CZT cardiac imaging: from Anger to flow measurements

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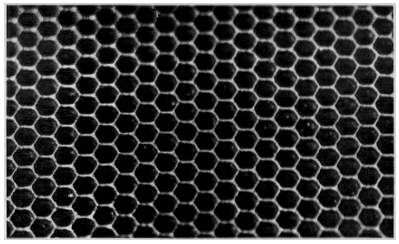
SPECT gamma camera



Anger 1958

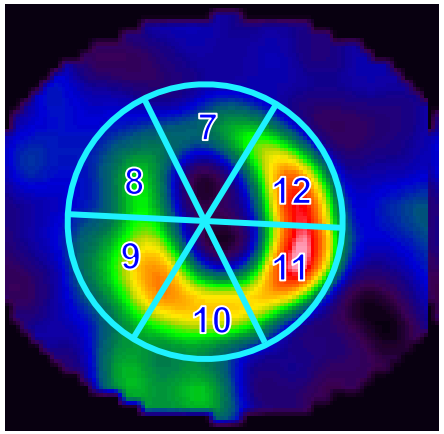




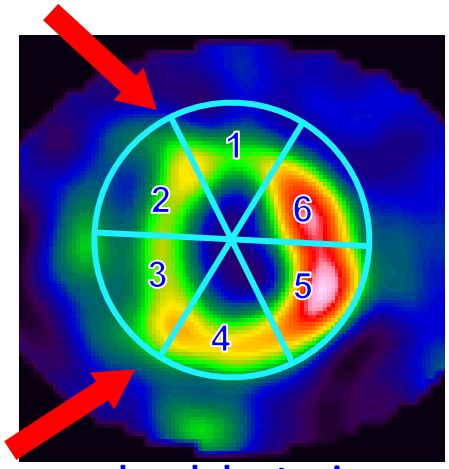


system requires collimator to define the origin of emission

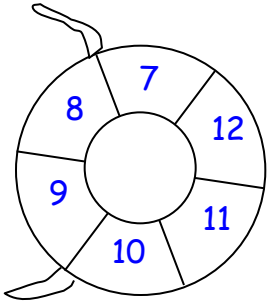
Myocardial Perfusion Imaging



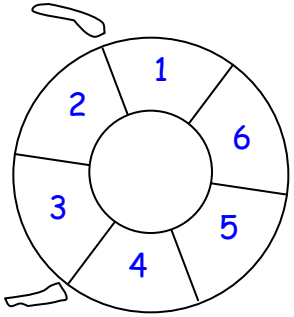
mid short axis



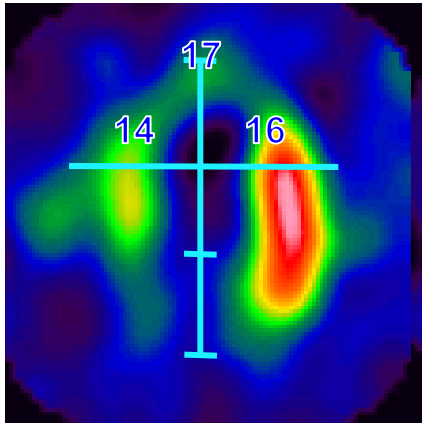
basal short axis



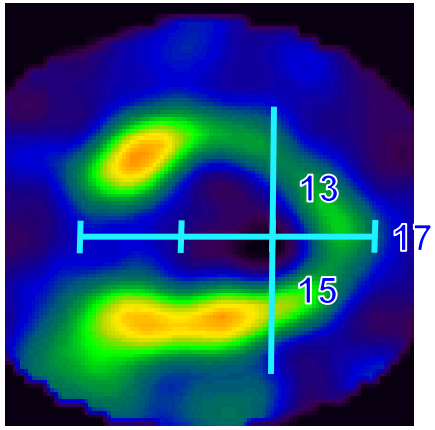
mid short axis



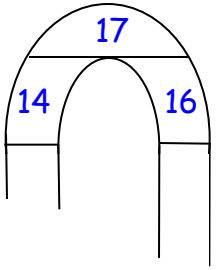
basal short axis



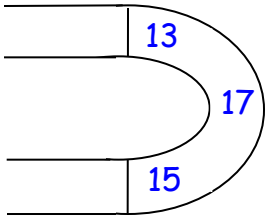
horizontal long axis



vertical long axis



horizontal long axis

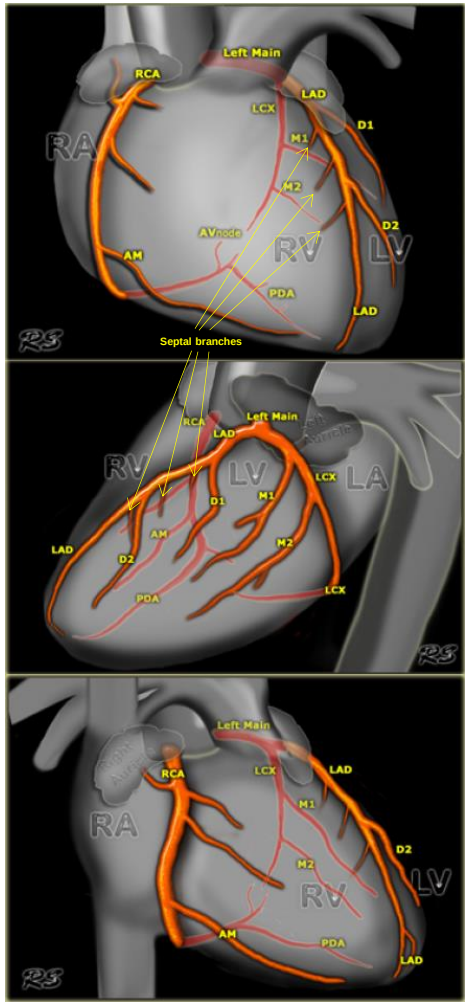


vertical long axis

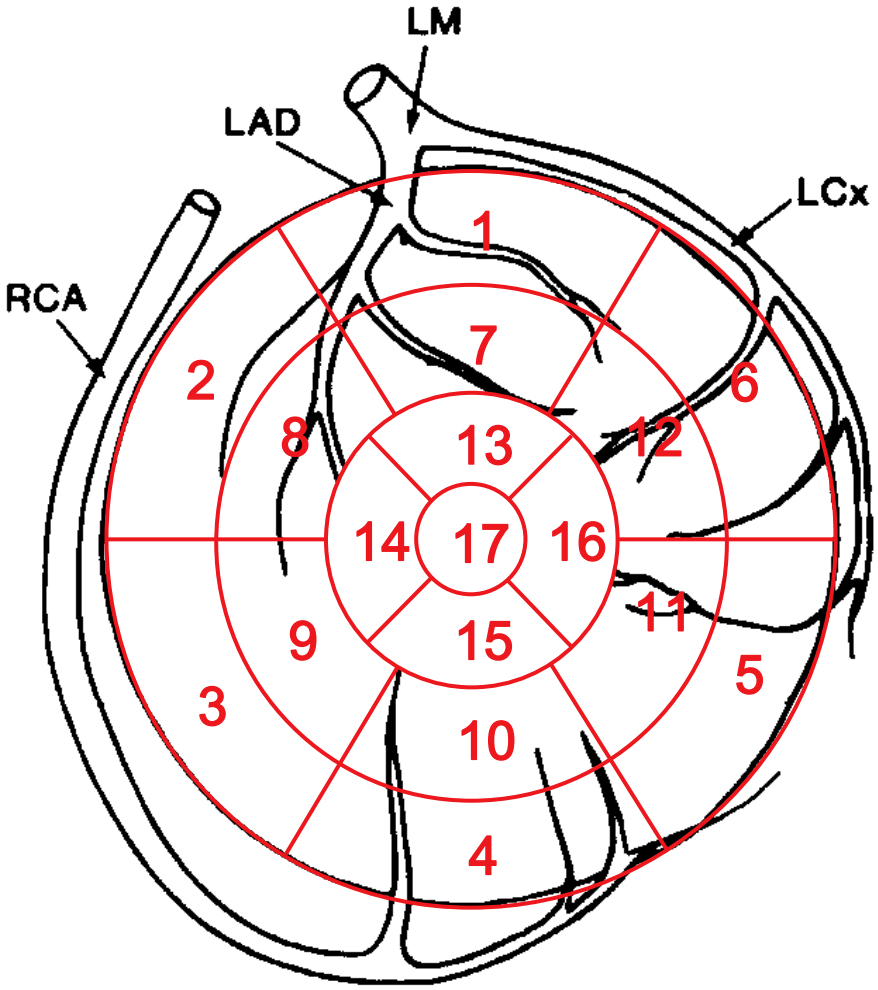
ANT

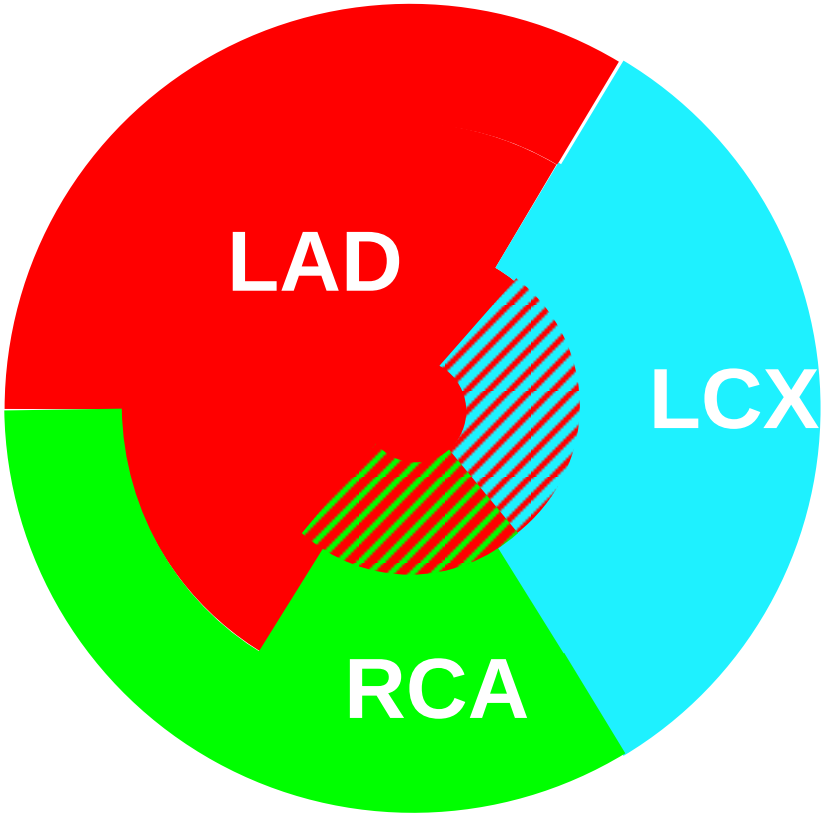
LAT

RAO

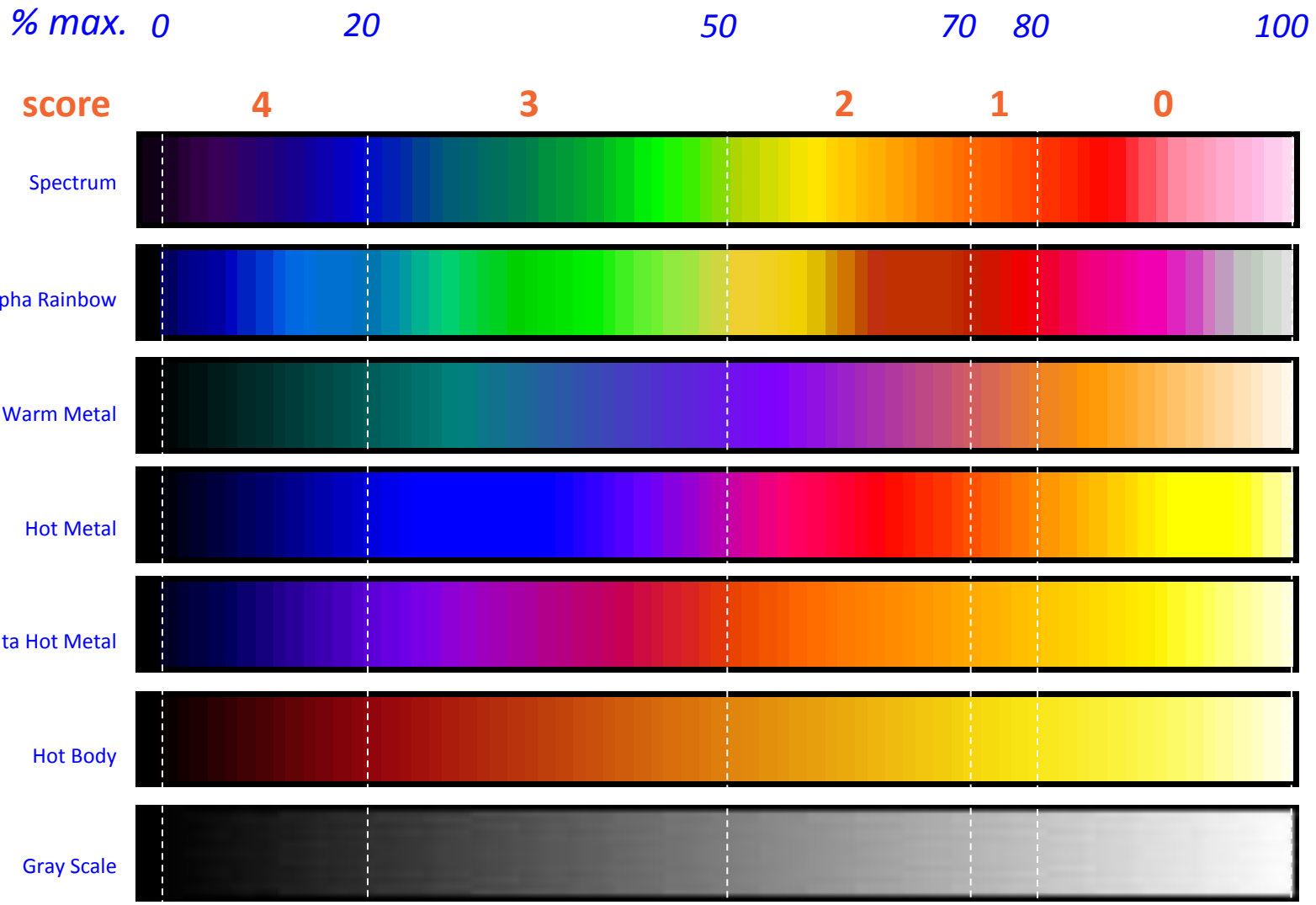


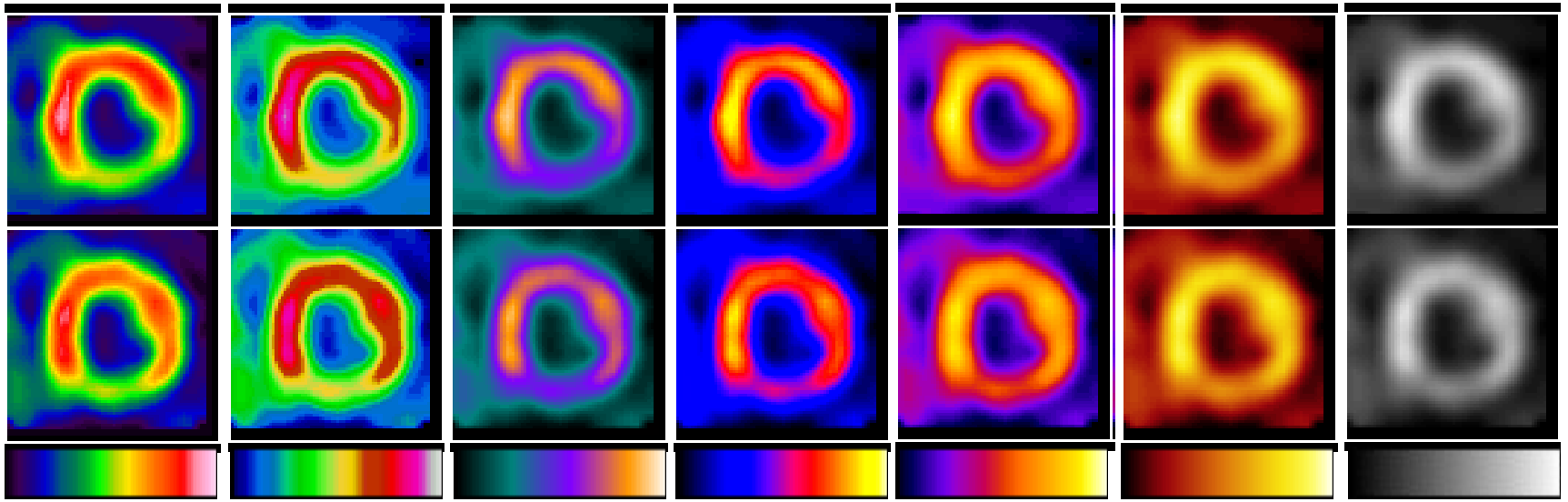
- Diagonal branches (D1, D2):
  - Origin from LAD
  - LV antero-lateral wall
- Marginal branches (M1, M2):
  - Origin from LCX
  - LV lateral wall
- Septal branches:
  - Origin from LAD
  - LV/RV septal wall
- Acute marginal branche (AM):
  - Origin from RCA
  - RV
- Posterior descending artery (PDA):
  - Origin from RCA (65% cases: right dominant)
  - LV inferior wall


LM
LAD
LCx
RCA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

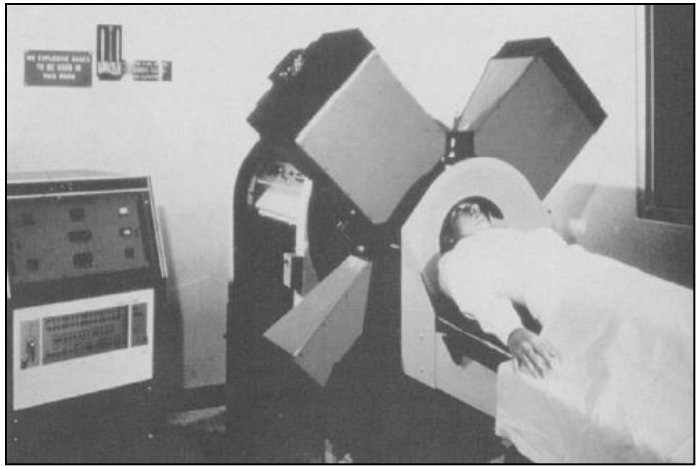

LAD
LCX
RCA

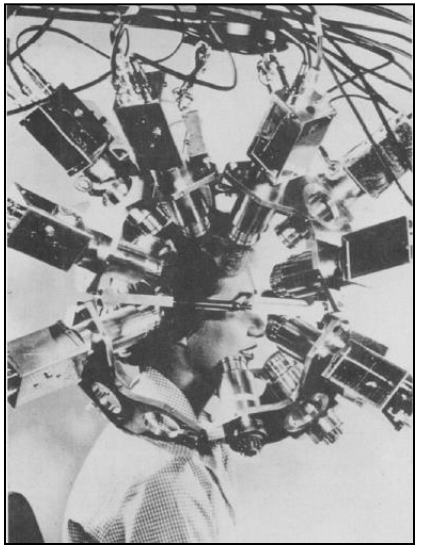
Semi-quantitative analysis of tracer fixation

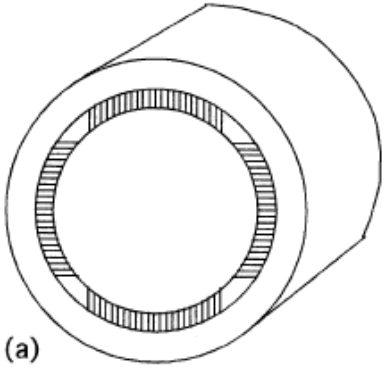



stress
rest
Spectrum
Sopha Rainbow
Warm Metal Cool
Hot Metal
Micro Delta Hot Metal
Hot Body
Gray Scale

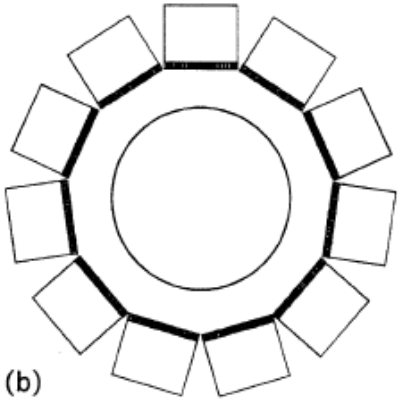
First dedicated organ specific SPECT: BRAIN



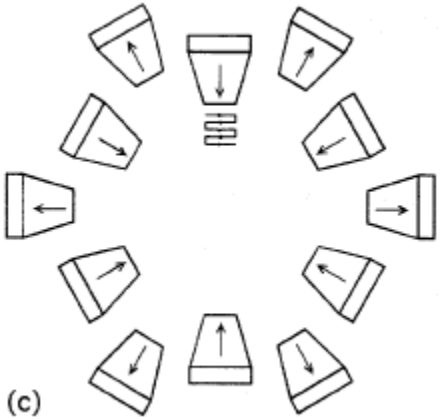




Cerespect



SPRINT



Cleon/ Strichman

All “recent” dedicated cardiac SPECT camera’s



GE Ventri



Spectrum Dynamics D-SPECT



Philips Cardio MD





GE Discovery 530c





Digirad Cardius 2xpo

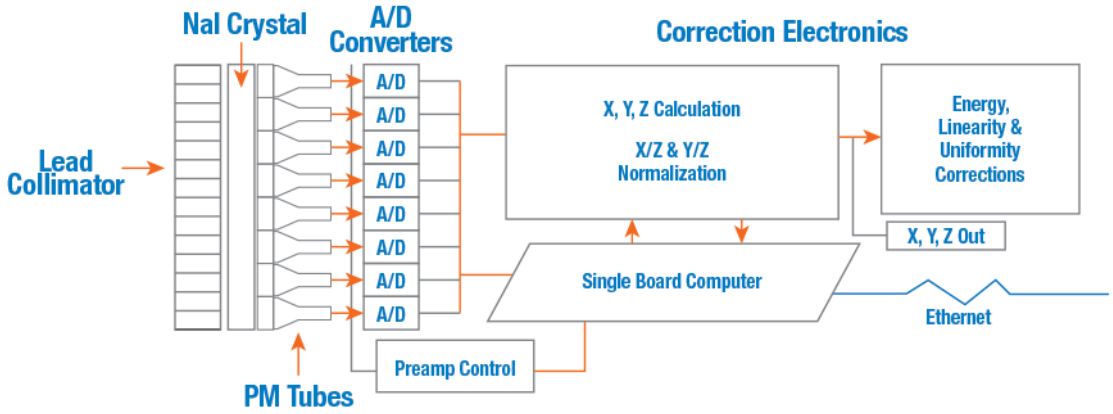
Siemens c.cam

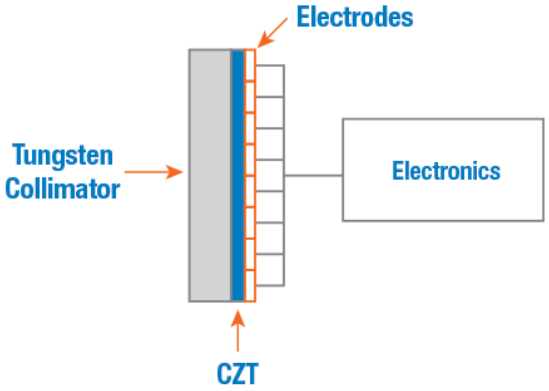


Advantages of organ-specific systems

- Optimized performance
  - Geometry permits optimal acquisition (resolution)
  - Cost-effective use of detecors (sensitivity)

- Improved utility
  - Patient comfort
  - Faster scan
  - Increased patient throughput
  - Compact installation
  - Extended use: dynamic or multiple radionuclides


Nal Crystal
A/D Converters
Correction Electronics
Lead Collimator
A/D
A/D
A/D
A/D
A/D
A/D
A/D
A/D
X, Y, Z Calculation
X/Z & Y/Z Normalization
Energy, Linearity & Uniformity Corrections
X, Y, Z Out
Single Board Computer
Ethernet
Preamp Control
PM Tubes


Electrodes
Tungsten Collimator
Electronics
CZT

Cardiac-centric SPECT with solid-state detectors

- The Digirad® Cardius:
  - Two or three parallel hole collimator cameras
  - solid state, segmented CsI (Tl) silicon photodiode



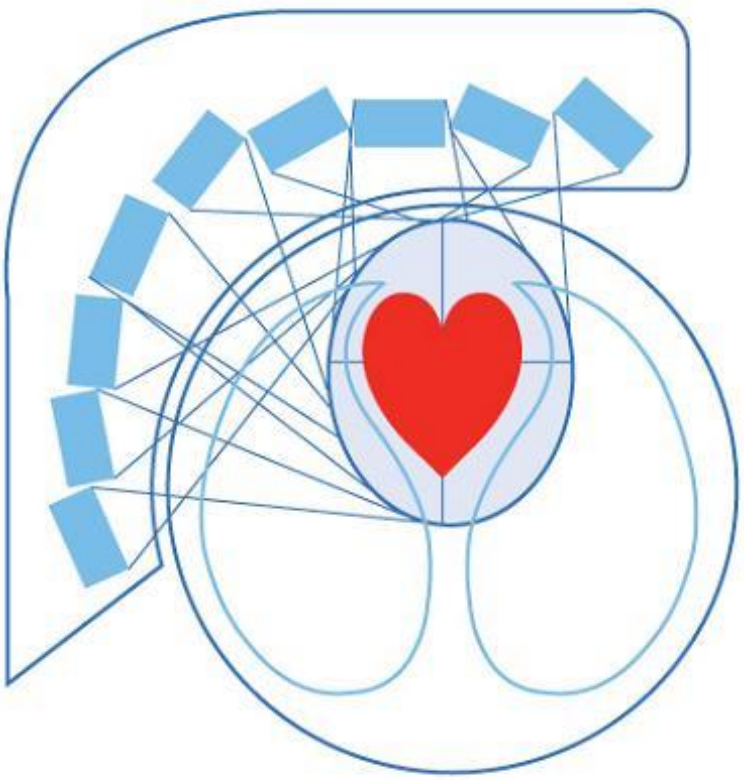
- The Spectrum Dynamics D-SPECT
  - 9 cadmium-zinc-telluride (CZT) fanning detectors
  - tungsten parallel large hole collimators



- The General Electric Discovery NM 530
  - 19 CZT static detectors
  - pinhole collimators (tungsten insert)



Solid state detector SPECT



Multiple fixed detectors
focussed on the heart :

- no motion of the camera

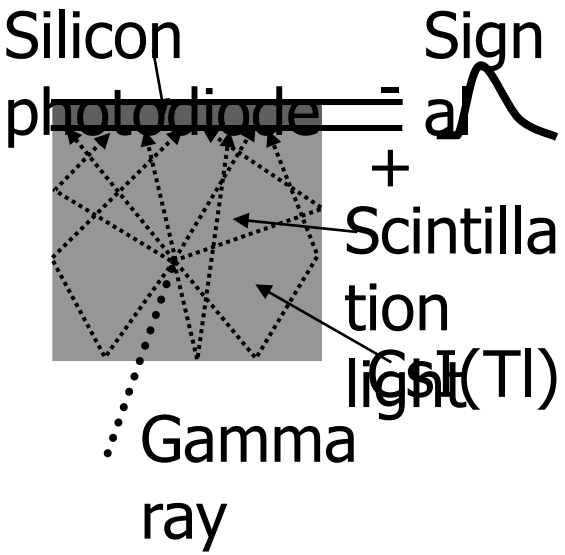
- simultaneous aquisition :
2 min scan time

- pinhole collimation :
increases resolution

Images from GE

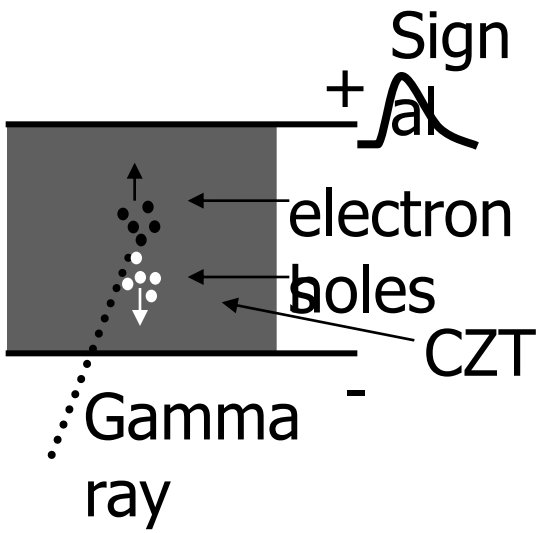
Higher sensitivity of camera: solid state detectors

Caesium iodide



- Gamma → scintillation
- Photodiode → electrical signal

Cadmium zinc telluride (CZT)



- Gamma → electrical signal

Alcyone 530 NMc (GE)

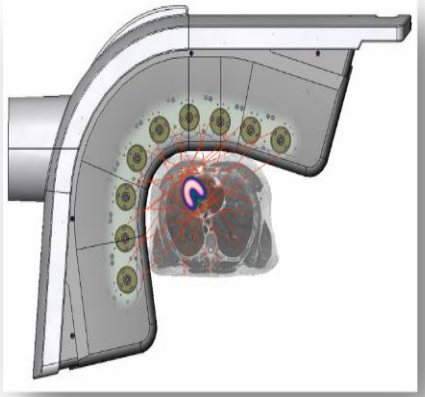
- 19 CZT crystal arrays
- Each 32x32 pixels, 2.5mm²
- Focused pinhole collimation
- 19cm diameter quality FOV
- High sensitivity
- No detector motion



D-SPECT (Spectrum Dynamics)





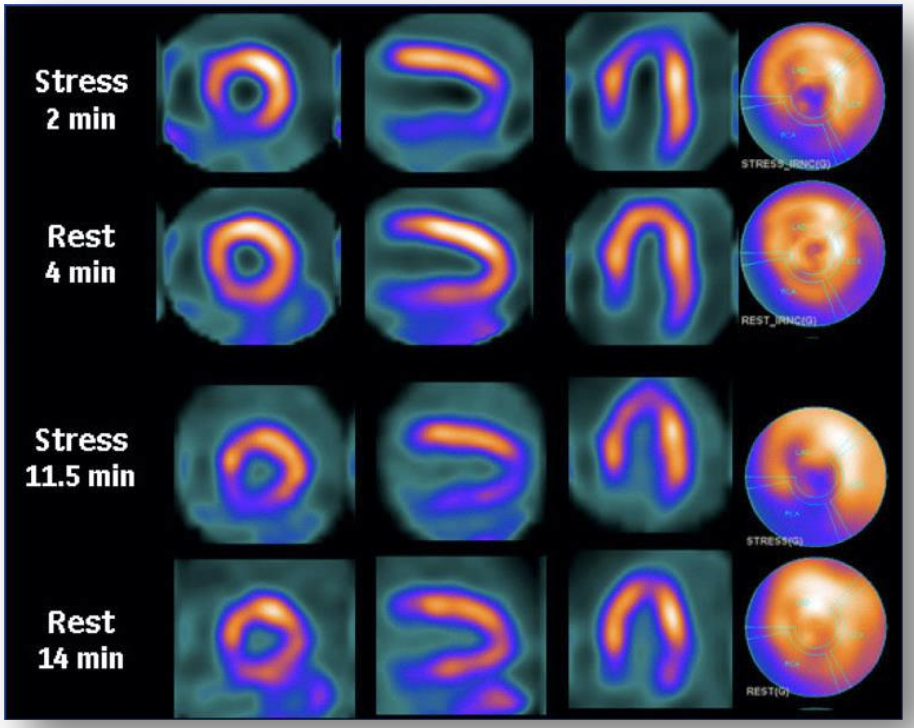


- 9 individual detectors
  - 16x64 array CZT crystals
  - Pixels each 2.5 mm²
  - Cardio-centric wobble
- Square hole collimators
  - One hole per pixel
- Stationary head
  - Semi-supine or supine
  - Movable 20cm diameter FOV

CZT camera versus conventional Anger camera

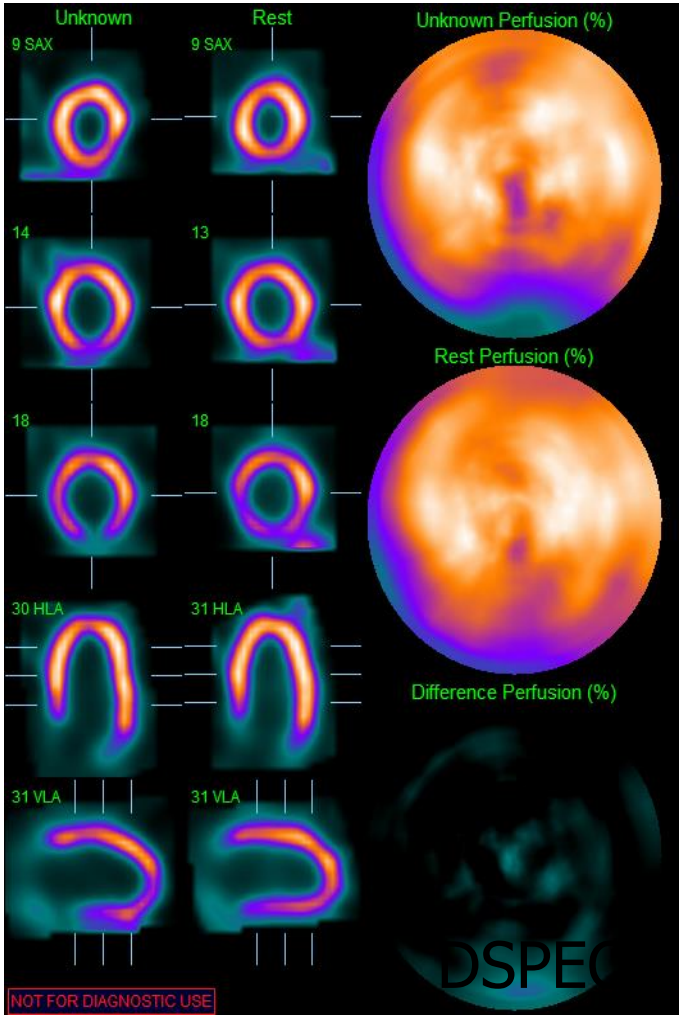
Alcyone

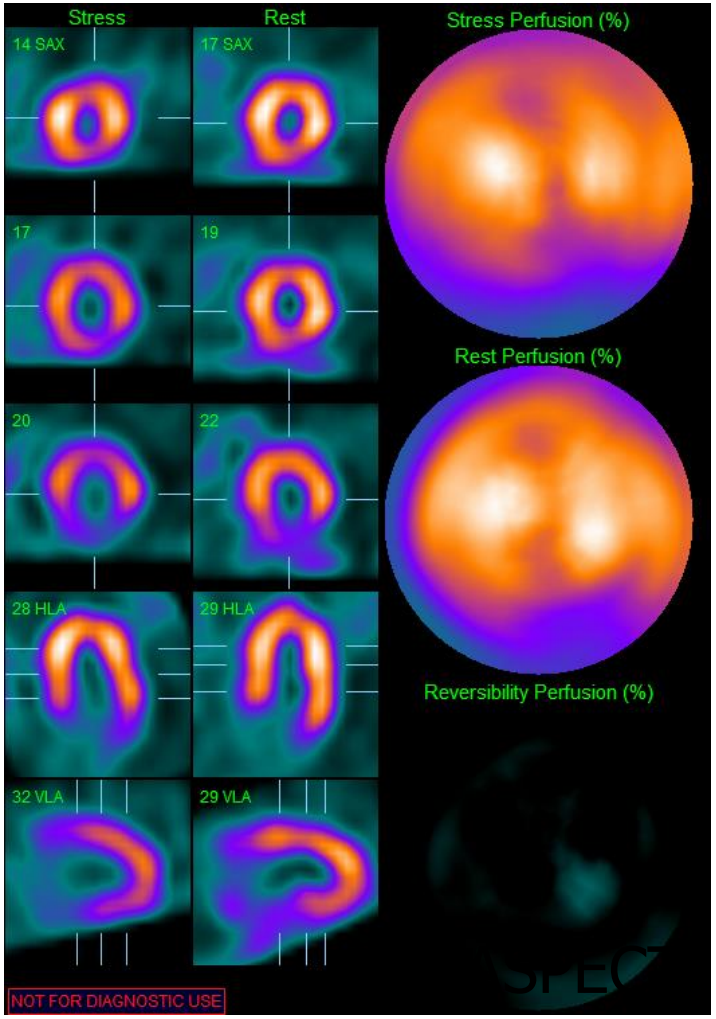
Conventional



Bocher M

CZT camera versus conventional Anger camera





Courtesy

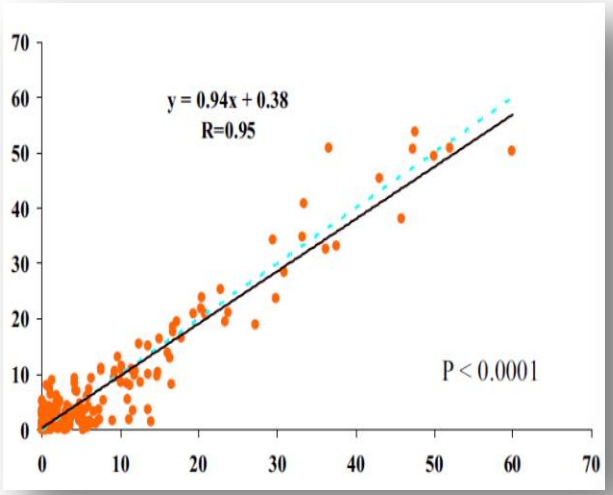
Performance of CZT camera

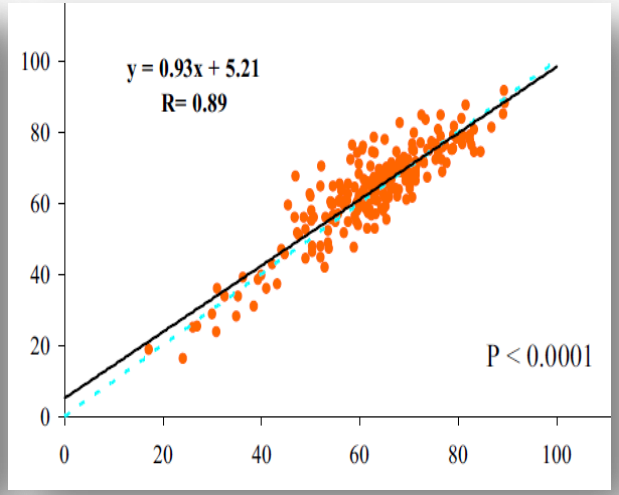
Sens 94%, Spec 86%

Nakazato R. JNM 2010; 51: 1724-31

Stress TPD (total perfusion deficit) **LVEF**

DSPECT





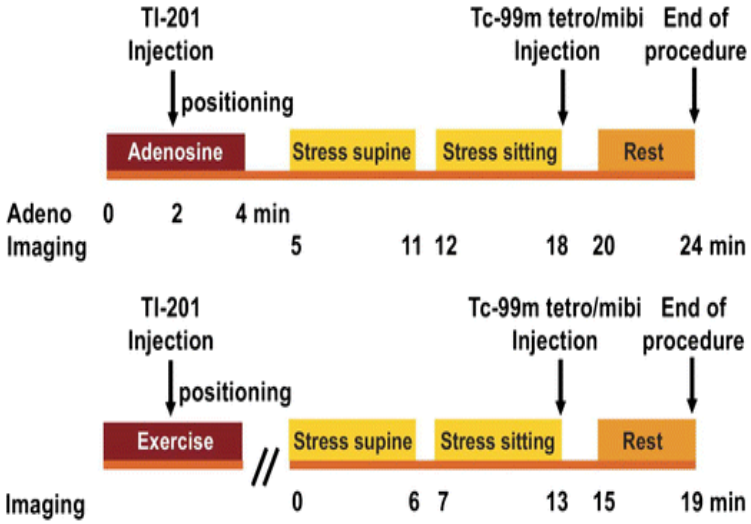
ASPECT

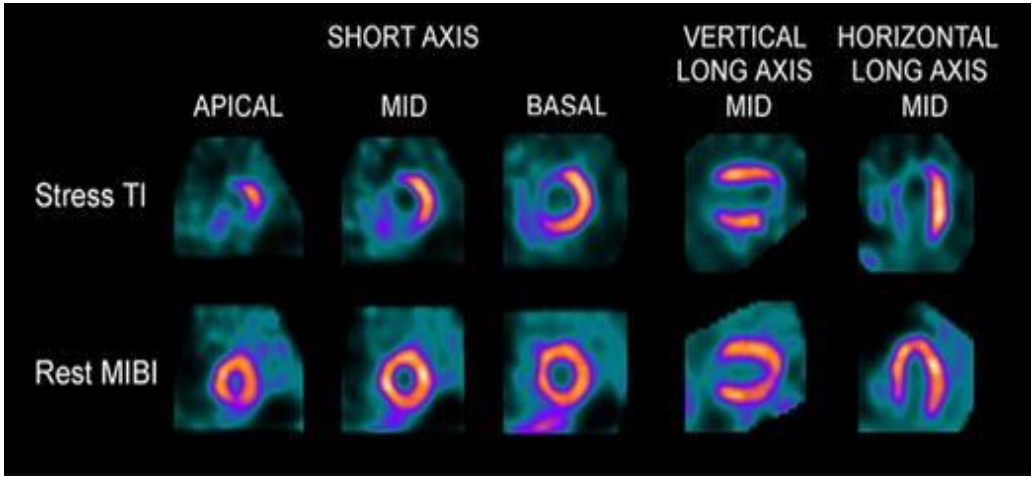
Sharir T. JACC 2010; 55; 1965-74

Advantages/possibilities of CZT technology

- Rapid Imaging
- Dose reduction
- Dual isotope imaging (energy resolution!)
- Perfusion quantification
- Innervation (high sensitivity)

Rapid imaging protocol





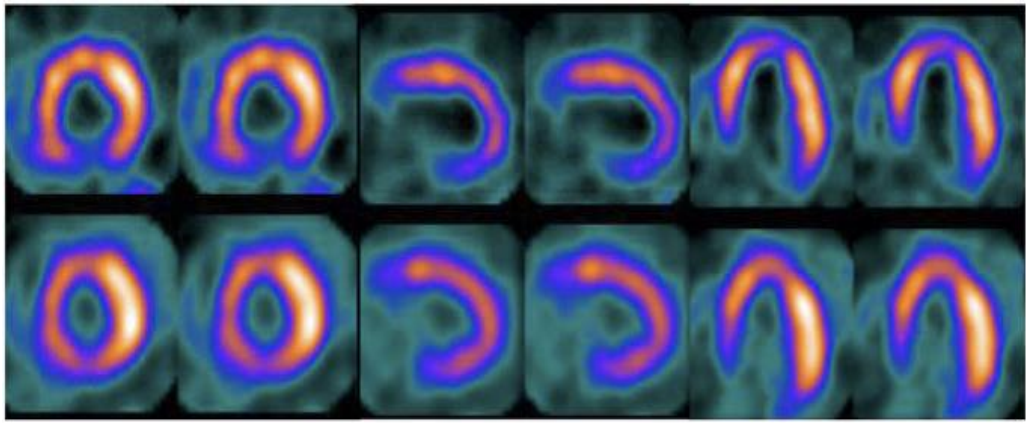
Berman D et al

Simultaneous dual isotope imaging

Conventional SPECT

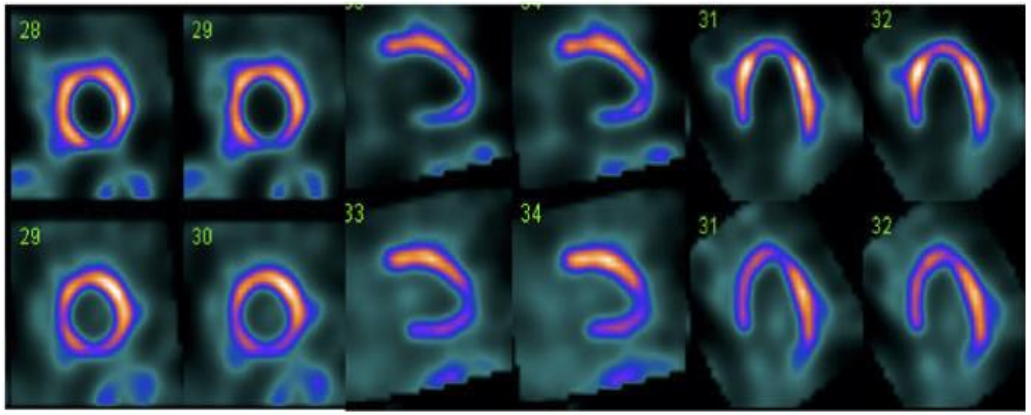
Stress Tc
250MBq

Rest Tl
80MBq



Stress Tc
250MBq

Rest Tl
80MBq



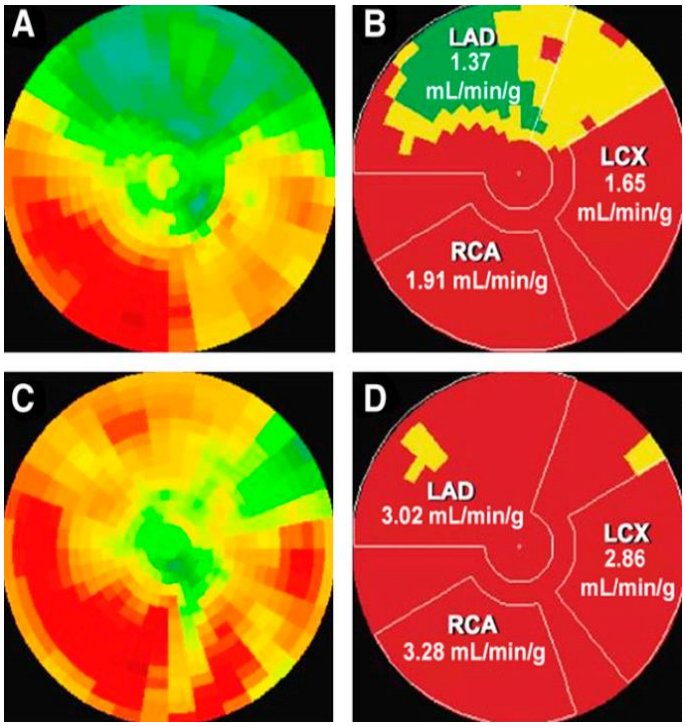
Simultaneous dual isotope

Ben Haim S et al

Relative vs absolute quantification: NH3

Baseline
after adenosine

After 1 year
of statins

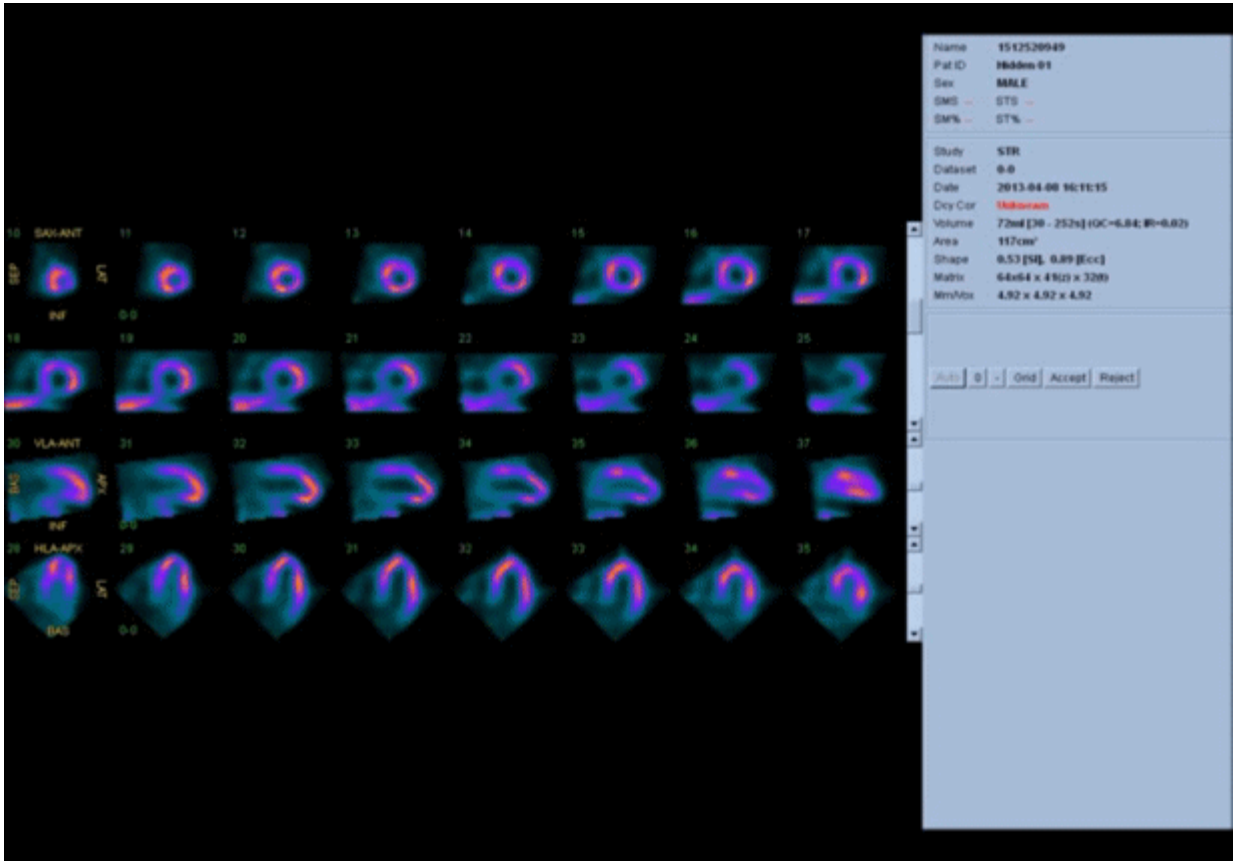


Relative Absolute

Vesely, J Nucl

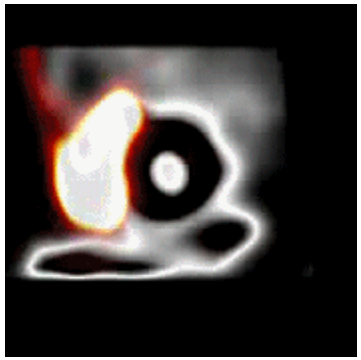
Perfusion quantification

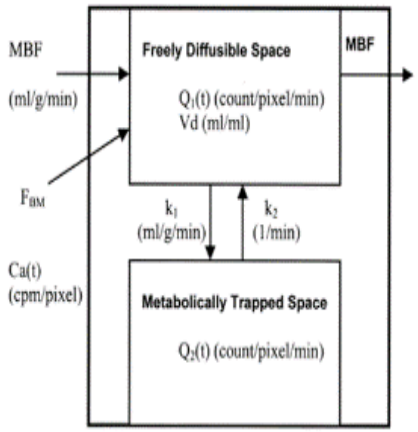
Dynamic Imaging with CTZ camera

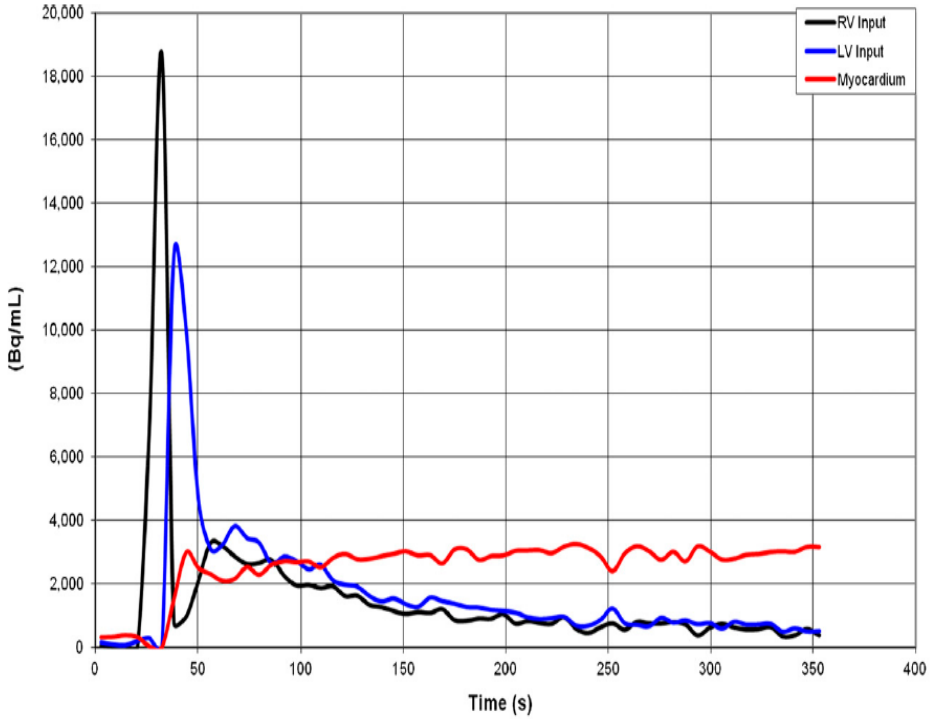


Perfusion quantification

Dynamic Imaging with CTZ camera







Ben Haim S et al

Imaging Technique

- SPECT

- Lower cost
  - tracer ^{99m}Tc
  - camera
- Lower resolution (now CZT camera)
- Only relative quantification

(maybe possible with CZT camera)

- High availability
- Lot of evidence and prognostic data

PET

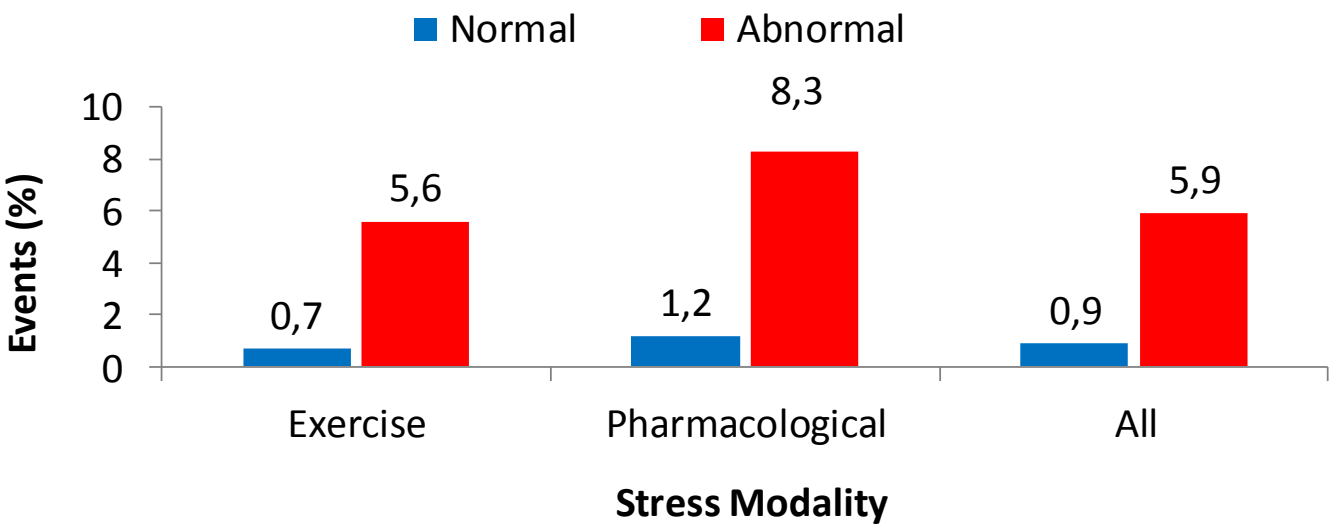
- Higher cost
  - tracer (cyclotron)
  - camera
- Higher resolution
- Absolute quantification possible
- Faster protocols
- Lower radiation dose (2,5 mSv)
- Less artefacts
  - Attenuation correction
  - Ring of detectors vs rotating camera

FFR versus MBF versus MFR

- FFR:
  - Cutoff: 0,8
- D-SPECT MBF:
  - < 2 ml/min/g = resting condition (RMBF)
  - > 4 ml/min/g = stress condition (SMBF)
- D-SPECT MFR:
  - SMBF/RMBF: Cutoff: 2,1 (or 2 in other)
  - SMBF – RMBF: cutoff: 1 ml/min/g
- PET MFR:
  - Cutoff: 2

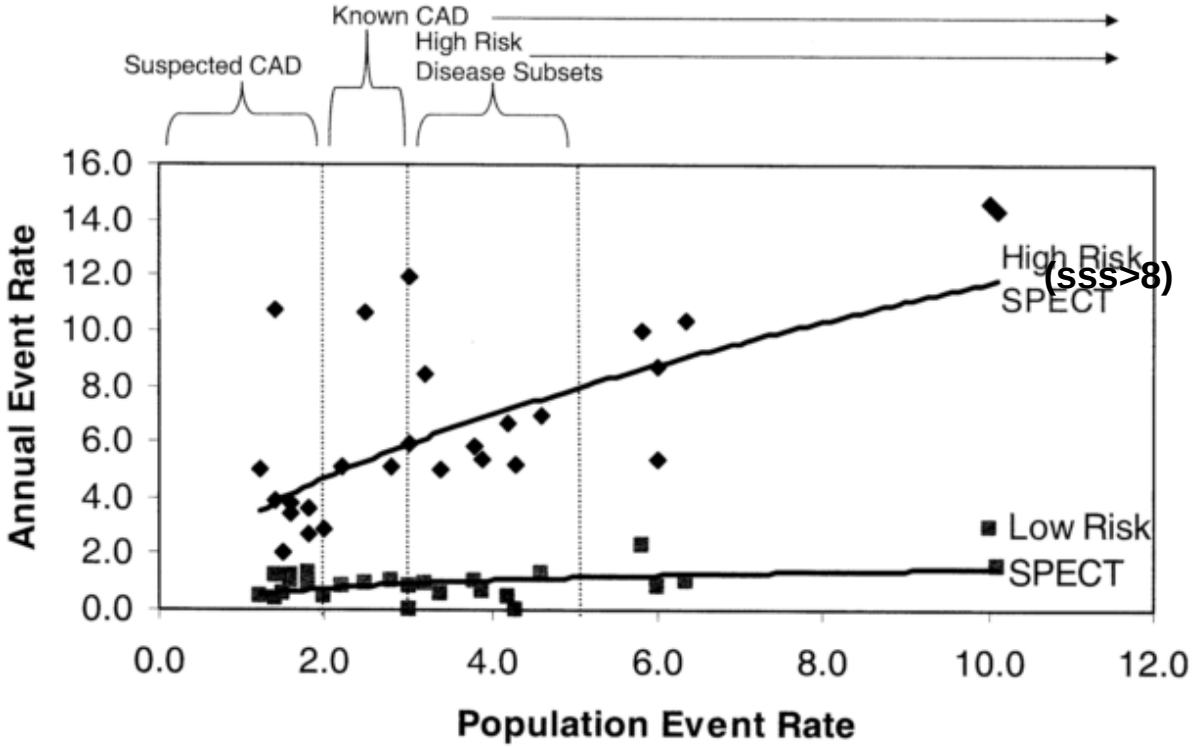
Prognostic value of SPECT MPI is excellent

N=69.655



Shaw L. J Nucl Cardiol 2004

However, event rates are lower in populations with suspected CAD as compared with patients with chronic CAD

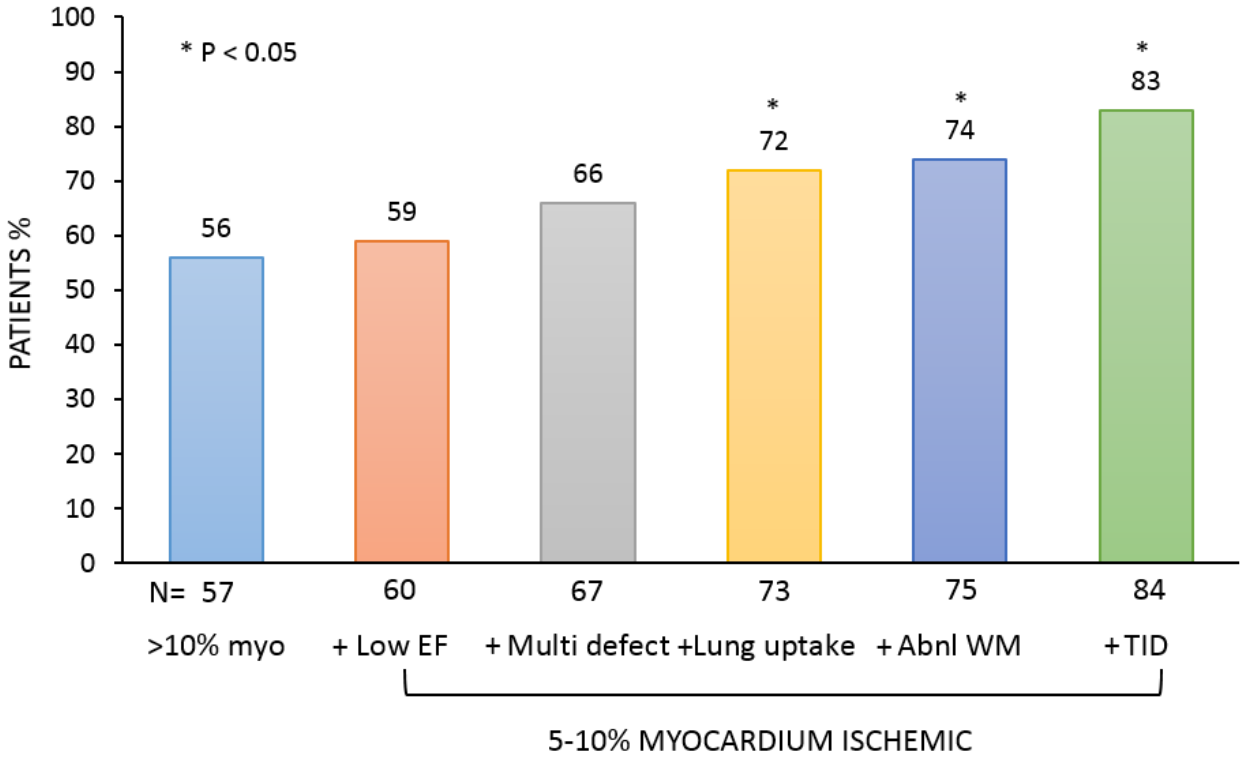


Shaw L. J Nucl Cardiol 2004

Patient risk related to a coronary stenosis

- **Non-ischemic stenosis: < 1% per year**
  (NUCLEAR studies, DEFER, FAME, PROSPECT)
- **Ischemic stenosis, if left untreated: 5-10% per year**
- **Stented stenosis: 2-3% per year**
  (DEFER, FAME, SYNTAX, many large studies and registries)

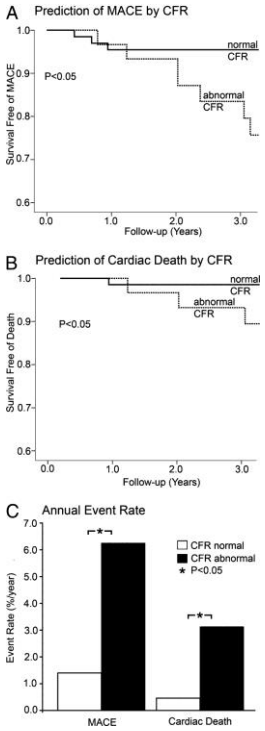
Limitations of perfusion SPECT to Detect High Risk CAD

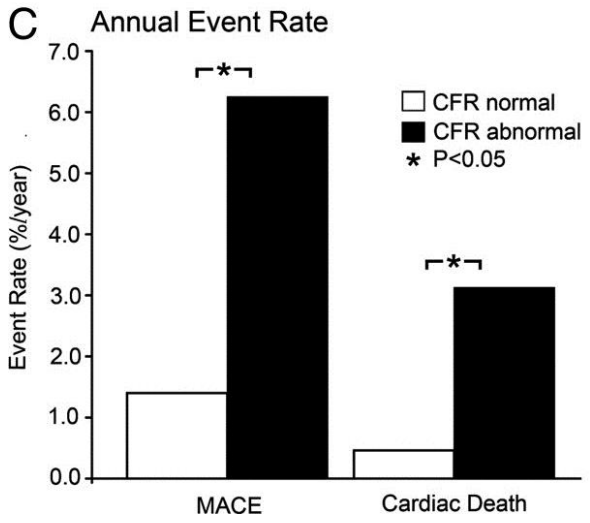


Berman D. J Nucl Cardiol. 2007

Long-Term Prognostic Value of ^{13}N-Ammonia PET in patients with CAD

N= 256

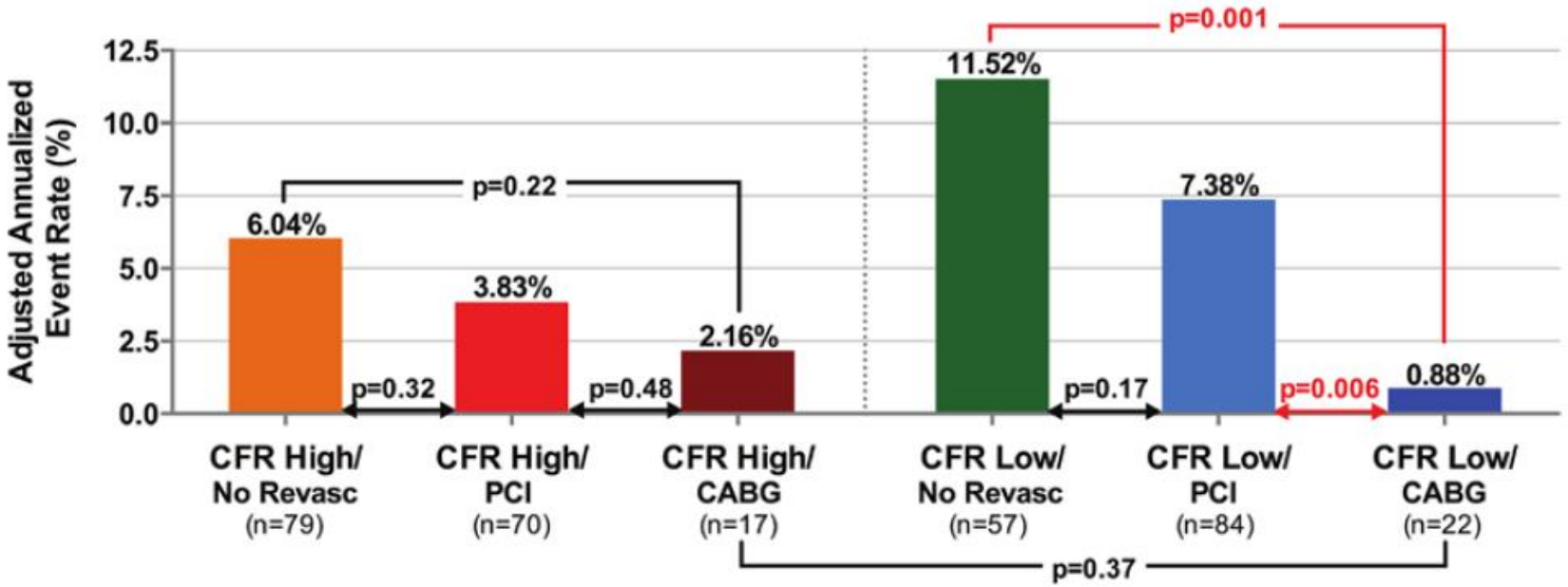




Herzog B. J Am Coll Cardiol 2009;54:150–6

Detection of all hemodynamically significant lesions is important to guide effective therapy

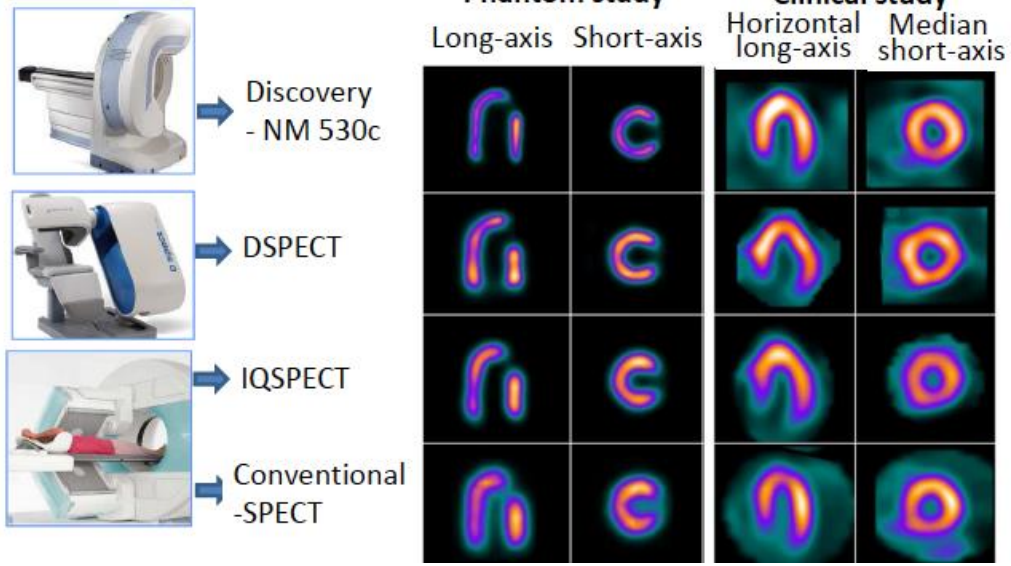
Perfusion PET, Coronary Flow Reserve, Revascularization, and Outcomes

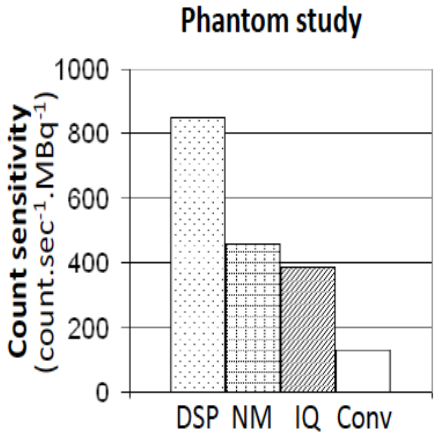


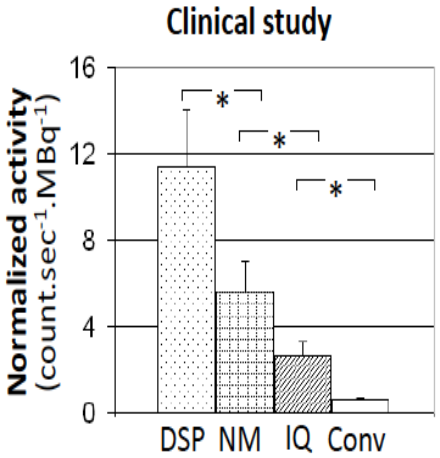
→ Only patients with angiographic obstruction AND low CFR seem to benefit for revascularization, especially CABG

Taqueti VR, et al. Circulation 2015

D-SPECT CZT camera increases count sensitivity

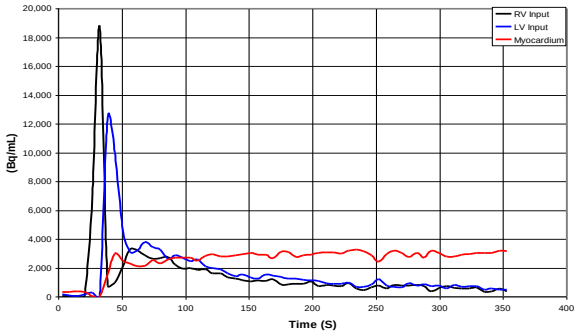






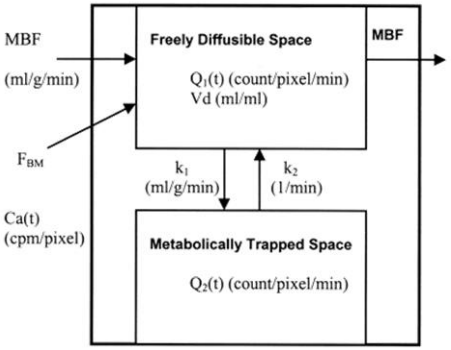
Imbert et al. J Nucl Med 2012

Dynamic Myocardial Perfusion SPECT

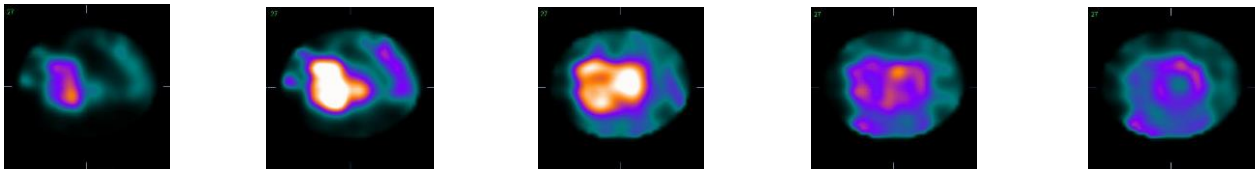


Kinetic modeling

2-compartment model







Ben-Haim et al., JNM 2013;54:873-879

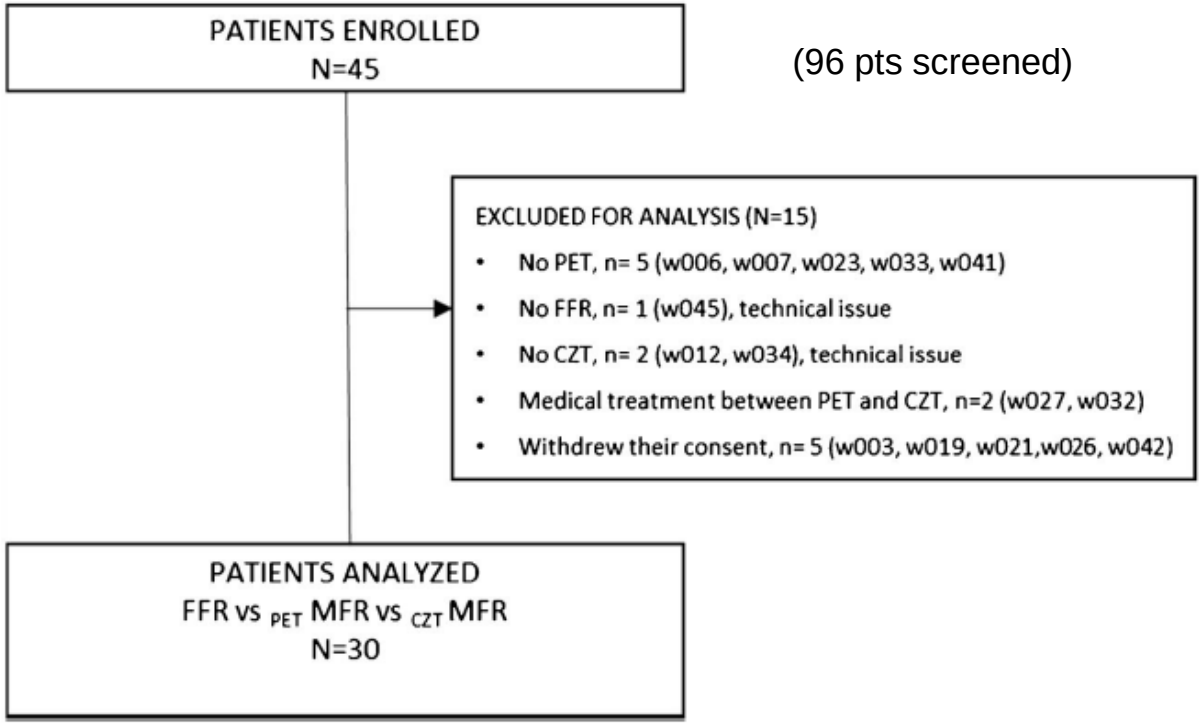
European Journal of Nuclear Medicine and Molecular Imaging
https://doi.org/10.1007/s00259-018-3958-7

ORIGINAL ARTICLE

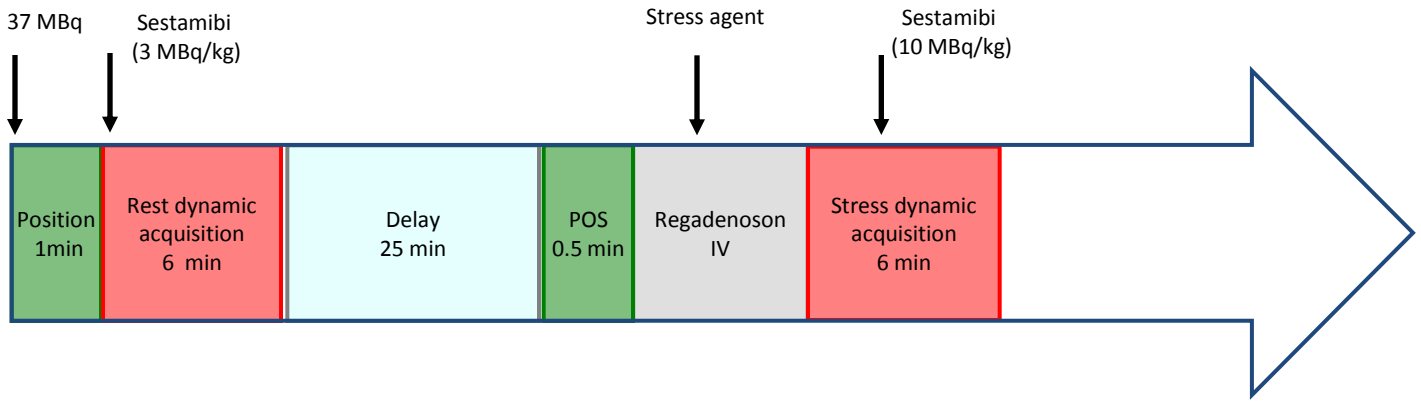
First validation of myocardial flow reserve assessed by dynamic ^{99m}Tc-sestamibi CZT-SPECT camera: head to head comparison with ^{15}O-water PET and fractional flow reserve in patients with suspected coronary artery disease. The WATERDAY study

Denis Agostini[1,2] · Vincent Roule[3] · Catherine Nganoa[1] · Nathaniel Roth[4] · Raphael Baavour[4] · Jean-Jacques Parienti[5] · Farzin Beygui[2,3] · Alain Manrique[1,2,6]

The Waterday study



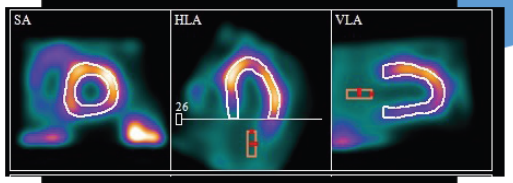
Dynamic CZT SPECT Imaging Protocol



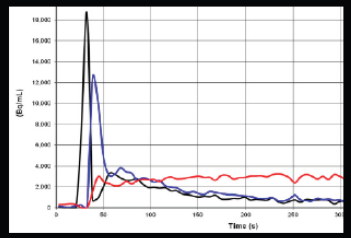
- MPI protocol duration: 45 min
- List mode dynamic acquisition
- Reconstruction: 31-frame (20x3 s, 1x9 s, 1x15 s, 1x21 s, 1x27 s, 7x30 s)
- Radiation exposure: < 9 mSv (2,6 mSv and 6 mSv)

Dynamic CZT SPECT processing (corridor 4DM®, Invia)

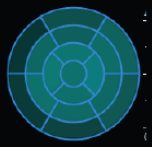
Bolus & LA ROIs



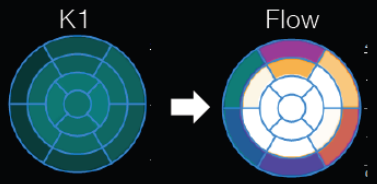
Time activity curves (TAC)



Sestamibi kinetic model (Net retention) & extraction factor K1 calculation

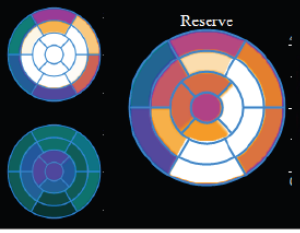


Apply sestamibi extraction fraction correction (Leppo)



$$K1 = Flow * \left(1 - A * e^{-\frac{B}{Flow}}\right)$$

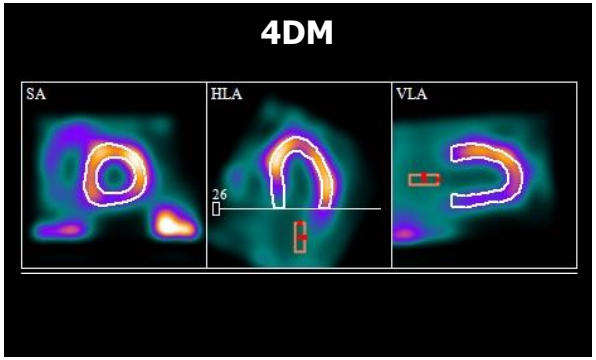
Calculate Relative flow & reserve



Region	Flow (ml/min/g) MC Str	MC Rst	Reserve
LAD	1.58	0.56	2.84
LCX	1.77	0.51	3.46
RCA	1.36	0.37	3.71
TOT	1.57	0.48	3.24

Dynamic CZT SPECT package

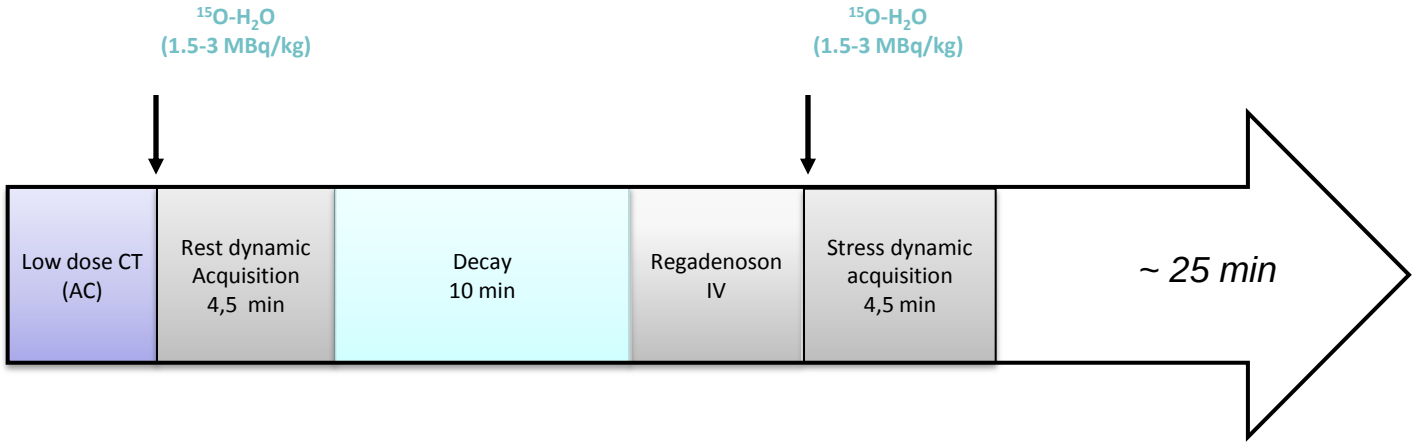
- D-SPECT acquisition station
  - SW upgrade (SW3.2.1 and above)
- D-SPECT processing station:
  - SW upgrade (SW3.2.1 and above)
  - Reconstruction SW upgrade
  - 4DM INVIA SW install
- Shielded box
- Injector





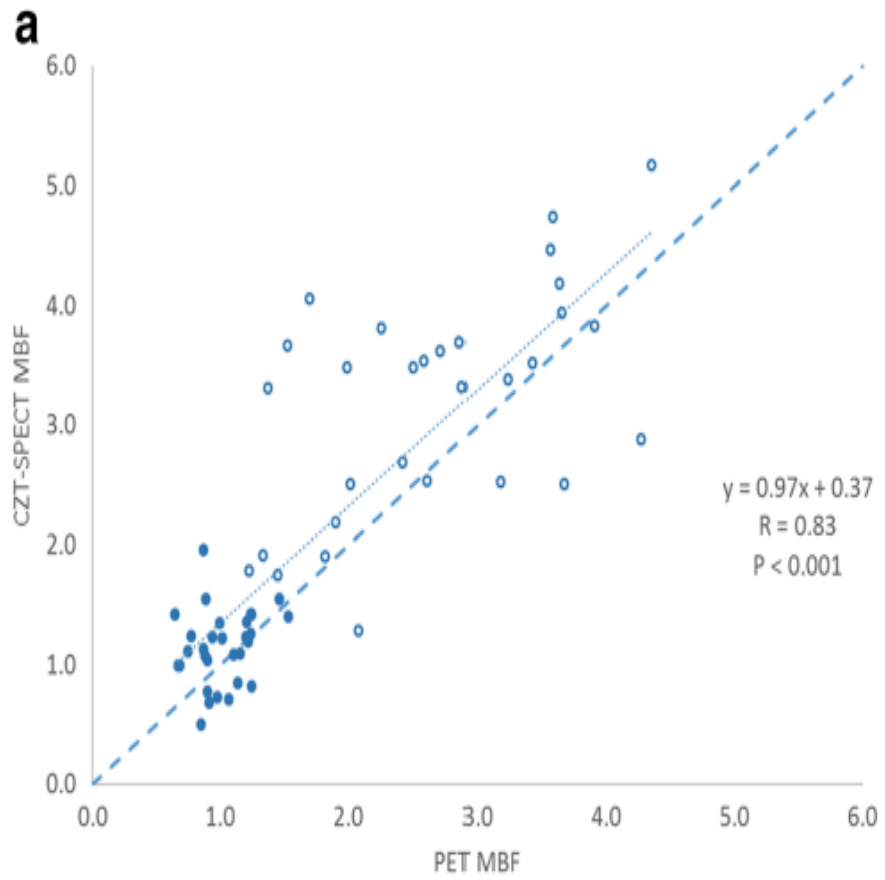


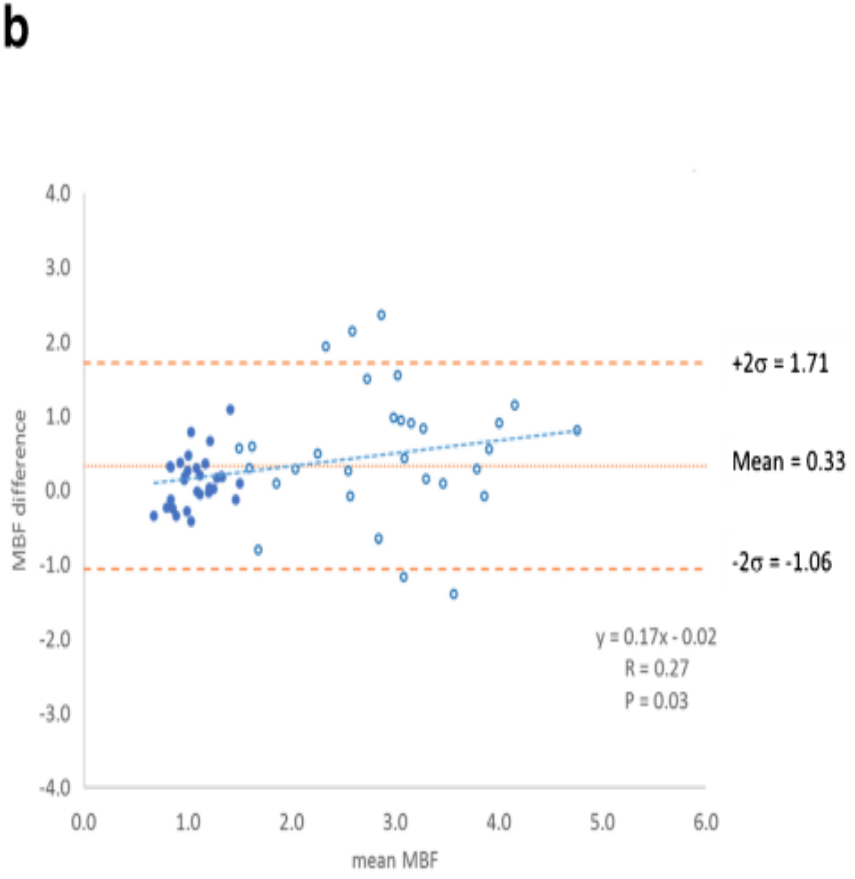
Dynamic ^{15}O-H_2O PET Imaging Protocol



- GE Discovery VCT RX 64
- Dynamic list mode PET acquisition
- 24-frame (14 x 5 s, 3 x 10 s, 3 x 20 s and 4 x 30 s)
- Image processing:
  - Carimas ® (Turku PET Centre)
  - Iida model, with spillover correction

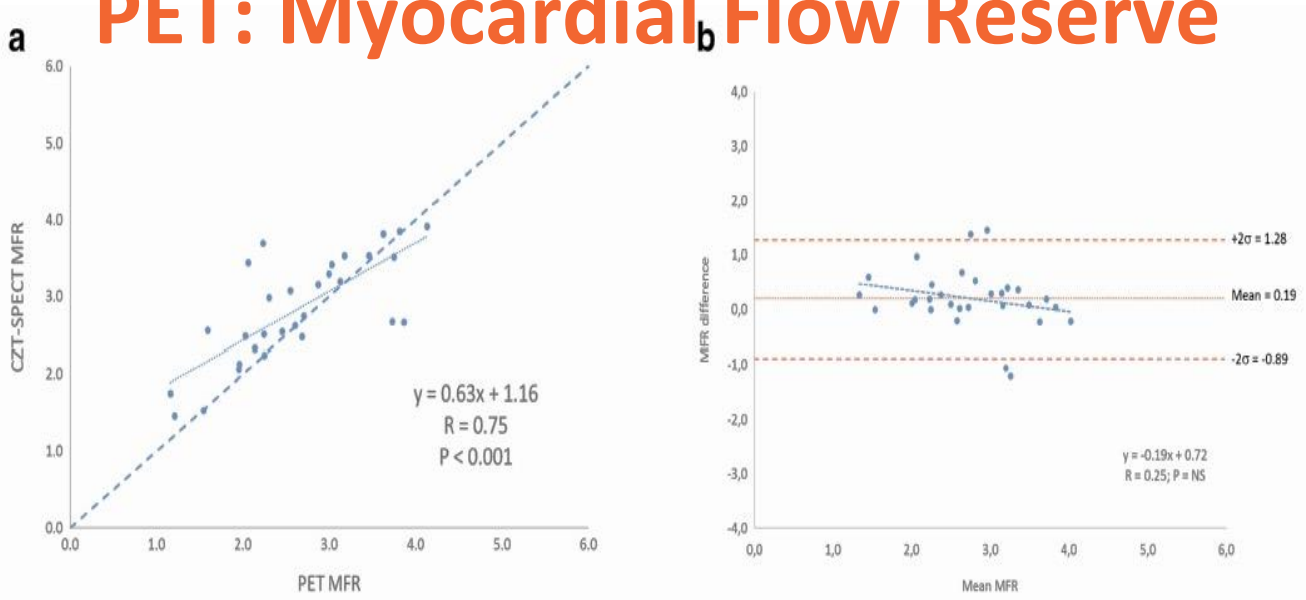
Waterday study: CZT-SPECT vs. ^{15}O-H_2O PET: stress MBF



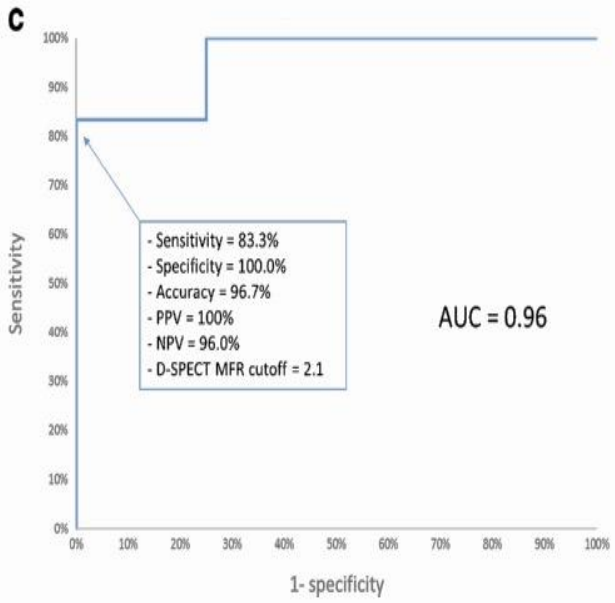


Agostini D. EJNMMI 2018

Waterday study: CZT-SPECT vs. ^{15}O-H_2O PET: Myocardial Flow Reserve

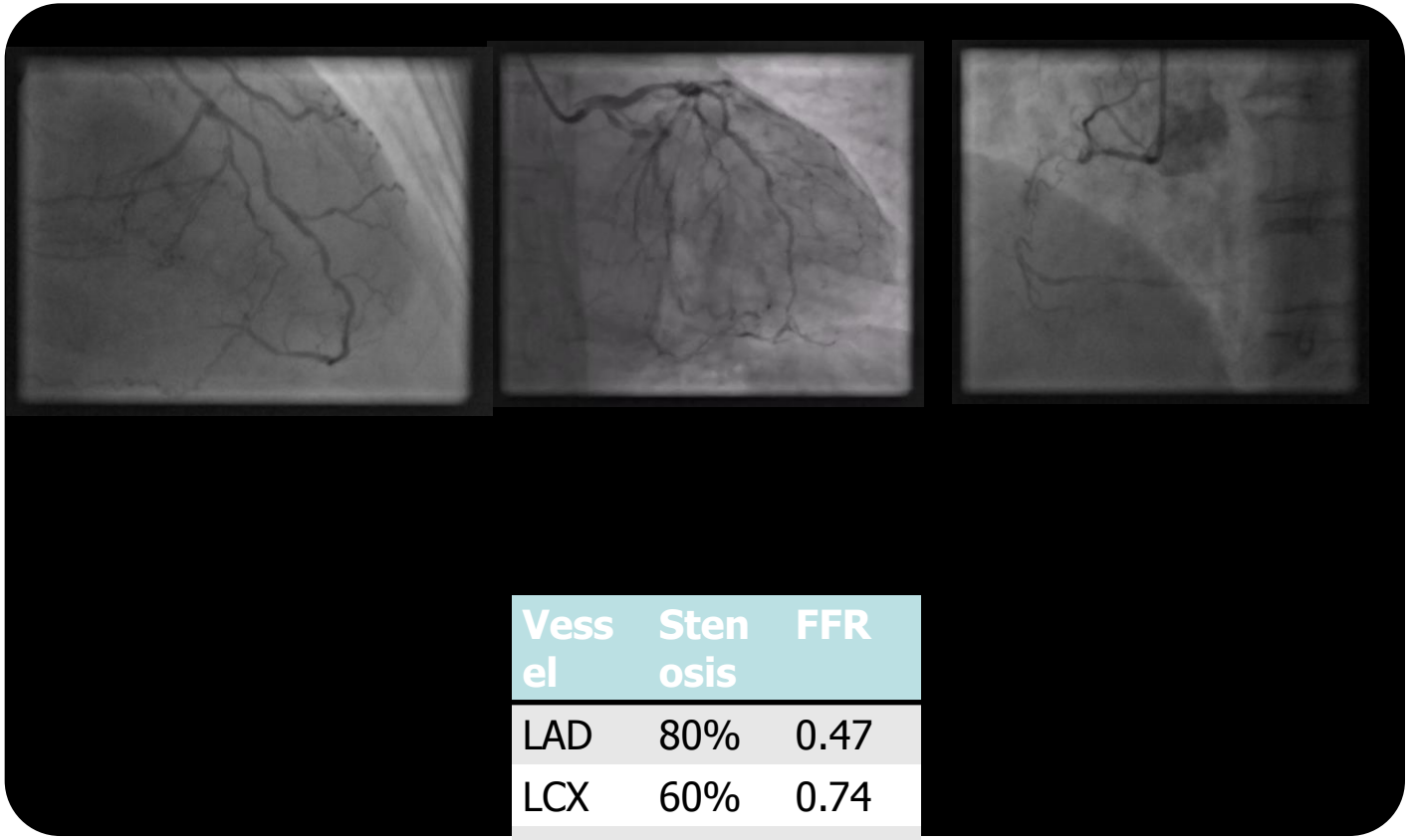


DSPECT cutoff: 2.1



Agostini D. EJNMMI 2018

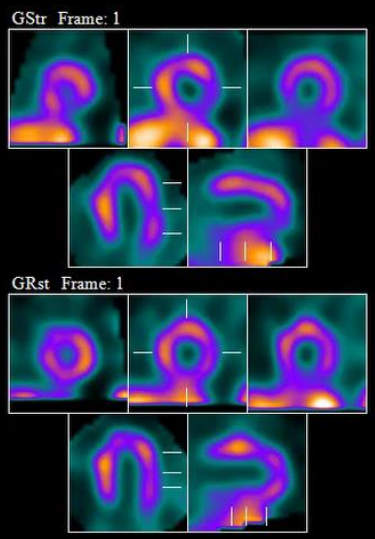
Case: WD008 Angiography



Vessel	Stenosis	FFR
LAD	80%	0.47
LCX	60%	0.74
RCA	100%	

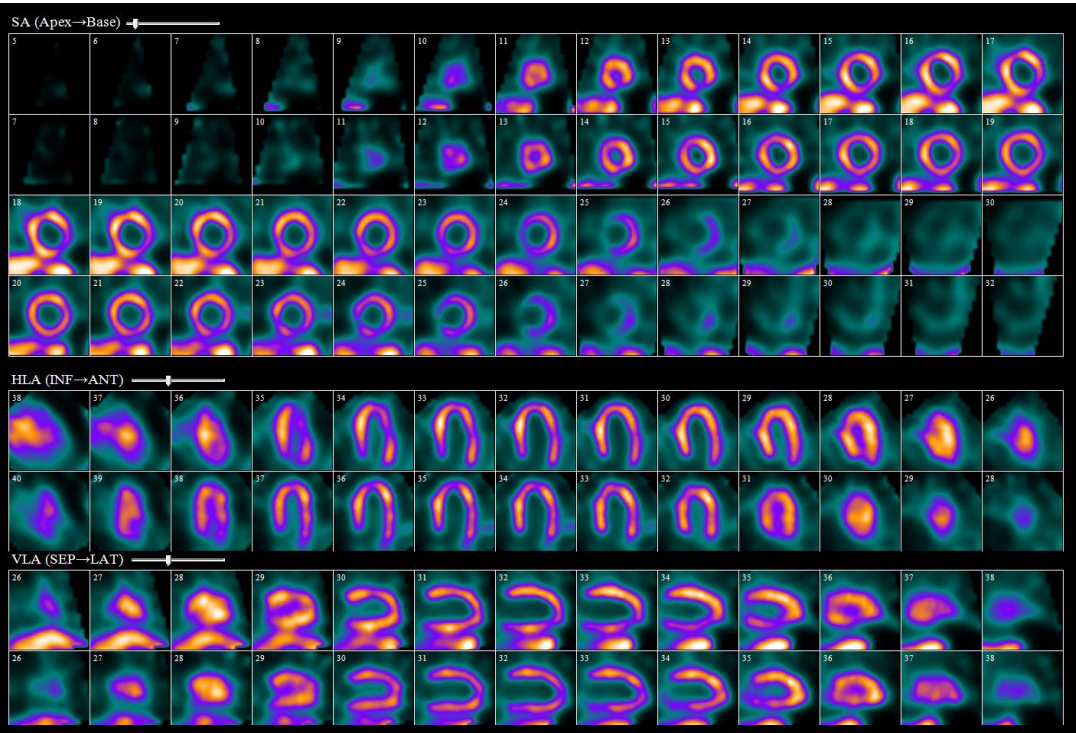
Case: WD008 Perfusion scan

64 yo, female
DM, Hypertension, Cholesterol, Family history
Angina

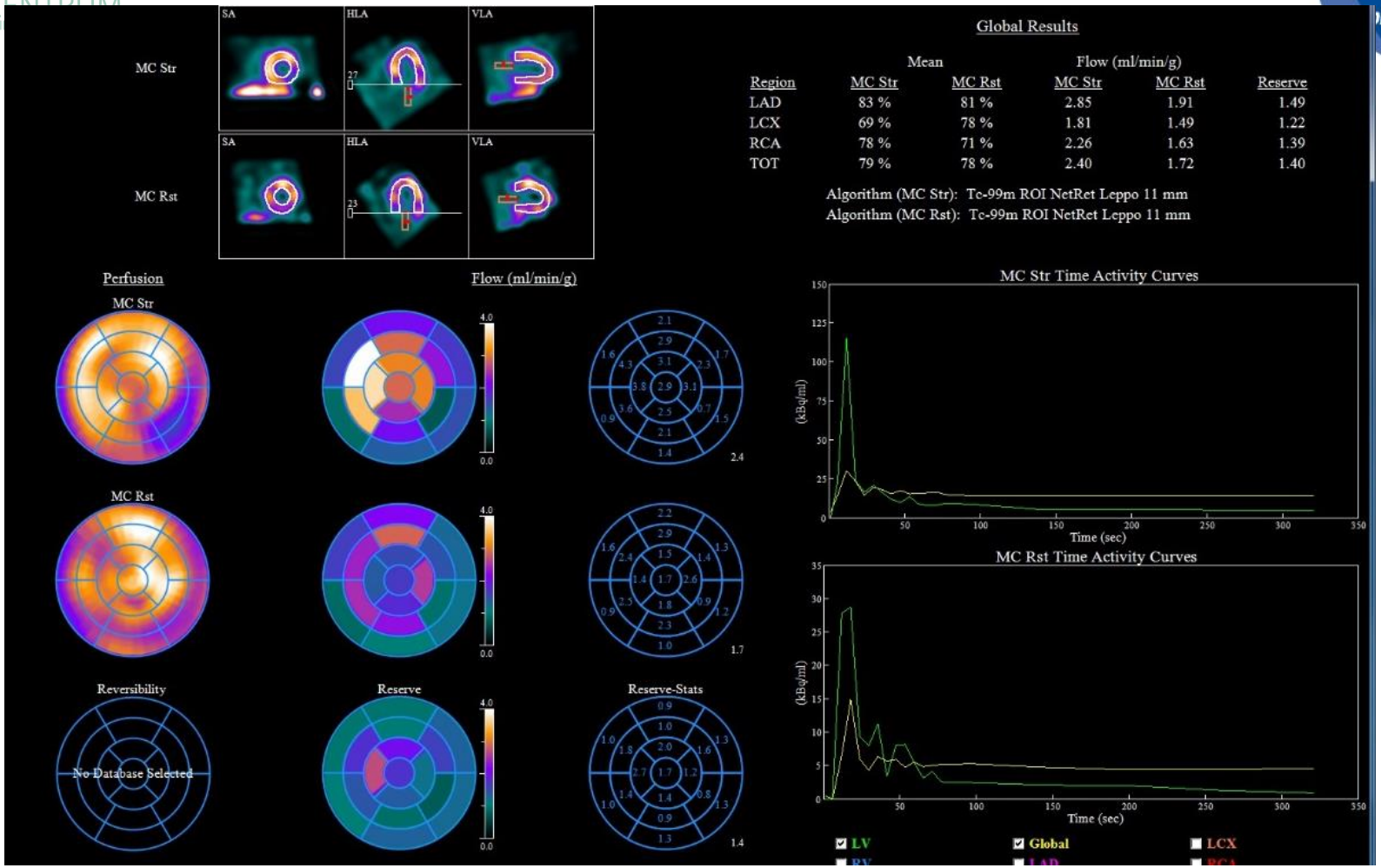


Stress

Rest

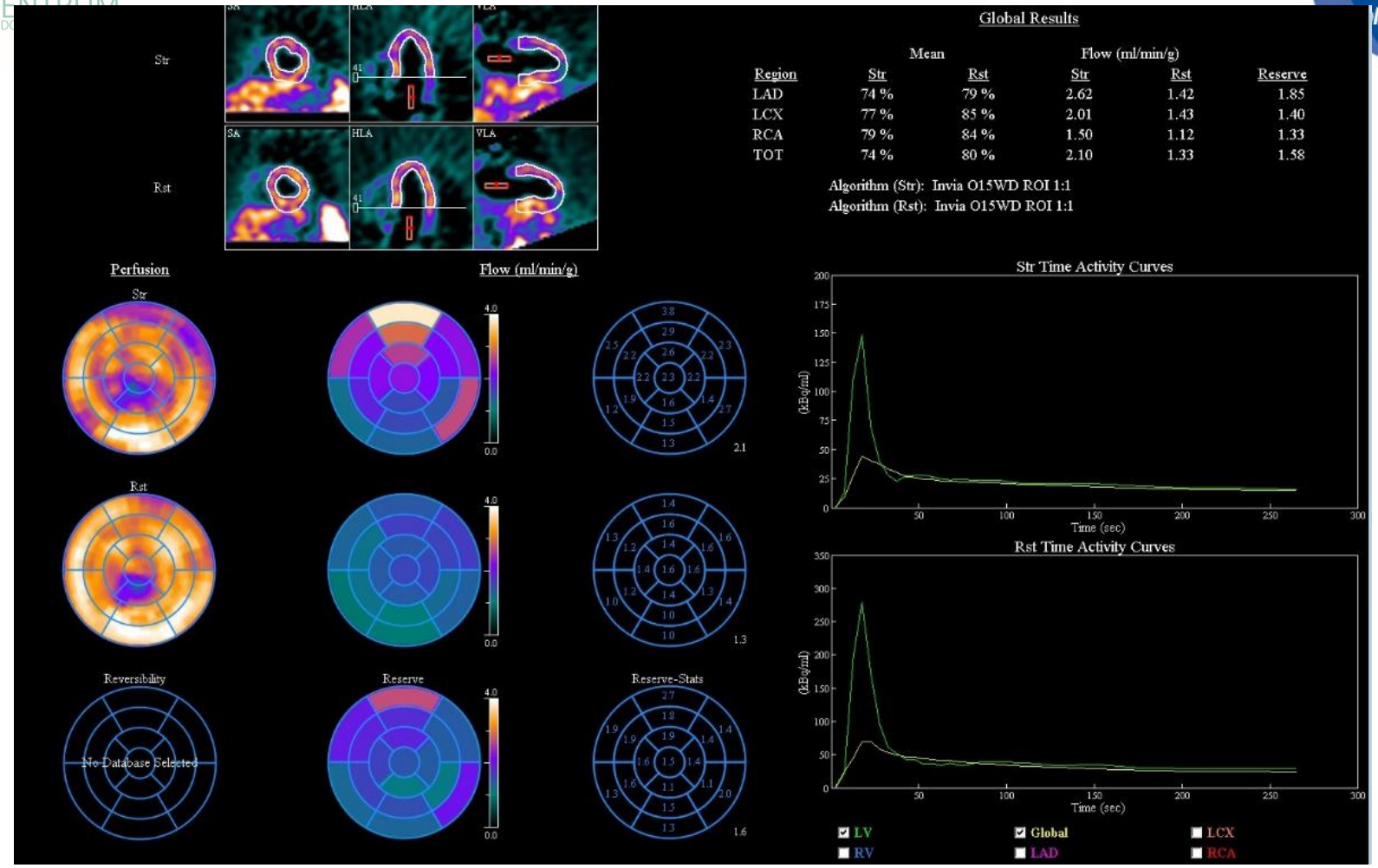


Case : WD008 Dynamic CZT scan



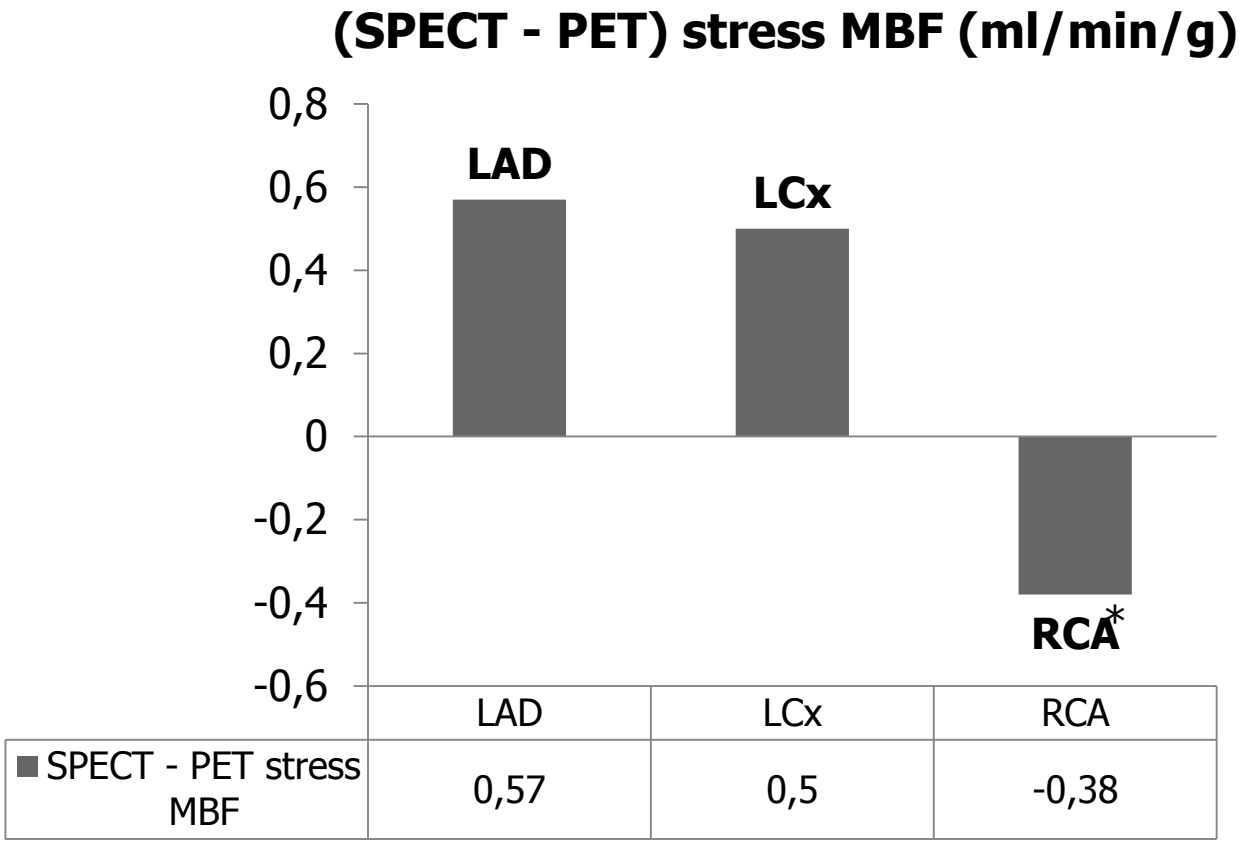
CFR is abnormal (< 2)
in LAD- LCX-RCA regions

Case : WD008 PET scan



CFR is abnormal (< 2)
in LAD- LCX-RCA regions

Linear model for the difference between SPECT and PET according to the coronary territory



*p < 0.01 vs. LAD and vs. LCx

Manrique A. EANM 2017

Conclusion

- Quantitative assessment is the next step in routine SPECT MPI
- The WATERDAY study was the first validation study vs. ^{15}O-H_2O PET, and demonstrated the feasibility of dynamic CZT SPECT acquisition
- Possible improvement:
  - New post-processing parameters (#frames, iterations, …),
  - Using the same software package for dynamic PET and SPECT data
  - Adding attenuation correction

PET CENTRUM
ZUIDOOST-VLAANDEREN

PET centrum Zuidoost-Vlaanderen

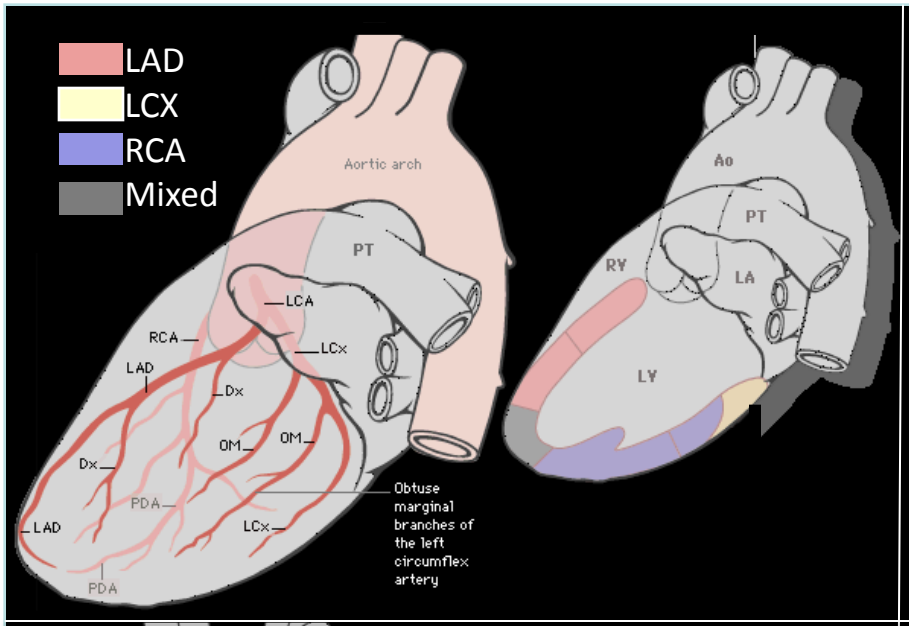


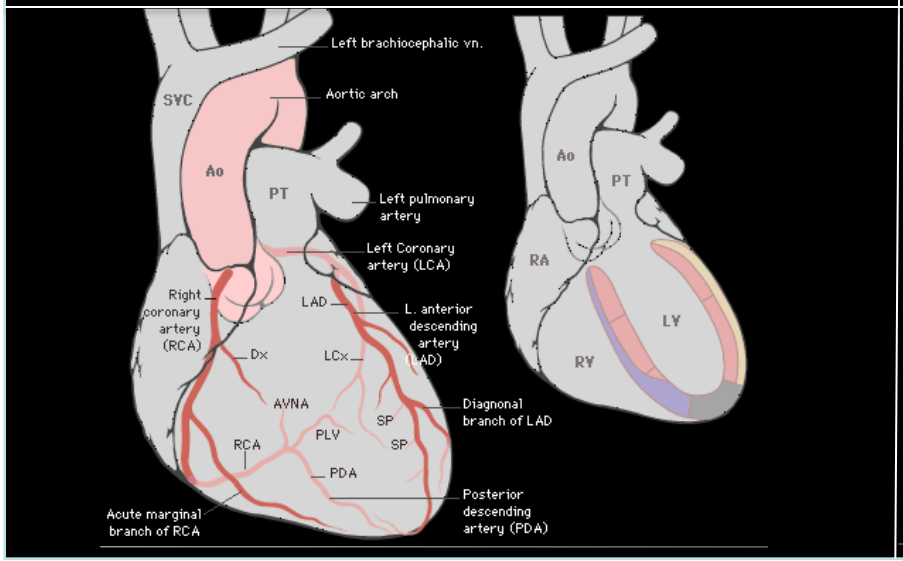


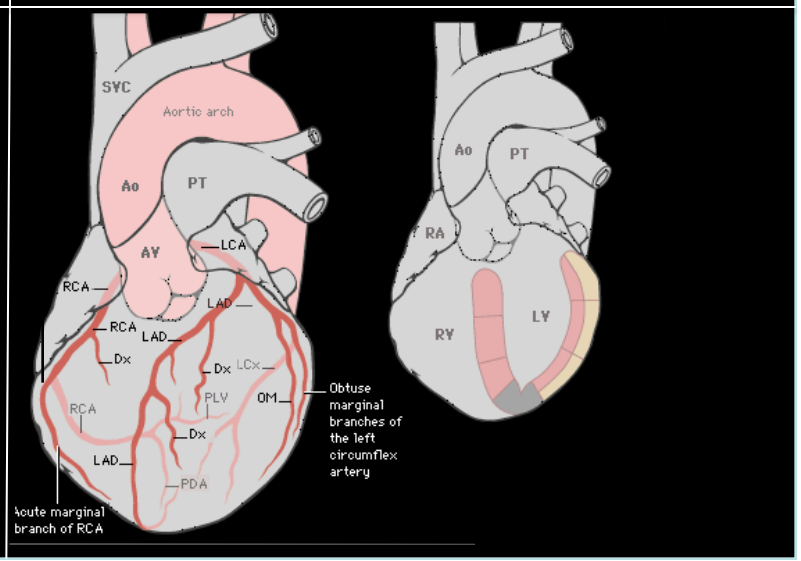
OLV Hospital

Dept of Nuclear Medicine

Aalst, Belgium


LAD
LCX
RCA
Mixed
Aortic arch
PT
LCA
RCA
LCx
LAD
Dx
OM
OM
Dx
PDA
LAD
LCx
PDA
Obtuse marginal branches of the left circumflex artery
Ao
PT
RV
LA
LV


Left brachiocephalic vn.
SVC
Aortic arch
Ao
PT
Left pulmonary artery
Left Coronary artery (LCA)
Right coronary artery (RCA)
LAD
L. anterior descending artery (LAD)
Dx
LCx
AVNA
Diagnonal branch of LAD
SP
SP
PLV
RCA
PDA
Posterior descending artery (PDA)
Acute marginal branch of RCA
Ao
PT
RA
LV
RV


SVC
Aortic arch
Ao
PT
AV
LCA
RCA
RCA
LAD
LAD
Dx
Dx
LCx
PLV
OM
Obtuse marginal branches of the left circumflex artery
RCA
Dx
LAD
PDA
Acute marginal branch of RCA
Ao
PT
RA
RV
LV