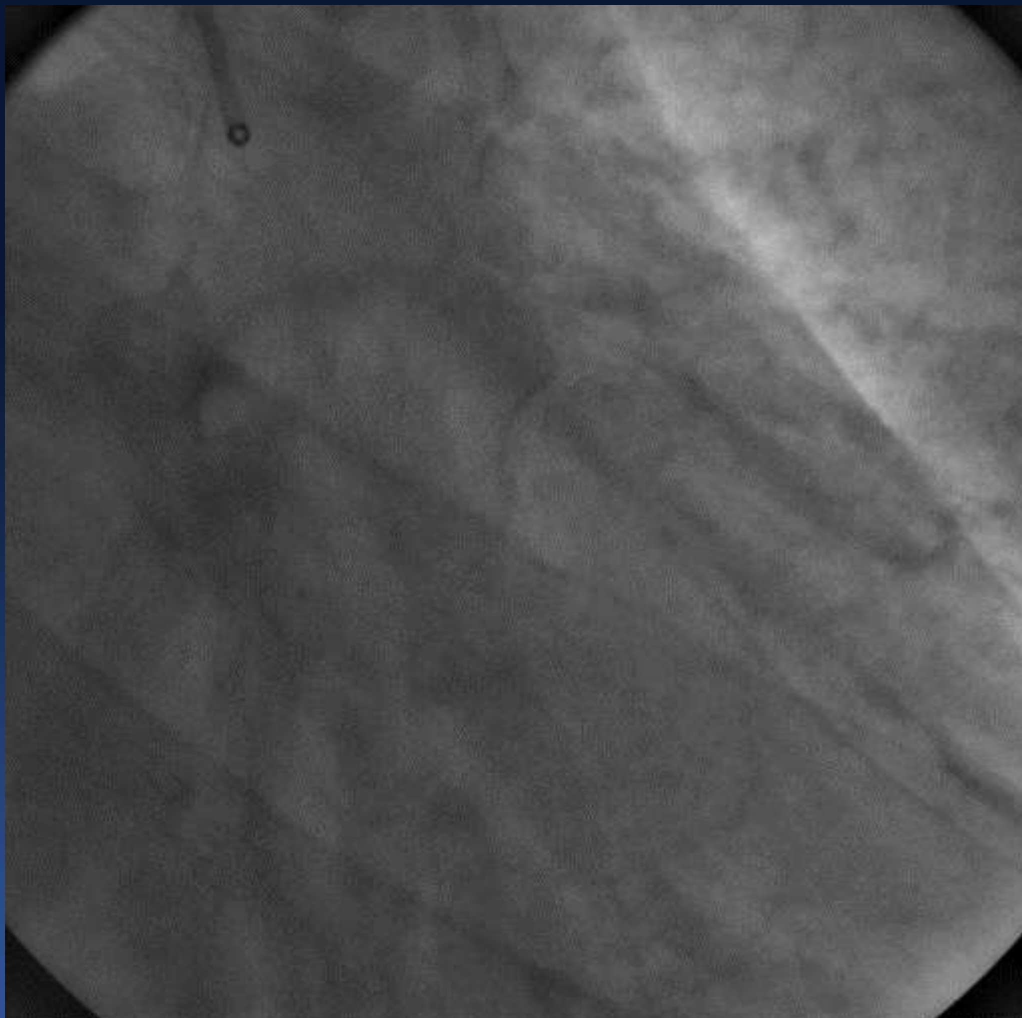
Visual Analysis of CTP

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

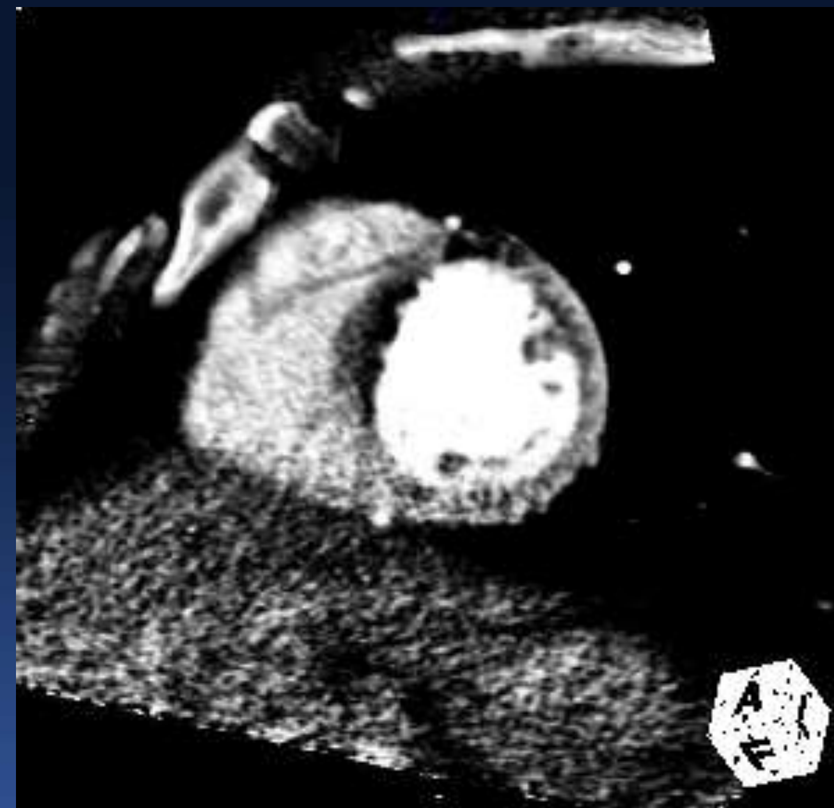
    DDx) Transient motion or beam-hardening artifact
  - **Wall motion abnormality (useful)**



Typical severe stenosis

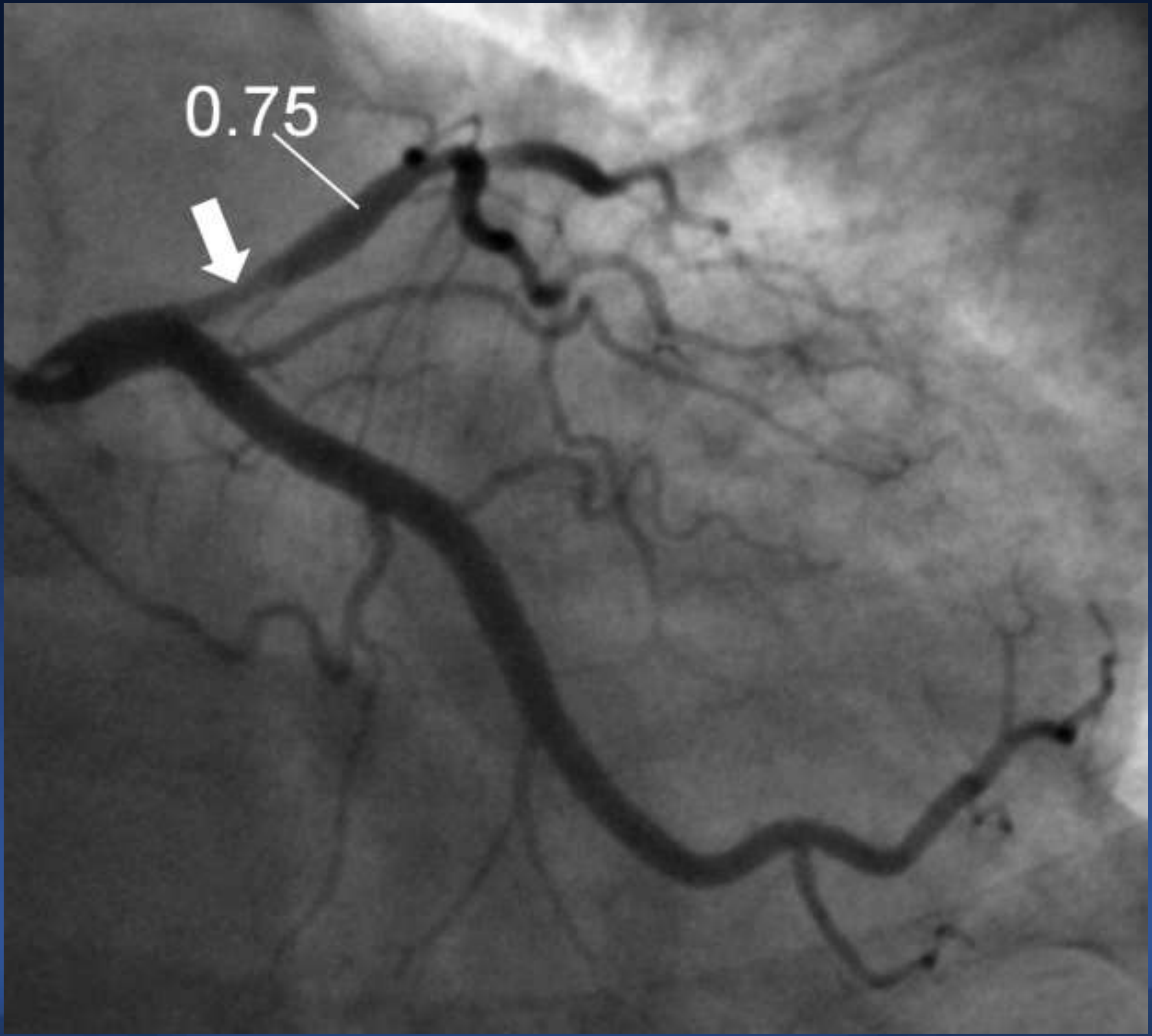


FFR 0.44 (pre-adenosine)

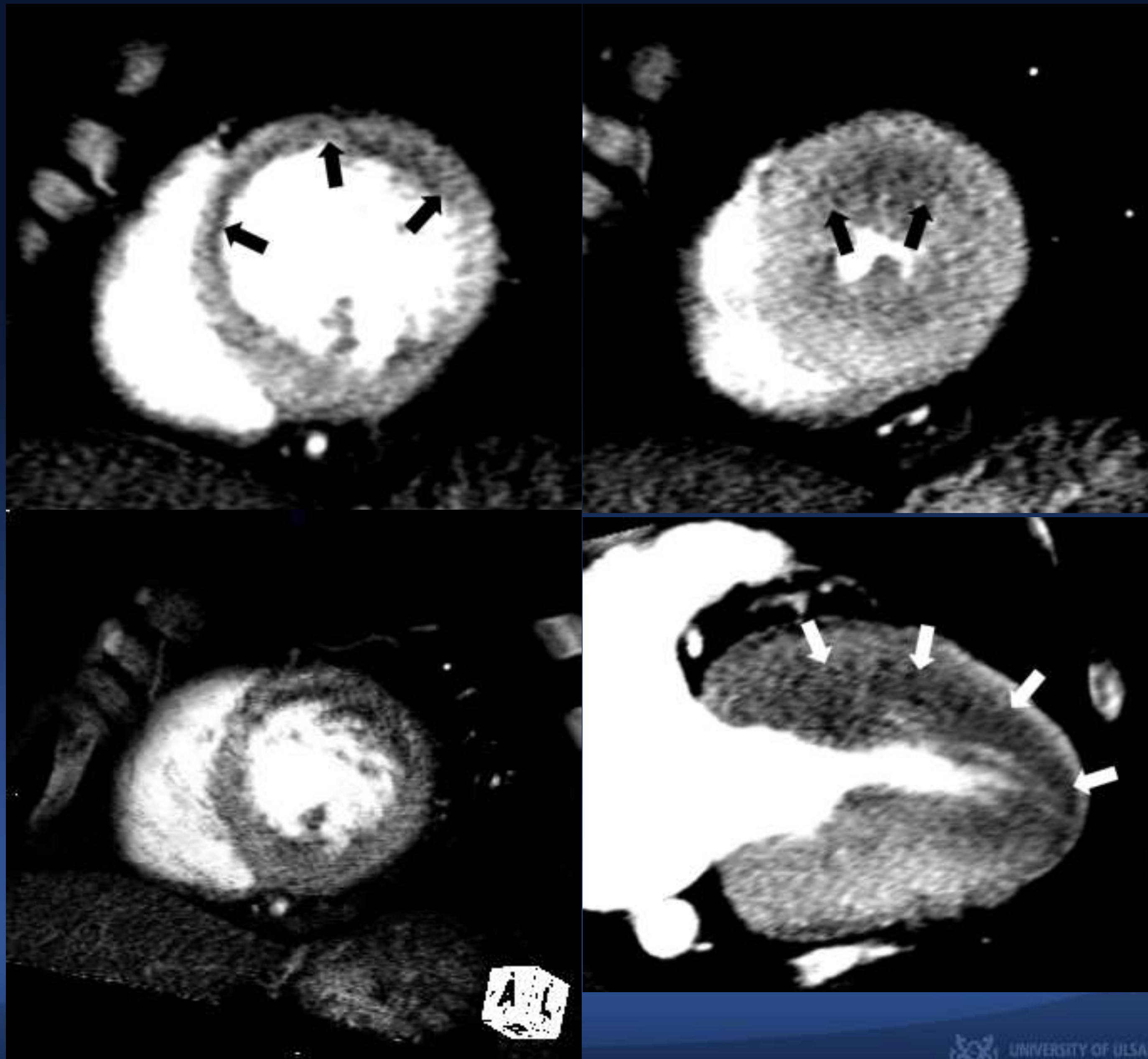


Cine

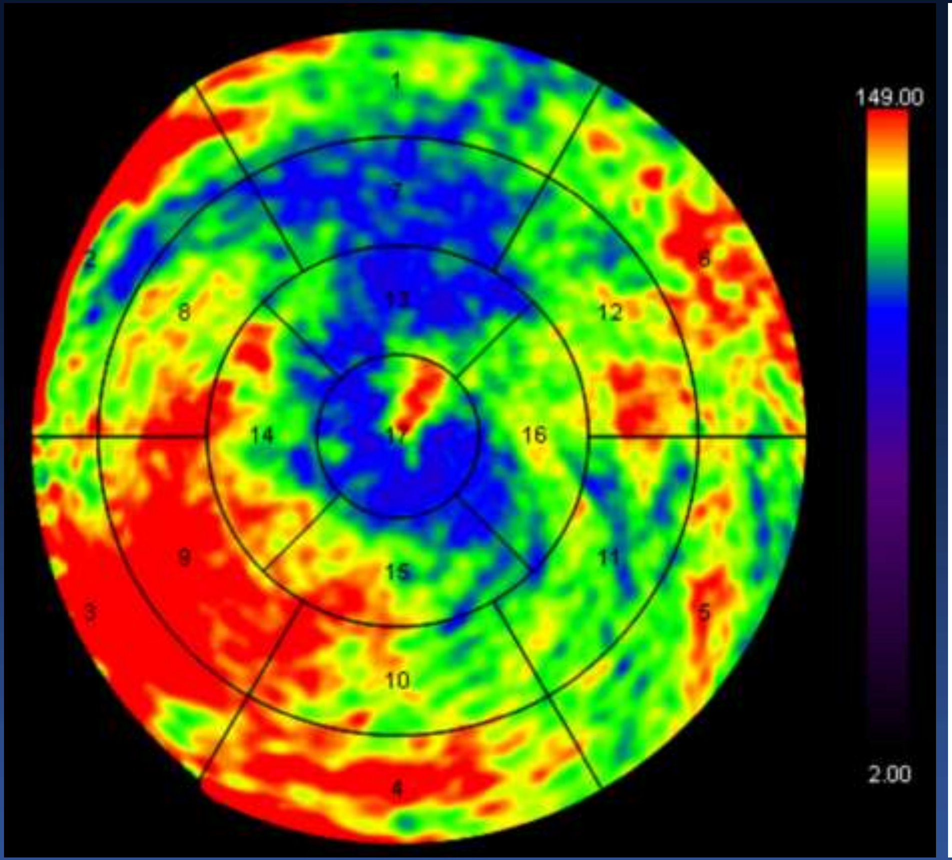
Intermediate stenosis

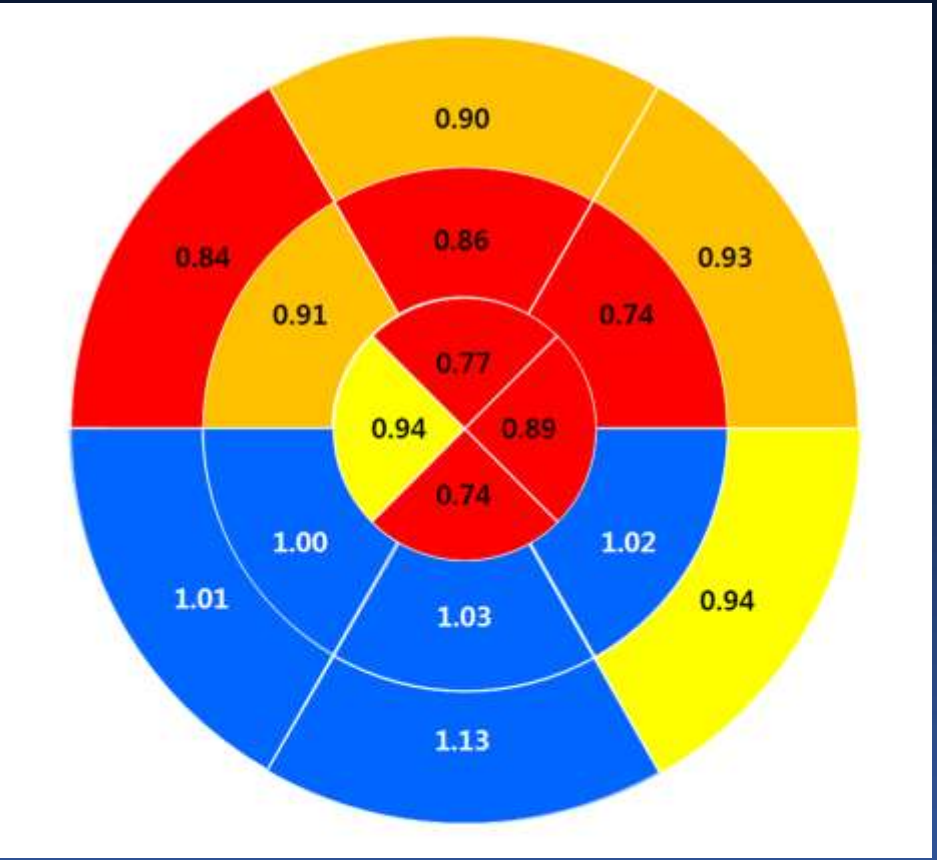


Intermediate stenosis



Quantitative Analysis





Density map
Syngo, Siemens

TPR map
Home-made, AMC

Early CTP Analysis in AMC

Enrolled patients, 197 patients

CT perfusion (CTP, defect) + CT angiography (CTA, > 50% DS)

CTA (-)
CTP (-)
(102 patients)

CTA (-)
CTP (+)
(5 patients)

CTA (+)
CTP (-)
(25 patients)

CTA (+)
CTP (+)
(65 patients)

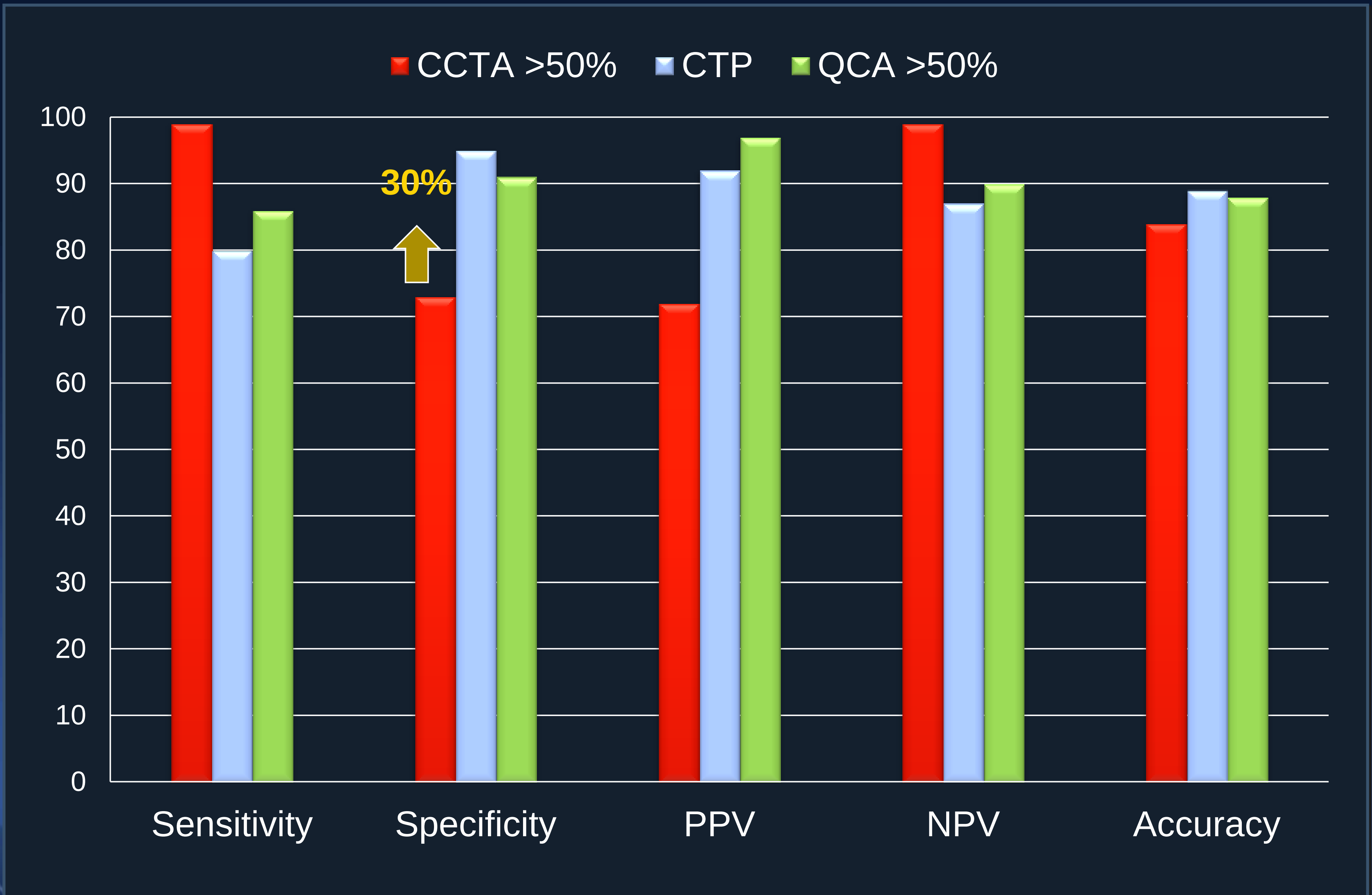
Intentional follow-up
(96 patients)

CAG and FFR
(75 patients)

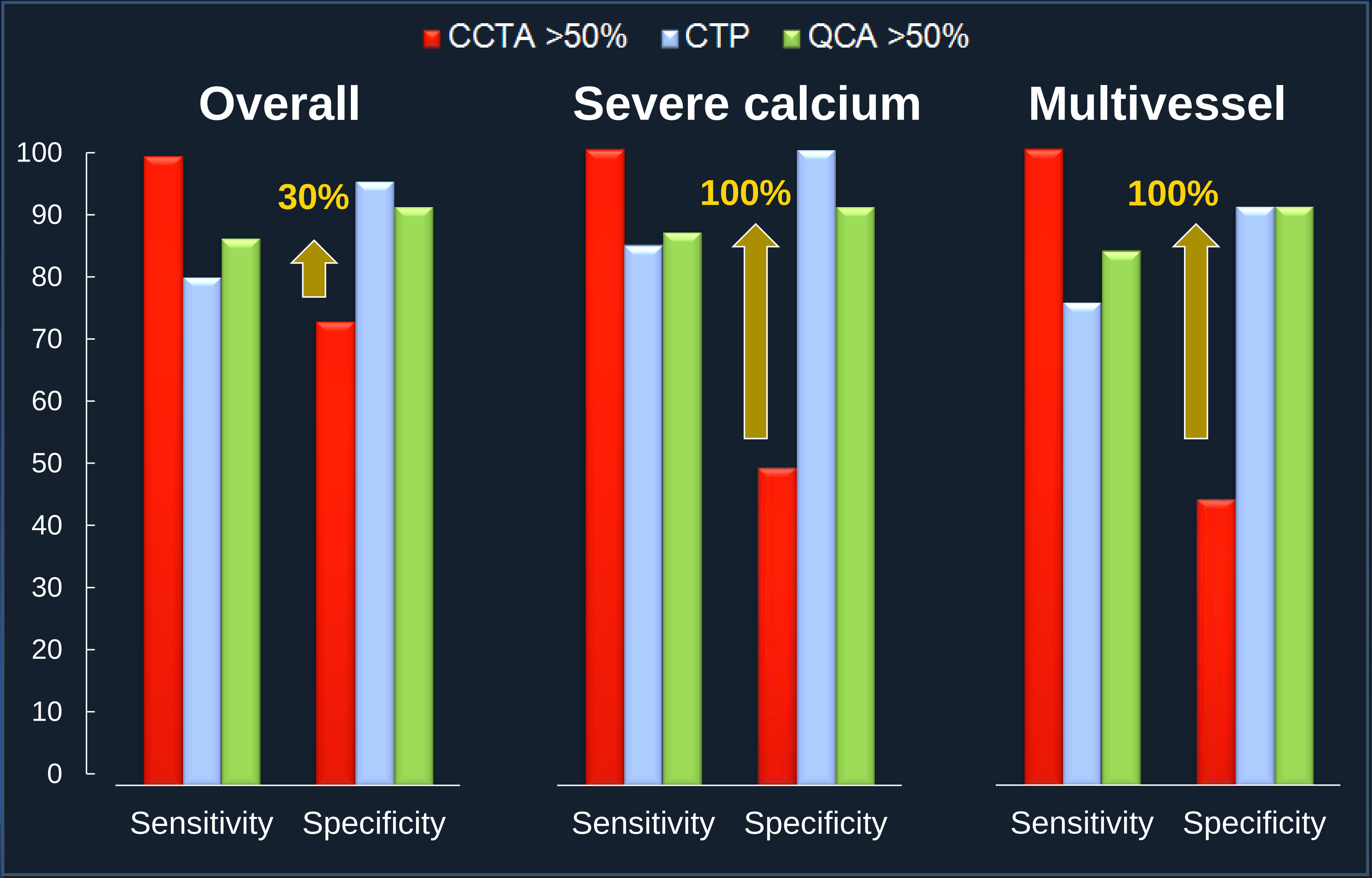
No CAG and follow-up
(26 patients)

Yang DH, Kim YH et al. Radiology 2015 (in print)

Visual Assessment Per-vessel

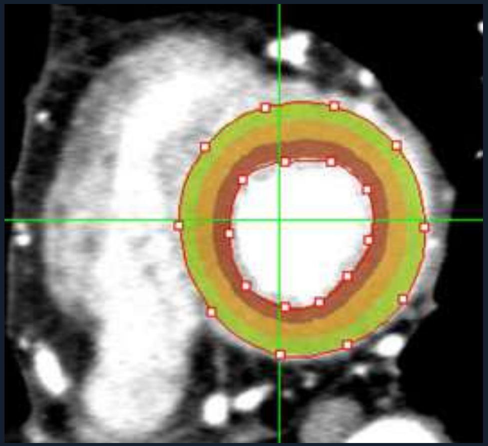


Subgroup Analysis



Quantitative Analysis

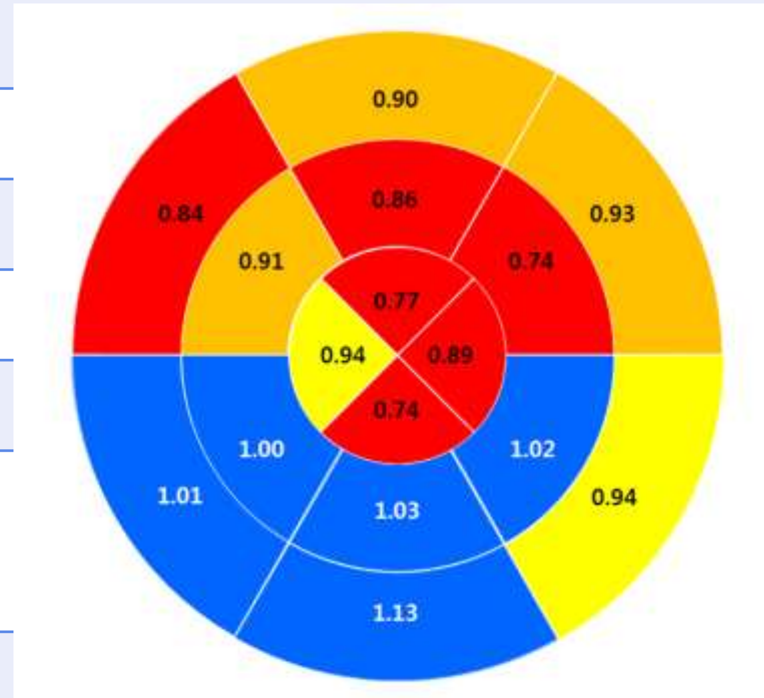
- Using customized software
  - Classification of whole myocardium into 16 segments and three layers



- Evaluation parameters
  - CT density on stress / rest CT
    - $\text{Density}_{\text{stress}}$ / $\text{Density}_{\text{rest}}$, HU
  - Transmural perfusion ratio (TPR)
    - $\text{Density}_{\text{endocardial}}/\text{Density}_{\text{epicardial}}$
  - Myocardial perfusion reserve index (MPRI),%
    - $(\text{Density}_{\text{stress}} - \text{Density}_{\text{rest}})/\text{Density}_{\text{rest}} \times 100$

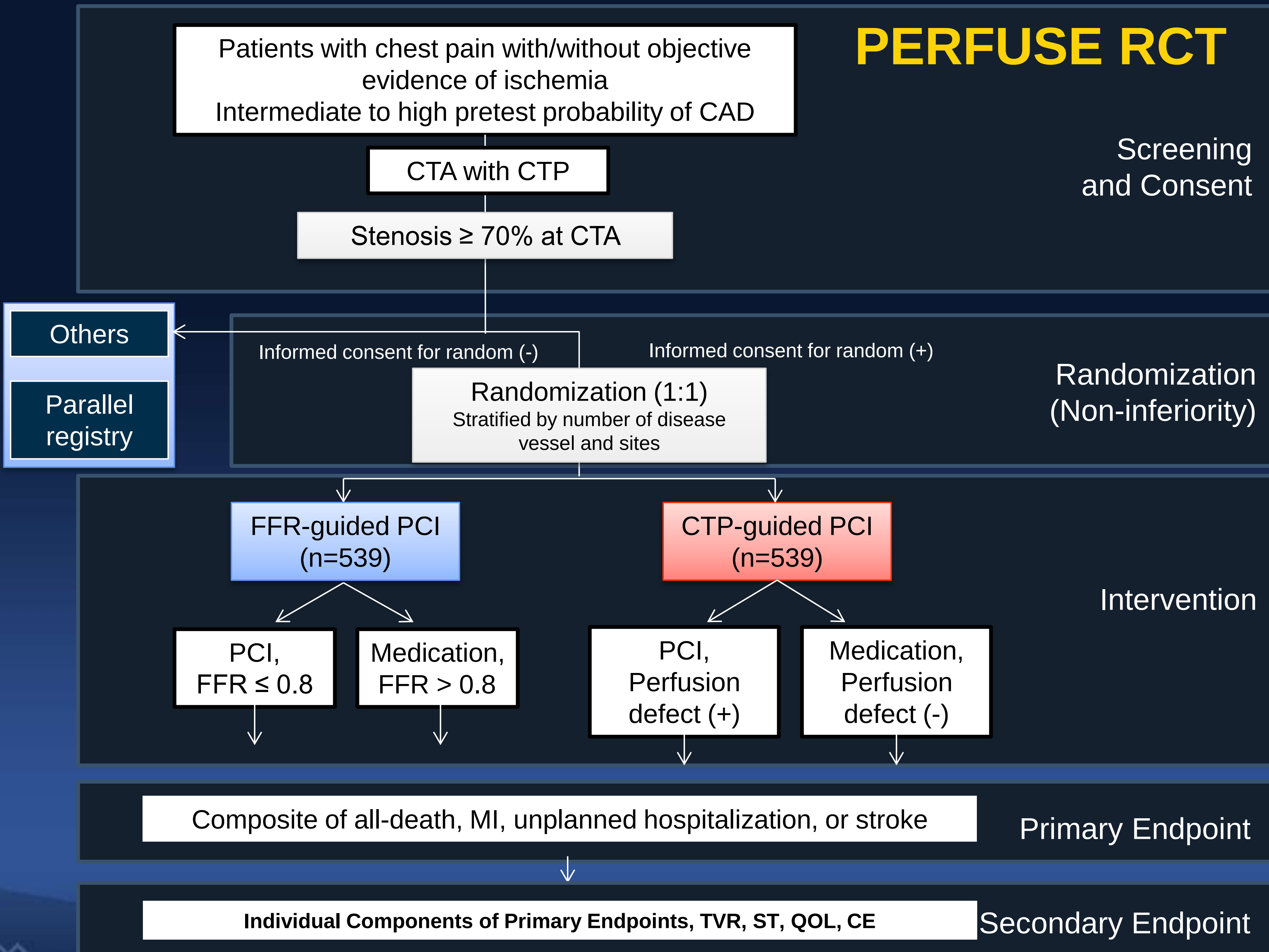
Quantitative Analysis

Parameter	AUC	Cut off	Sensitivity	Specificity
All patients (n=75)				
TPR				[illegible]1
$Density_{stress}$, HU				[illegible]6
$Density_{rest}$, HU				[illegible]1
MPRI, %				[illegible]2
Quantitative composite of TPR, $Density_{stress}$, or MPRI *				[illegible]5
Combination of visual and quantitative composite **	**0.878**	-	89	73



TPR: transmural perfusion ratio
MPRI: myocardial perfusion reserve index

PERFUSE RCT



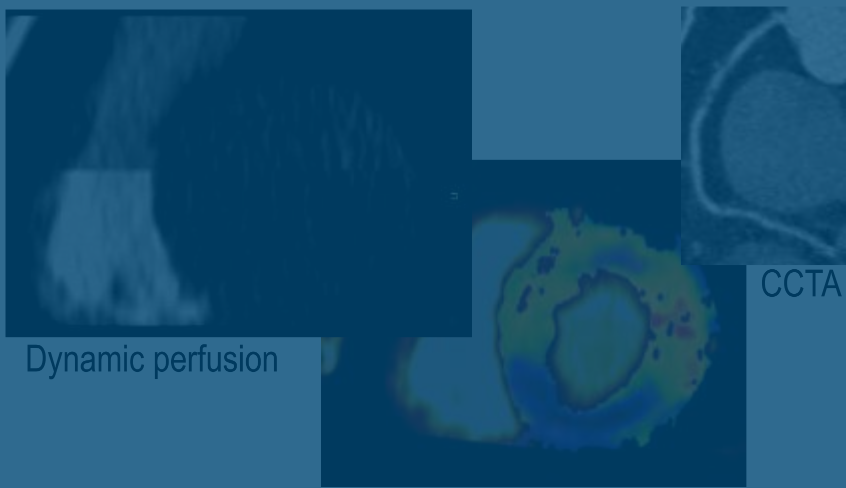
PI: Kim YH, MD, co-PI: Choi BW, MD

CTP-guided PCI

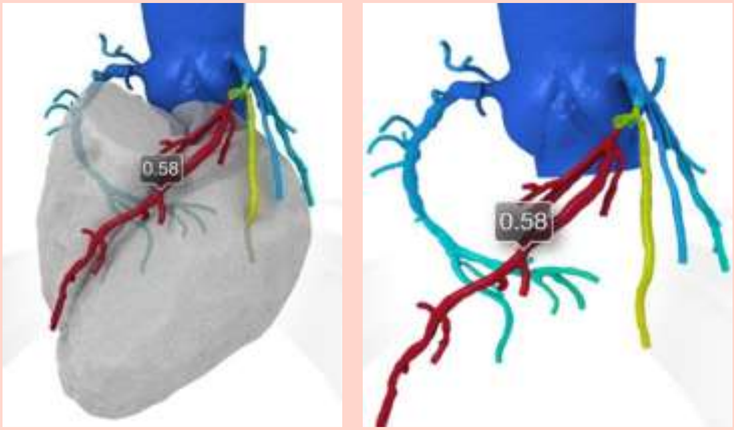
PD in LAD

No defect in LCX

CT-based Functional Imaging



Computational fluid dynamics simulation



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

FFR-CT

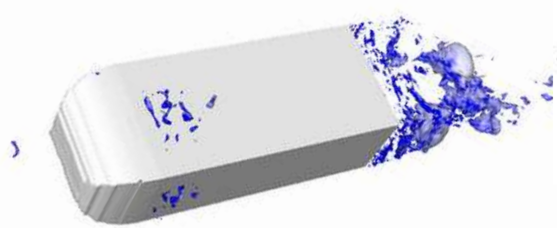
Pros
- ✓ No additional scan
- ✓ No requirement of adenosine

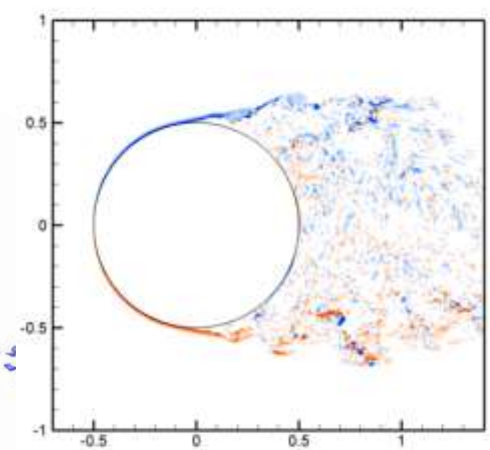
Cons
- ✓ Indirect view of ischemia
- ✓ Need supercomputer
- ✓ No information on perfusion.

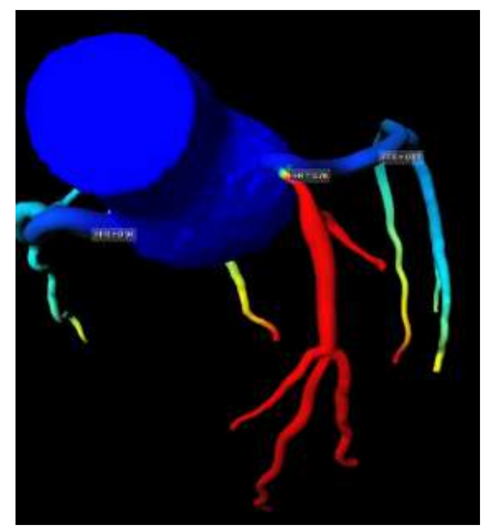
CT-Based FFR (cFFR): Principle

What is CFD?

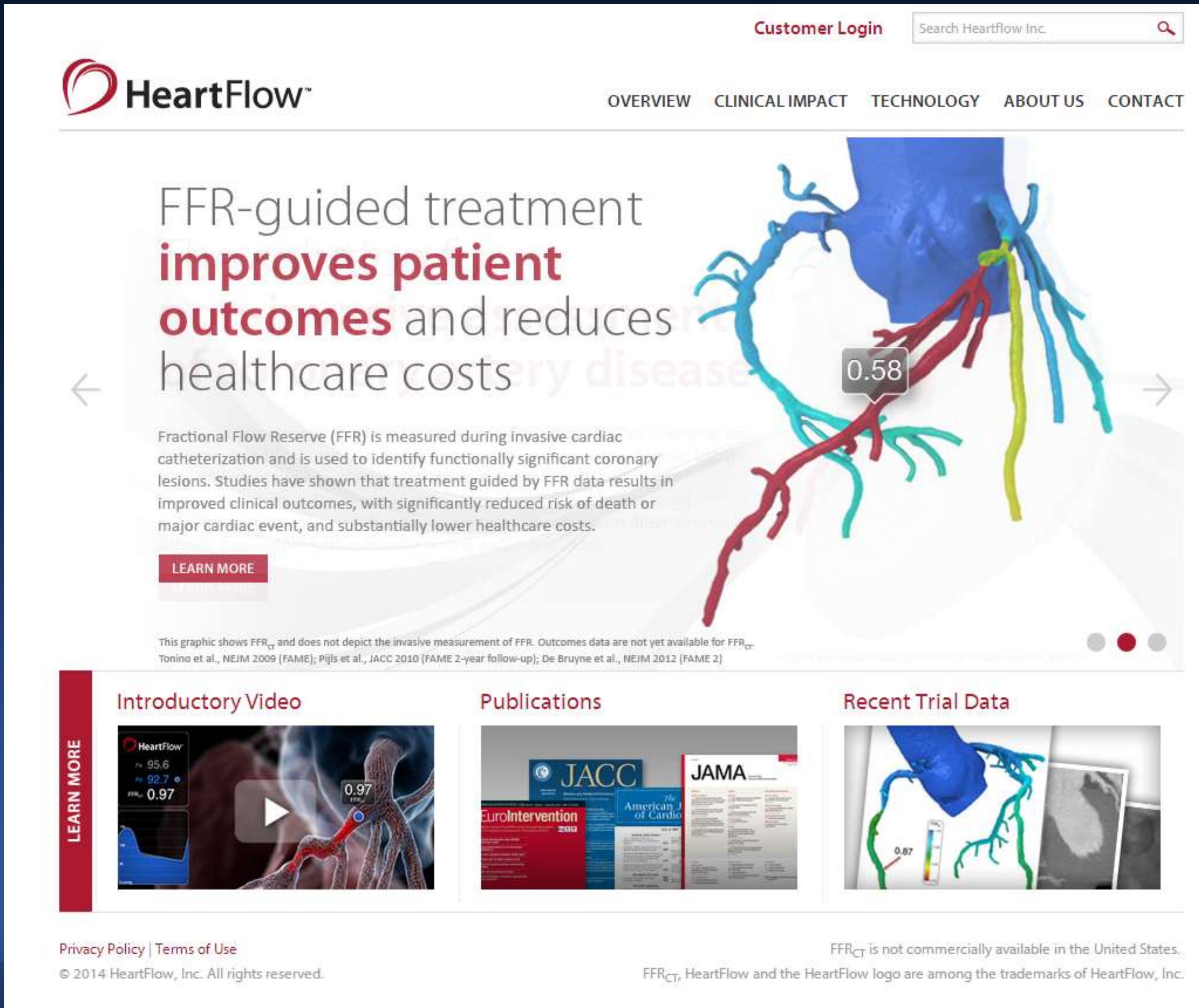
Computational Fluid Dynamics (CFD) is the science of **predicting** fluid flow, heat transfer, mass transfer, chemical reactions, and related phenomena by solving **the mathematical equations** which govern these processes using a **numerical process** (that is, on a computer).







HeartFlow: Pioneer of FFR-CT



FFR-CT Published Data: HeartFlow

	DISCOVER-FLOW		DeFACTO		NXT	
Year, Journal	2011, JACC		2012, JAMA		2013, JACC	
Pts. No	103		252		251	
Design	Single-center		Multicenter		Multicenter	
	CT	cFFR	CT	cFFR	CT	cFFR
Sensitivity	94%	93%	84%	90%	94%	86%
Specificity	25%	82%	42%	54%	34%	79%
PPV	58%	85%	91%	67%	40%	65%
NPV	80%	91%	72%	84%	92%	93%
Accuracy	61%	81%	64%	73%	53%	81

Hecht HS. The Game Changer? JACC 2014 April 1, 1156-8

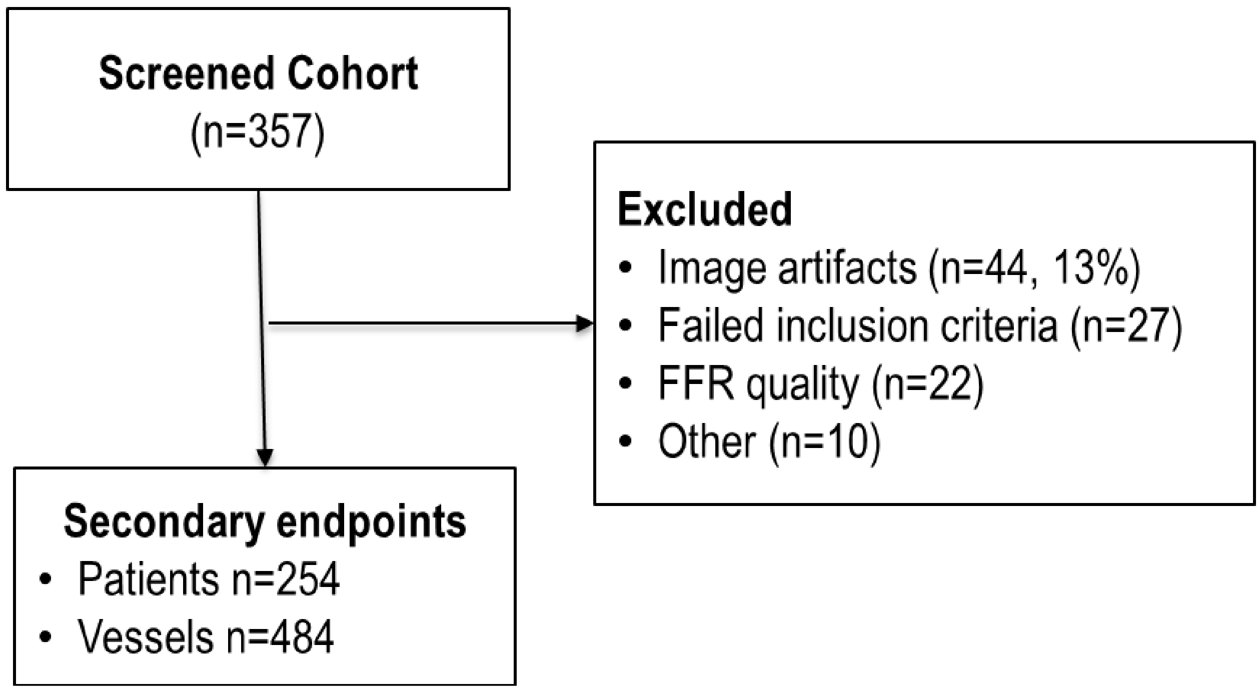
NXT study

Incorporates learning from previous FFR_{CT} trials:

- Newest generation of FFR_{CT} analysis software
- Strict CT acquisition protocol according to societal guidelines

CT Characteristics

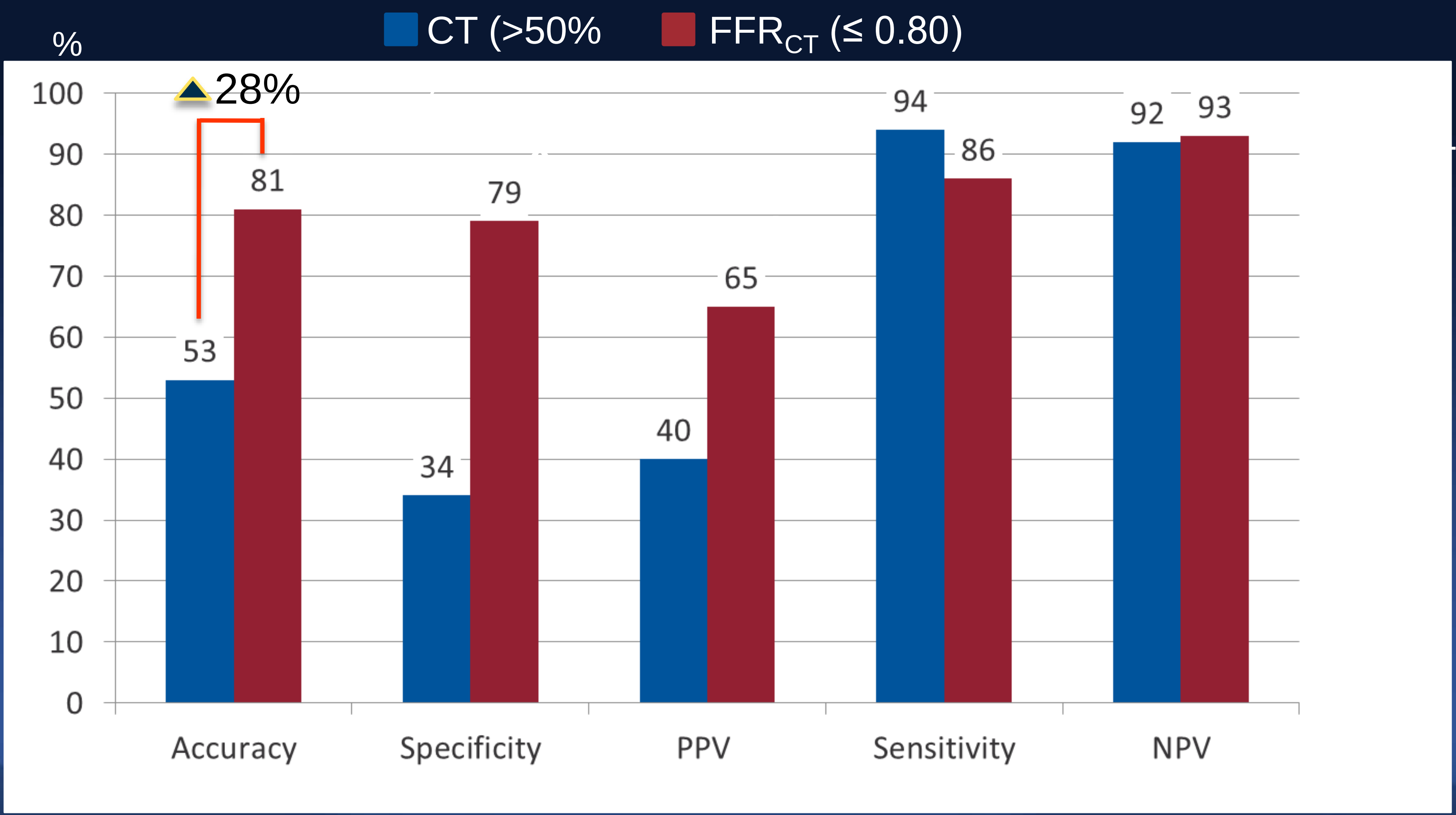
Nitrates	99.6%
Beta Blockers	78%
Heart Rate (bpm)	63
Range	37-110
Prospective	54%
mean dose (mSv)	3
Retrospective	46%
mean dose (mSv)	14
Calcium score*	
Mean	302
>400	26%



Nørgaard B, JACC 2014

NXT study

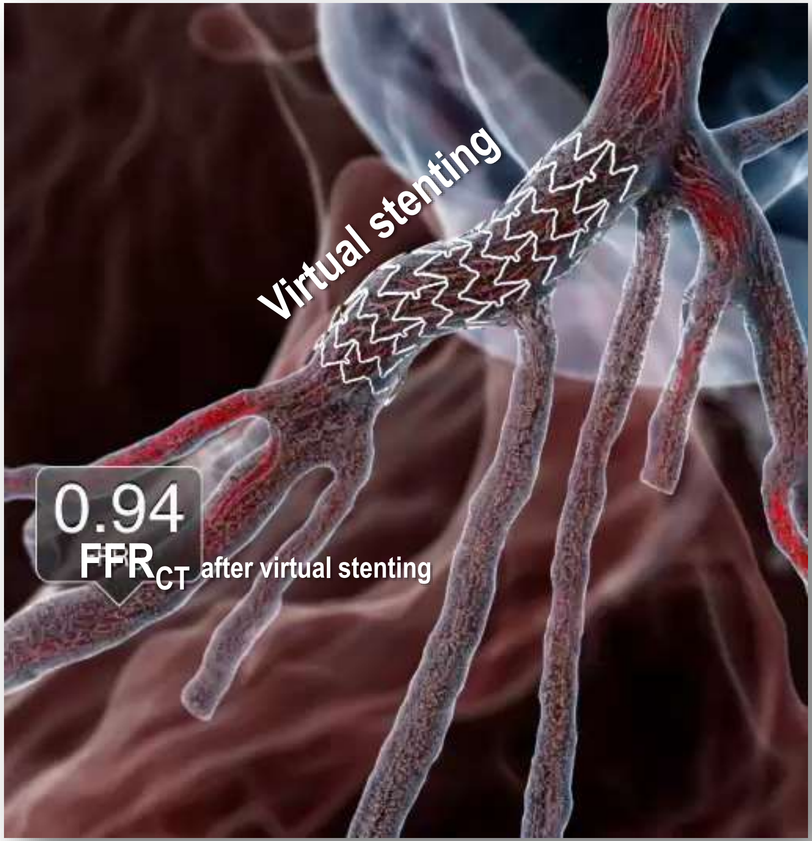
Per-patient analysis (n=254)



Nørgaard B, JACC 2014

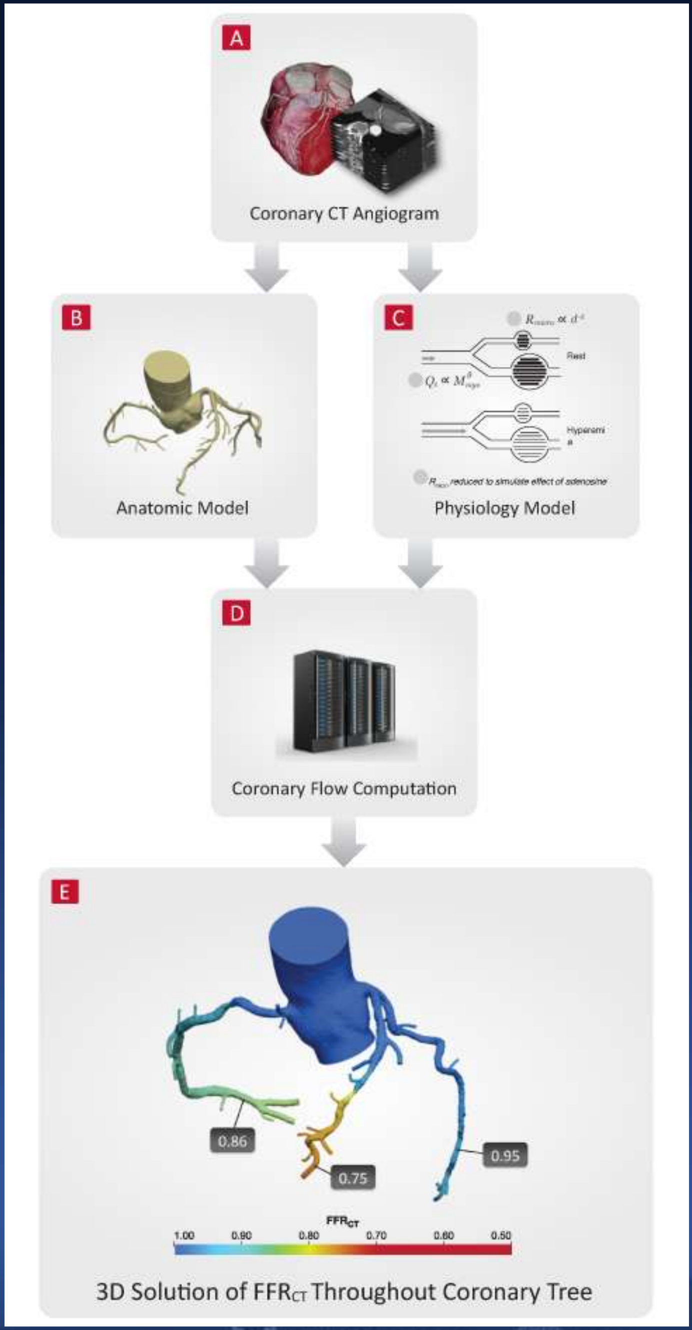
Image-based computerised modelling of coronary circulation: **Future direction**

Planning the treatment strategy using **Virtual revascularization & CT-derived computed FFR**

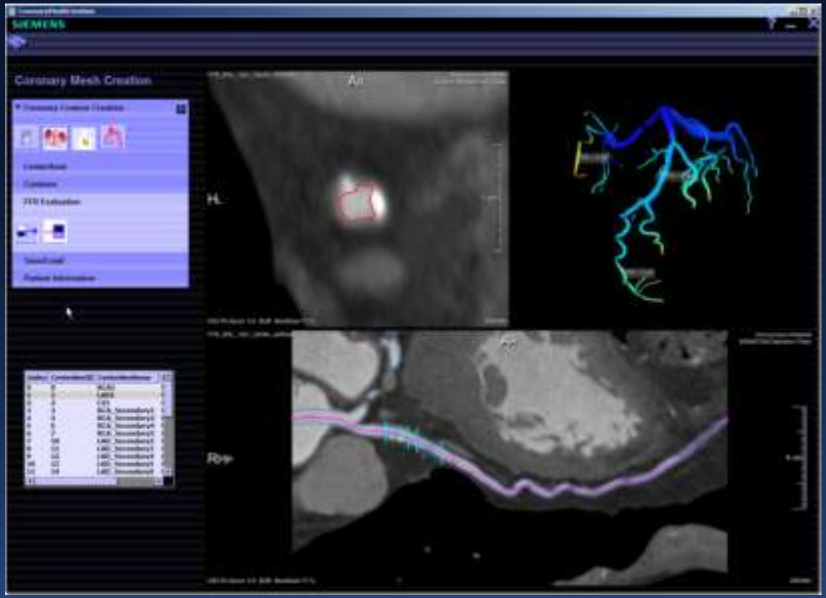


Limitations

- High cost
- Long assessing time
- Transportation of patient's medical record and imaging
- Not high specificity
- Lack of evidence for clinical application

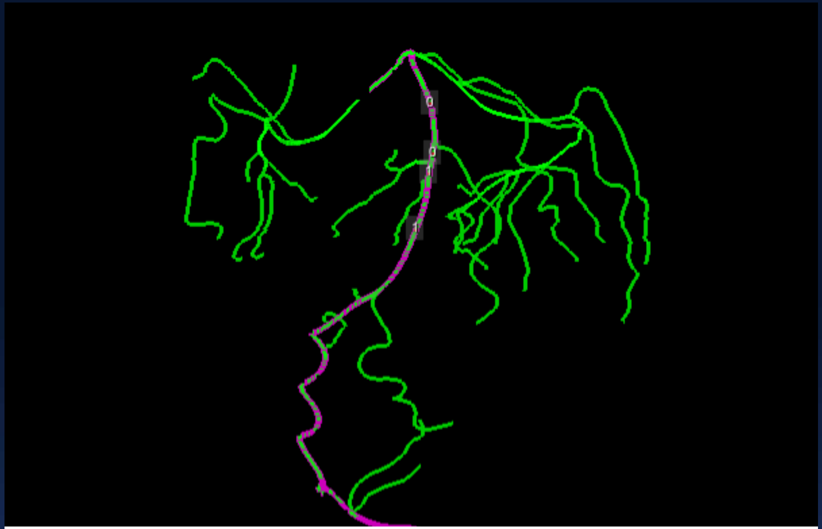


Siemens CT-based FFR: cFFR
stand-alone, prototype, not commercialized yet

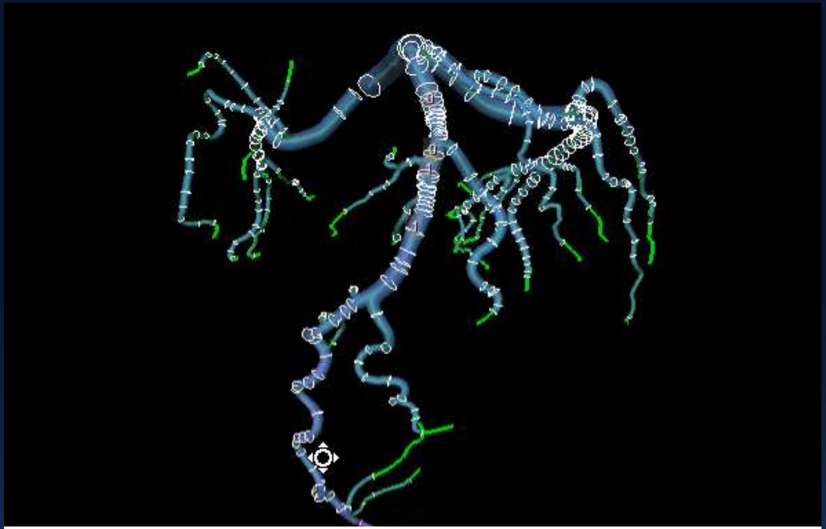


- On-site analysis of CT-based FFR on a standalone workstation
  - No need of transferring CT images to a remote site
  - No need of super-computer for analysis
  - Relatively cheep
- Relatively fast turn-around time (approximately 50 min per case)

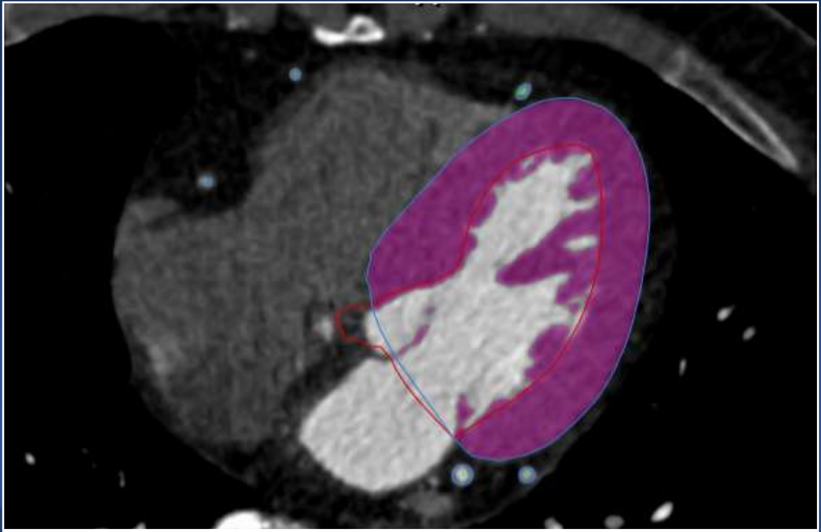
cFFR: Processing Steps



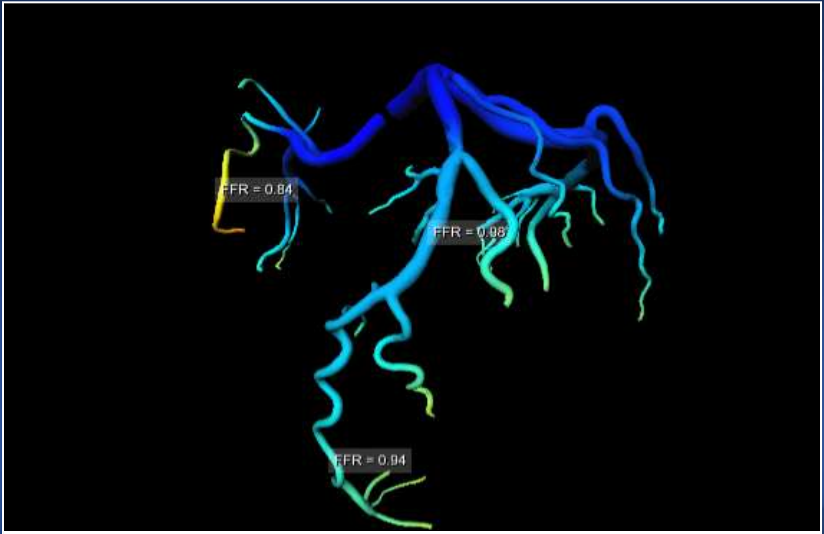
1. Centerline definition



2. Lumen segmentation



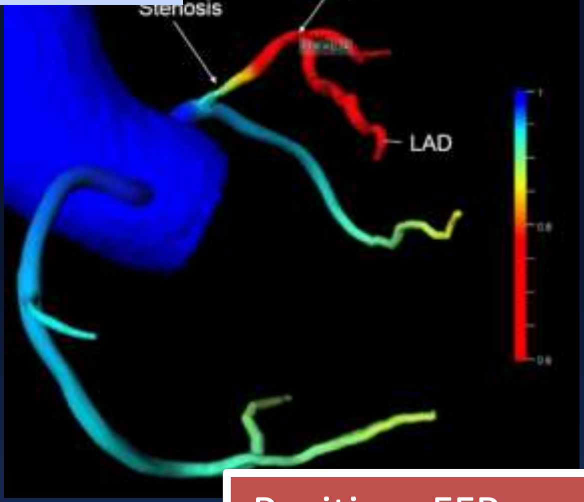
3. Definition of boundary condition

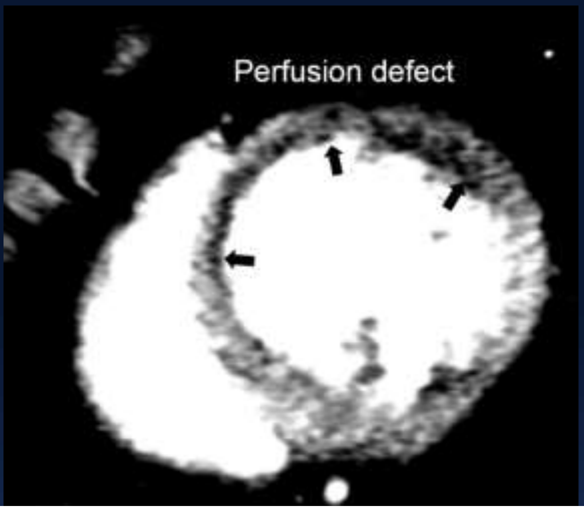


4. cFFR computation

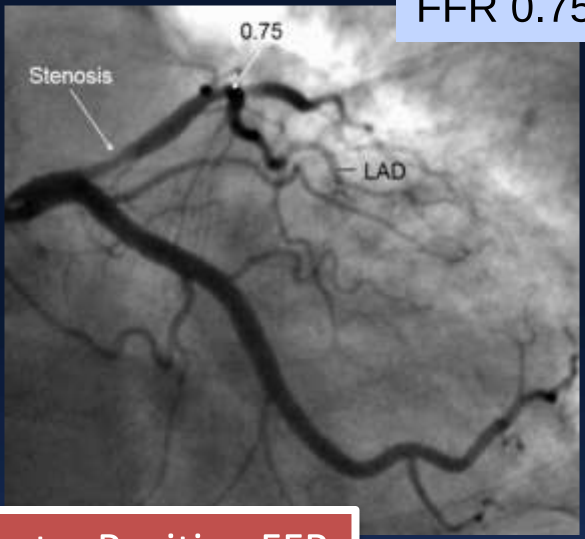
cFFR and CT perfusion

cFFR 0.74



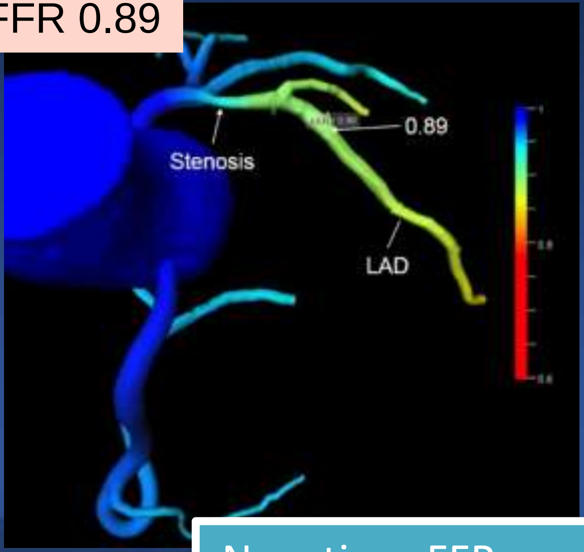


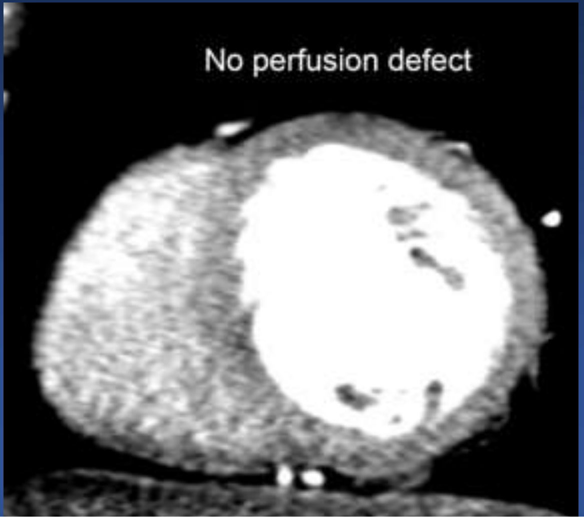
FFR 0.75



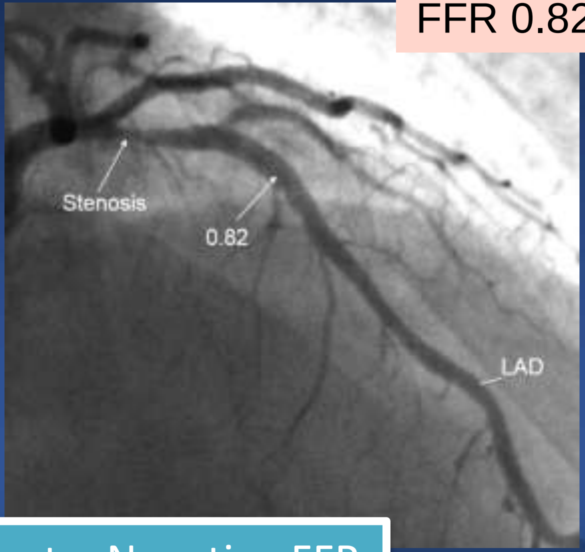
Positive cFFR – positive myocardial perfusion defect – Positive FFR

cFFR 0.89





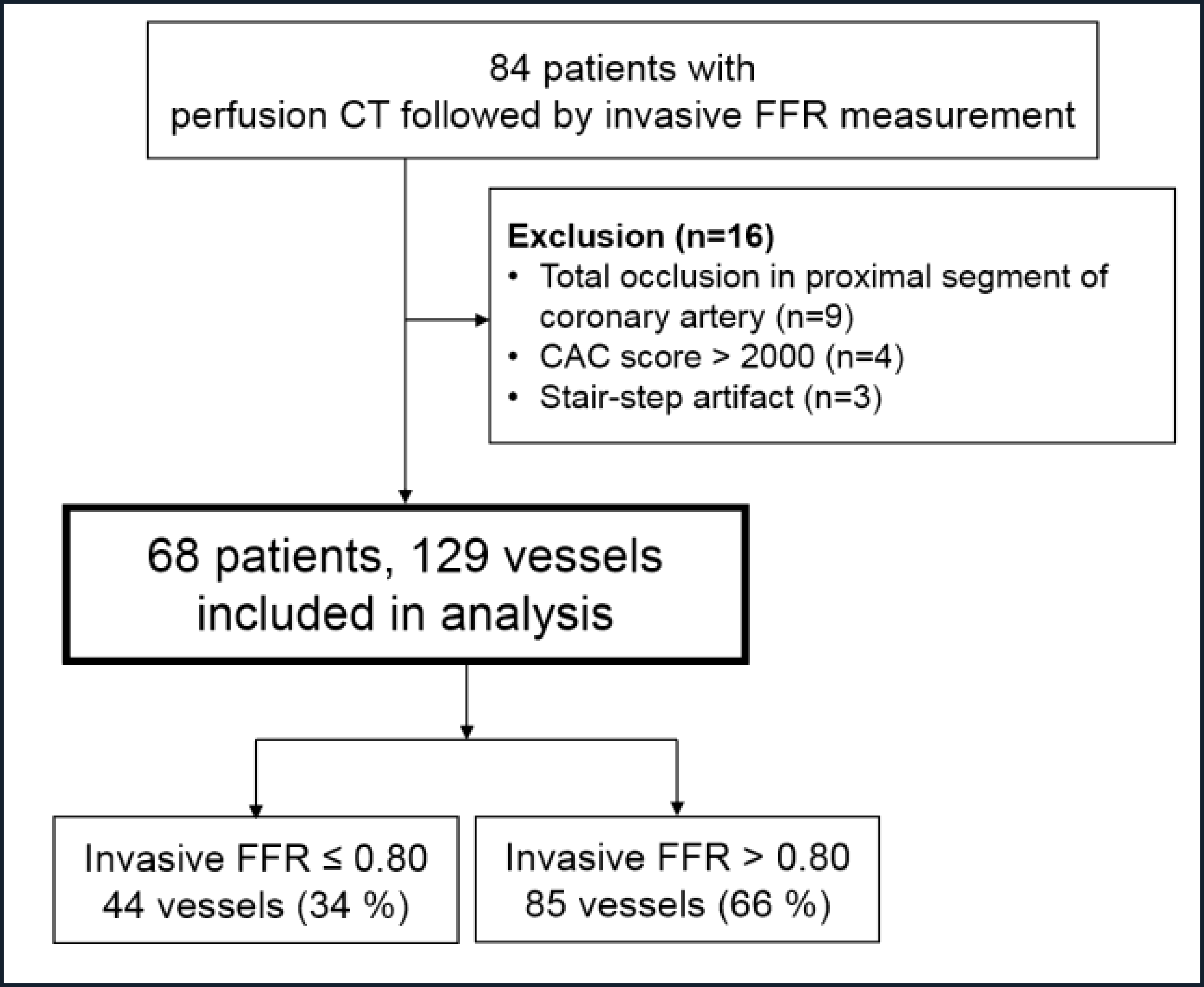
FFR 0.82



Negative cFFR – negative myocardial perfusion defect – Negative FFR

Yang DH, Kim YH et al. Submitted

Siemens cFFR Analysis Compared with CTP and FFR



Yang DH, MD, Kim YH, MD, et al (in review)

CTP and cFFR Protocol in AMC

25 minutes

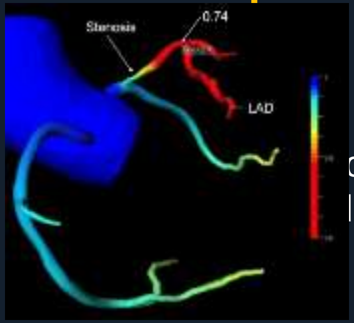
using dual-source 126 ch. CT (Siemens)

		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

Optio

1. S n

2. D



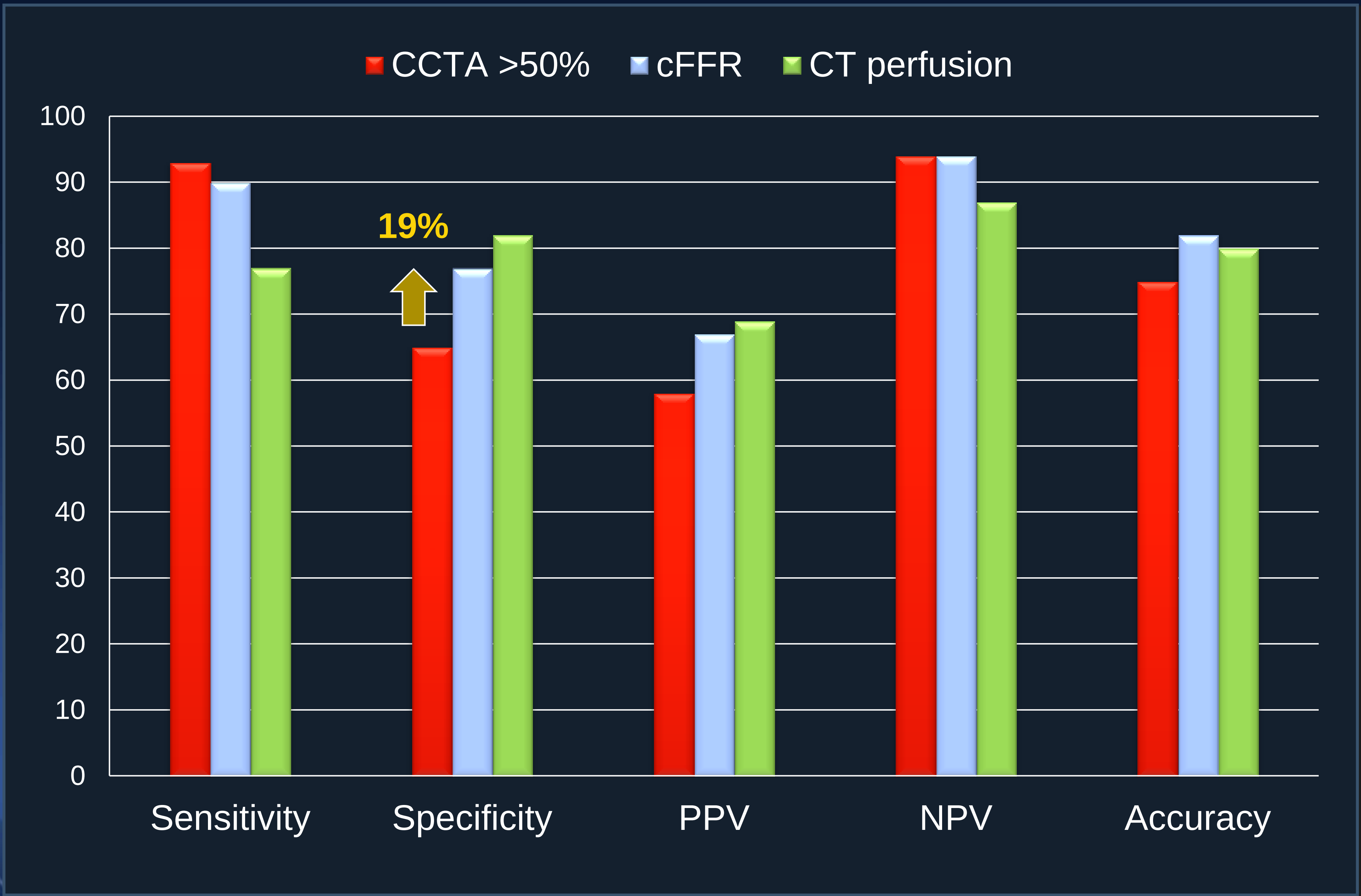
ode

le

Patients

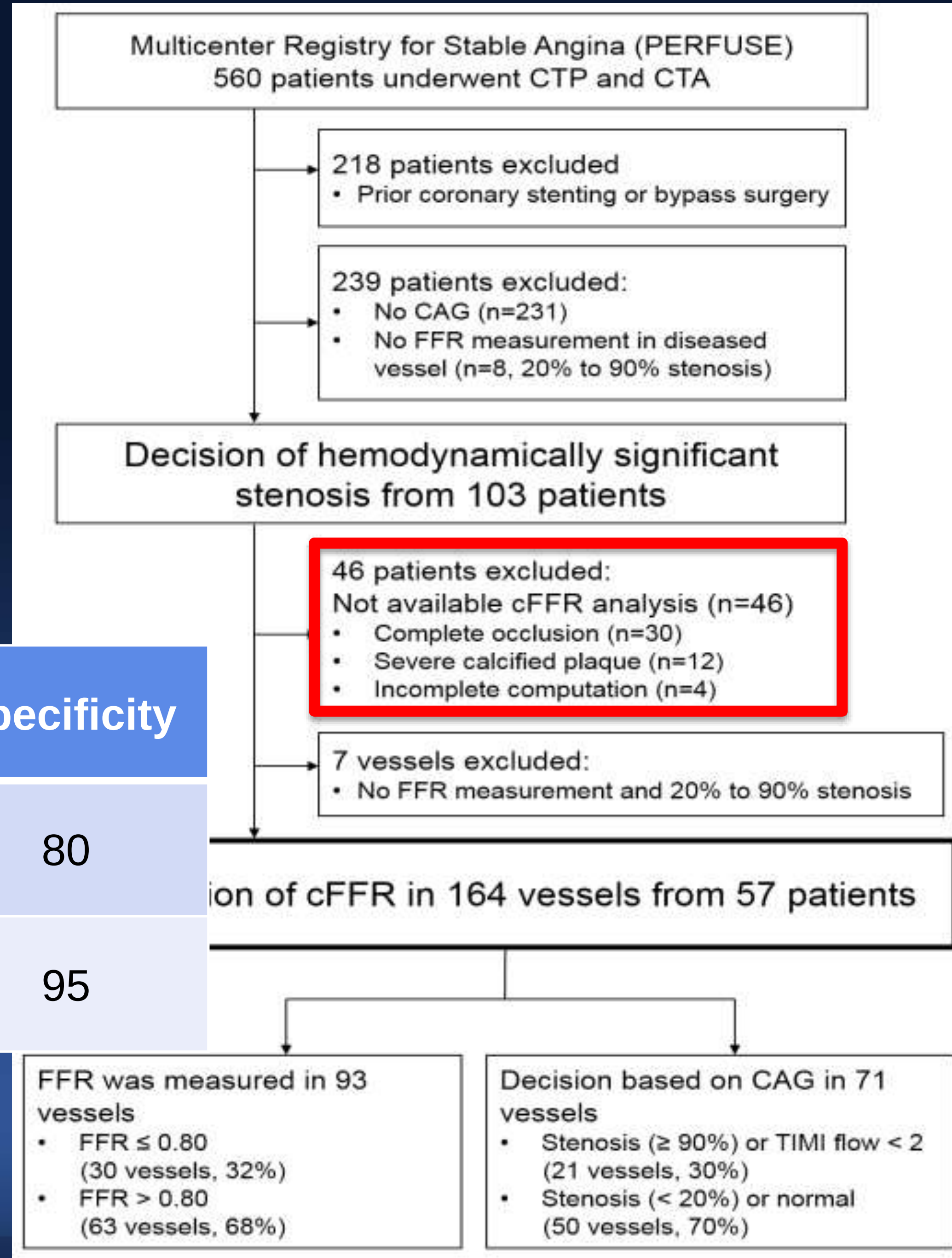
	Patients (N=68)
Age, years	62.0 ± 8.9
Male gender	60 (88)
Body mass index, kg/m^2	25.5 ± 3.4
Risk factors	
Diabetes	27 (40)
Hyperlipidemia	17 (25)
Hypertension	30 (44)
Family history	22 (32)
Current smoking	35 (52)
Symptoms	
Atypical chest pain	16 (24)
Typical chest pain	52 (76)
Number of diseased vessel	
No disease	15 (22)
One vessel	32 (47)
Two vessels	14 (21)
Three vessels	7 (10)
Coronary calcium score, Agatston	373.2 ± 790.4

Per-vessel Accuracy

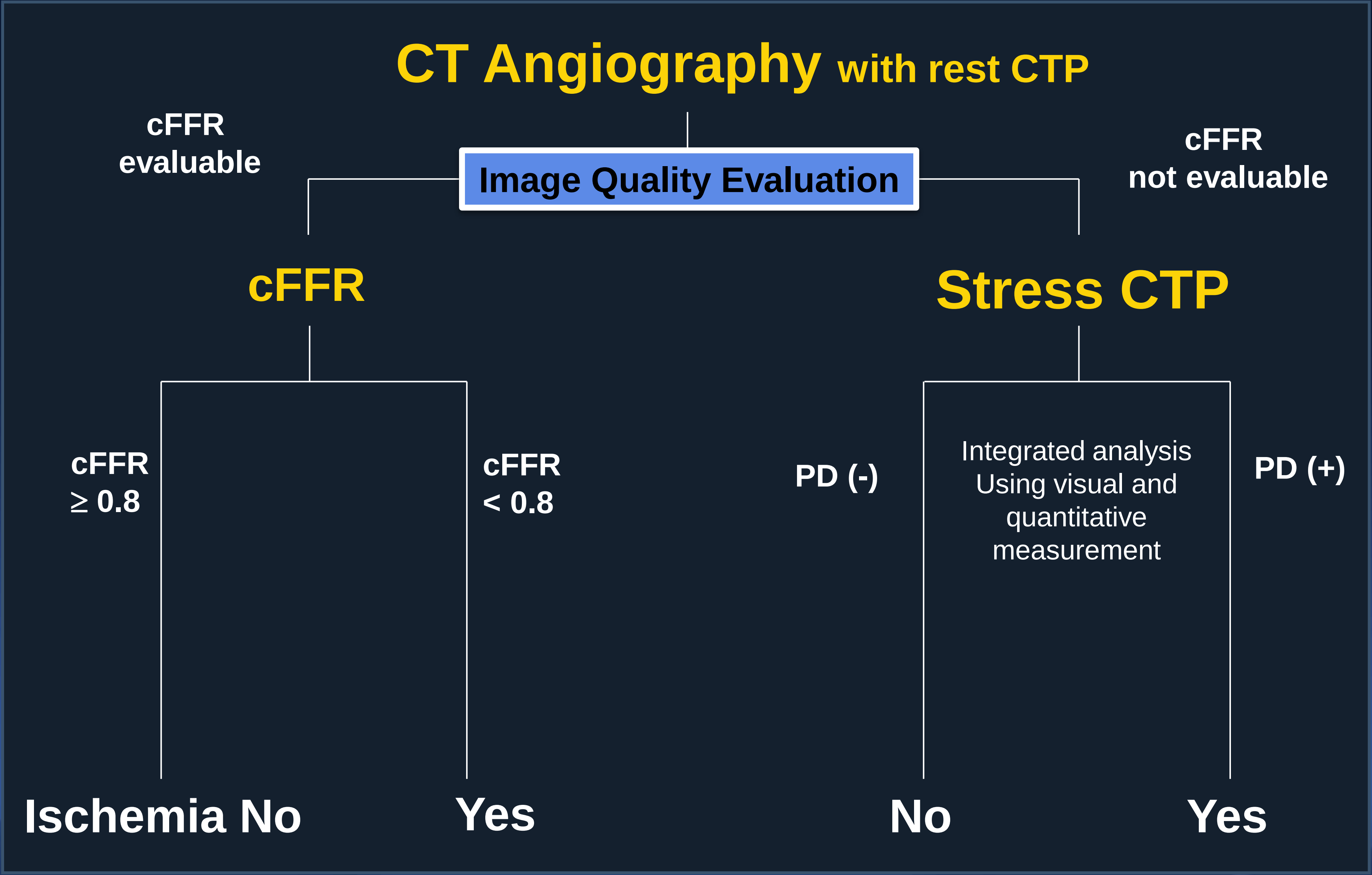


CT Perfusion
for 46 excluded patients

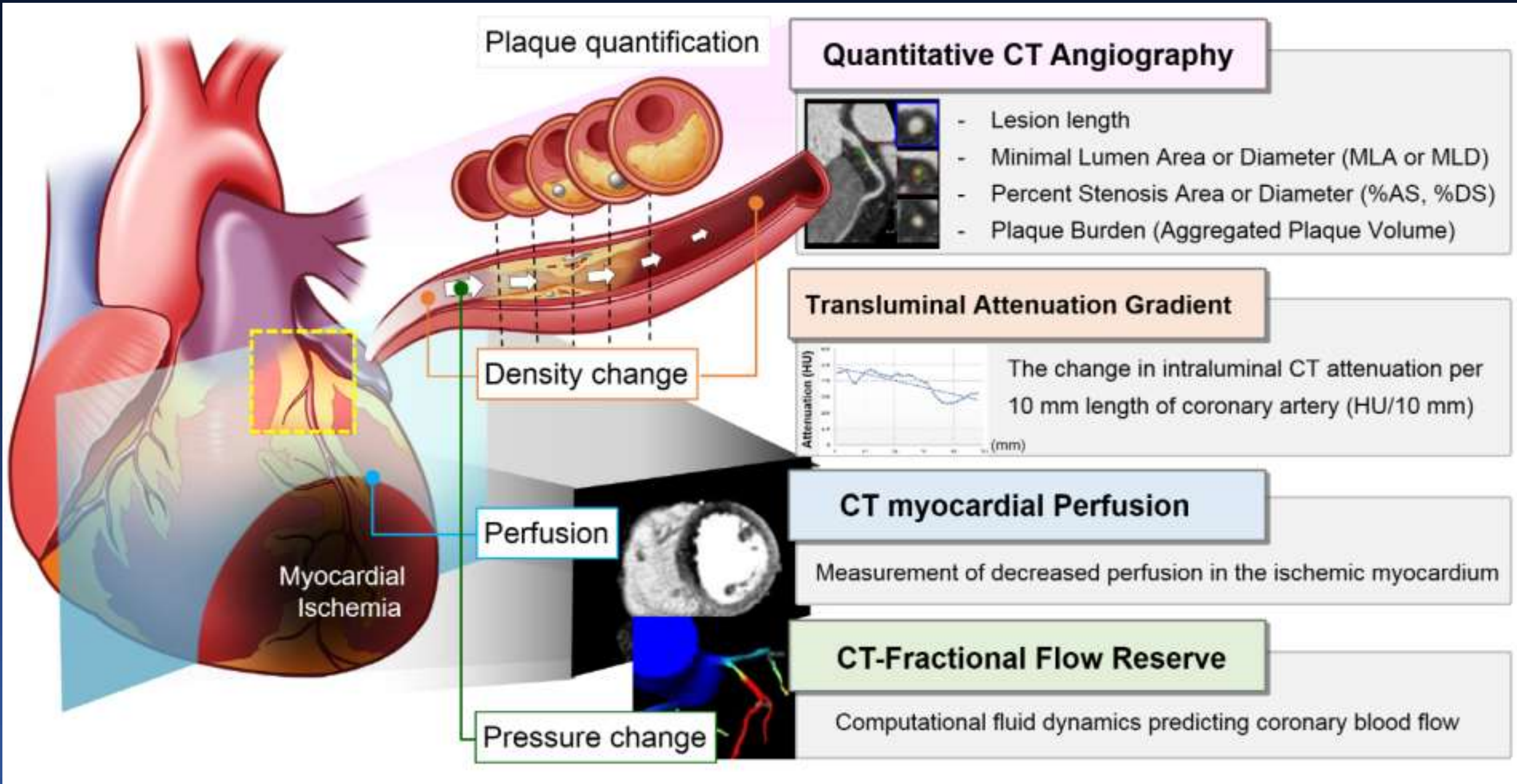
	Sensitivity	Specificity
Per patients	92	80
Per vessels	89	95



Pathway of CT-based Functional Imaging



Cardiac CT: One Stop Shop



Yang DH, Kim YH et al. Radiographics 2015 (in print)