Moderne kardiale Bildgebung bei Verdacht auf KHK

24. Birsecker Herzfortbildung, 29.01.2026

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FMH Kardiologie und Nuklearmedizin

LA / Stv. Klinikdirektor

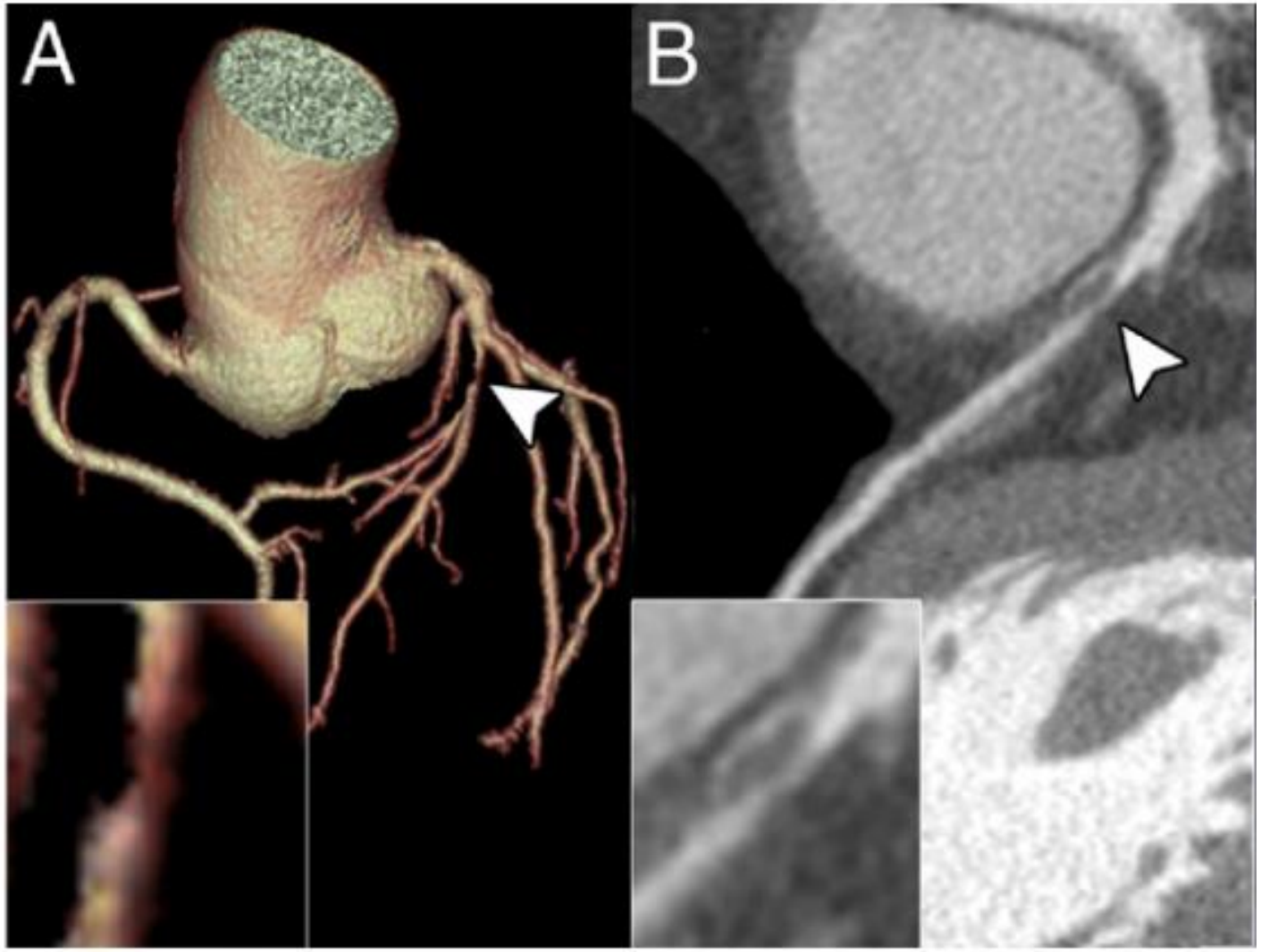
Klinik für Nuklearmedizin

Universitätsspital Zürich

Disclosures

Multimodality imager: CT, PET, SPECT, MRI

Speaker honoraria from:	Gilead and GE Healthcare
Research funding from:	Swiss Heart Foundation and GE Healthcare



70% stenosis in mid-LAD
What now?

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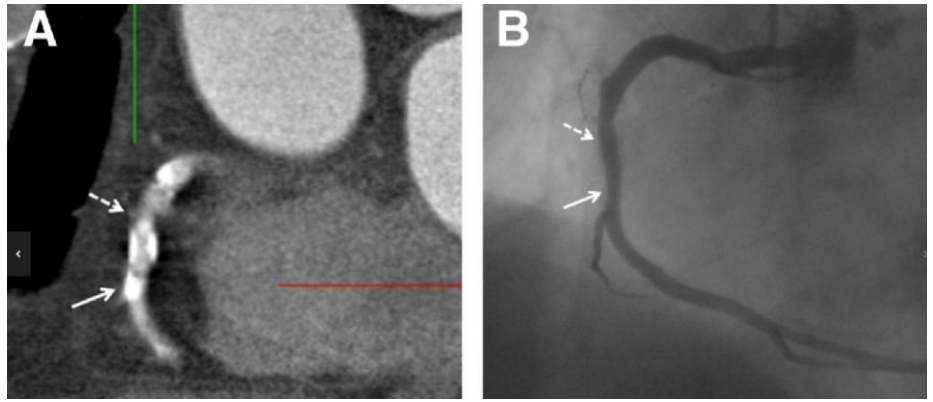
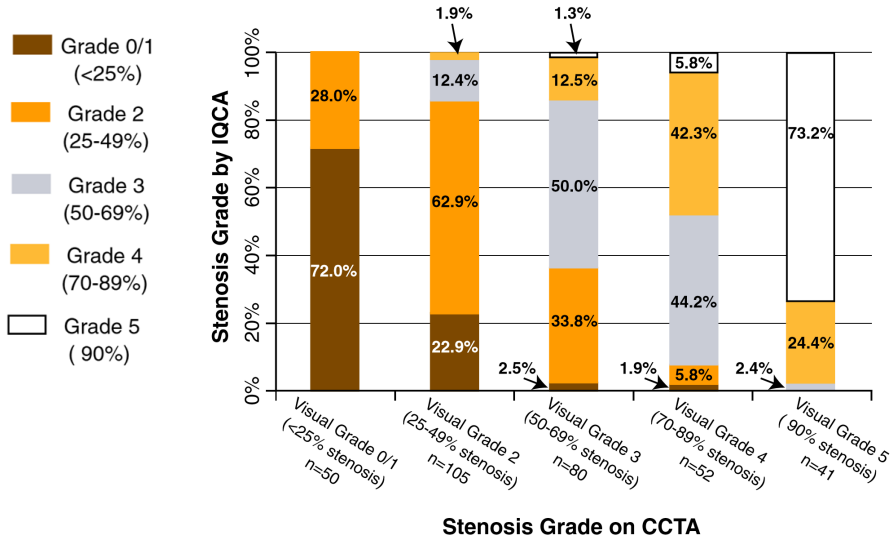
Buechel RR et al. JACC. 2011 Jan 18;57(3):332-6

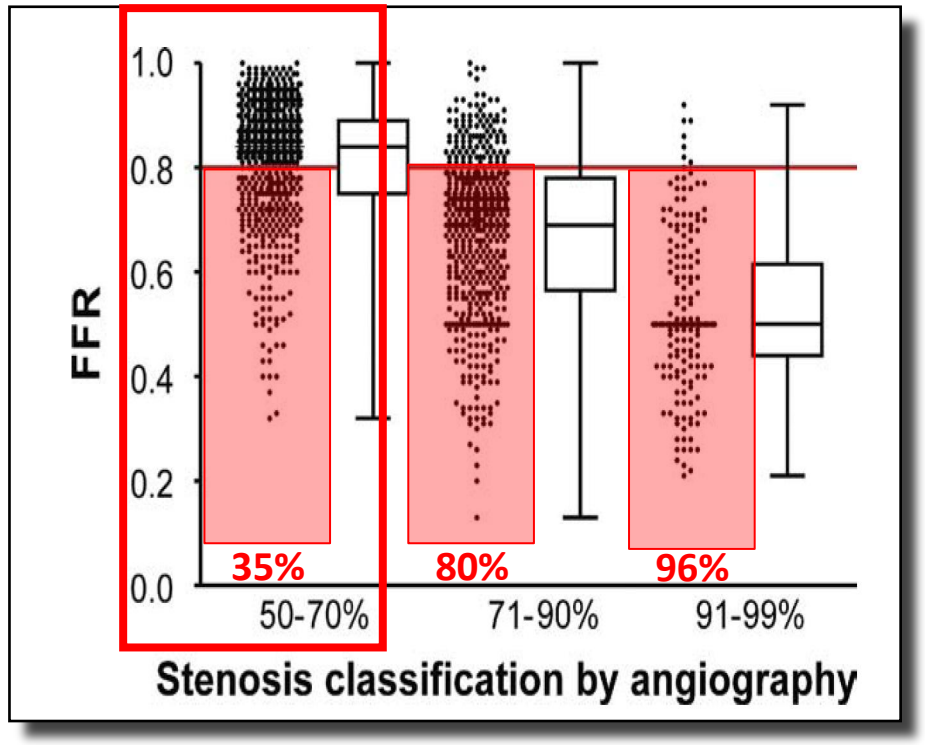
CCTA overestimates stenosis





False-positive findings in up to 35%

Stenosis ≠ Ischemia



Arbab-Zadeh et al. JACC Cardiovasc Imaging. 2011 Feb;4(2):191-202.
Cheng et al. JACC Cardiovasc Imaging. 2008 Jul;1(4):460-71
Tonino et al. FAME. J Am Coll Cardiol. 2010 Jun 22;55(25):2816-21

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What to chose if everything (!) is available

CT

Echo

SPECT

PET

MR

Stress echocardiography

Stress Echocardiography

Advantages
- Good diagnostic accuracy (good specificity, moderate sensitivity)
- No ionizing radiation exposure
- Relatively low costs

Disadvantages
- Dependent on good acoustic window
- Dependent on operator

Magentic resonance imaging

Stress CMR

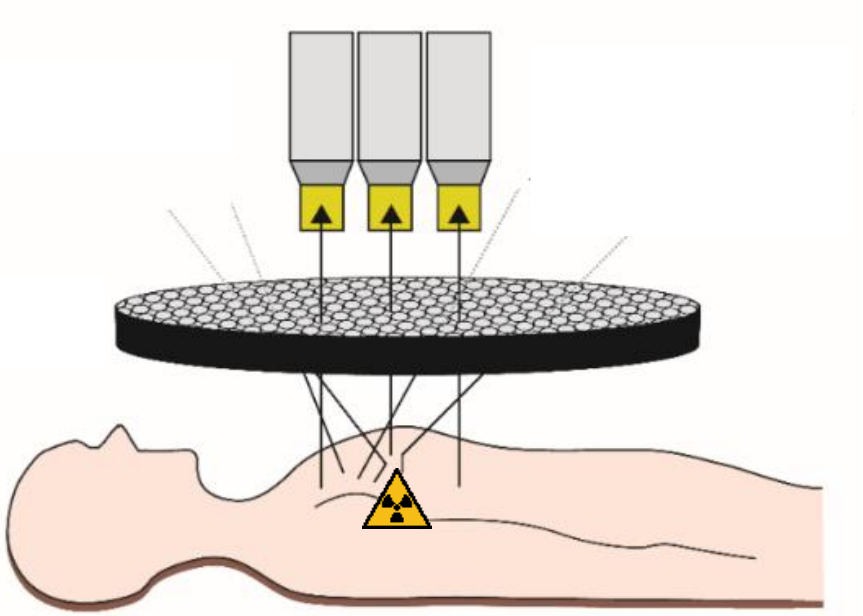
Advantages
- Combination of perfusion, tissue characterization and function
- Good diagnostic accuracy
- No ionizing radiation exposure

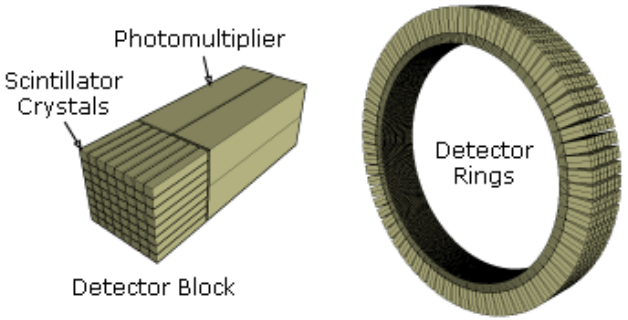
Disadvantages
- Many contraindications
- Long protocols

Cardiac SPECT

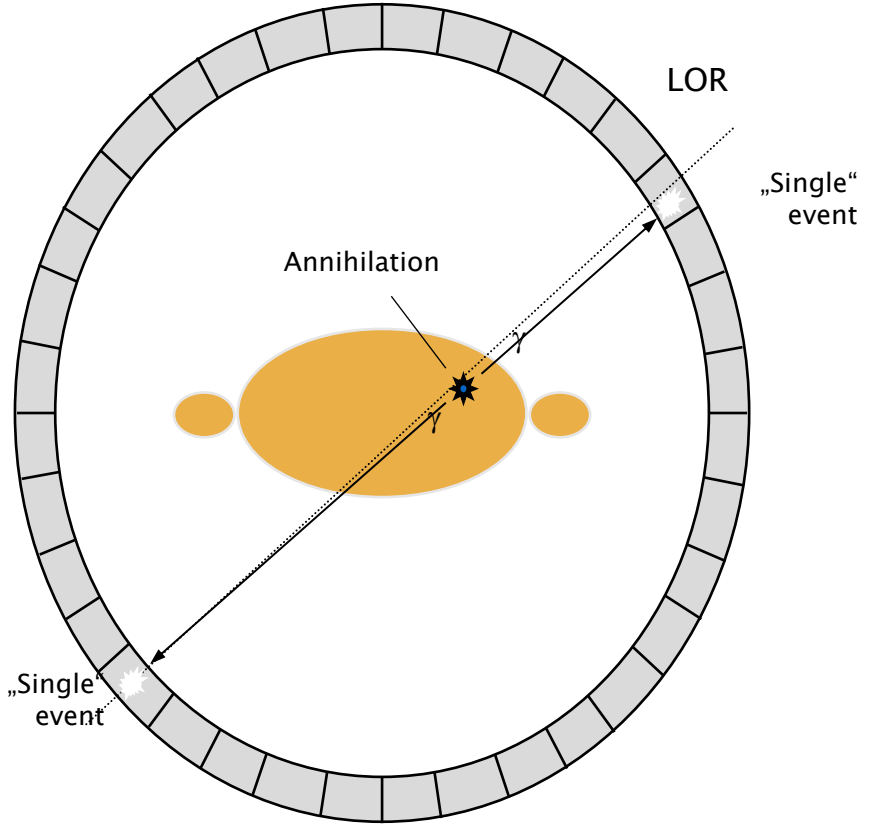
Cardiac PET

Nuklearkardiologie – Myokardperfusions-PET



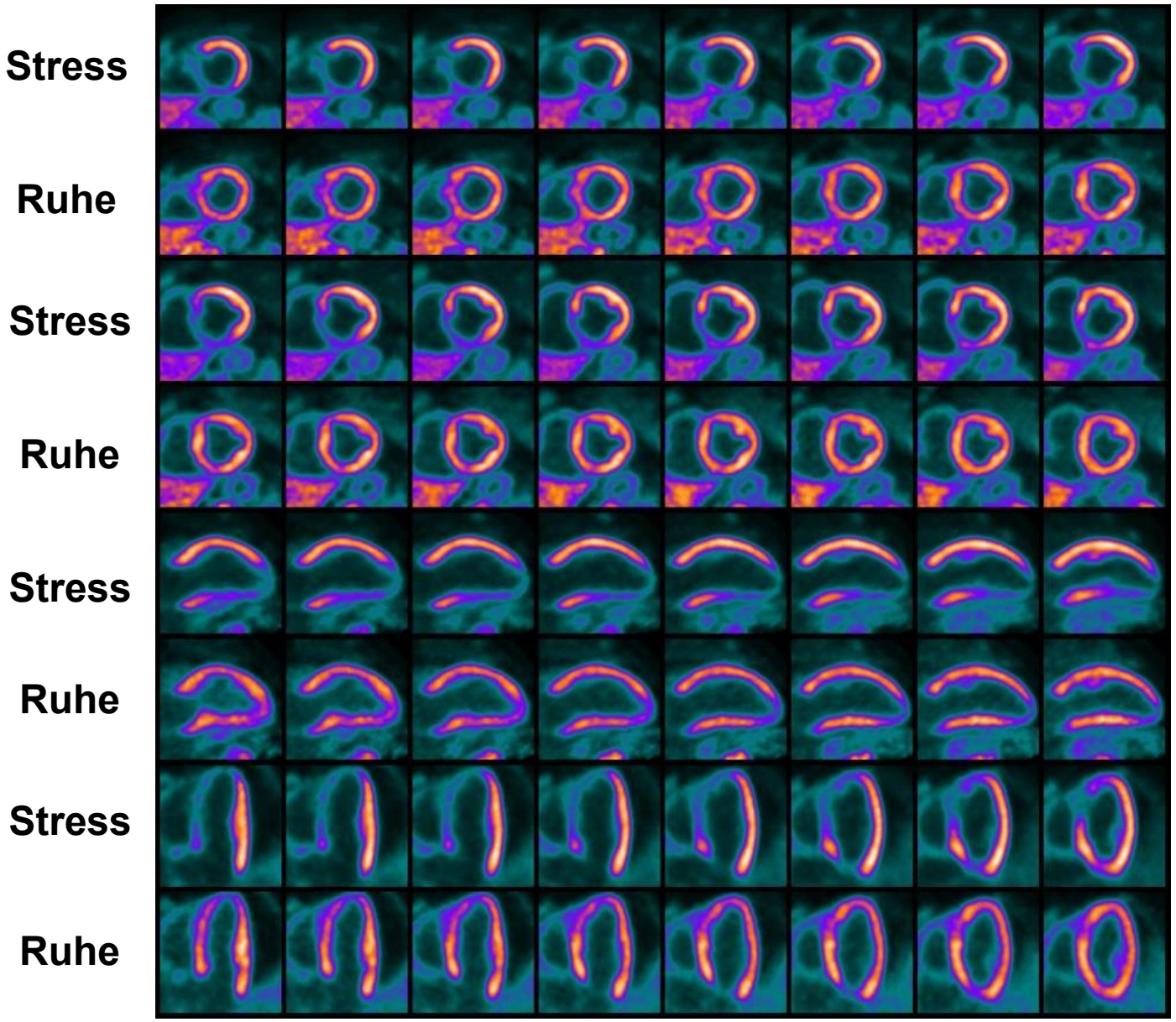


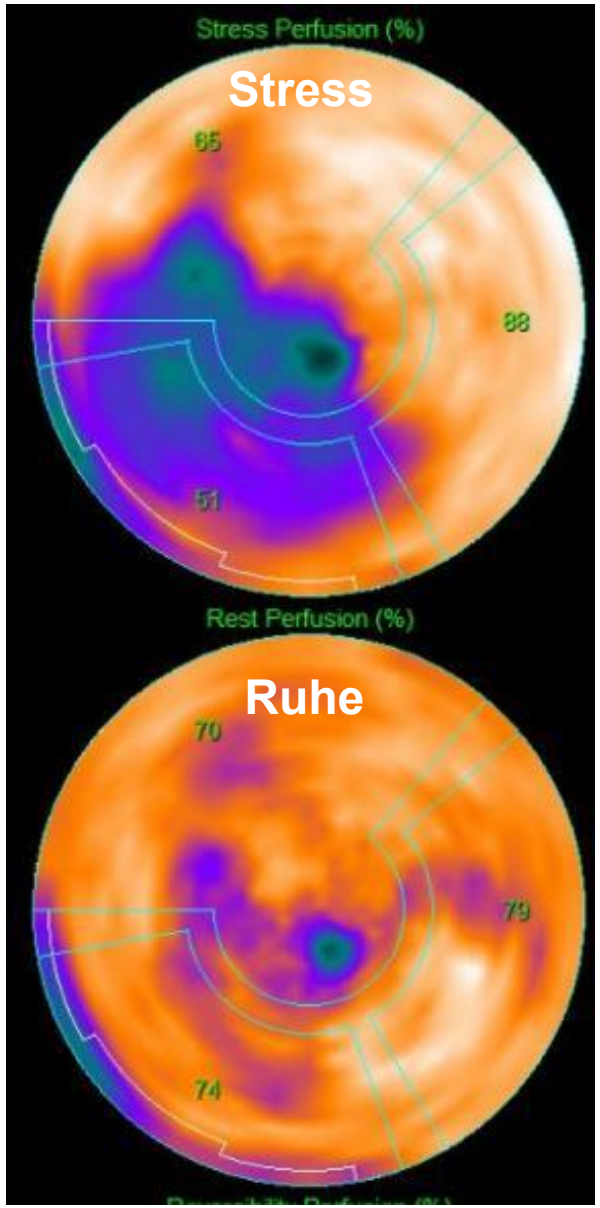
$$p \longrightarrow n + e^{+} + \nu_e$$



Buechel RR et al. Technological developments – SPECT. In Nieman K, Gaemperli O, Lancelotti P and Plein S (Eds.), Advanced Cardiac Imaging. Cambridge, GB: Woodhead Publishing. 2015 Aug 10.

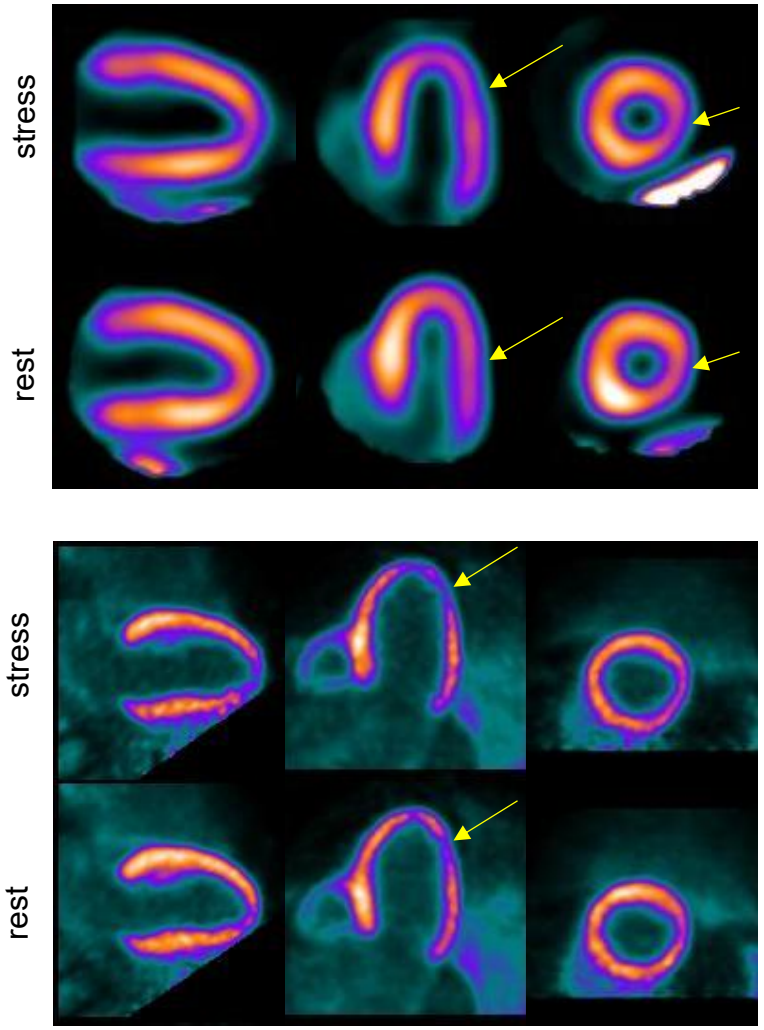
PET myocardial perfusion imaging - Semiquantitative





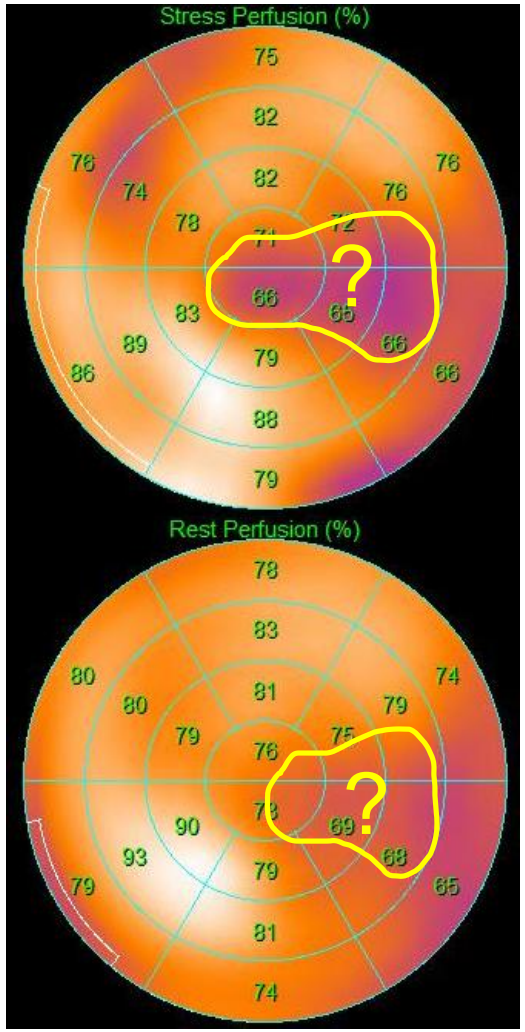
PET With Superior Image Quality (at lower radiation dose)

SPECT



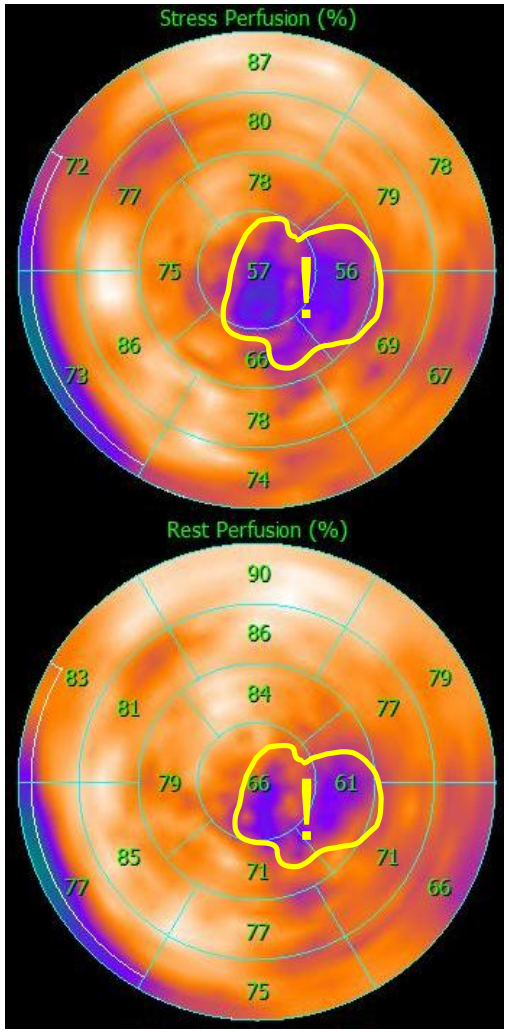
NH3-PET

SPECT



5.0 mSv

PET



1.03 mSv

Male patient, 80y, BMI 23kg/m^2

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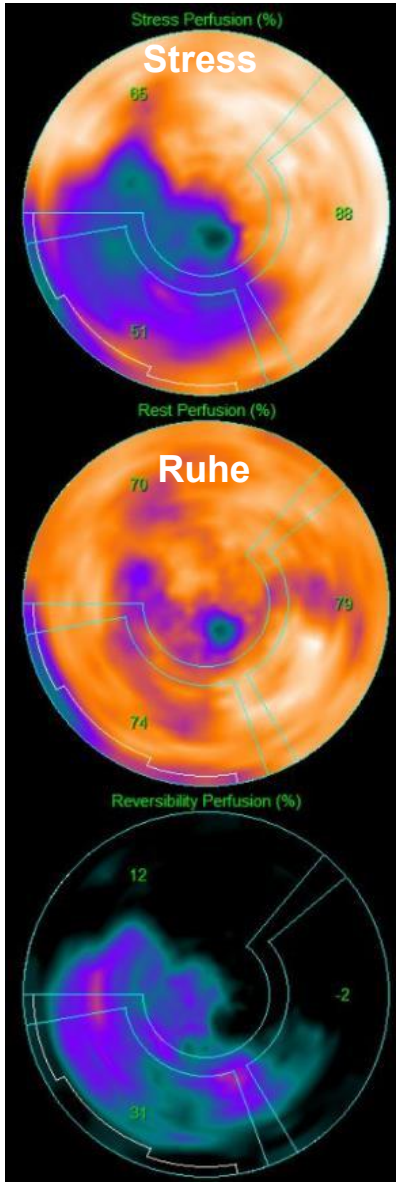
PET myocardial perfusion imaging - Quantitative

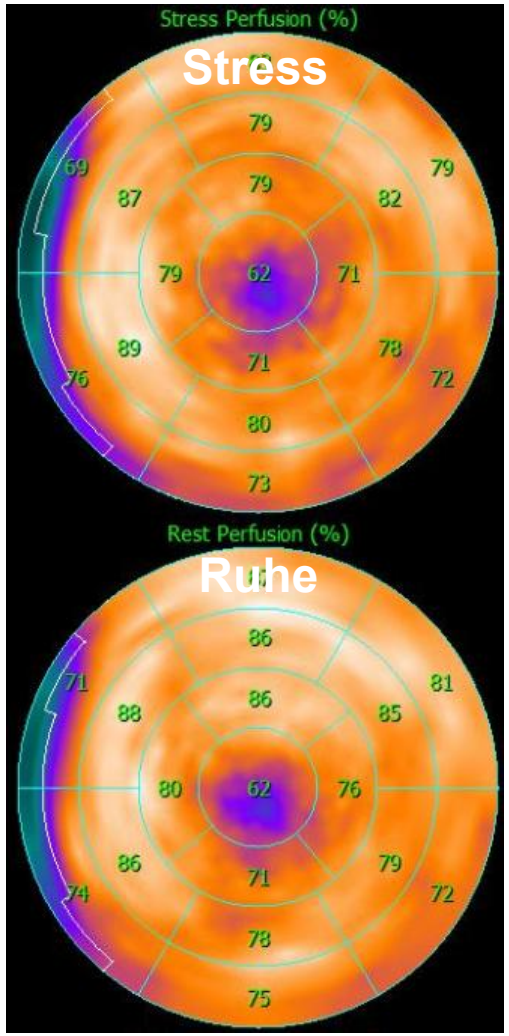
Quantitative information

+

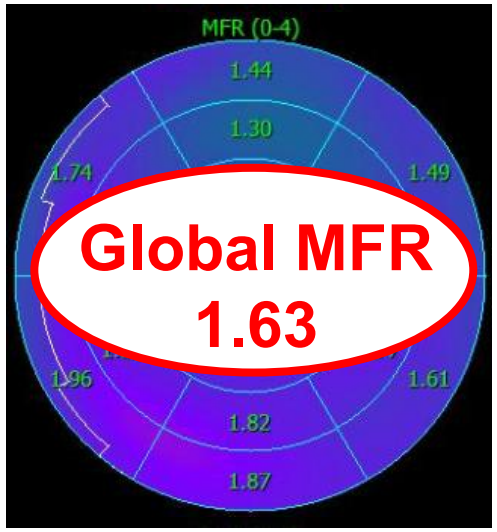
Semiquantitative information

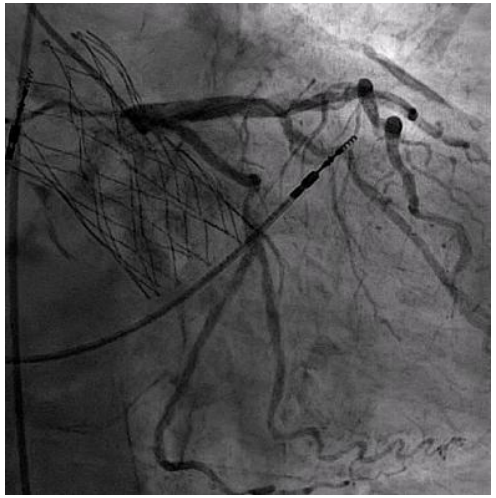


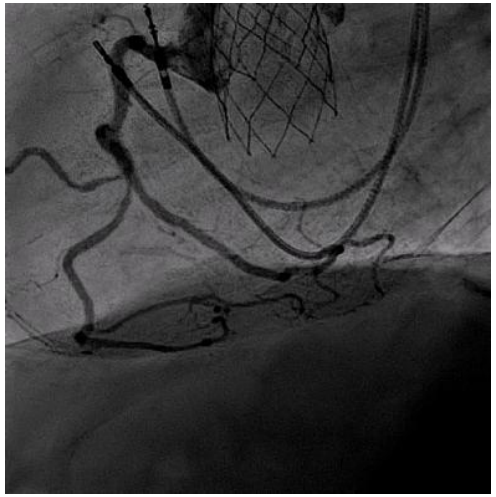
A picture is worth a thousand words
But if you add numbers… you get increased sensitivity

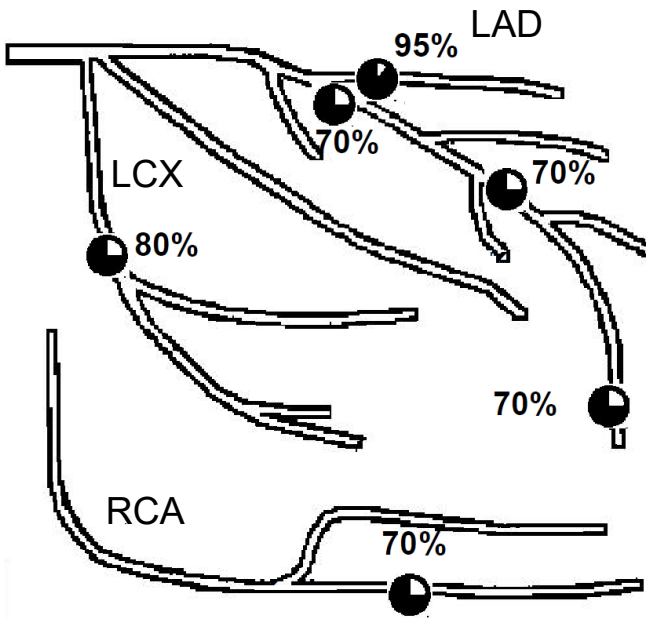


Flow reserve









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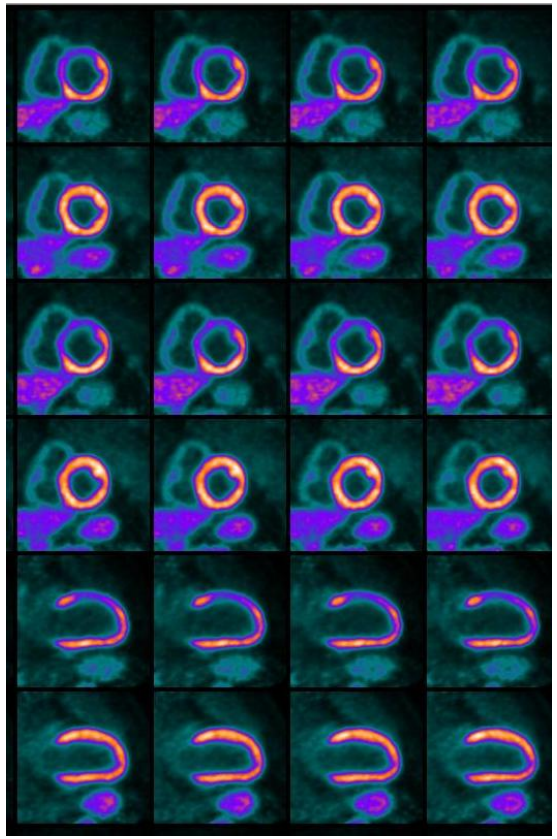
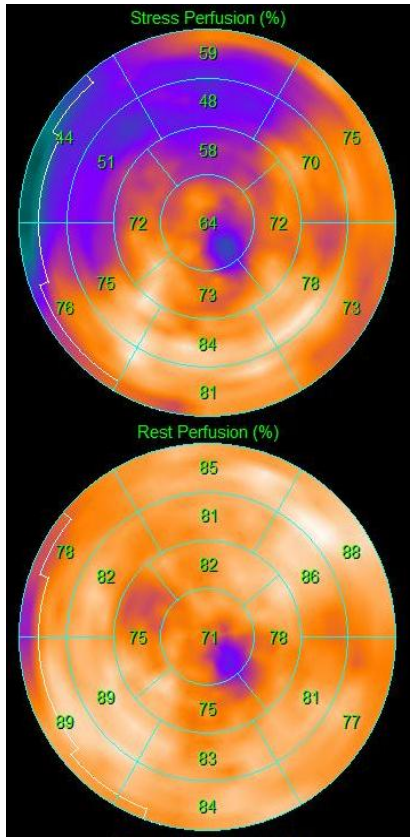
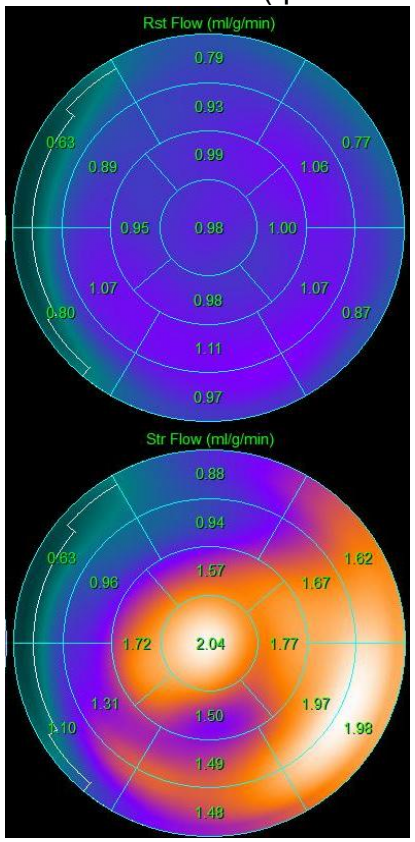
PET myocardial perfusion imaging

13N-NH3 PET-MPI (semiquant)





13N-NH3 PET-MPI (quantitative)



Advantages
- Excellent image quality
- Routine blood flow quantification
- Excellent diagnostic accuracy
- Low radiation dose exposure (1-2mSv)
- No contraindications

Disadvantages
- Cost
- Availability

	^{15}O-Water	^{13}N-Ammonia	^{82}Rb
Isotope half-life (min)	2.03	9.97	1.27
Total dose for PET (mSv)	1.6-2.0	1.5-2.2	1.1-2.2
Rest-Stress interval (min)	0	30	0
Production method	Cyclotron (on-site)	Cyclotron (on-site)	Generator

Modified from Buechel RR et al. Protocols, Data Analysis, Normal Scans, and Pitfalls in Cardiac PET and SPECT. In von Schulthess GK (Ed.), Molecular Anatomic Imaging: Lippincott Williams & Wilkins. 2015 Jun 16.

What do the guidelines recommend?

CCTA

In individuals with suspected CCS and low or moderate (>5%–50%) pre-test likelihood of obstructive CAD, CCTA is recommended to diagnose obstructive CAD and to estimate the risk of MACE.	I	A

Stress Echo

In individuals with suspected CCS and moderate or high (>15%–85%) pre-test likelihood of obstructive CAD, stress echocardiography is recommended to diagnose myocardial ischaemia and to estimate the risk of MACE.	I	B

Nuclear

In individuals with suspected CCS and moderate or high (>15%–85%) pre-test likelihood of obstructive CAD, SPECT or, preferably, PET myocardial perfusion imaging is recommended to: • diagnose and quantify myocardial ischaemia and/or scar; • estimate the risk of MACE; • quantify myocardial blood flow (PET).	I	B

CMR

In individuals with suspected CCS and moderate or high (>15%–85%) pre-test likelihood of obstructive CAD, CMR perfusion imaging is recommended to diagnose and quantify myocardial ischaemia and/or scar and estimate the risk of MACE.	I	B

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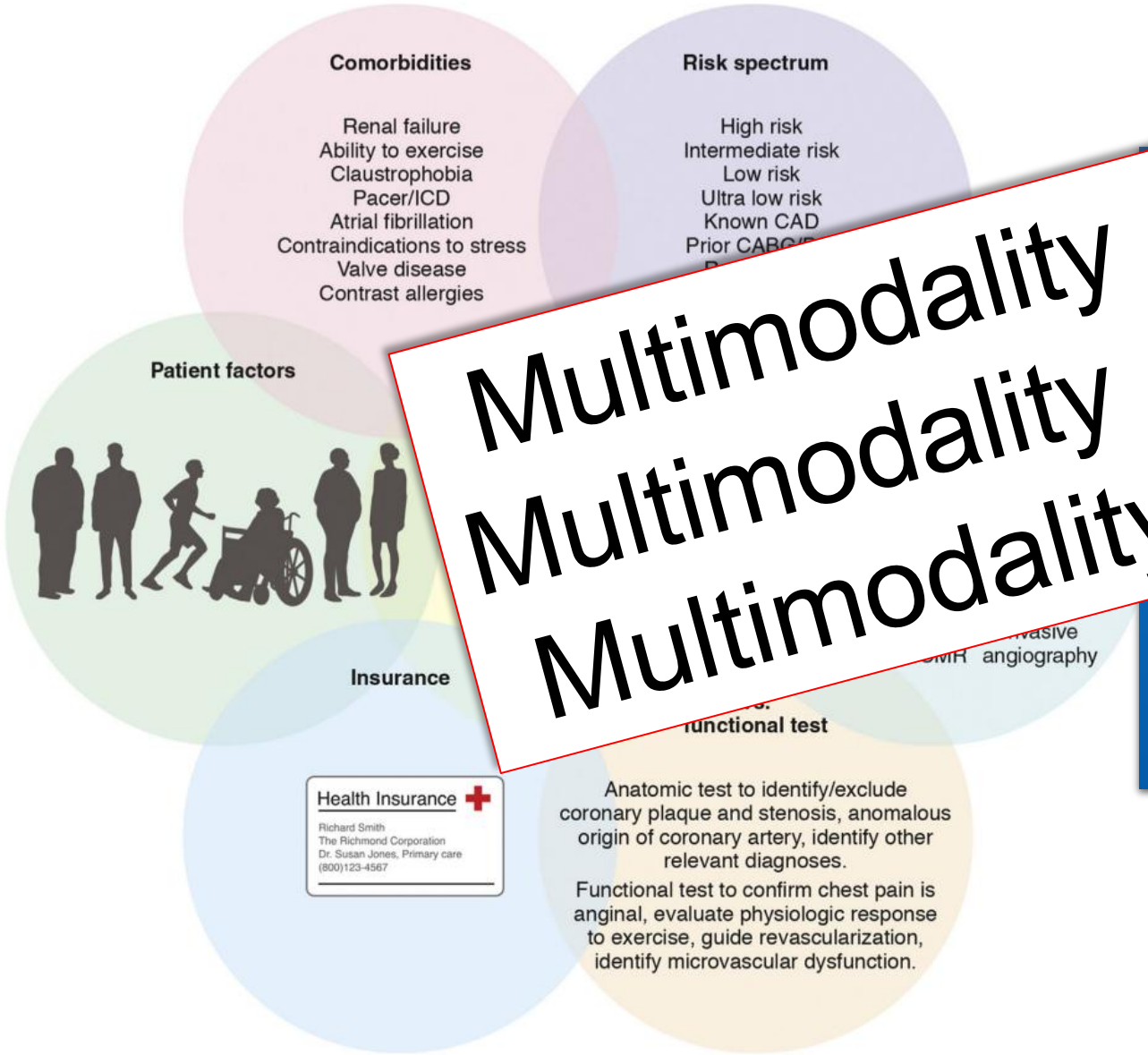
2024 ESC guidelines on the management of chronic coronary syndromes

Patient-centered approach



Multimodality mindset
Multimodality approach
Multimodality imagers

maging should be
ed on

ihood

Local expertise
- **Patient characteristics**
- **Patient preference**

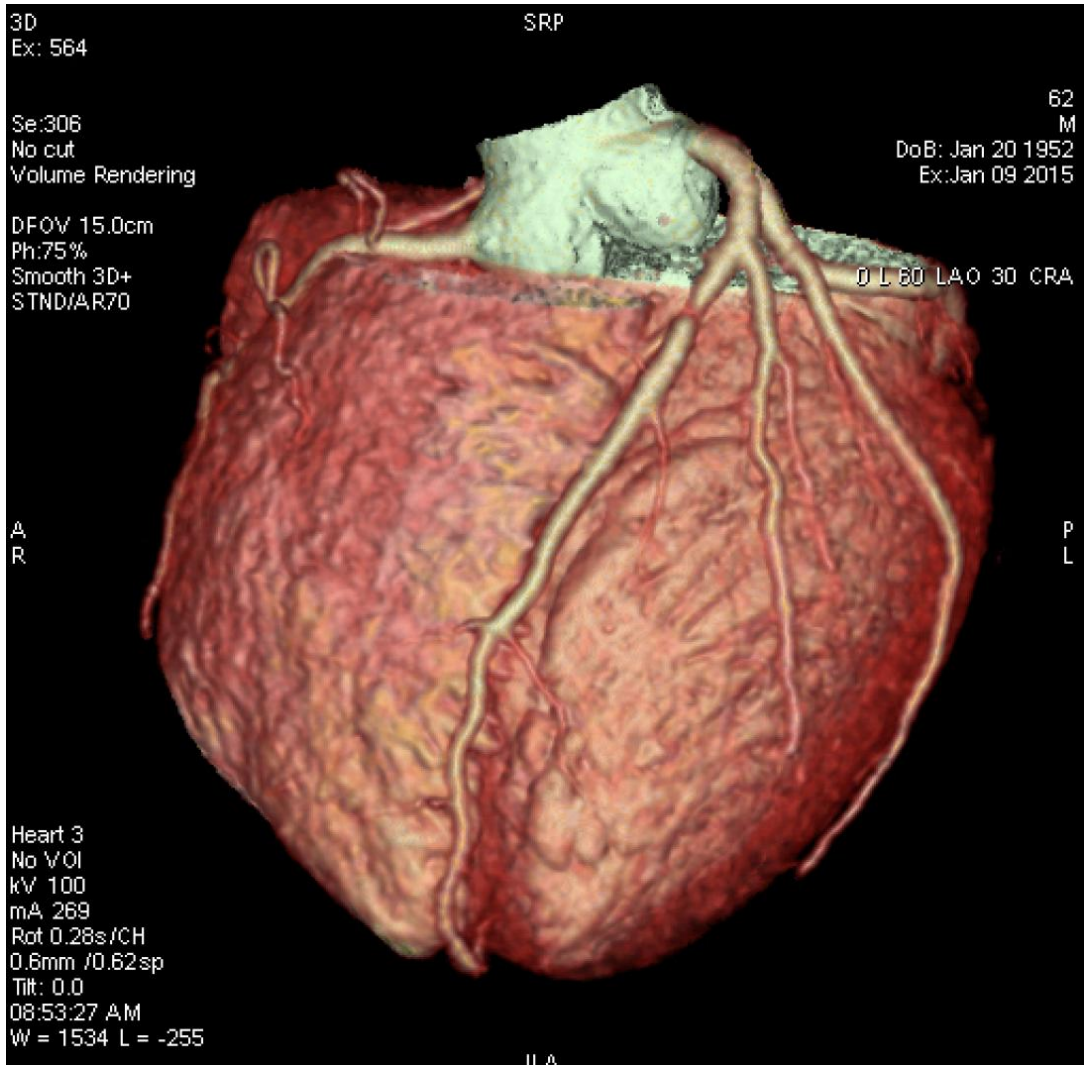
J Am Coll Cardiol. 2021 Sep 28;78(13):1385-1389.

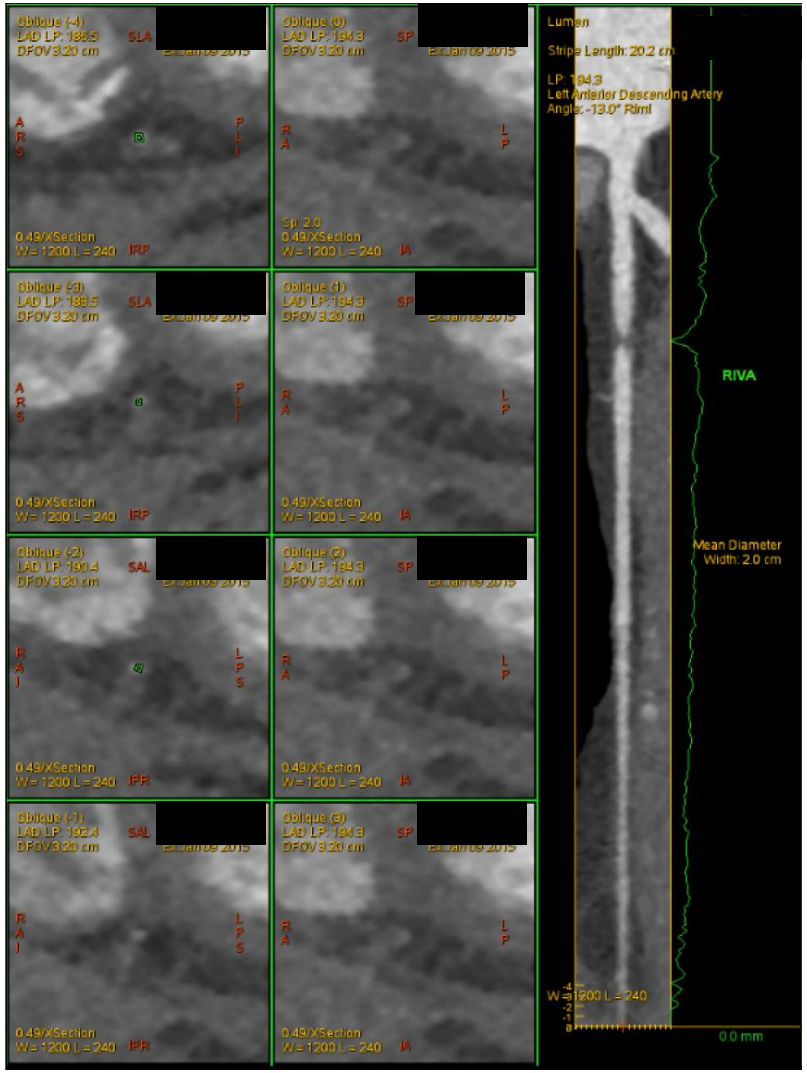
Thank you!

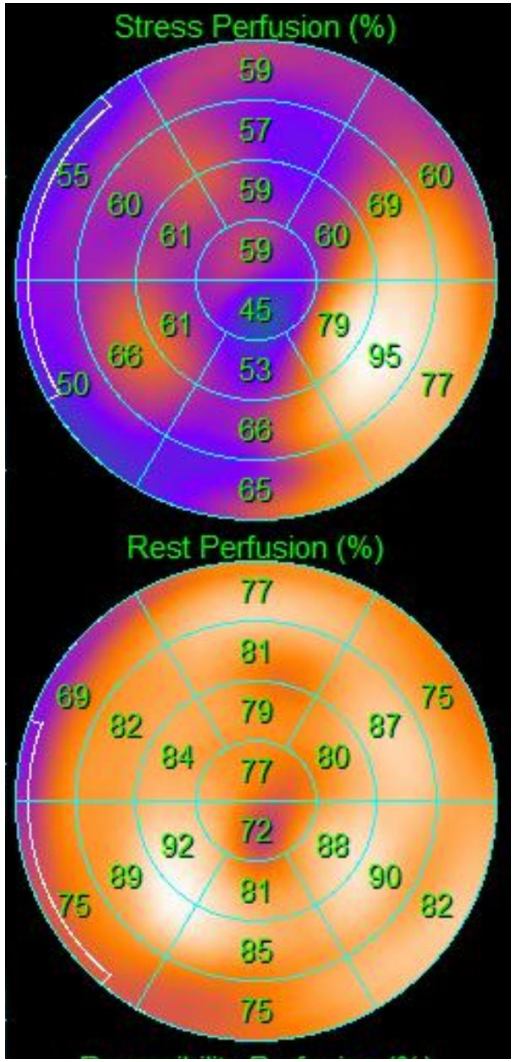
ronny.buechel@usz.ch

Diverses

Case

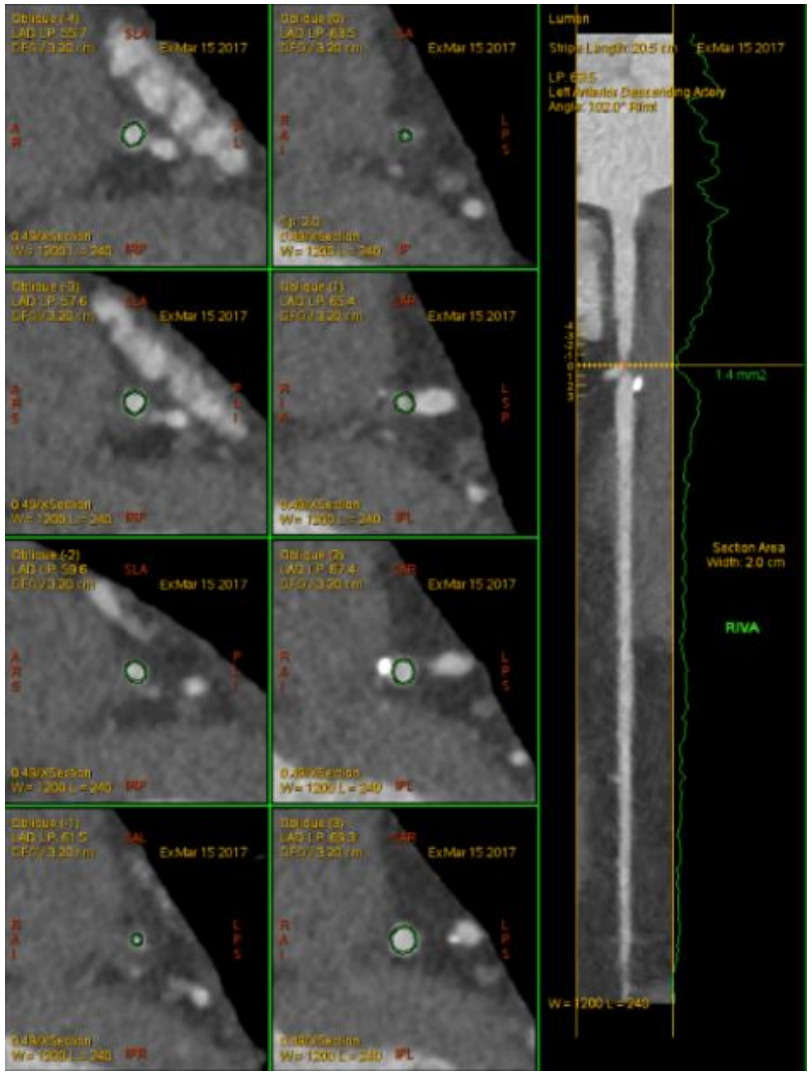

3D
Ex: 564
SRP
Se:306
No cut
Volume Rendering
62
M
DoB: Jan 20 1952
Ex:Jan 09 2015
DFOV 15.0cm
Ph:75%
Smooth 3D+
STND/AR70
0 L 60 LAO 30 CRA
A
R
P
L
Heart 3
No VOI
kV 100
mA 269
Rot 0.28s/CH
0.6mm /0.62sp
Tilt: 0.0
08:53:27 AM
W = 1534 L = -255

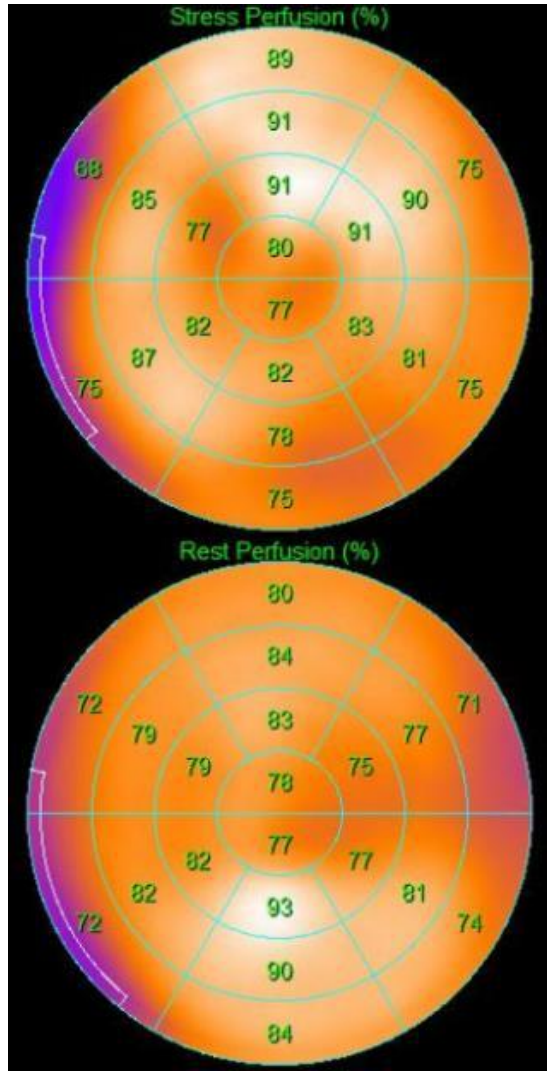

Lumen
Stripe Length: 20.2 cm
LP: 194.3
Left Anterior Descending Artery
Angle: -13.0° RIm
RIVA
Mean Diameter
Width: 2.0 cm
0.0 mm


Stress Perfusion (%)
59
57
55
60
59
60
69
61
60
59
45
61
79
66
95
50
53
77
66
65
Rest Perfusion (%)
77
81
69
82
79
75
87
84
80
77
72
92
88
89
90
81
75
82
85
75

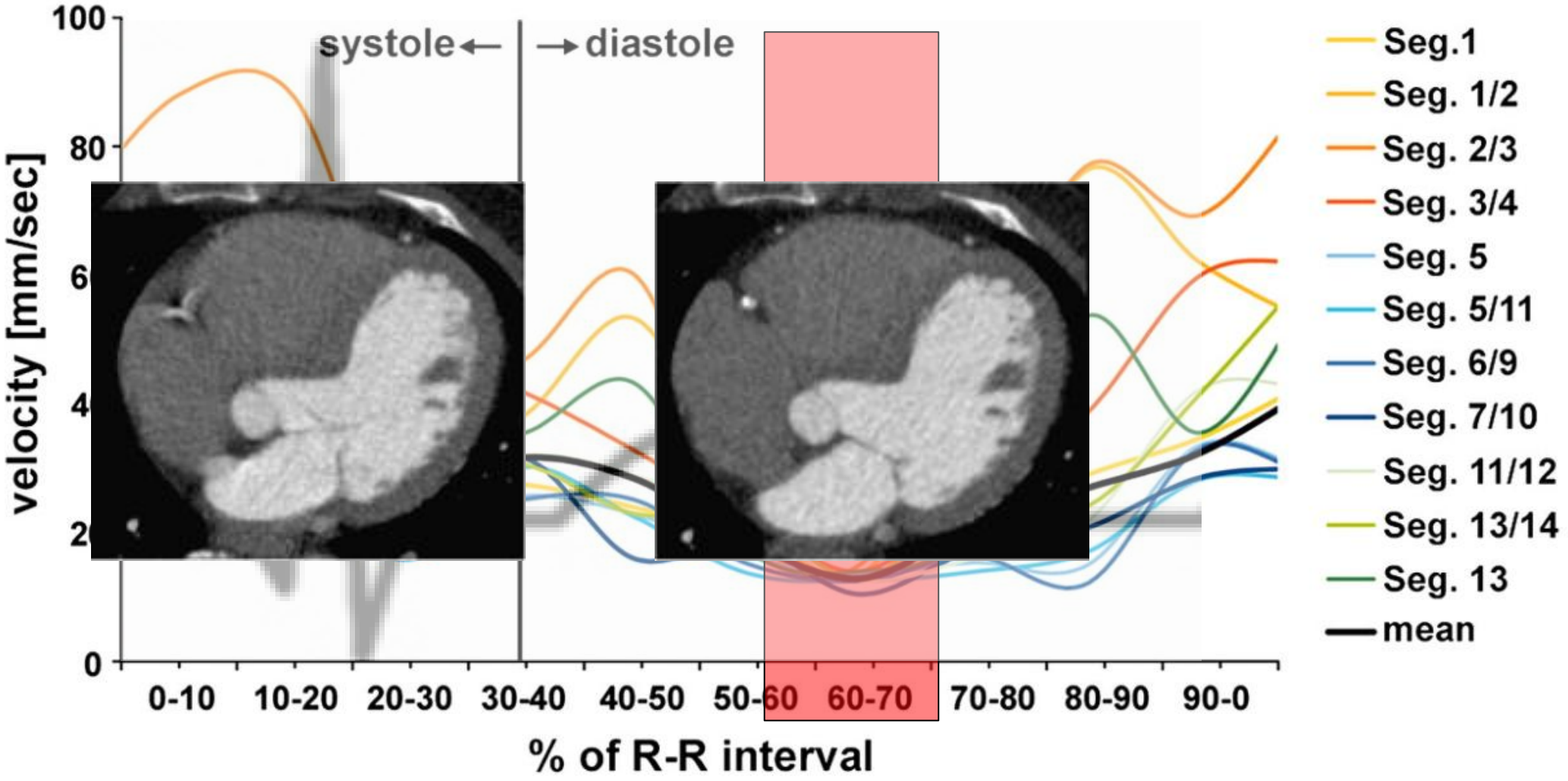
Case

3D
Ex: 6381
RSP
Se:308
No cut
Volume Rendering
DFOV 11.9cm
Smooth 3D+
64
M
DoB: Jun 11 1952
Ex:Mar 15 2017
-15 L 29 LAO 58 CRA
A
I
R
P
S
L
Heart 3
No VOI
0.6mm /0.62sp
10:25:33 AM
W = 1534 L = -255
LIA


ExMar 15 2017
Lumen
Section Area
Width: 2.0 cm
RIVA


Stress Perfusion (%)
89
91
88
75
85
90
91
77
80
77
82
83
87
81
82
75
75
78
75
Rest Perfusion (%)
80
84
72
71
79
77
83
79
75
78
77
82
77
82
81
72
74
93
90
84

Coronary CT angiography (CCTA)



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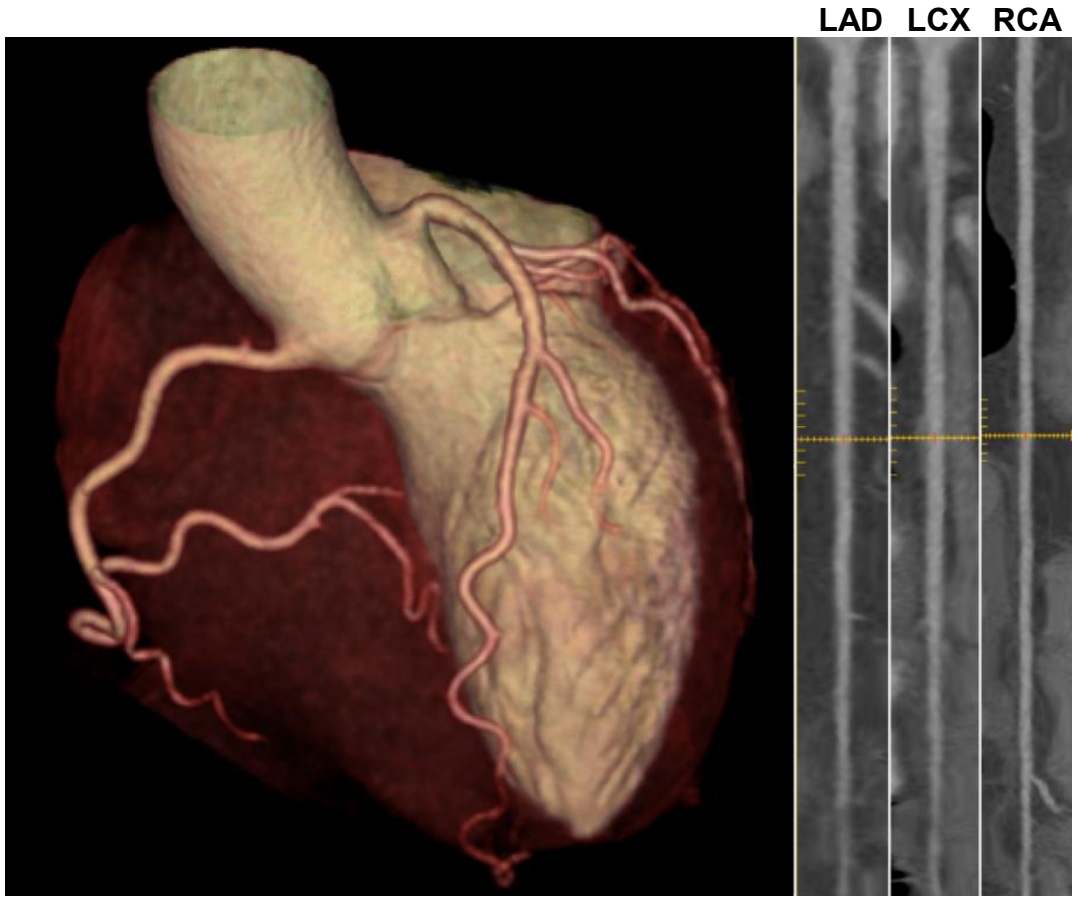
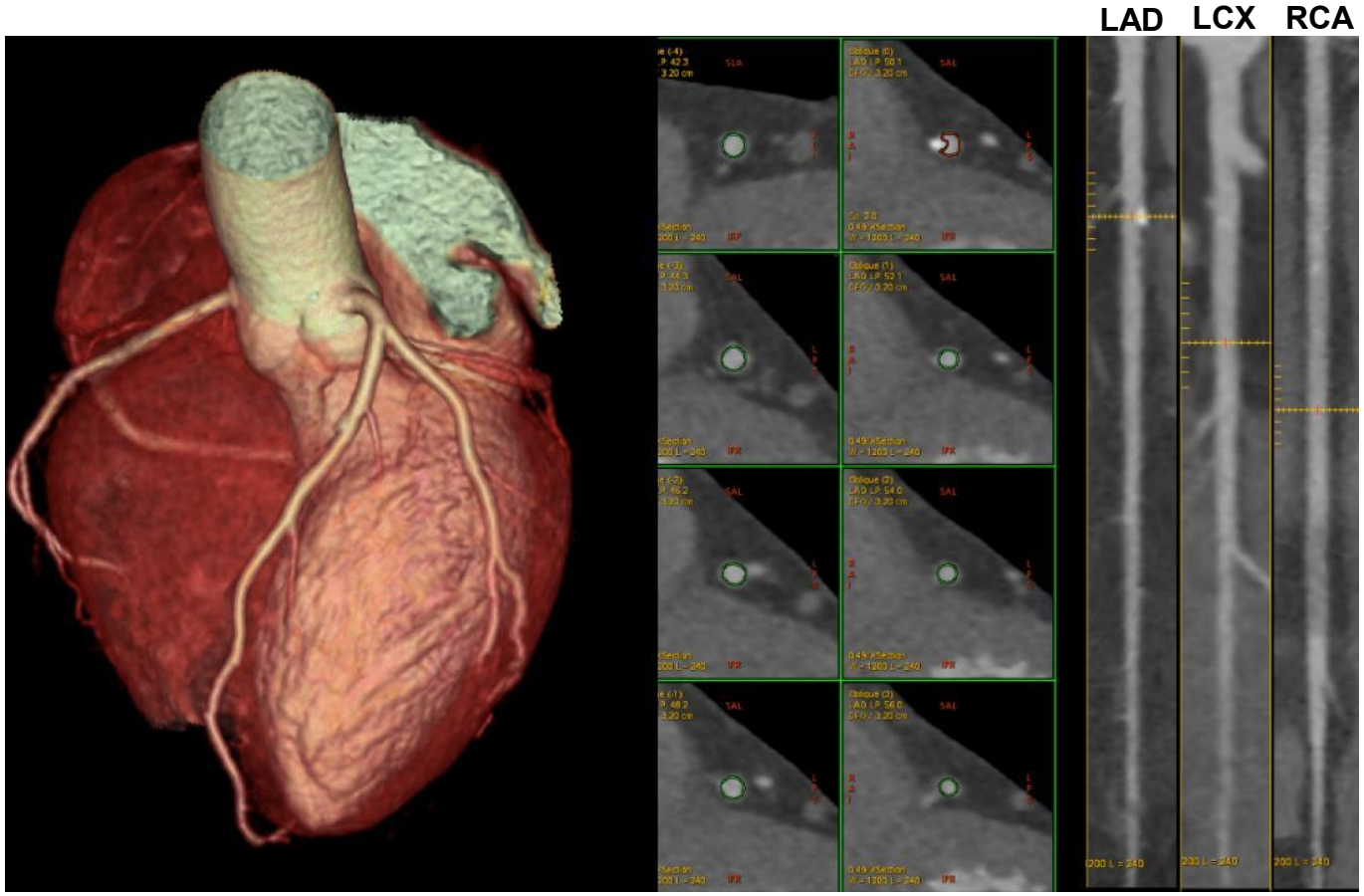
Husmann et al. Radiology. 2007 Nov;245(2):567-76.





Obstructive CAD definitely excluded
in less than 30 minutes and with <1mSv of radiation exposure

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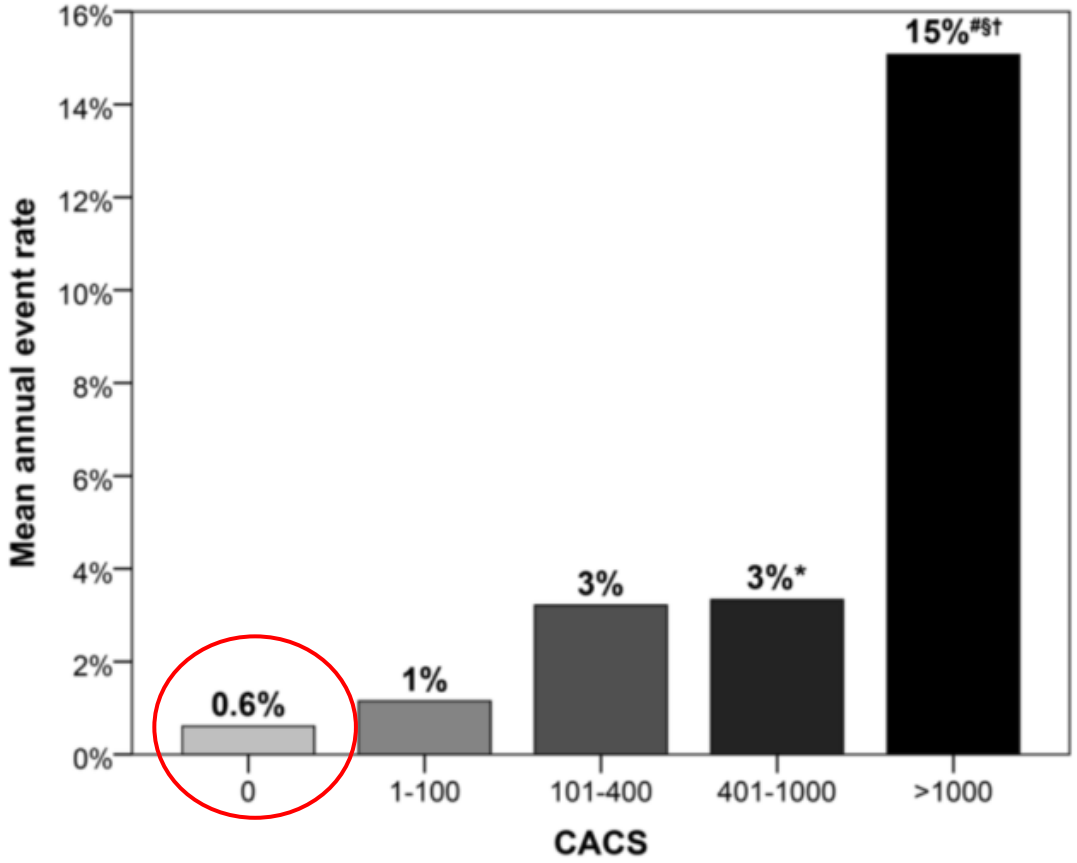
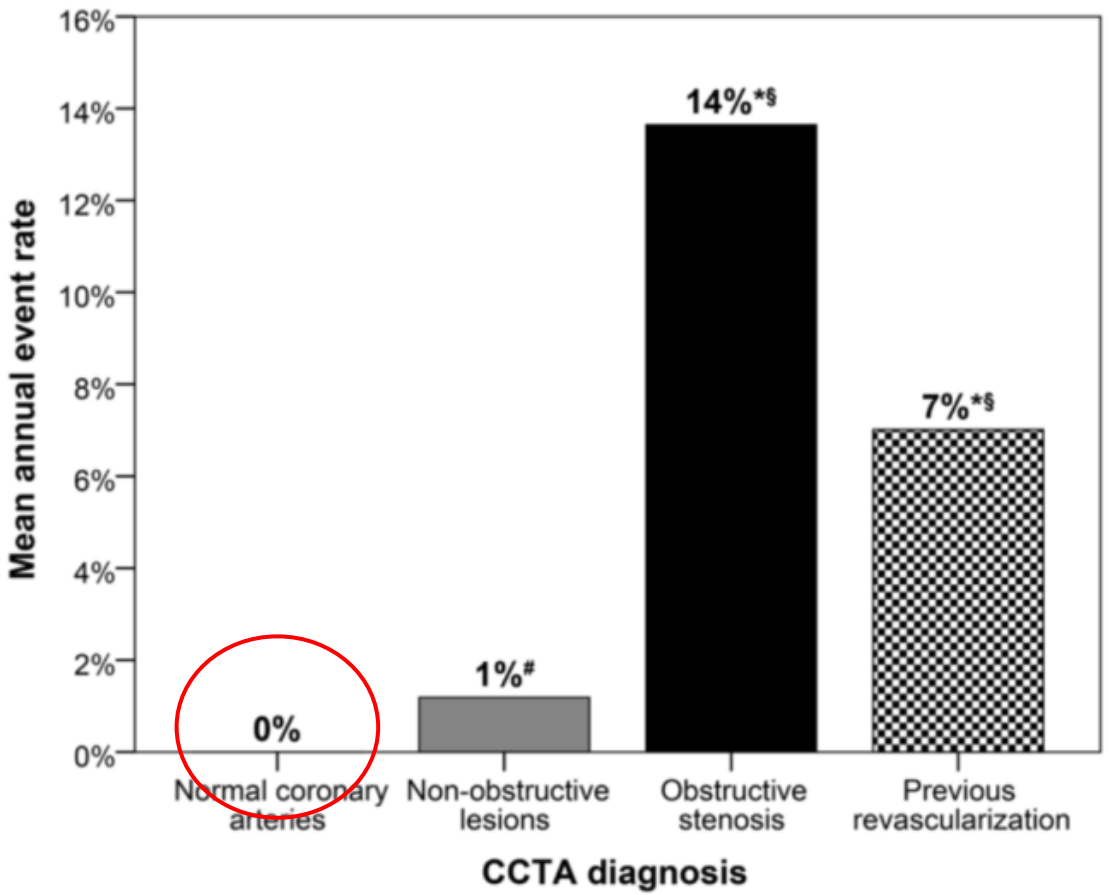
Prognostischer Wert: Kalzium-Score versus Koro-CT





n = 434

Follow-Up = 6.1 ± 0.6 Jahre

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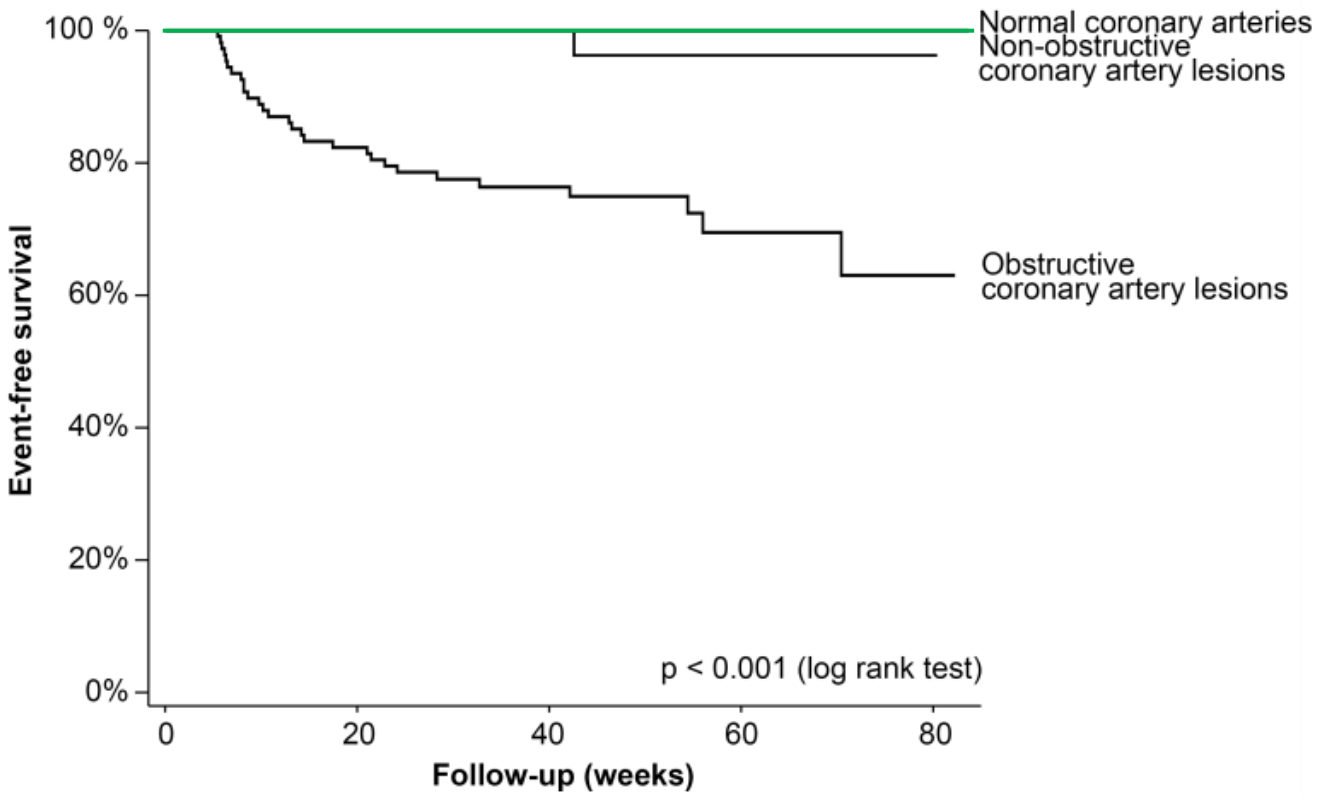
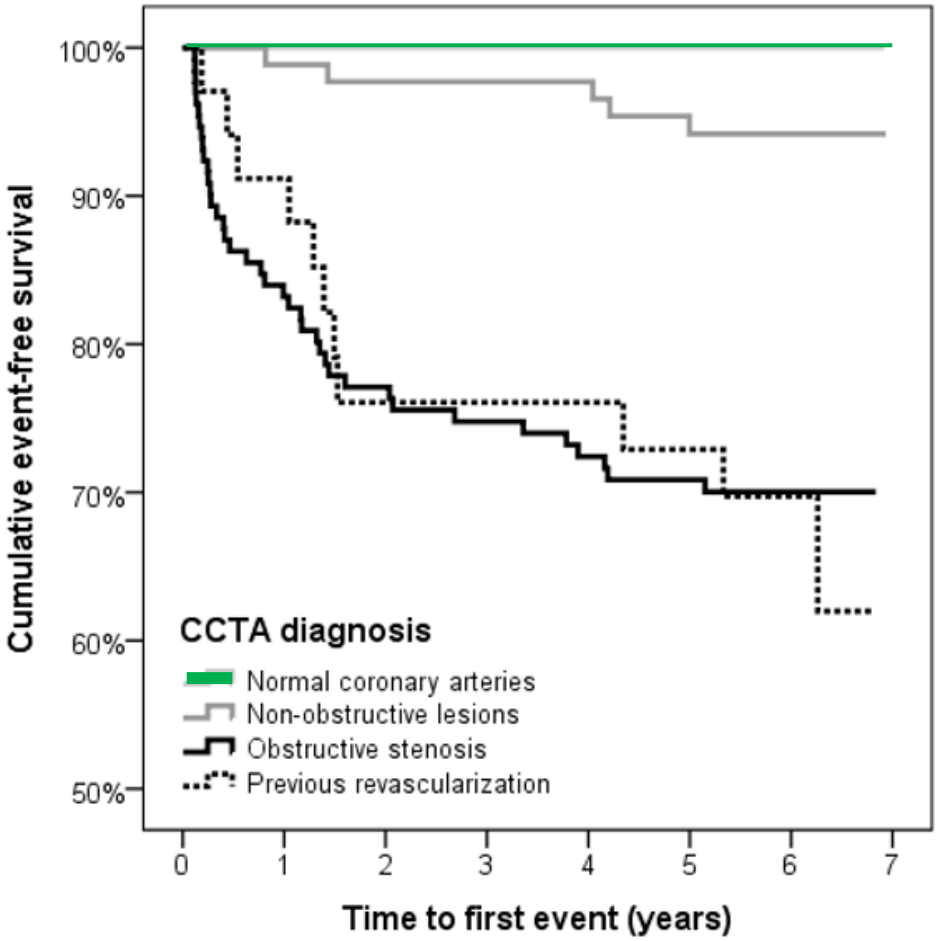
Cerc OF & Buechel RR et al. Eur Radiol. 2017 May 12.

Prognostische Wertigkeit der Koro-CT

n = 434; mittlerer Follow-up 47±16 Wochen [1]



n = 405; medianer Follow-up 6.1 Jahre [2]



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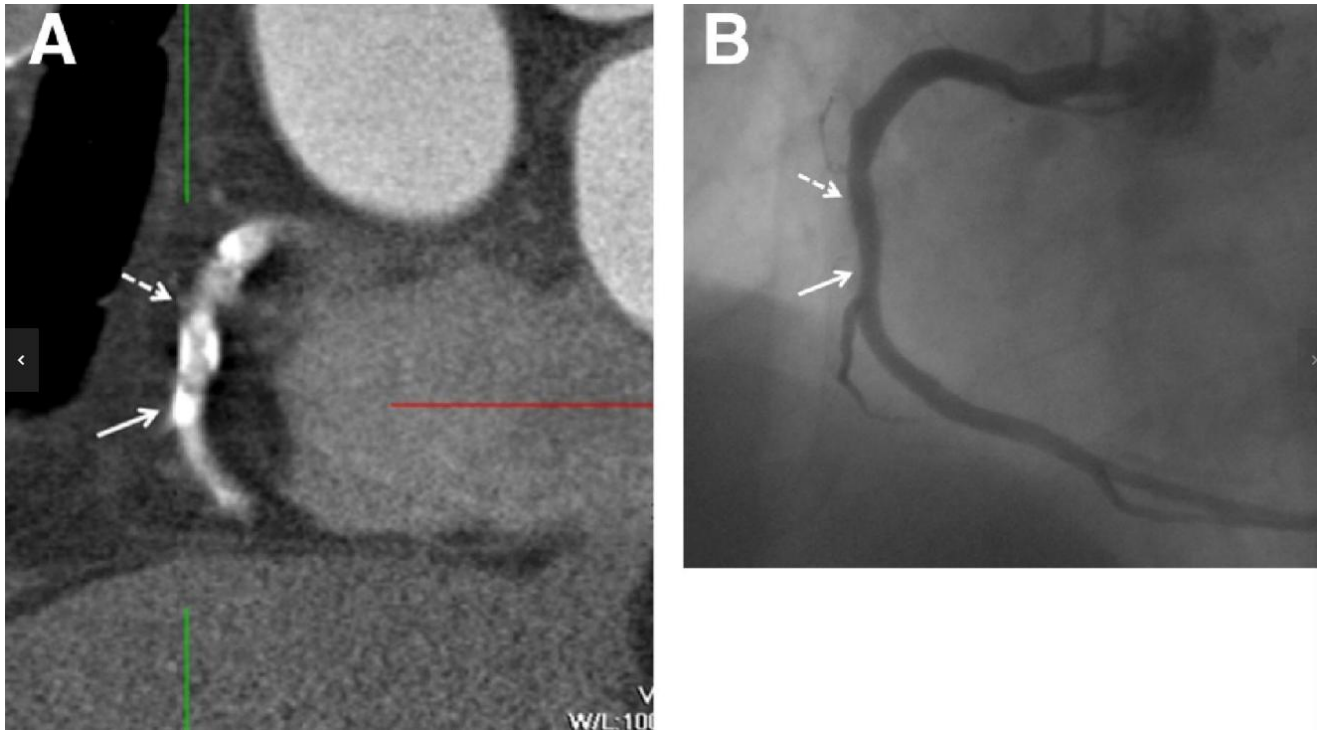
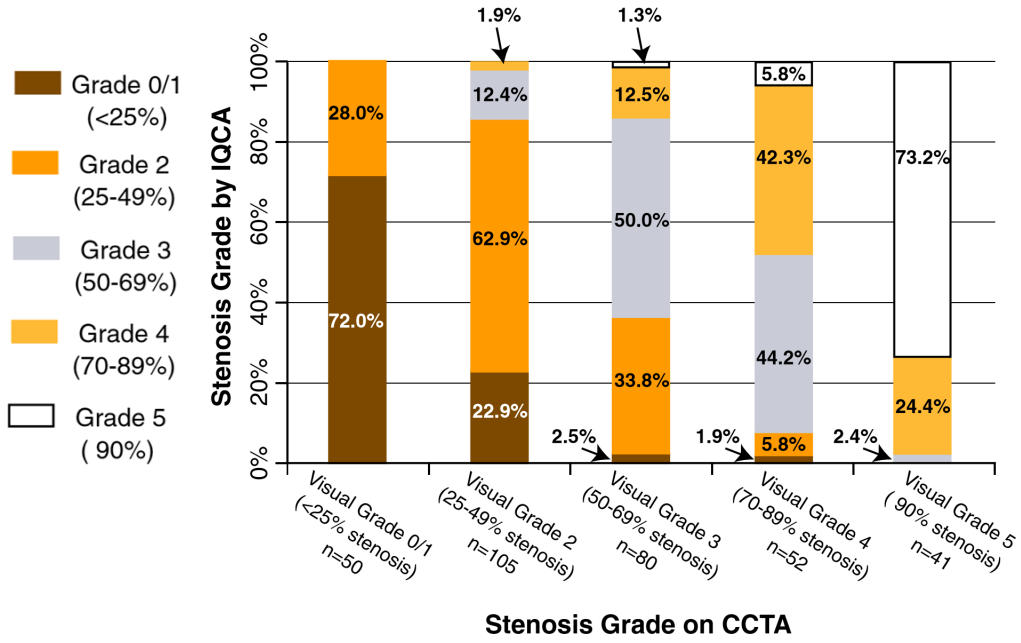
[1] *Buechel RR et al. Heart. 2011 Sep;97(17):1385-90.*

[2] *Clerc OF and Buechel RR et al. Eur Radiol. 2017 Nov;27(11):4650-4660*

CCTA overestimates stenoses





False-positive findings in up to 35%

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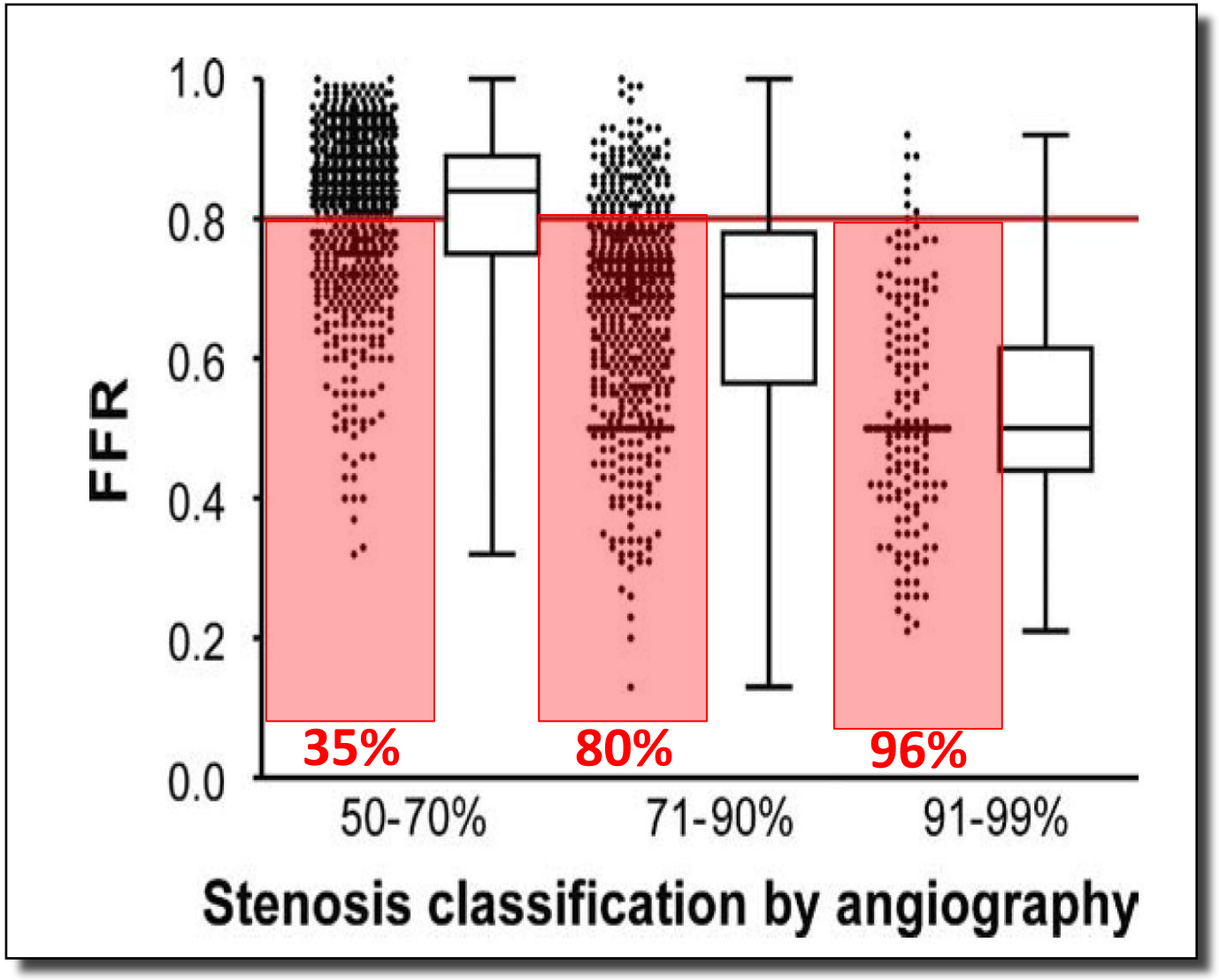
Arbab-Zadeh et al. JACC Cardiovasc Imaging. 2011 Feb;4(2):191-202.
Cheng et al. JACC Cardiovasc Imaging. 2008 Jul;1(4):460-71

Ischemia versus stenosis



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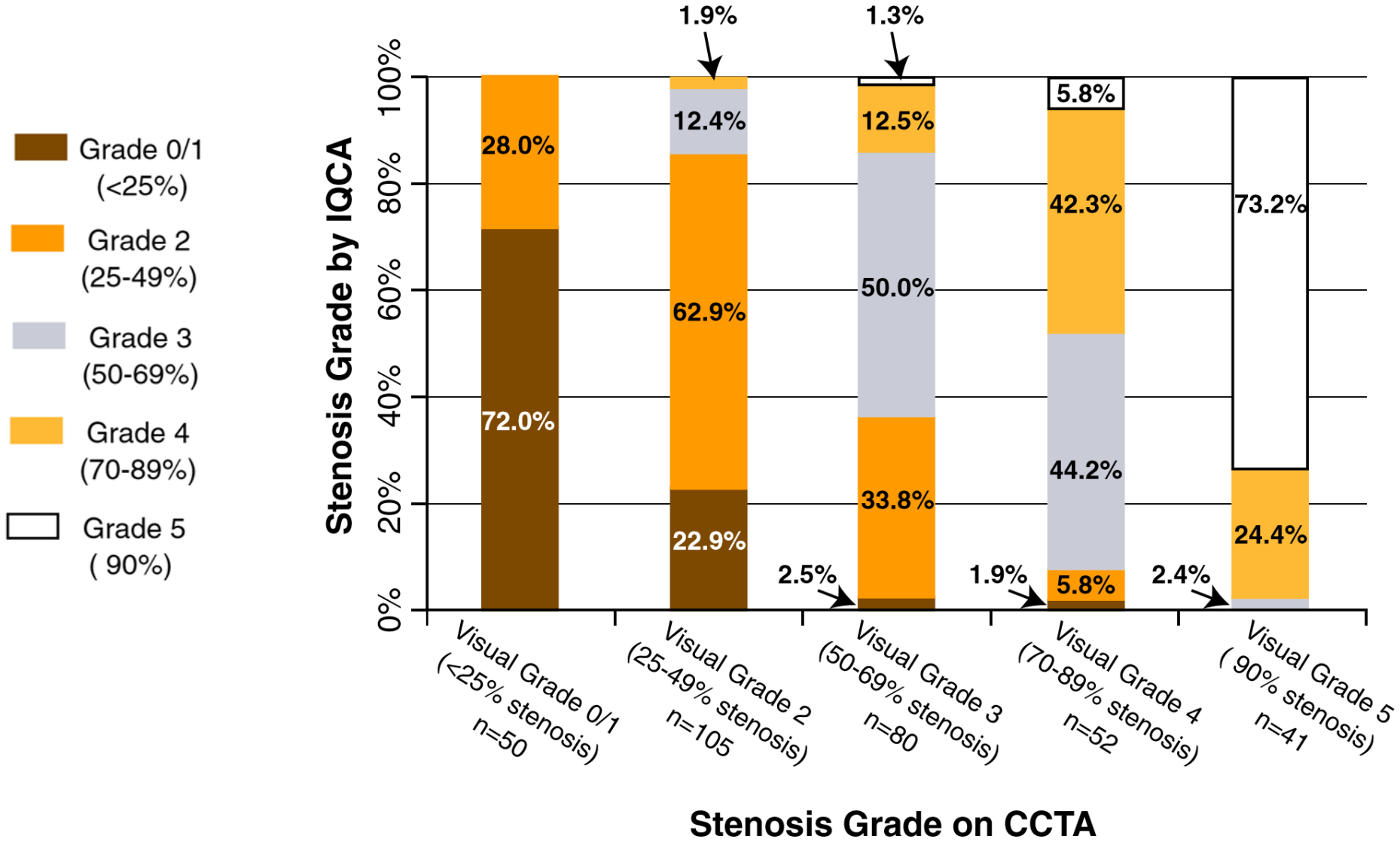
Tonino et al. FAME. J Am Coll Cardiol. 2010 Jun 22;55(25):2816-21

CCTA overestimates stenoses



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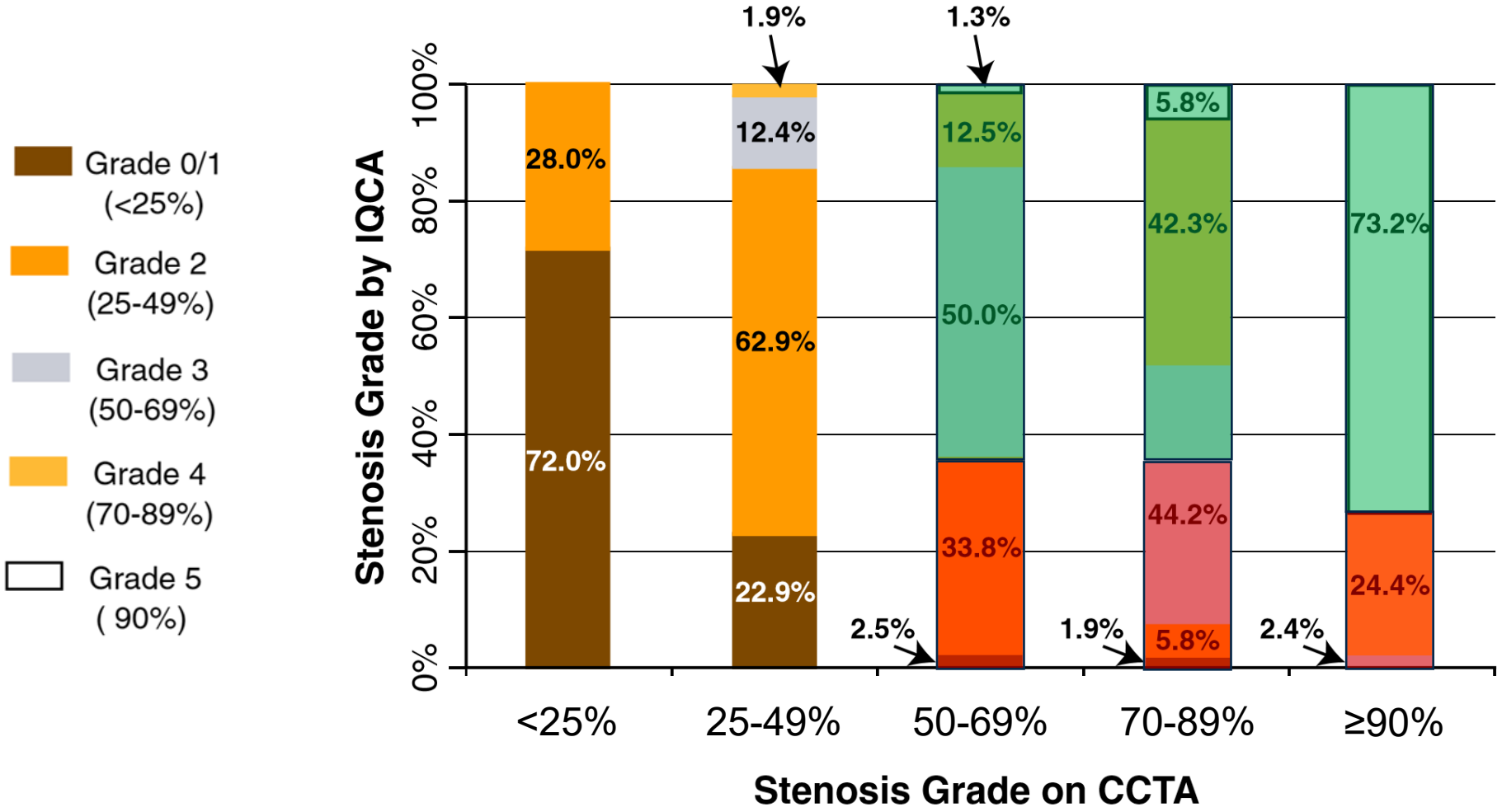

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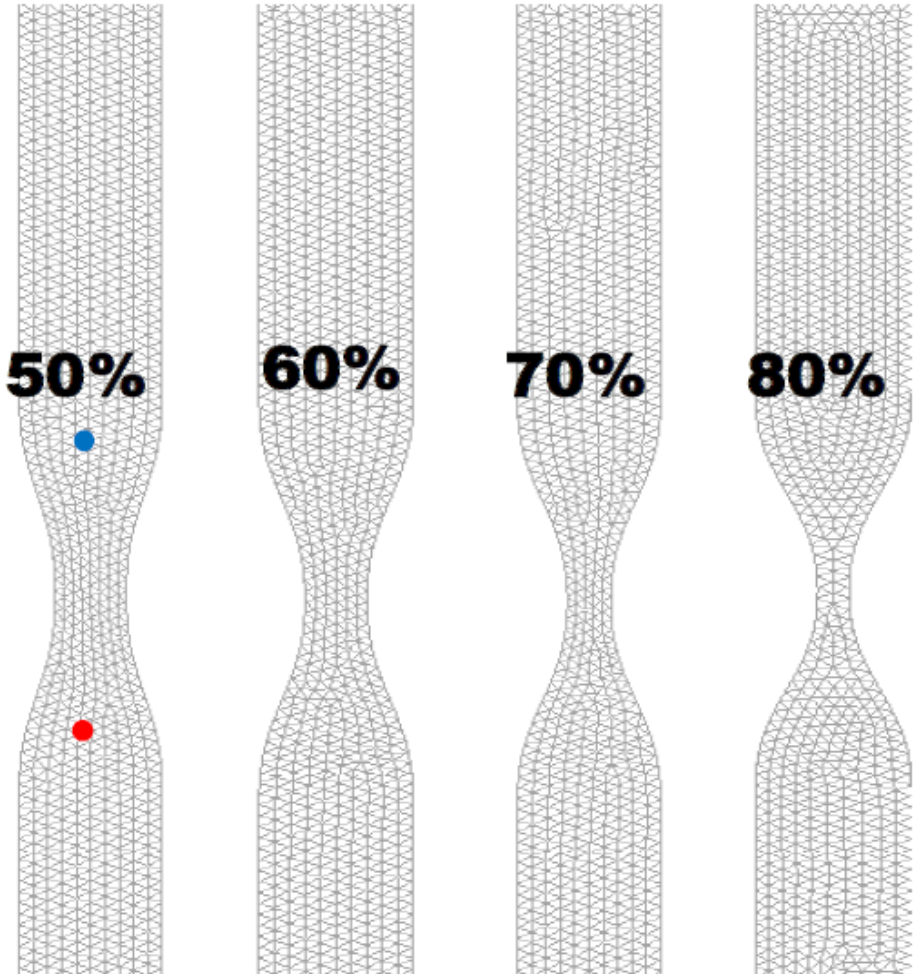
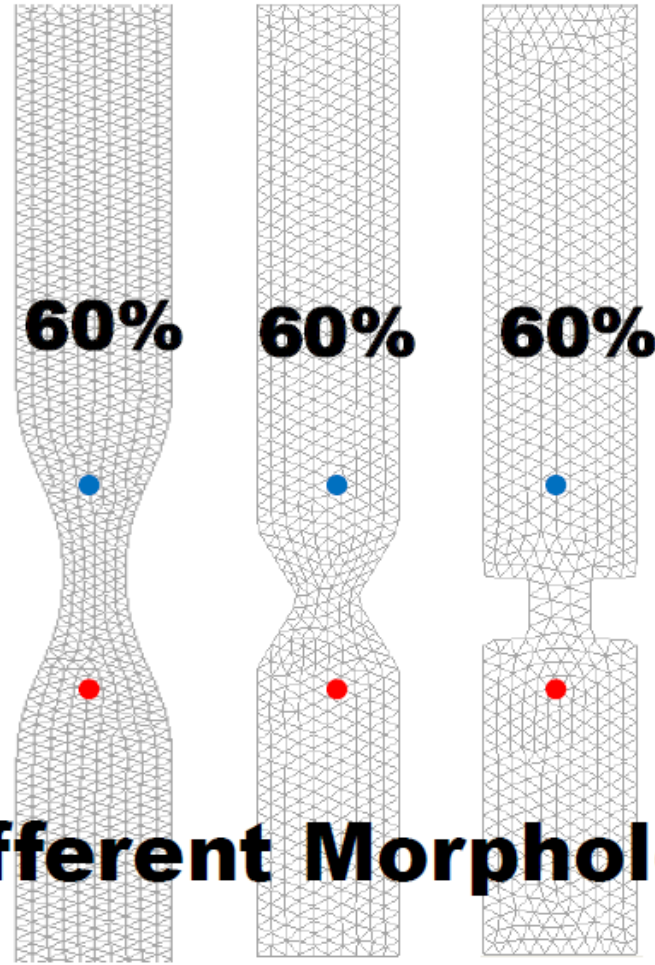
Modified from Cheng et al. JACC Cardiovasc Imaging. 2008 Jul;1(4):460-71

Impact of plaque morphology on perfusion



FFR

0.89 0.81 0.76 0.70



Different Morphology

0.81 0.77 0.63

Different FFR

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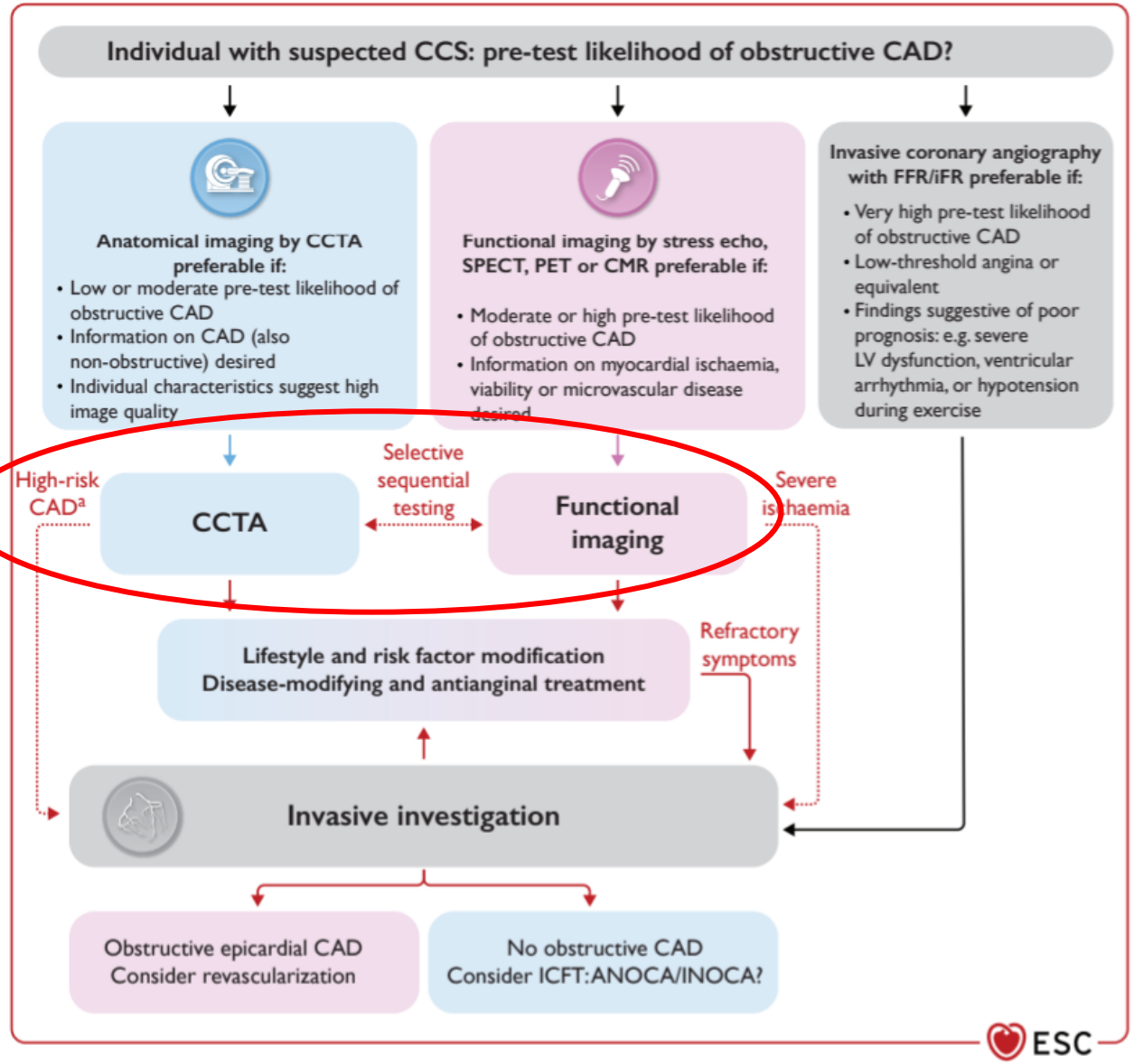
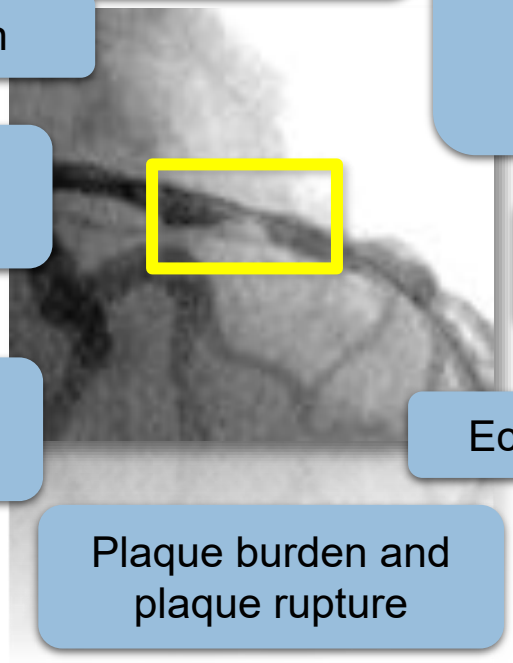
Courtesy of SJ Park

What do the guidelines recommend?



2024 ESC guidelines on the management of chronic coronary syndromes

Stenosis ≠ Ischemia



Severity of diameter stenosis

Lesion length

Reference vessel diameter

Lesion morphology

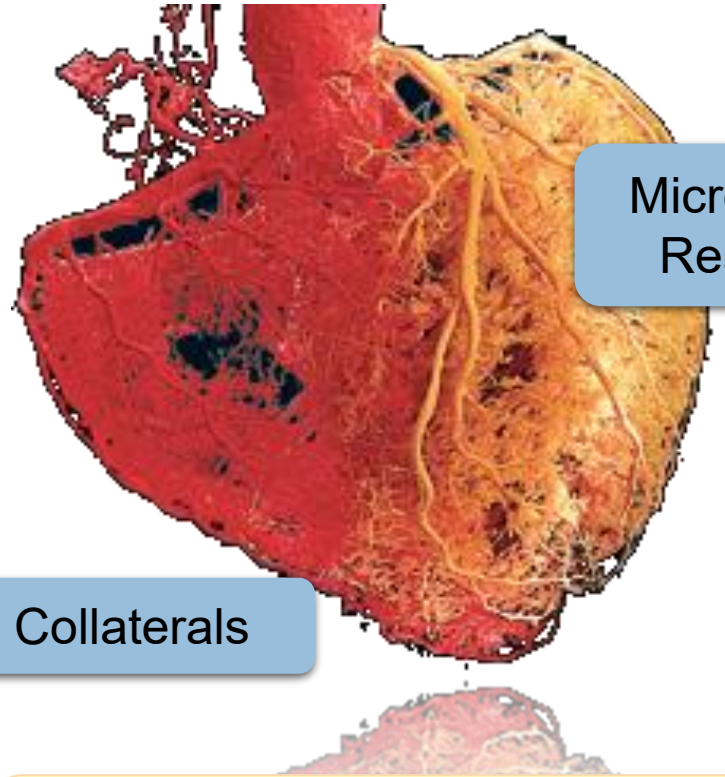
Viscous friction, flow separation, turbulence and eddies

Surface roughness

Eccentricity

Plaque burden and plaque rupture

Lesions-specific factors



Microvascular Resistance

Collaterals

Factors that affect myocardial blood flow

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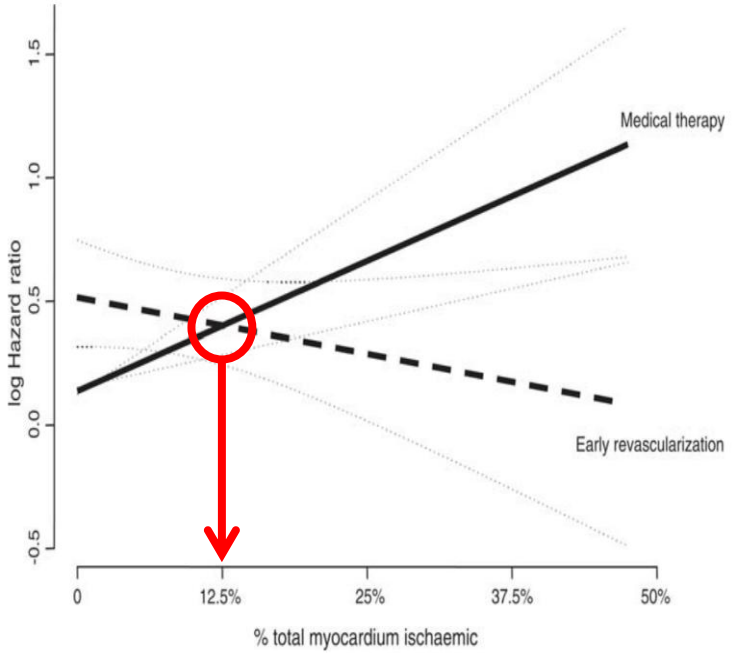
The functional significance of coronary lesions is determined by many factors

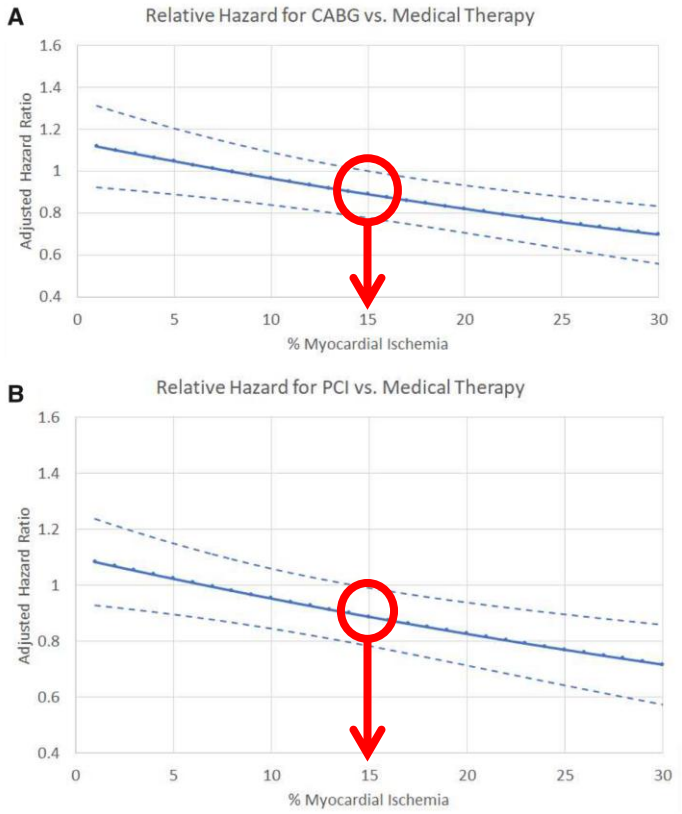
Prognosic benefit of revascularization depends on ischemic burden

SPECT

n = 14‘627

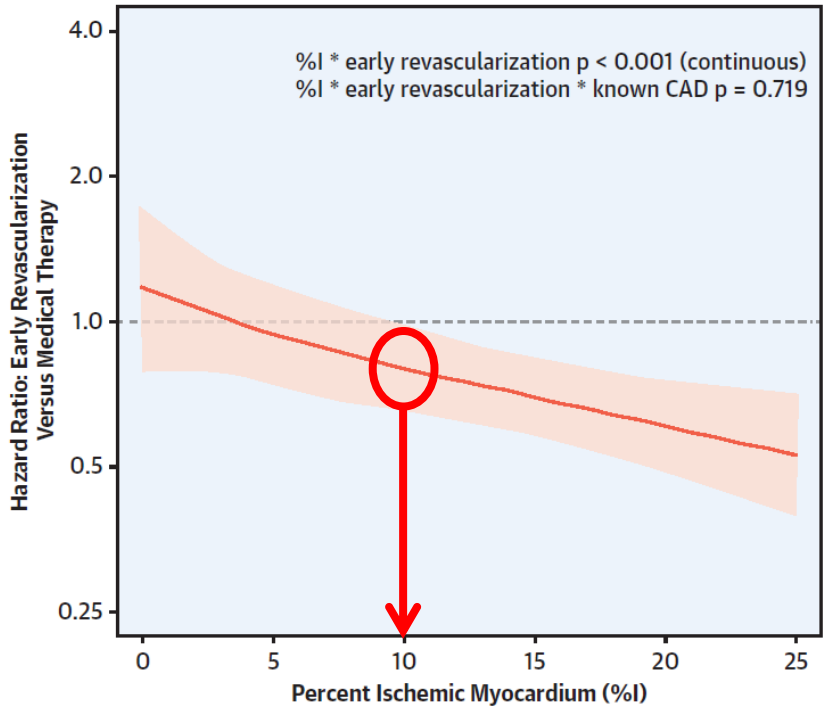


n = 7’832



PET

n = 16‘029



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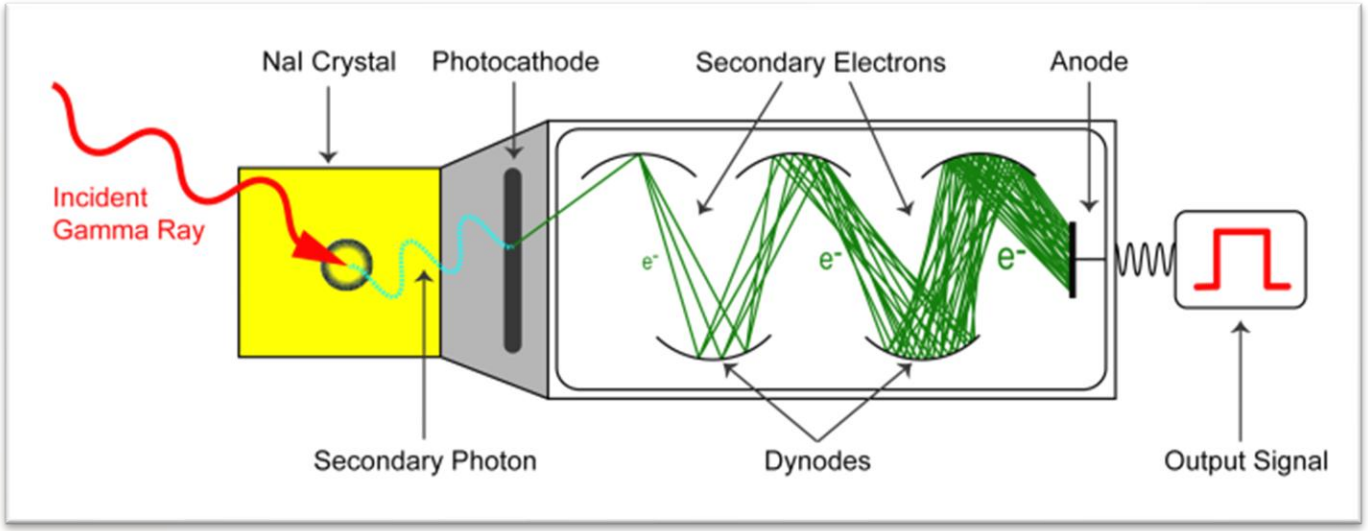
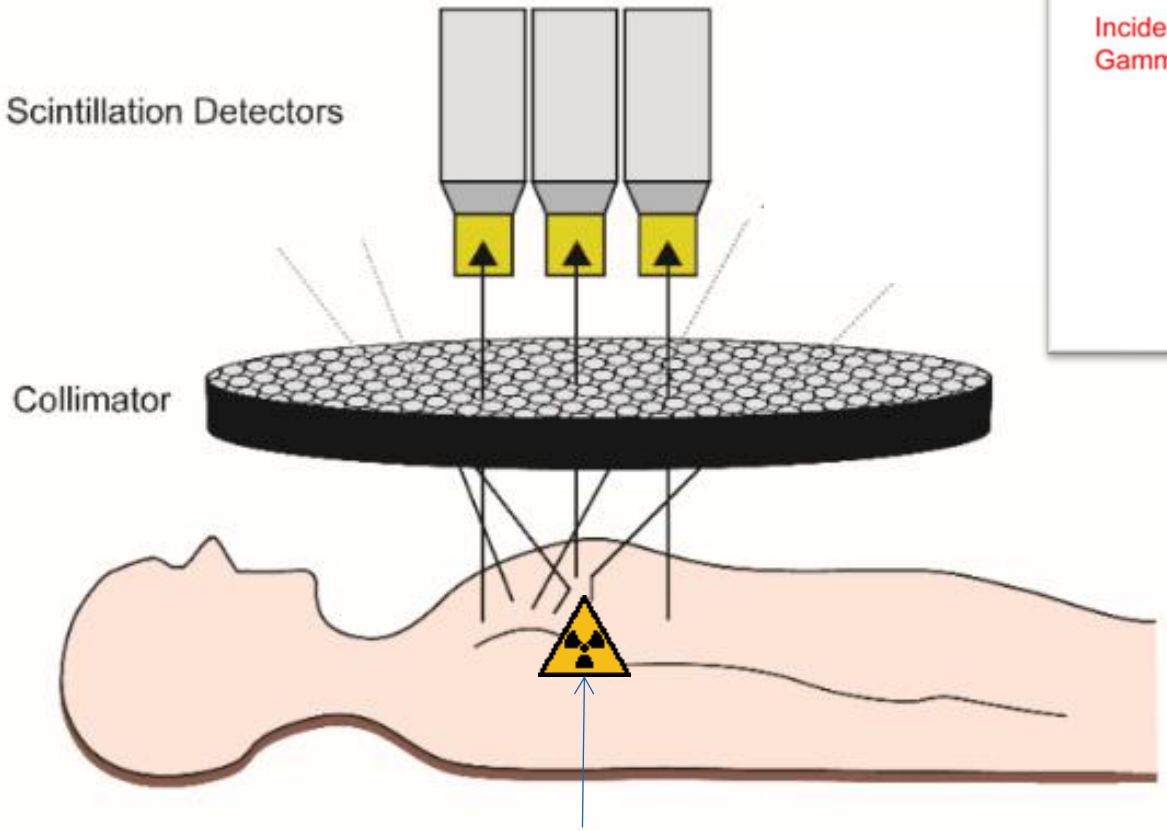
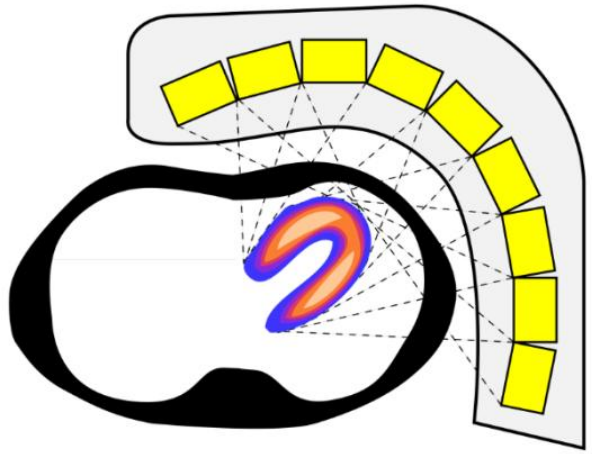
Hachamovitch R et al. Eur Heart J. 2011 Apr;32(8):1012-24
Miller et al. Eur Heart J Cardiovasc Imaging. 2020 Sep 1;21(9):961-970.
Patel KK et al. J Am Coll Cardiol. 2019 Oct; 74(13):1645-1654.

Principle of Scintigraphy and SPECT



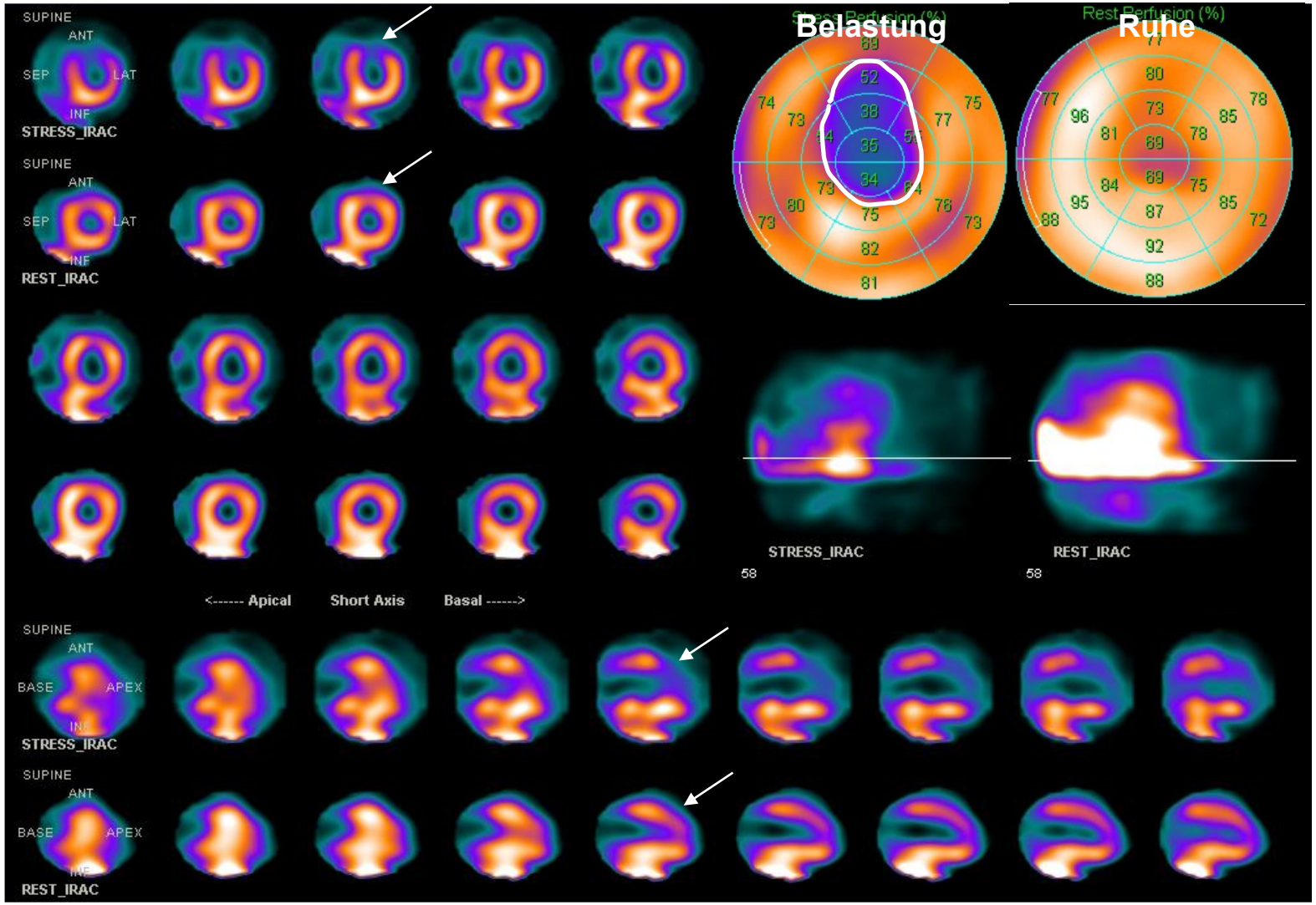


^{99m}Tc-Tetrofosmin / ^{99m}Tc-MIBI

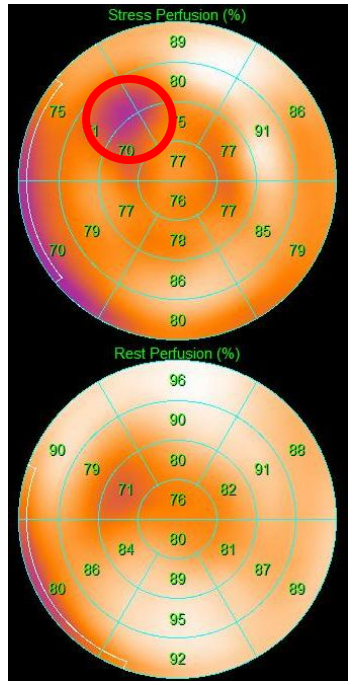


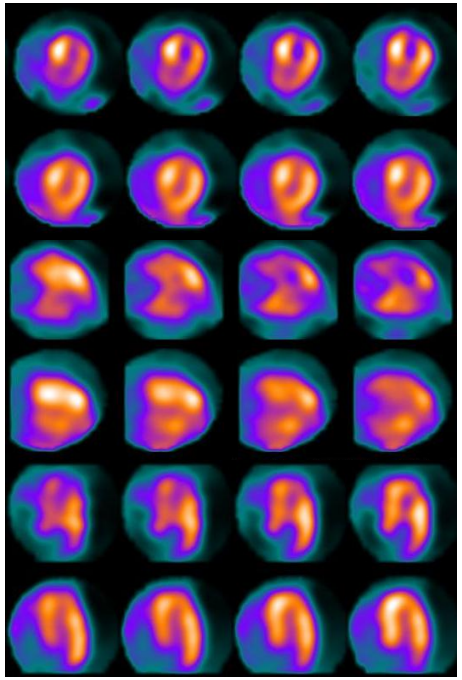
Buechel RR et al. Technological developments – SPECT. In Nieman K, Gaemperli O, Lancelotti P and Plein S (Eds.), Advanced Cardiac Imaging. Cambridge, GB: Woodhead Publishing. 2015 Aug 10.

SPECT myocardial perfusion imaging



99mTc-Tetrofosmin SPECT-MPI





Advantages
- Widely available
- Good diagnostic accuracy
- No contraindications

Disadvantages
- Image artifacts (attenuation)
- Radiation dose exposure (5-10mSv)
- Relative perfusion assessment

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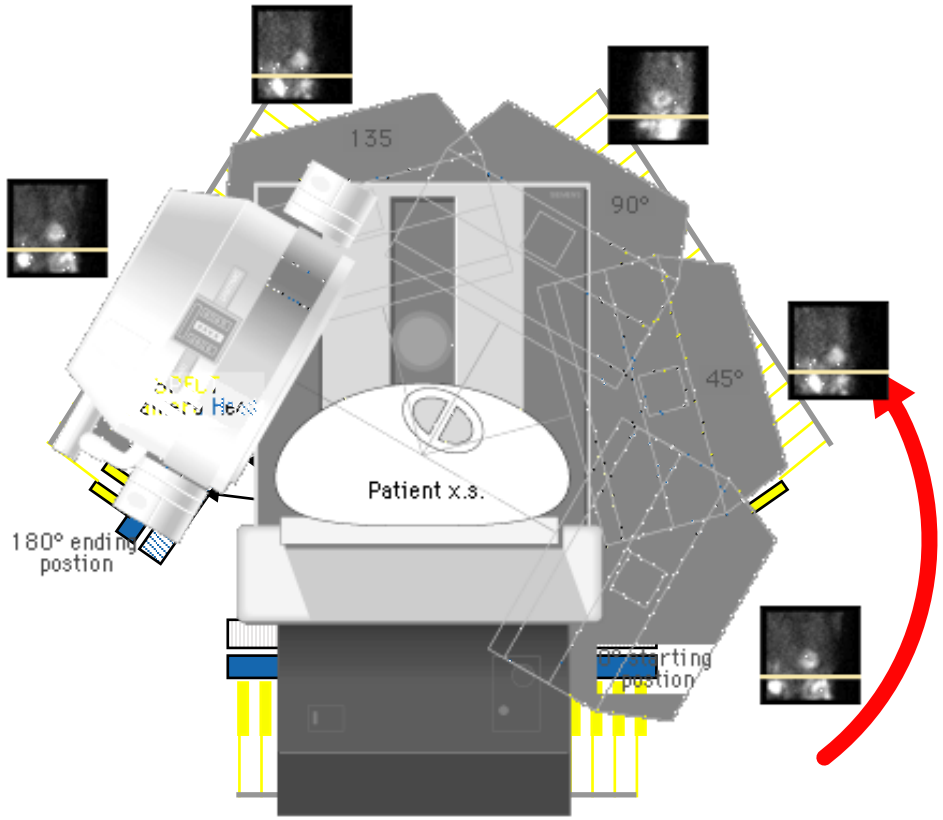
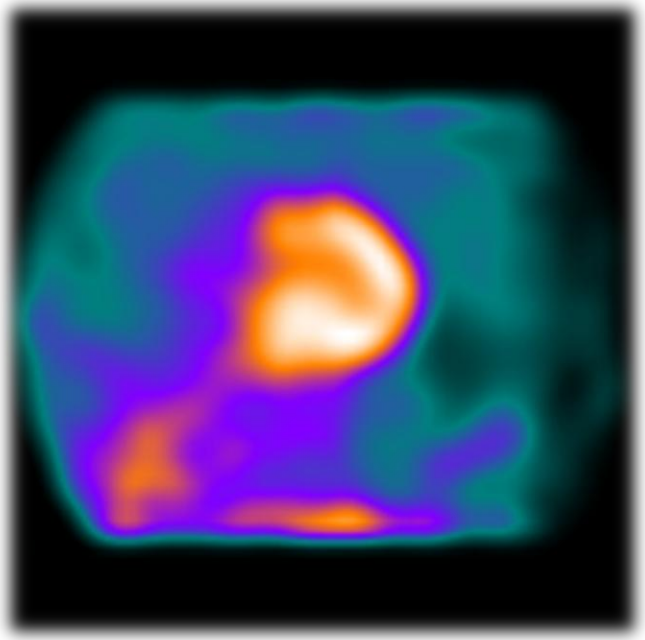
Single-Photon-Emission-Computed-Tomography (SPECT)

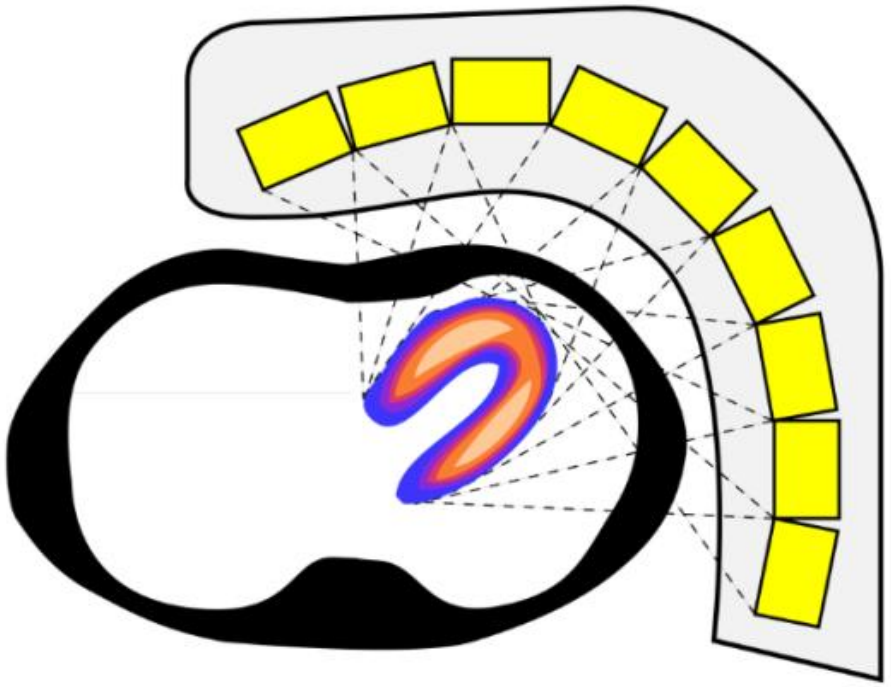




Dauer Bildakquisition: ca. 15-20 Minuten
Strahlenbelastung: 8-10 mSv

Konventionelle SPECT-Kamera

SPECT mit Halbleiter-Detektoren aus Cadmium-Zink-Tellurit



Dauer Bildakquisition: 2-3 Minuten[1,2]
Strahlenbelastung: 4-6 mSv

Moderne CZT-Kamera

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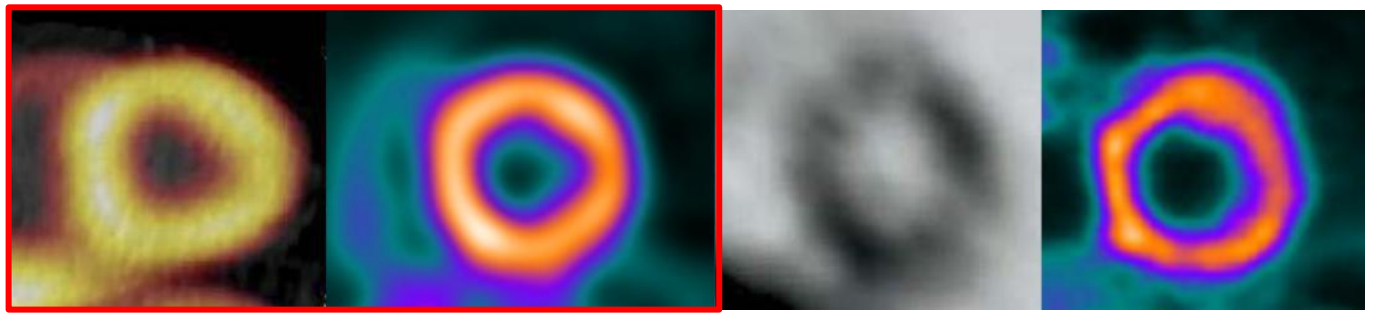
[1] Buechel RR et al. Eur J Nucl Med Mol Imaging. 2010 Apr;37(4):773-8.
[2] Herzog BA & Buechel RR et al. J Nucl Med. 2010 Jan;51(1):46-51.

PET Myokardperfusions-Tracer

Tracer	*Production*	*Half-life*
^{15}O-Water	Cyclotron	2 min
^{13}N-Ammonia	Cyclotron	10 min
^{82}Rubidium	Generator	1 min
^{18}F-Flurpiridaz*	Cyclotron	110 min

** currently in phase III study*



^{82}Rb ^{13}N-NH_3 ^{15}O-H_2O ^{18}F-Flurpiridaz

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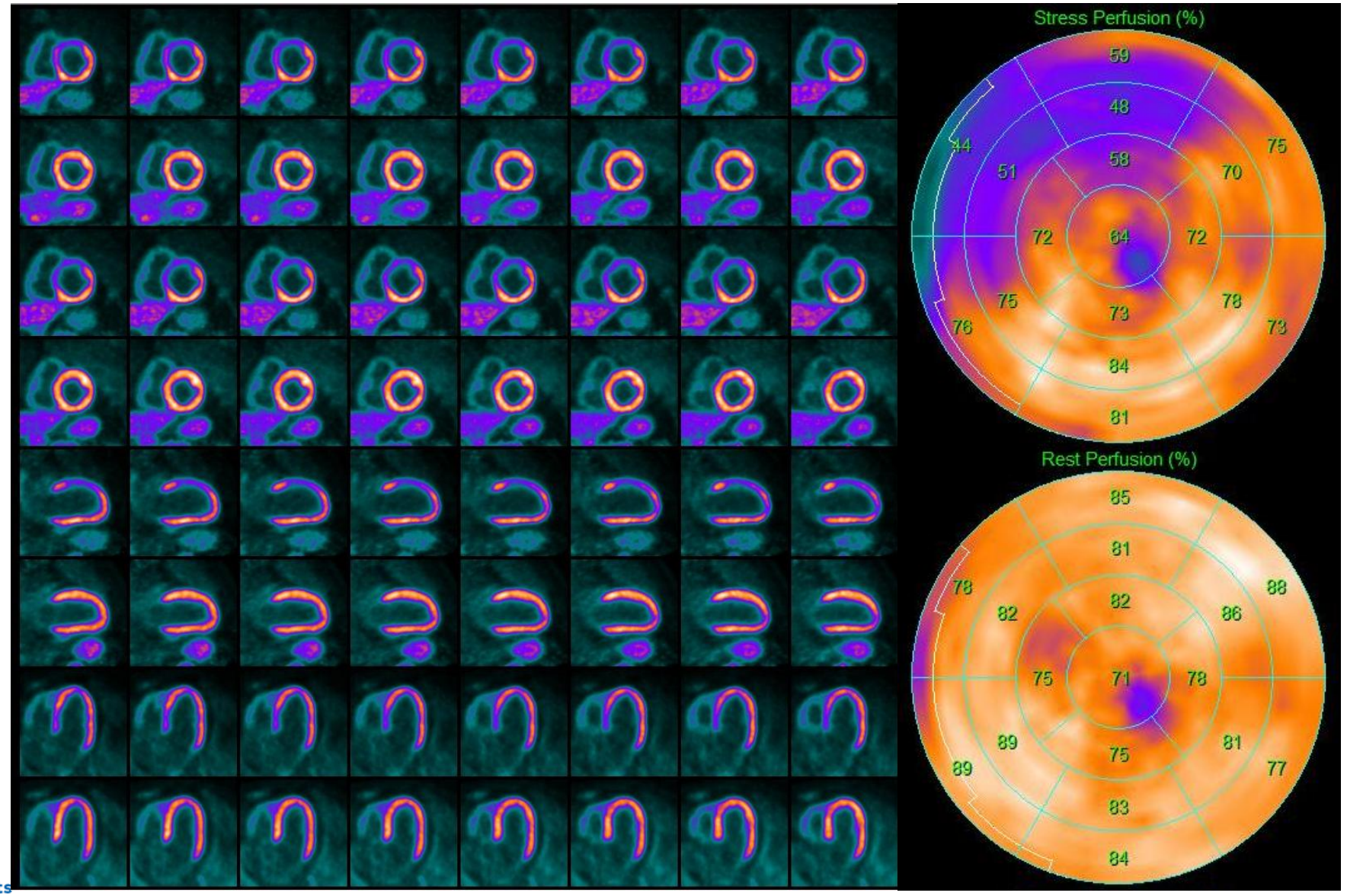
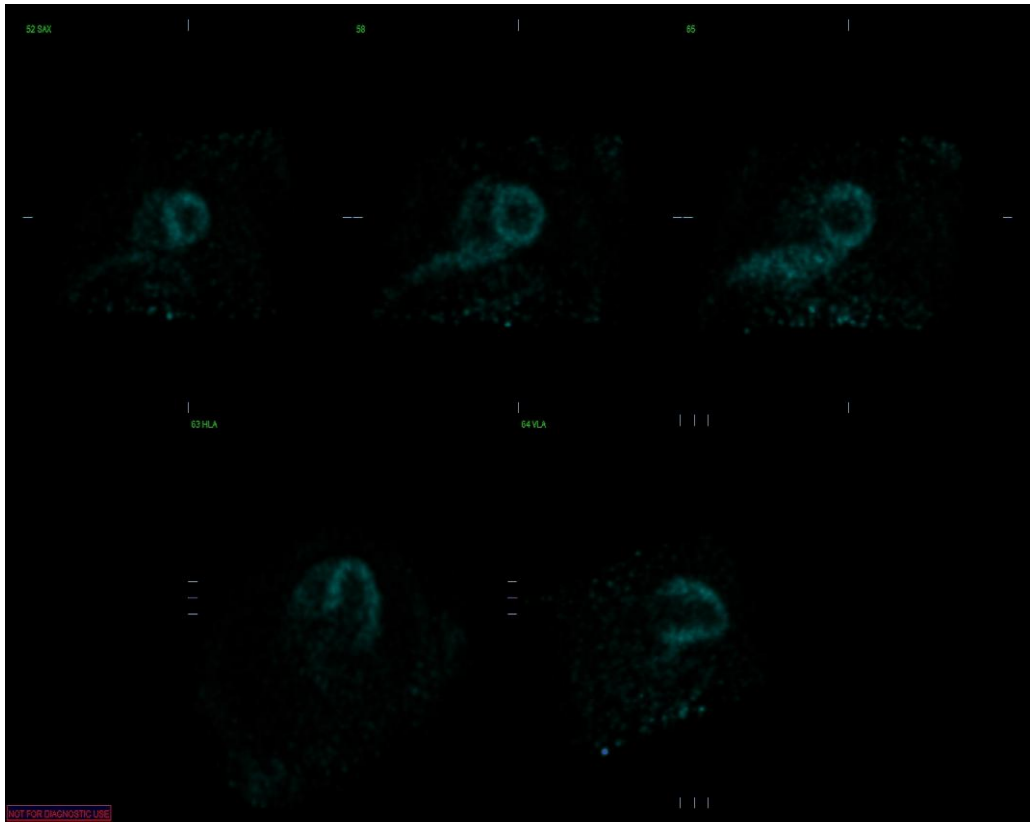
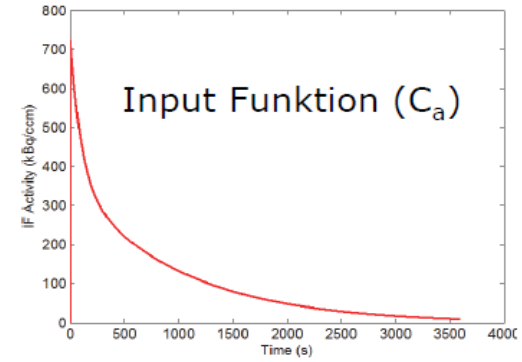
modified from Schindler et al. JACC Cardiovasc Imaging. 2010 Jun;3(6):623-40

Myocardial perfusion PET - Semiquantitative (relative)

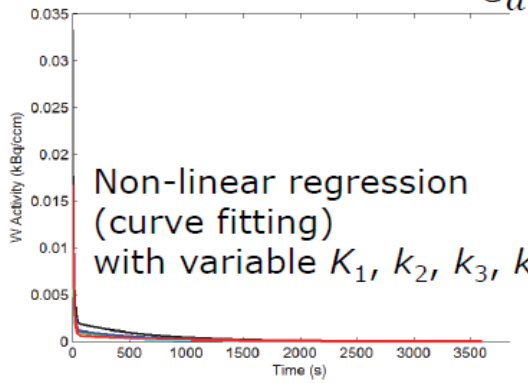


Myocardial blood flow quantification

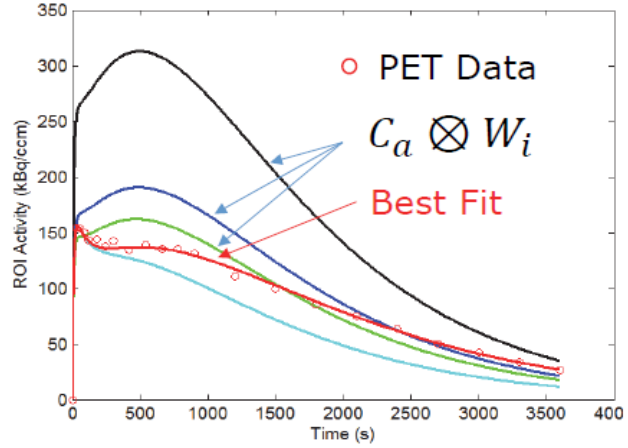




$C_a \otimes W$



Non-linear regression
(curve fitting)
with variable K_1, k_2, k_3, k_4 (W)



Best Fit:
K_1 = 1.0 mL/min/cm^3
k_2 = 5.0 min^{-1}
k_3 = 0.2 min^{-1}
k_4 = 0.06 min^{-1}

rest MBF (ml/min/g)
stress MBF (ml/min/g)
MFR (stress:rest)

$$\frac{dC_t(t)}{dt} = K_1 \cdot C_a(t) - k_2 \cdot C_t(t)$$

$$C_t(t) = K_1 e^{-k_2 t} \otimes C_a(t)$$

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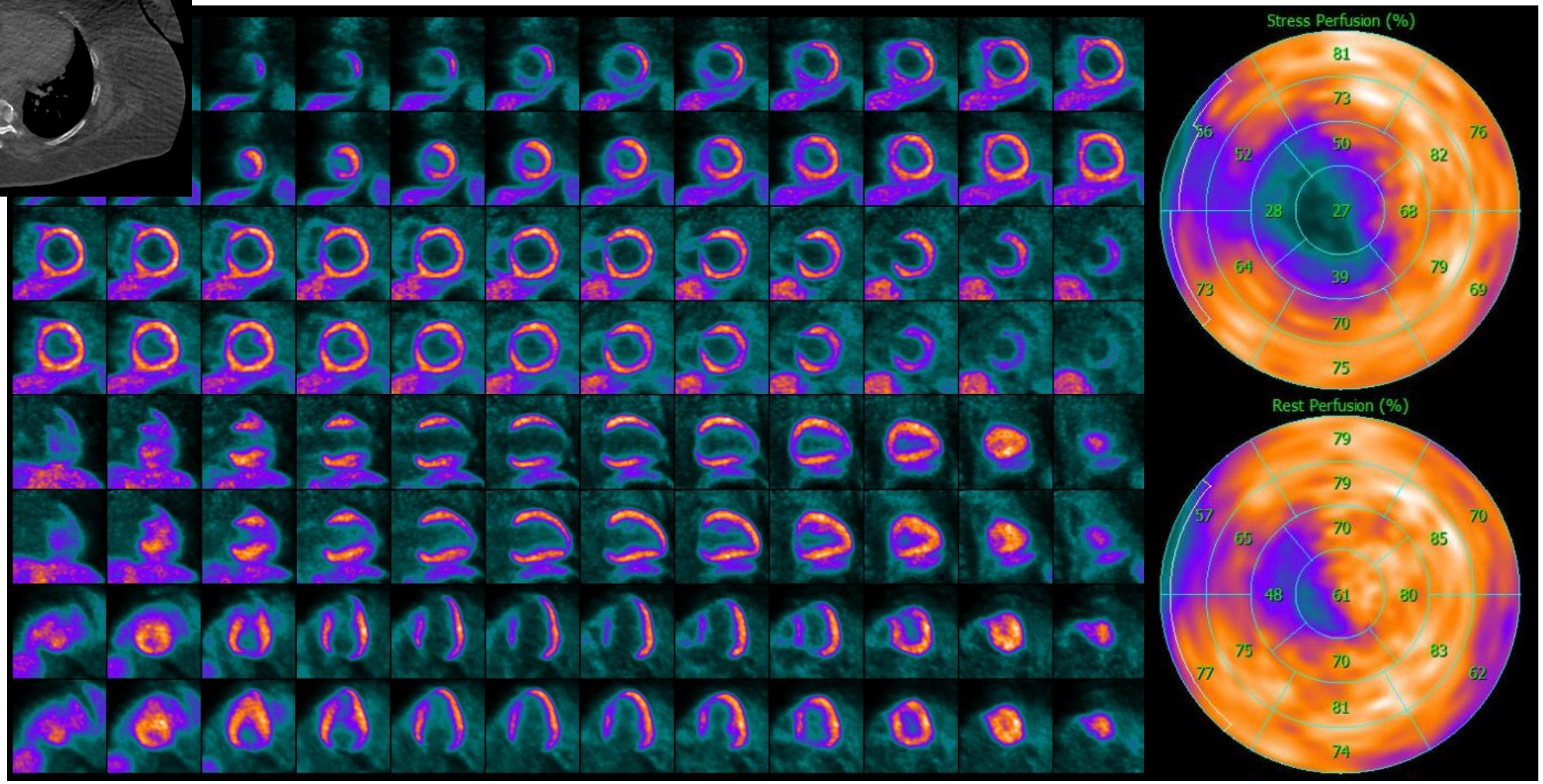
MFR normal **> 2.5**
MFR pathological **< 2.0**

Broad Applicability / No Absolute Contraindications

13N-ammonia PET/CT



Female patient with a BMI of **64kg/m²**
Effective radiation dose = **2.4 mSv**

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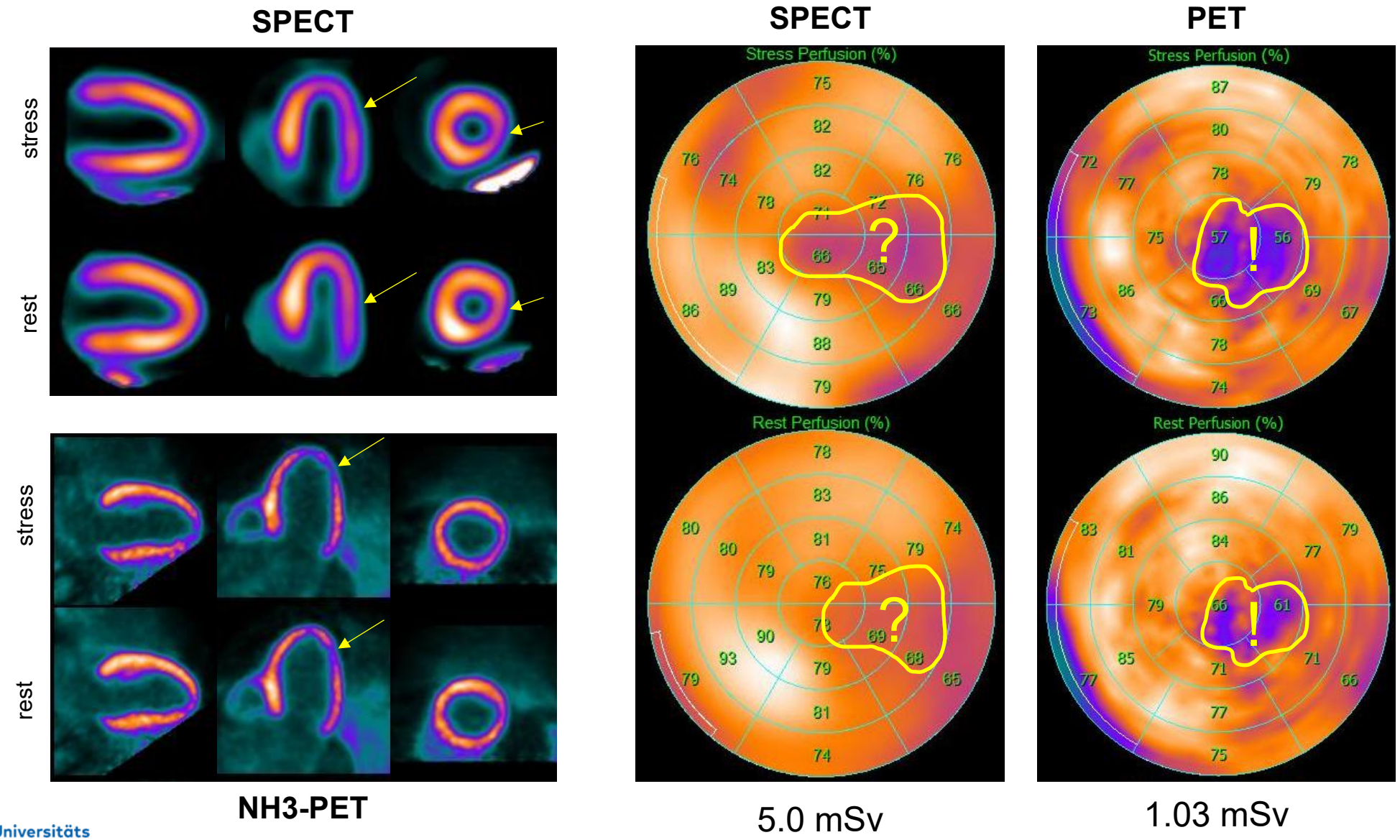
Superior Image Quality (at lower radiation dose)

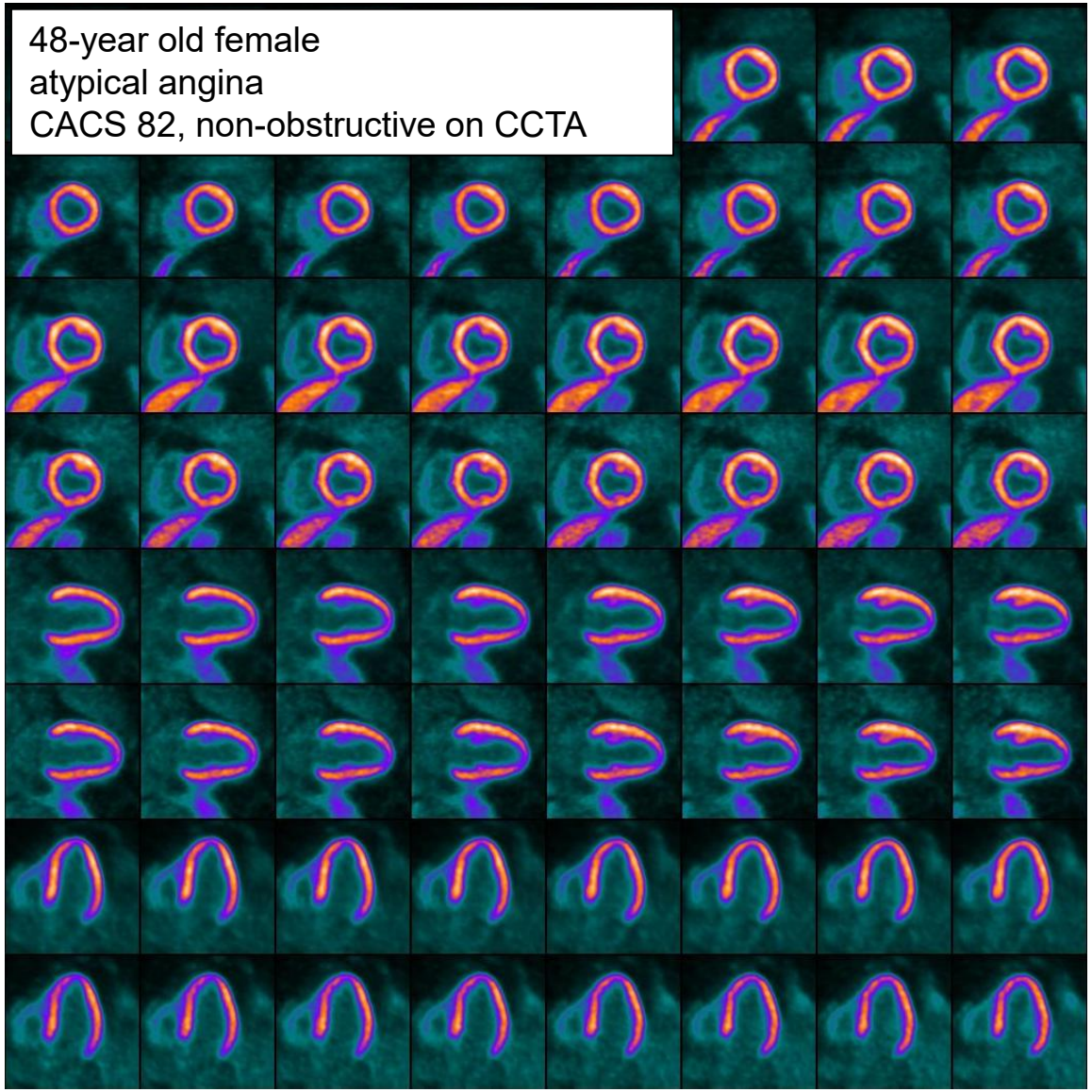


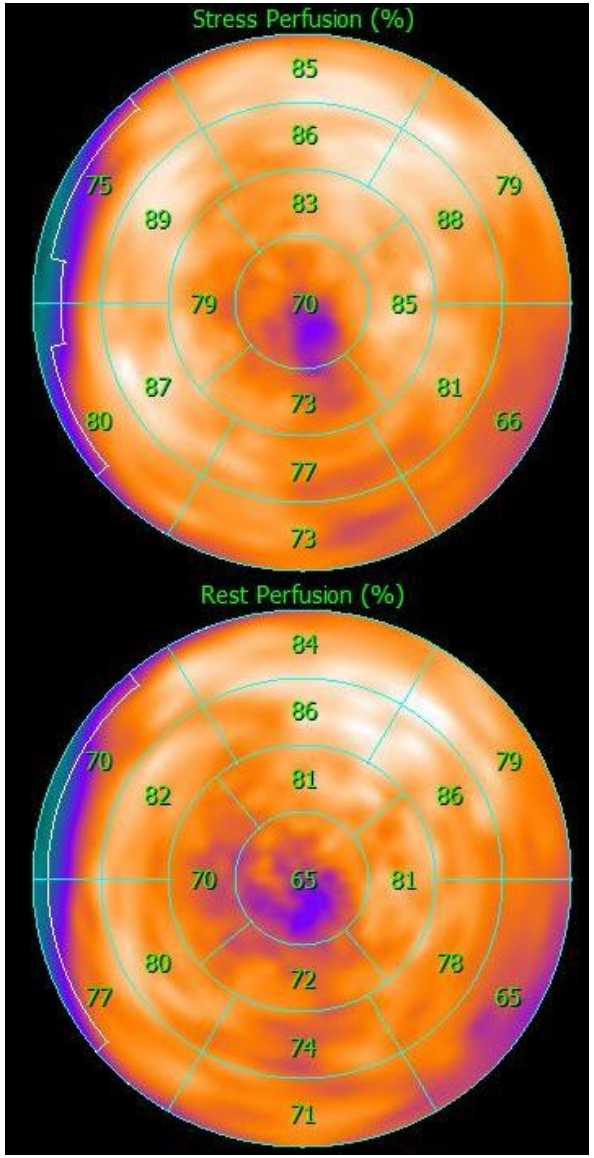
Male patient, 80y, BMI 23kg/m^2

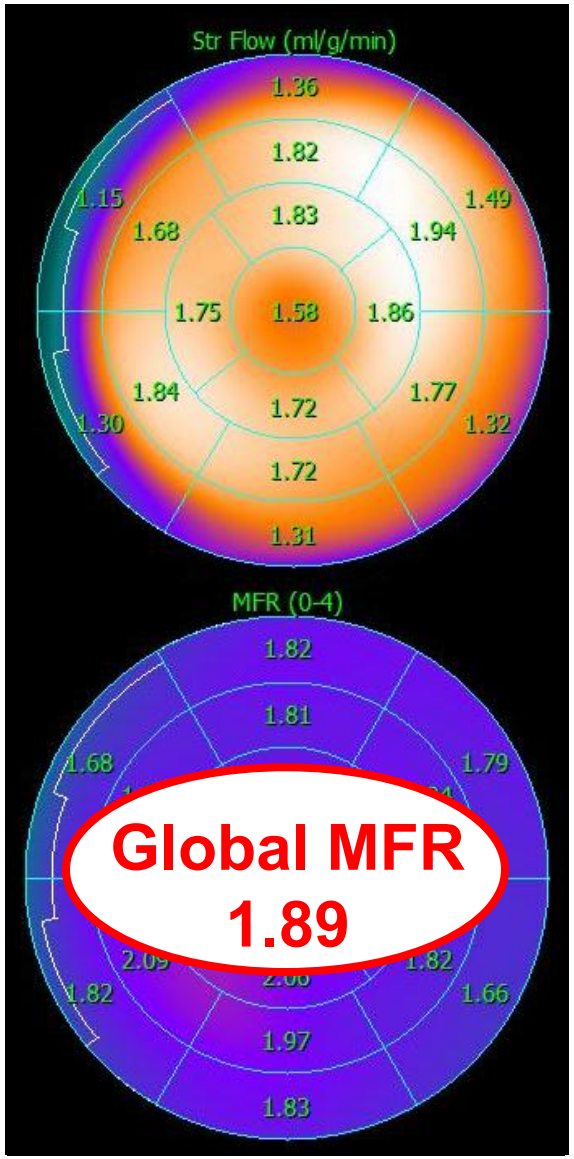
A picture is worth a thousand words

But if you add numbers…

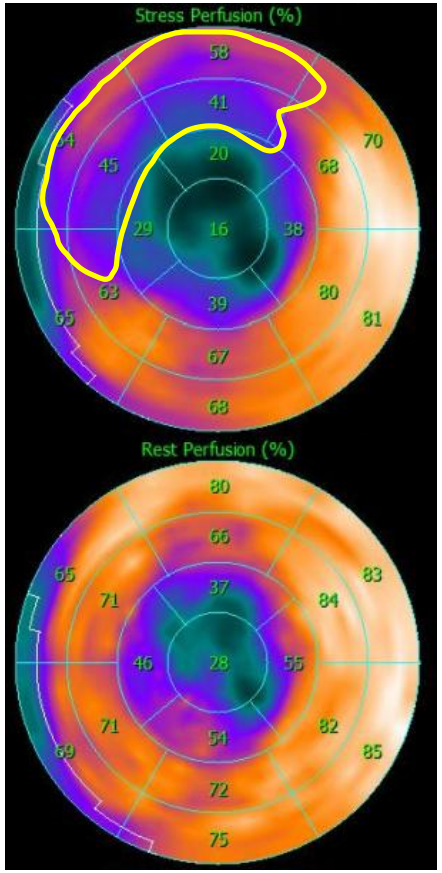
you get to see the «hidden side»



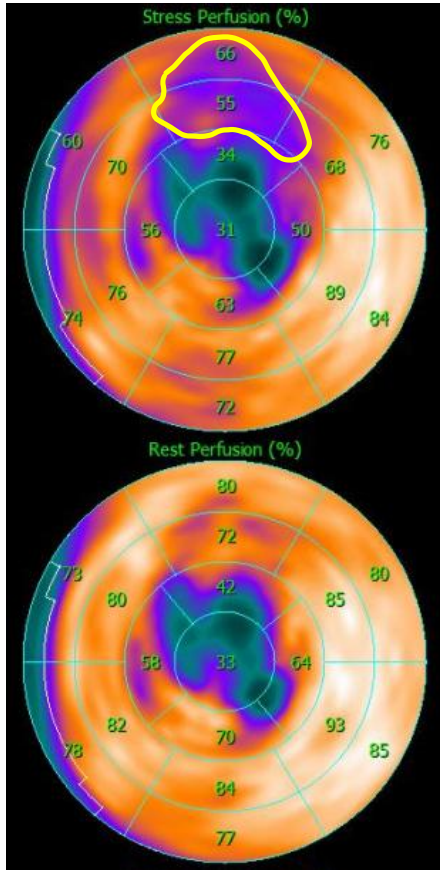




High Reproducibility – Ideal for Follow-Up in Complex Situations

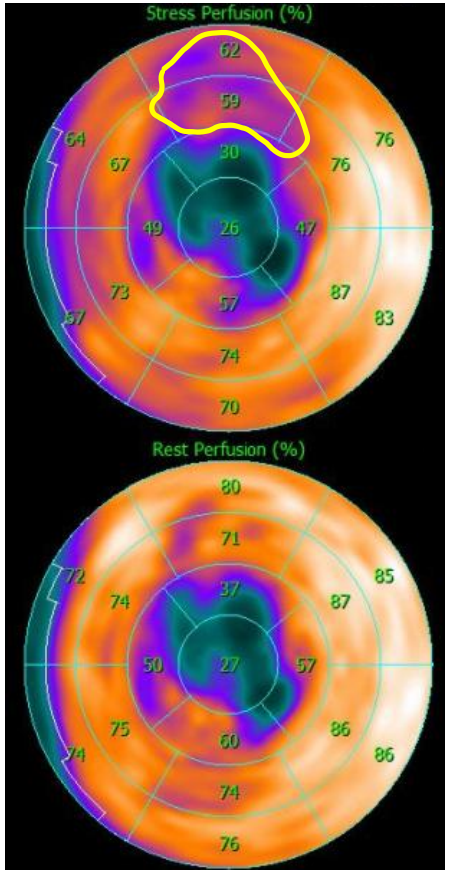


06/2018



12/2020

Recurrent
typical angina



03/2024

NSTEMI
hypertensive
situtation

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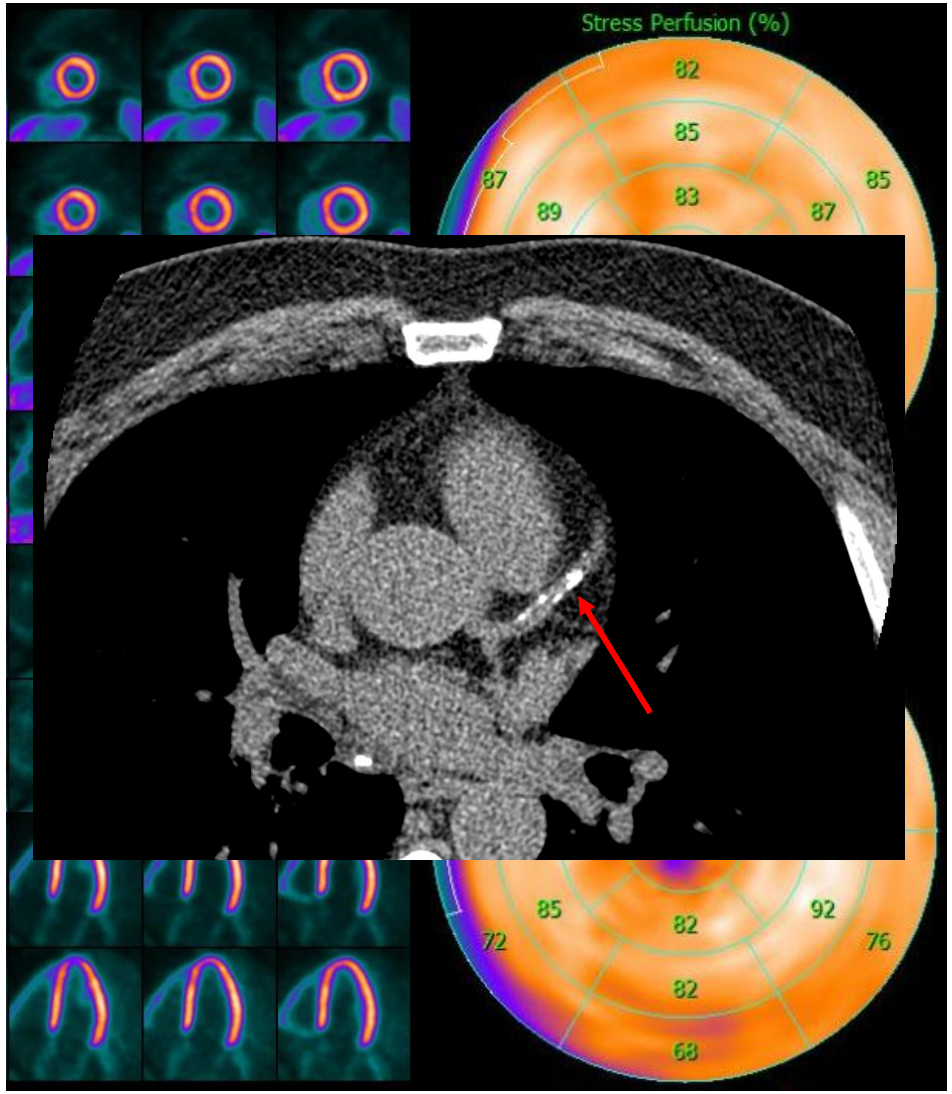
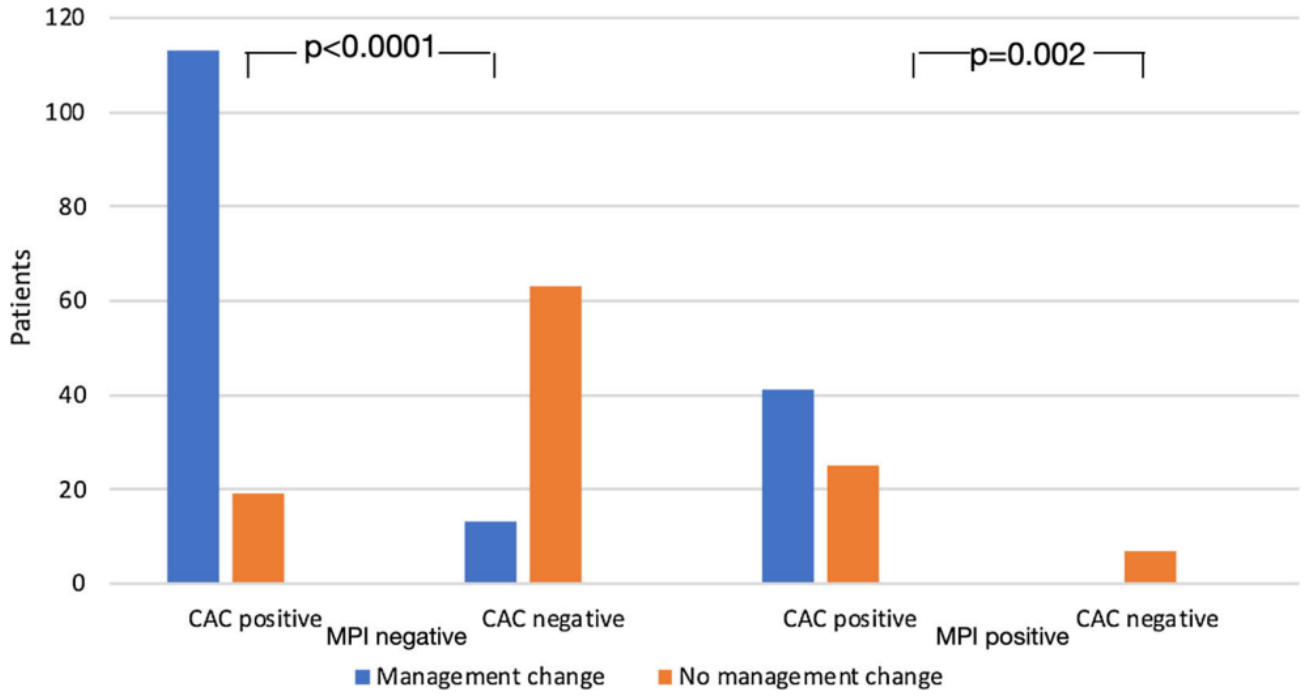
Routine Calcium Scoring





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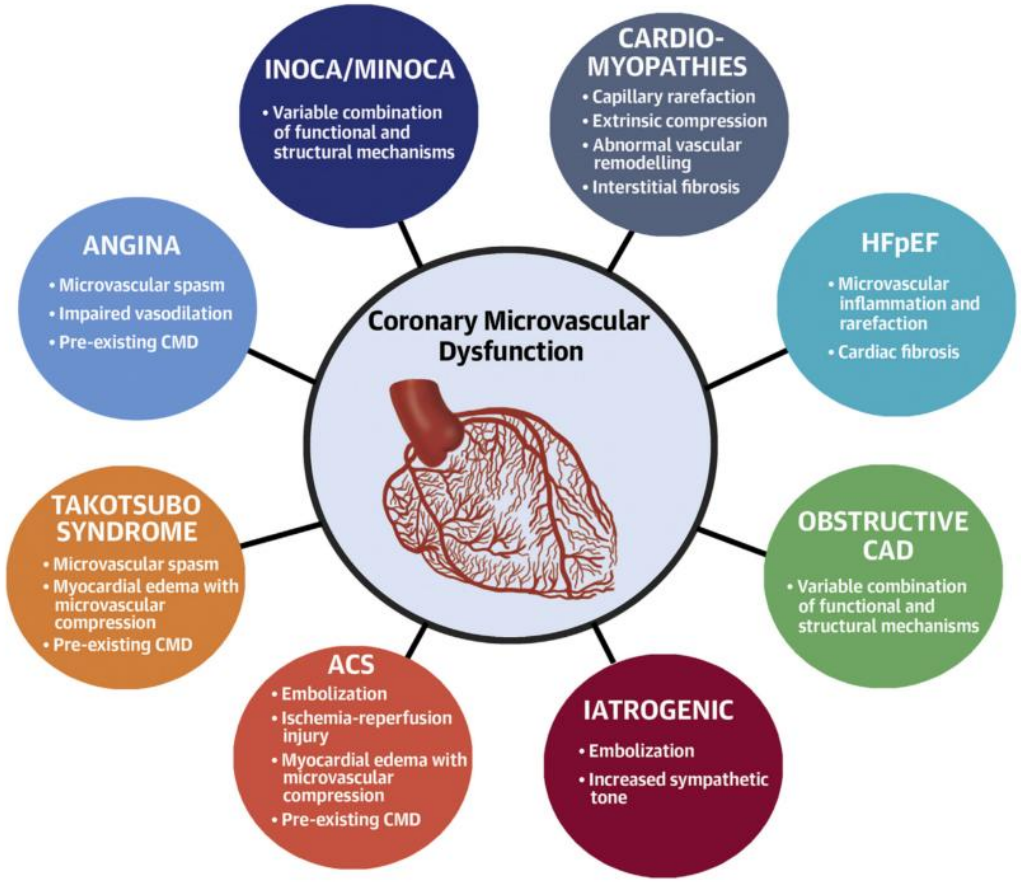
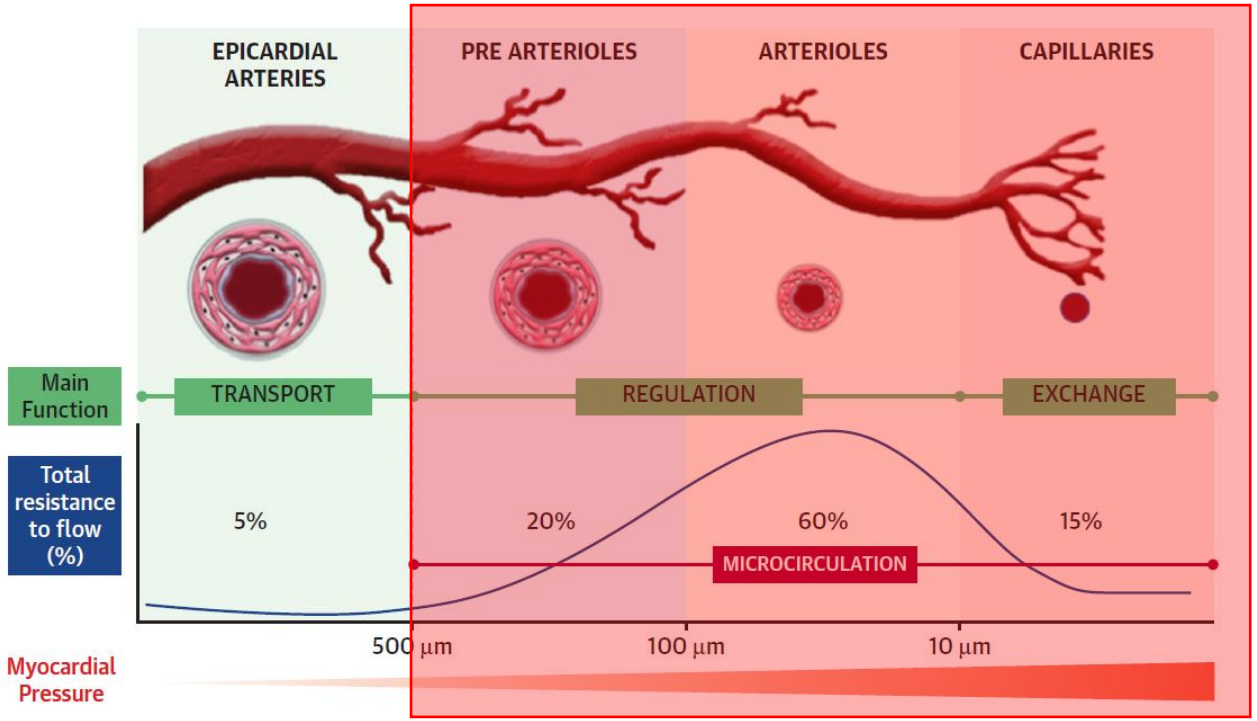
Jayadeva et al. J Nucl Cardiol. 2023 Jun;30(3):1004-1018..

Small Vessels – Large Impact

Role of Coronary Microvascular Dysfunction Across Different Cardiovascular Diseases





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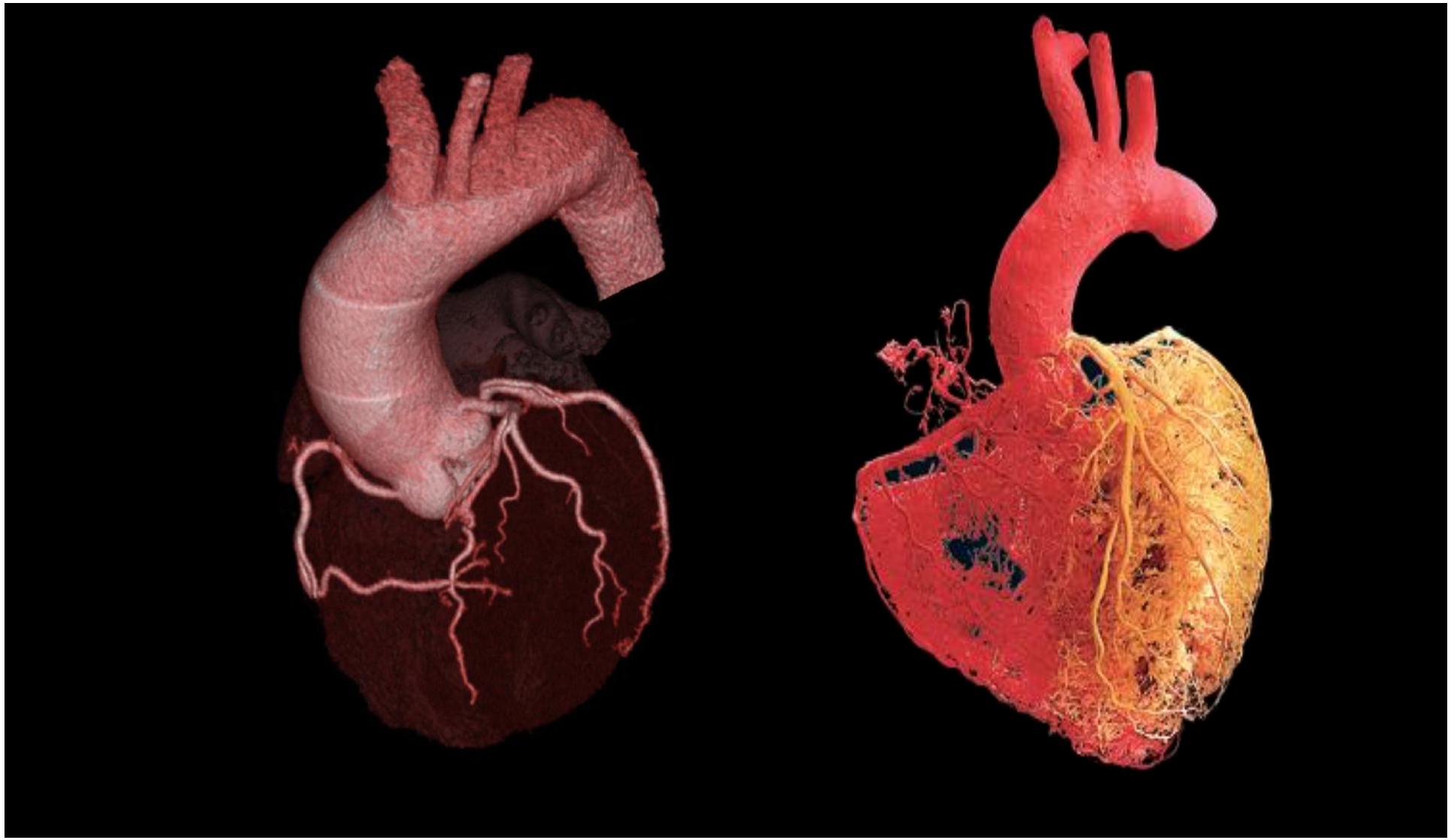
Del Buono et al. J Am Coll Cardiol. 2021 Sep 28;78(13):1352-1371.

PET is Ideal for Assessing the Macro- and Microcirculation



Microvascular Disease is Prevalent

Prevalence of Coronary Microvascular Disease and Coronary Vasospasm in Patients With Nonobstructive Coronary Artery Disease: Systematic Review and Meta-Analysis

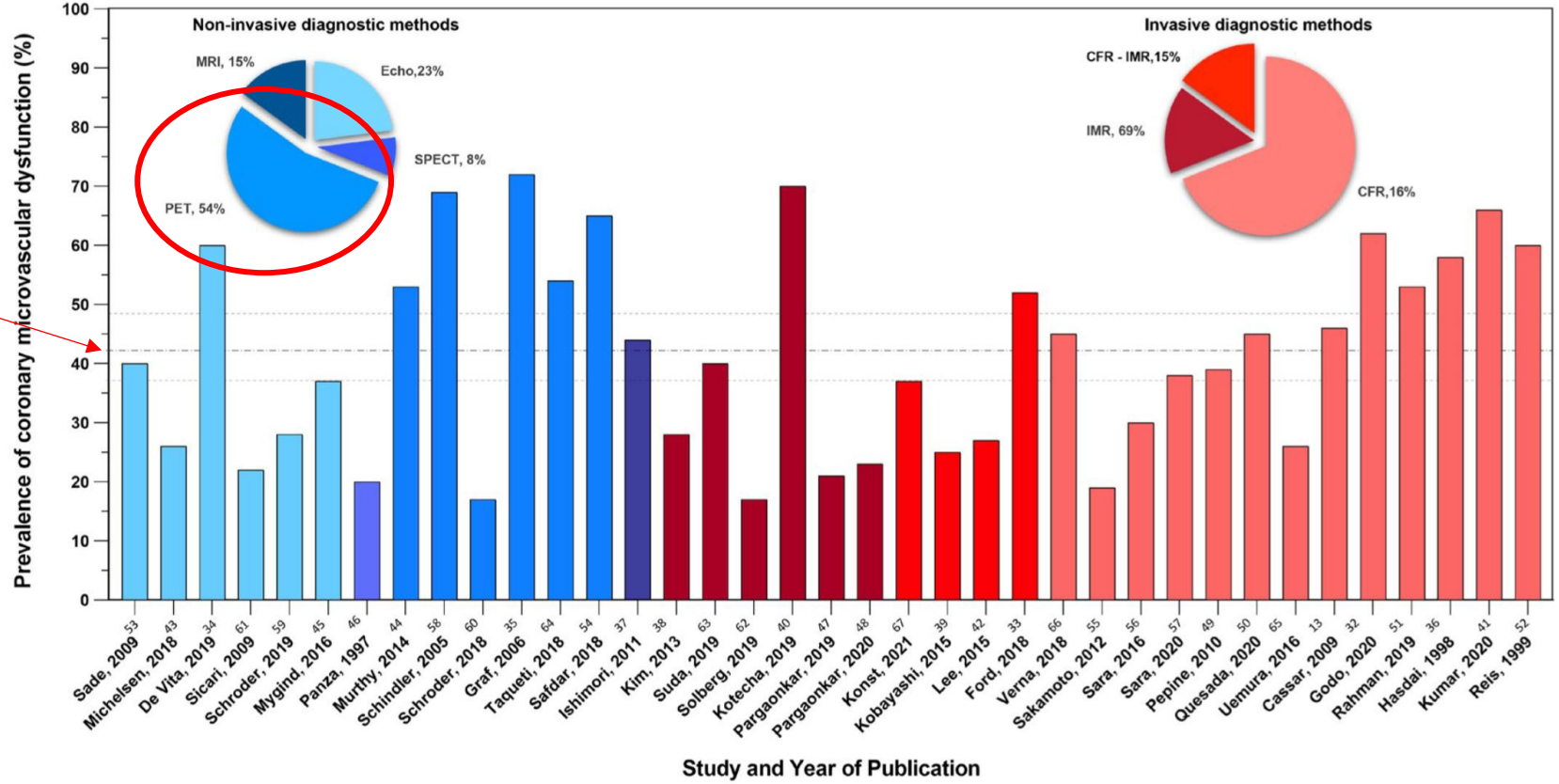
Niya Mileva, MD; Sakura Nagumo, MD, PhD; Takuya Mizukami, MD, PhD; Jeroen Sonck, MD; Colin Berry, MD, PhD; Emanuele Gallinoro, MD; Giovanni Monizzi, MD; Alessandro Candreva, MD; Daniel Munhoz, MD, PhD; Dobrin Vassilev, MD, PhD; Martin Penicka, MD, PhD; Emanuele Barbato, MD, PhD; Bernard De Bruyne, MD, PhD; Carlos Collet, MD, PhD

14427 patients with no obstructive CAD

Among noninvasive methods, a higher rate of CMD was found in patients who underwent PET compared with other modalities

(0.46 [95% CI, 0.46–0.65]) vs. (0.40 [95% CI, 0.30–0.55]; p=0.019

Pooled prevalence of CMD
0.41 [95% CI, 0.36–0.47]



J Am Heart Assoc. 2022 Apr 5;11(7):e023207.

Quantitativ vs. Semi-quantitativ

Leaving Relativity Behind

Quantitative Clinical Perfusion Imaging*

Frank M. Bengel, MD

Hannover, Germany

EDITORIAL COMMENT

Absolute Figures Are Better Than Percentages*

Paolo G. Camici, MD

London, United Kingdom

JACC: CARDIOVASCULAR IMAGING
VOL. 2, NO. 6, 2009
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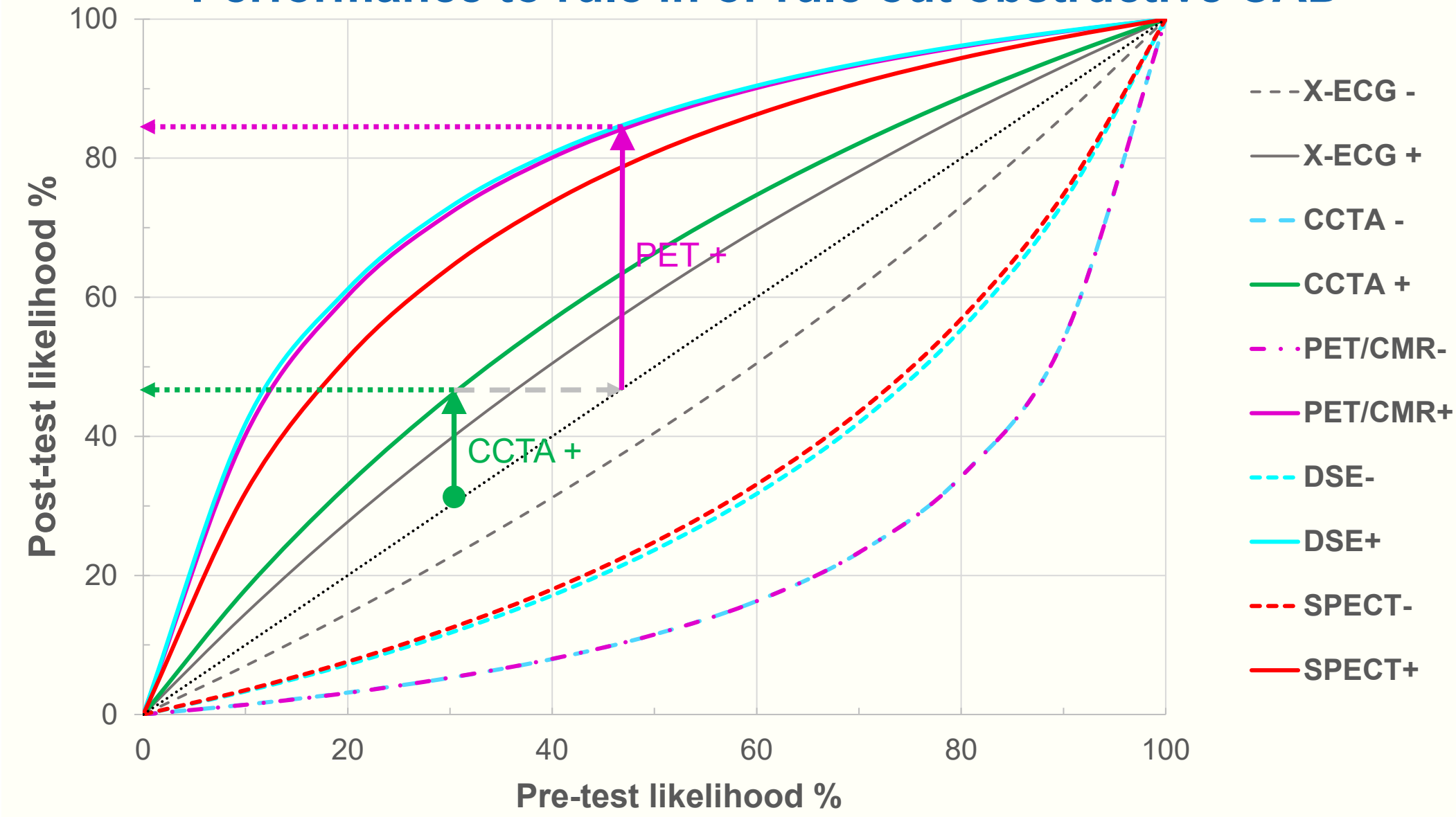
ISSN 1936-878X/09/$36.00
PUBLISHED BY ELSEVIER INC.
DOI:10.1016/j.jcmg.2009.04.005

Performance to rule in or rule out obstructive CAD



So which modality should we use in clinical routine?

28’664 patients from 132 studies

The performance of different tests for anatomically significant CAD

Anatomically significant CAD				
Test	**Sensitivity (%), (95% CI)**	**Specificity (%), (95% CI)**	**+LR (95% CI)**	**−LR (95% CI)**
Stress ECG	58 (46–69)	62 (54–69)	1.53 (1.21–1.94)	0.68 (0.49–0.93)
Stress echo	85 (80–89)	82 (72–89)	4.67 (2.95–7.41)	0.18 (0.13–0.25)
CCTA	97 (93–99)	78 (67–86)	4.44 (2.64–7.45)	0.04 (0.01–0.09)
SPECT	87 (83–90)	70 (63–76)	2.88 (2.33–3.56)	0.19 (0.15–0.24)
PET	90 (78–96)	85 (78–90)	5.87 (3.40–10.15)	0.12 (0.05–0.29)
Stress CMR	90 (83–94)	80 (69–88)	4.54 (2.37–8.72)	0.13 (0.07–0.24)

Knuuti et al. Eur Heart J. 2018 Sep 14;39(35):3322-3330.

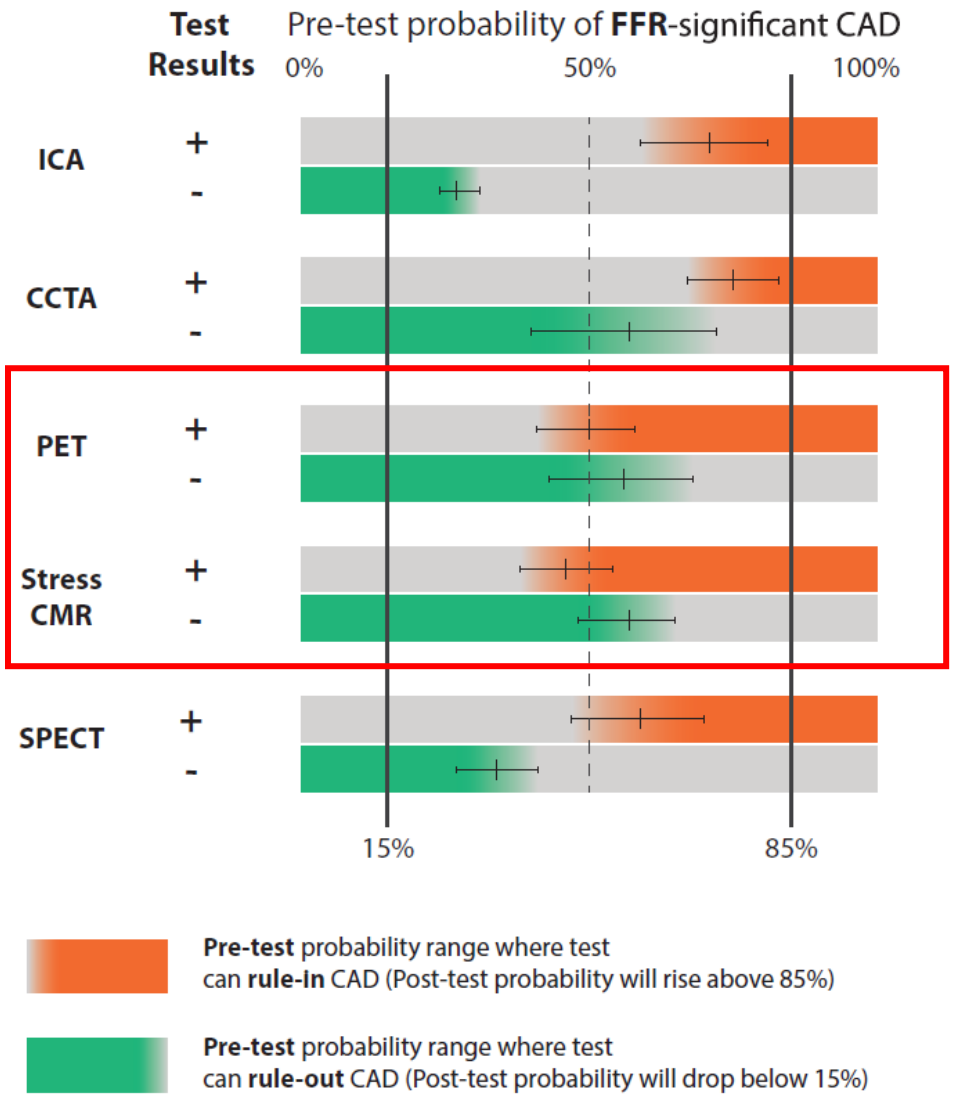
Diagnostic Performance

ESC European Society of Cardiology
European Heart Journal (2018) **39**, 3322–3330
doi:10.1093/eurheartj/ehy267

META-ANALYSIS

The performance of non-invasive tests to rule-in and rule-out significant coronary artery stenosis in patients with stable angina: a meta-analysis focused on post-test disease probability

Juhani Knuuti[1]*, Haitham Ballo[1†], Luis Eduardo Juarez-Orozco[1†], Antti Saraste[1], Philippe Kolh[2], Anne Wilhelmina Saskia Rutjes[3], Peter Jüni[4], Stephan Windecker[5], Jeroen J. Bax[6], and William Wijns[7]



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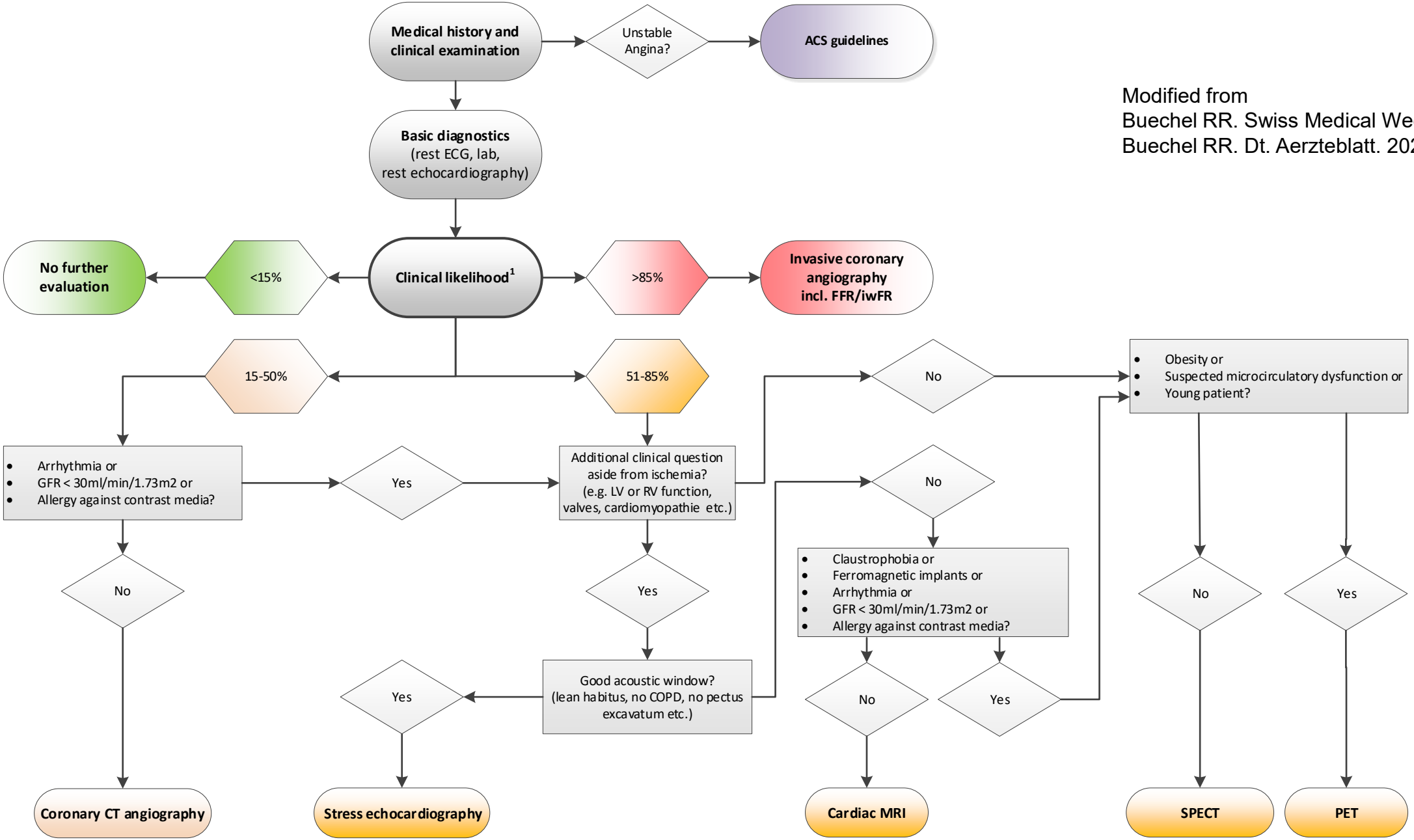
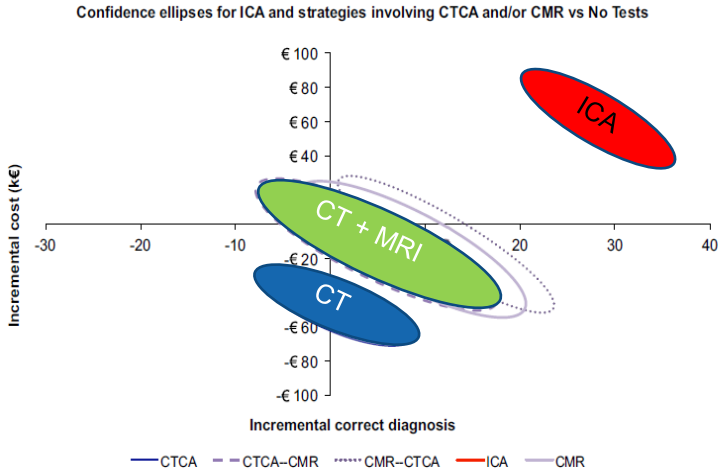
A Personalized Approach To Evaluating CAD

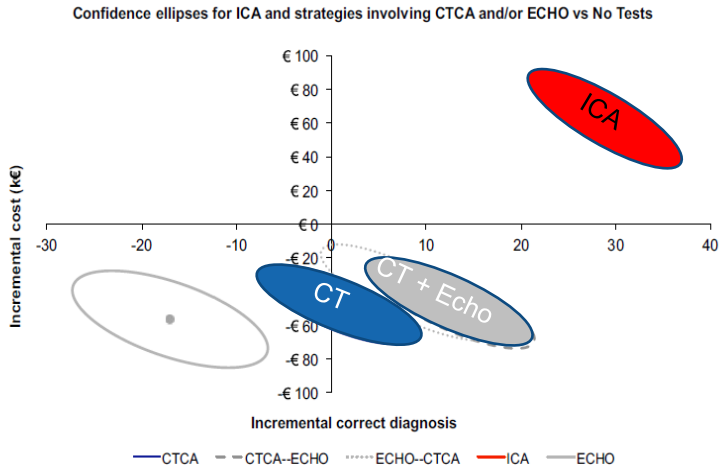


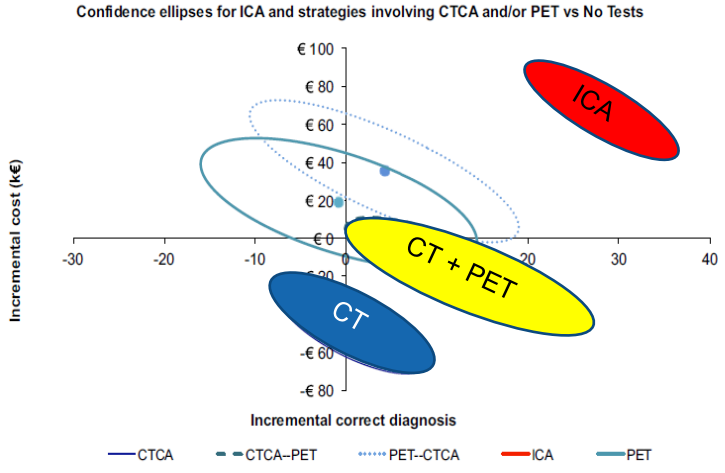
Modified from
Buechel RR. Swiss Medical Weekly, 2019
Buechel RR. Dt. Aerzteblatt. 2020

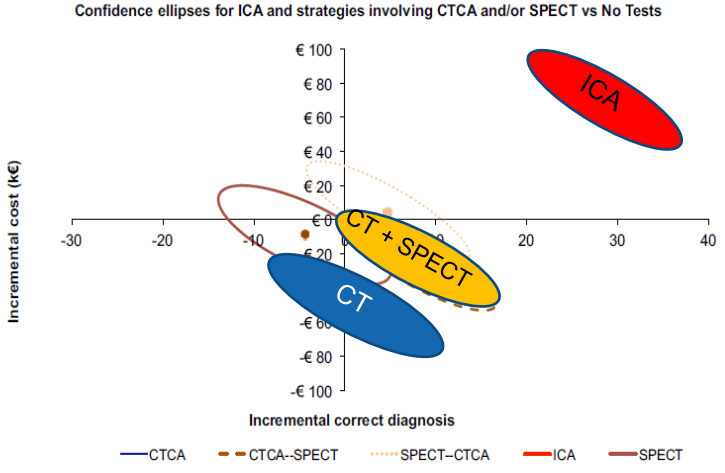
Clinical and Cost Effectiveness

Data from EVINCI study
n=350
Endpoint: 50% stenosis at ICA









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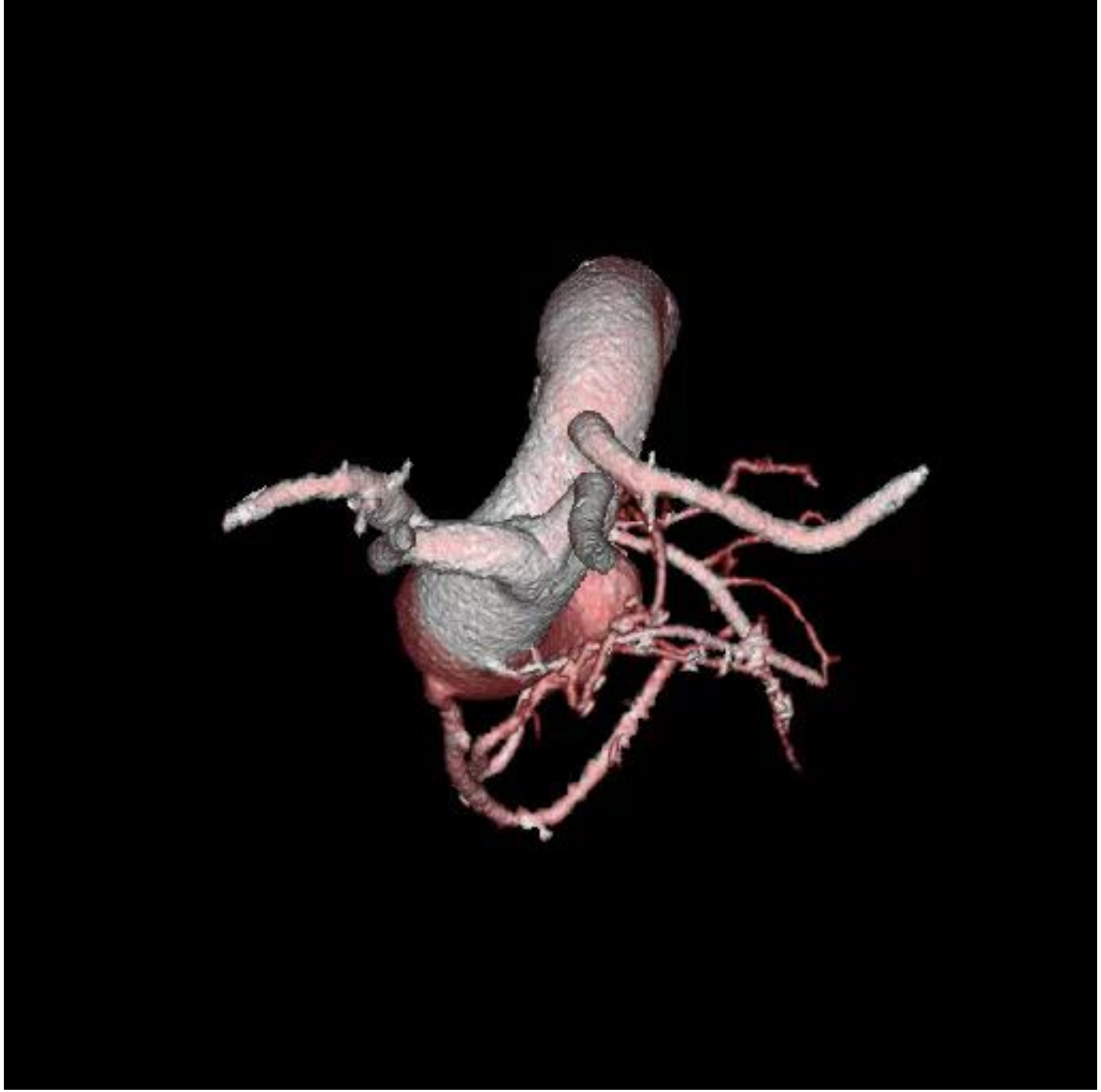
Lorenzoni et al. Eur J Health Econ. 2019 Aug 13.



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CAC score percentiles specific for Switzerland – CH-CACS

Contents lists available at ScienceDirect

IJC Heart & Vasculature

journal homepage: www.sciencedirect.com/journal/ijc-heart-and-vasculature

Distribution of coronary artery calcium in a large European all-comer population referred for cardiac imaging

Julia Duelli, Christoph Ryffel, Magdalena Stuetz, Raffael Ghenzi, Marko Gajic, Dimitrios Moysidis, Dominik C. Benz, Aju P. Pazhenkottil, Andreas A. Giannopoulos, Philipp A. Kaufmann, Ronny R. Buechel

Department of Nuclear Medicine, Cardiac Imaging, University and University Hospital of Zurich, Raemistrasse 100, CH-8091 Zurich, Switzerland

Swiss population

n = 18‘225

www.cardiacimaging.ch/cacs

CACS Percentile Calculator

Sex:

Male | Female

Age:

65

CACS:

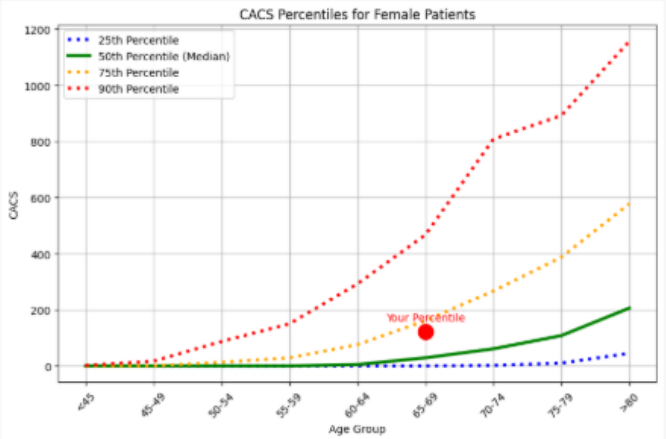
123

Submit

Result:

Percentile: 76
Median CACS: 16

CACS Percentile Plot:



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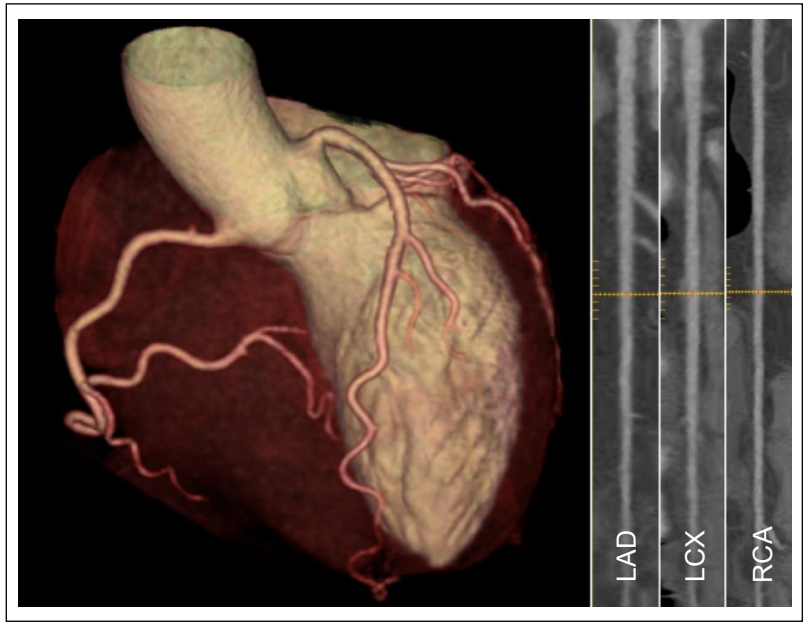
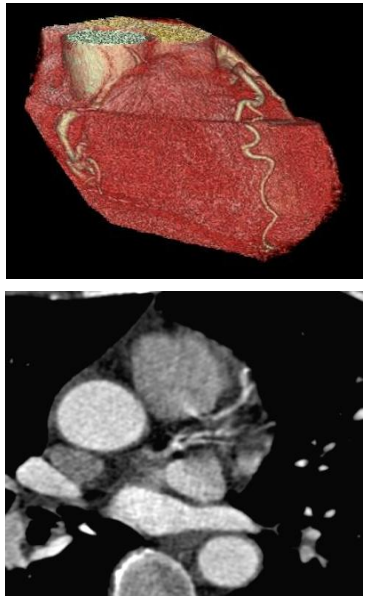
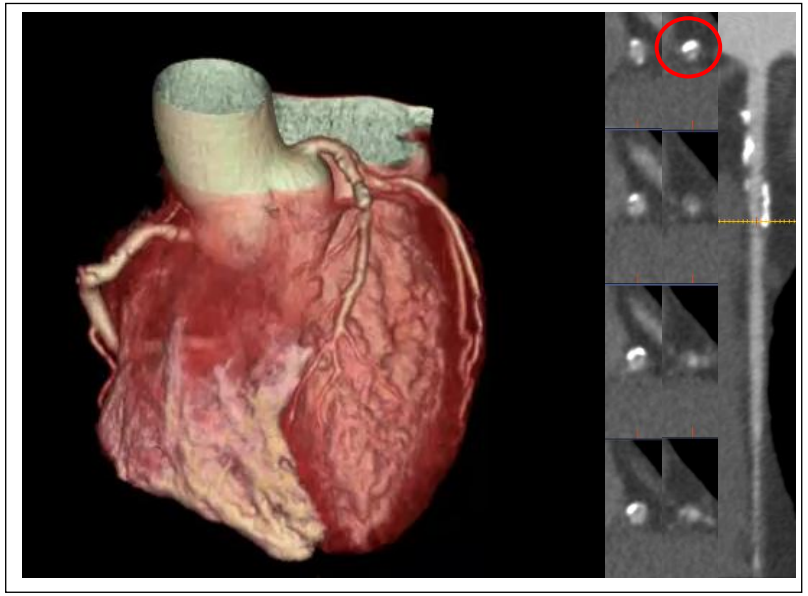
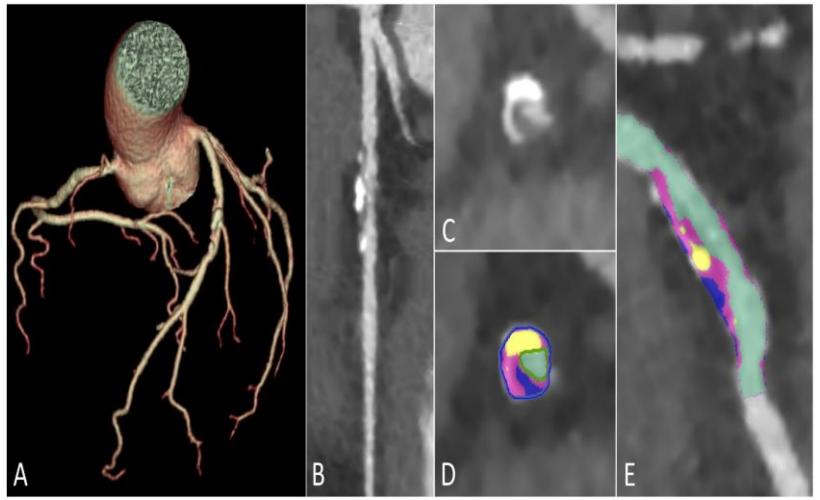
Vor- und Nachteile

Coronary CT Angiography (CCTA)









Giannopoulos AA & Buechel RR. J Nucl Cardiol. 2019 Feb;26(1):141-153.

Advantages
- Widely available
- Fast (<30min)
- Excellent sensitivity (High NPV)
- Very low radiation dose exposure (<1mSv)
- Assessment of plaque composition

Disadvantages
- Pt preparation necessary (BB, Nitro)
- Pts with arrhythmias and tachycardia remain challenging
- Modest specificity (Low PPV)