"Potentially Practical" or "Usable" ~~Practical~~ Approaches to Dose Reduction in Nuclear Cardiology

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游離輻射防護的兩大原則

- 『正當性 (justification)』
  - 使用游離輻射能種類、目的及時機須合理且合法。
- 『最佳化 (optimization)』
  - 使用游離輻射能方式的能做到『合理抑低(As Low As Reasonably Achievable, ALARA)』。

2

游離輻射防護的目的

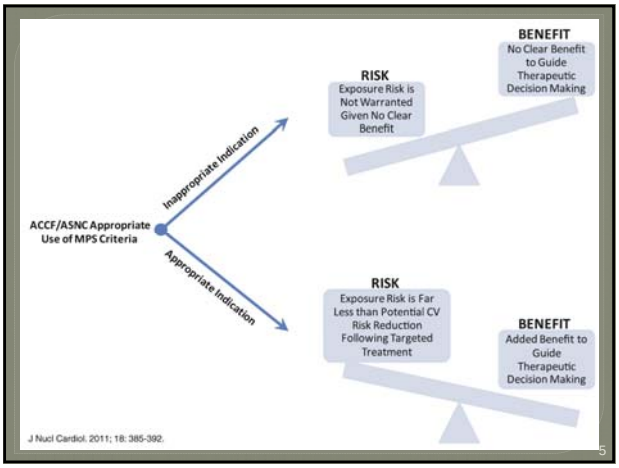
- 減少個體(病患、相關工作同仁及一般大眾)之輻射暴露
  - 減少游離輻射能對人體之機率性效應發生率
  - 防止非機率性效應的產生

3

Justification

- Appropriate Use Criteria (AUC)

4



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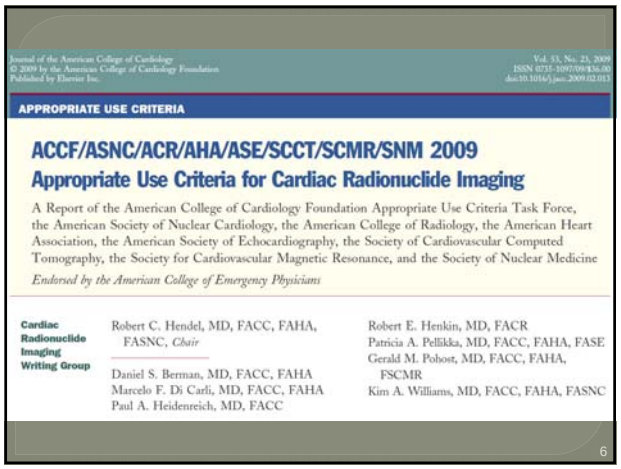


6

Appropriate Use Criteria for Cardiac Radionuclide Imaging Ratings
Moderator

Indication	Median	MAD/M	R	Agree
Table 1. Detection of CAD: Symptomatic				
Initial Evaluation (Chest Pain)				
1 • Low pre-test probability of CAD • ECG interpretable AND able to exercise	7	1.1	A	
2 • Low pre-test probability of CAD • ECG uninterpretable OR unable to exercise	7	1.1	A	-
3 • Intermediate pre-test probability of CAD • ECG interpretable AND able to exercise	7	1.4	A	-
4 • Intermediate pre-test probability of CAD • ECG uninterpretable OR unable to exercise	9	0.3	A	-
5 • High pre-test probability of CAD • Regardless of ECG interpretability and ability to exercise	9	1.3	A	
Acute Chest Pain				
6 • Possible ACS • ECG—no ischemic changes or with LBBB or electronically paced ventricular rhythm • Low-Risk TIMI Score • Peak Troponin: borderline, equivocal, minimally elevated	8	0.9	A	-
7 • Possible ACS • ECG—no ischemic changes or with LBBB or electronically paced ventricular rhythm • High-Risk TIMI Score • Peak Troponin: borderline, equivocal, minimally elevated	7	2.1	A	
8 • Possible ACS • ECG—no ischemic changes or with LBBB or electronically paced ventricular rhythm • Low-Risk TIMI Score • Negative troponin levels	8	1.3	A	-
9 • Possible ACS • ECG—no ischemic changes or with LBBB or electronically paced ventricular rhythm • High-Risk TIMI Score • Negative troponin levels	8	1.3	A	-
10 • Definite ACS	9	0.3	A	-
Acute Chest Pain (Need Imaging Only)				
11 • Possible ACS • ECG—no ischemic changes or with LBBB or electronically paced ventricular rhythm • Initial troponin negative • Recent or on-going chest pain	8	1.5	A	

# of Appropriate Indications (INLCUDES TEST)	33
# of Uncertain Indications	9
# of Inappropriate Indications	25
	67

7

Limitations of AUC

- **Expert opinion** and expert interpretation of existing clinical and trial evidence.
- Not account for:
  - Costs of the test
  - Cost-effectiveness
  - Relative performance compared to alternative tests
  - Ionizing radiation of individual test
  - Impact of repeat testing or layered testing

8

Original Article

Can Physicians Identify Inappropriate Nuclear Stress Tests?

An Examination of Inter-Rater Reliability for the 2009 Appropriate Use Criteria for Radionuclide Imaging

... The cardiologists rated 256 **(64%)** of 400 nuclear stress tests **as appropriate**, 68 (18%) as uncertain, 55 **(14%) as inappropriate**; 21 (5%) tests were unable to be classified...

... ***Inter-rater reliability for noncardiologist raters was modest (unweighted Cohen κ, 0.51***, 95% confidence interval, 0.45–0.55)... Inter-rater reliability for the 2009 Appropriate Use Criteria for radionuclide imaging is modest, and there is **considerable variation in the ability of raters at different levels of training** to identify inappropriate tests.

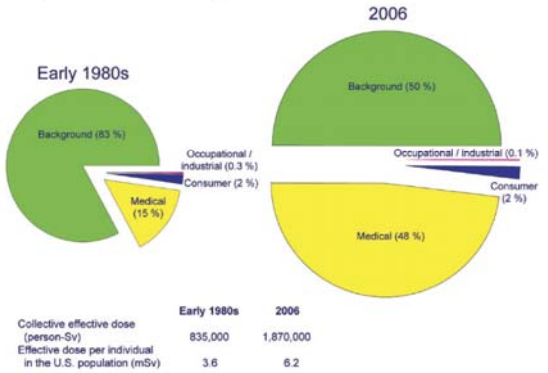
9

Recommendations for achieving MPI radiation reduction — J Nucl Cardiol. 2010; 17: 709-718.

Feature	Potential for dose reduction	Recommendation
Patient selection	Significant	Apply appropriate use criteria. Consider alternative modalities with comparable diagnostic accuracy without radiation in younger patients. Consider utilization in the following patients in whom MPI has the most clinical utility: intermediate CAD risk, those requiring prognostic or management information, and those with persistent and unexplained symptoms. Layered or serial testing should be avoided
Protocols, radiotracers and imaging systems	Significant	The clinical indications and physical stature of each patient should be reviewed and the best combination of radiotracers and protocols selected using the following guidelines: use radionuclides with shorter half-life such as Tc-99m and PET tracers, perform stress-only testing, and use weight-based dosing
Reconstruction-FBP	Standard	No recommendation
Reconstruction-iterative	Potential for significant	Strongly recommend
Multi-detector systems	Significant	Strongly recommend minimum of two detectors
New camera geometries	Significant (same effect as multi-detector systems)	Use when available. Consider for new equipment purchase
Solid-state detector systems	Minor unless part of a multi-detector or new geometry system.	No recommendation
Collimators-custom	Unproven, probably minor	Further exploration and research
Energy settings	Probably minor	Further exploration and research
Step and shoot	Minor	No recommendation
Count consistency	Minor	No recommendation

10

NCRP Report No. 160, *Ionizing Radiation Exposure of the Population of the United States*



	Early 1980s	2006
Collective effective dose (person-Sv)	835,000	1,870,000
Effective dose per individual in the U.S. population (mSv)	3.6	6.2

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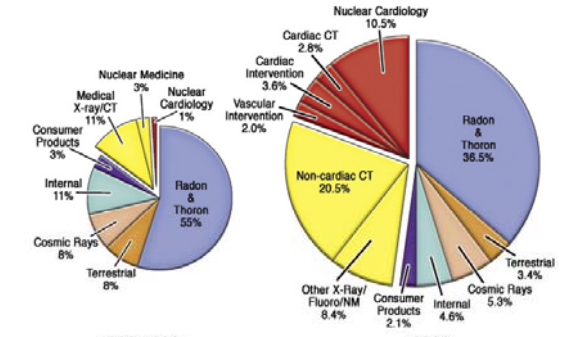

J Nucl Med. 2015 Mar 12. [Epub ahead of print]

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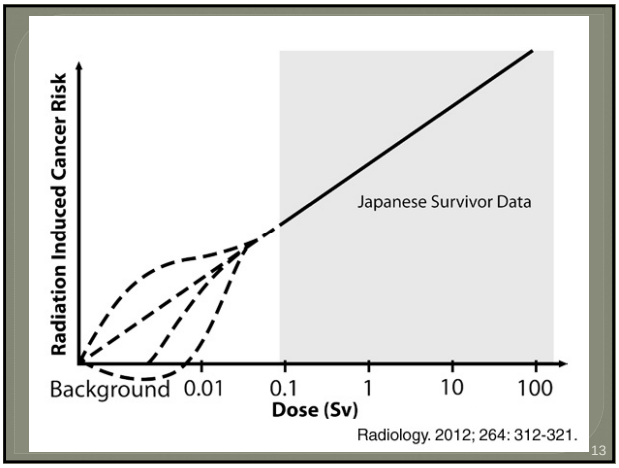
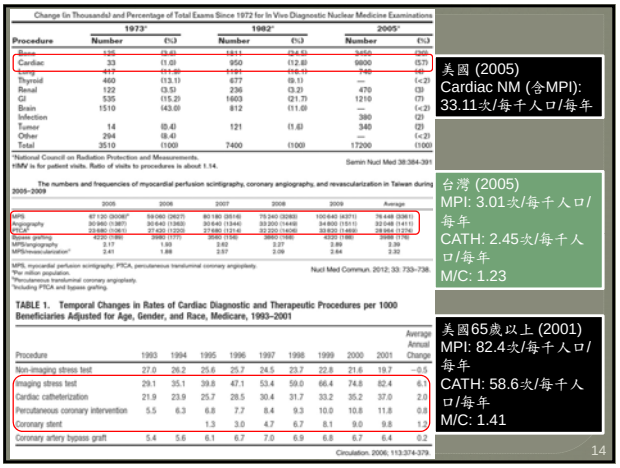


Radiology. 2012; 264: 312-321.

13



Change (in Thousands) and Percentage of Total Exams Since 1972 for In Vivo Diagnostic Nuclear Medicine Examinations

Procedure	1973* Number	1973* (%)	1982* Number	1982* (%)	2005* Number	2005* (%)
Bone	135	(3.4)	1811	(24.5)	3450	(20)
Cardiac	33	(1.0)	950	(12.8)	9800	(57)
Lung	417	(11.8)	1191	(16.1)	740	(4.3)
Thyroid	460	(13.1)	677	(9.1)	—	(<2)
Renal	122	(3.5)	236	(3.2)	470	(3)
GI	535	(15.2)	1603	(21.7)	1210	(7)
Brain	1510	(43.0)	812	(11.0)	—	(<2)
Infection					380	(2)
Tumor	14	(0.4)	121	(1.6)	340	(2)
Other	294	(8.4)			—	(<2)
Total	3510	(100)	7400	(100)	17200	(100)

*National Council on Radiation Protection and Measurements.
†MIV is for patient visits. Ratio of visits to procedures is about 1.14.

Semin Nucl Med 38:384-391

The numbers and frequencies of myocardial perfusion scintigraphy, coronary angiography, and revascularization in Taiwan during 2005–2009

	2005	2006	2007	2008	2009	Average
MPS	67 120 (3036)*	59 060 (2627)	80 190 (3516)	75 240 (3283)	100 640 (4371)	76 448 (3361)
Angiography	30 940 (1387)	30 640 (1360)	30 640 (1344)	33 200 (1448)	34 800 (1511)	32 048 (1411)
PTCA	23 680 (1061)	27 420 (1220)	27 680 (1214)	32 220 (1406)	33 920 (1469)	28 964 (1276)
Bypass grafting	4220 (189)	3980 (177)	3680 (156)	3860 (168)	4220 (186)	3998 (176)
MPS/angiography	2.17	1.93	2.62	2.27	2.89	2.39
MPS/revascularization†	2.41	1.88	2.57	2.09	2.64	2.32

MPS, myocardial perfusion scintigraphy; PTCA, percutaneous transluminal coronary angioplasty.
*Per million population.
†Percutaneous transluminal coronary angioplasty.
‡Including PTCA and bypass grafting.

Nucl Med Commun. 2012; 33: 733–736.

TABLE 1. Temporal Changes in Rates of Cardiac Diagnostic and Therapeutic Procedures per 1000 Beneficiaries Adjusted for Age, Gender, and Race, Medicare, 1993–2001

Procedure	1993	1994	1995	1996	1997	1998	1999	2000	2001	Average Annual Change
Non-imaging stress test	27.0	26.2	25.6	25.7	24.5	23.7	22.8	21.6	19.7	−0.9
Imaging stress test	29.1	35.1	39.8	47.1	53.4	59.0	66.4	74.8	82.4	6.1
Cardiac catheterization	21.9	23.9	25.7	28.5	30.4	31.7	33.2	35.2	37.0	2.0
Percutaneous coronary intervention	5.5	6.3	6.8	7.7	8.4	9.3	10.0	10.8	11.8	0.8
Coronary stent			1.3	3.0	4.7	6.7	8.1	9.0	9.8	1.1
Coronary artery bypass graft	5.4	5.6	6.1	6.7	7.0	6.9	6.8	6.7	6.4	0.2

Circulation. 2006; 113:374-379.

美國 (2005)
Cardiac NM (含MPI): 33.11次/每千人口/每年

台灣 (2005)
MPI: 3.01次/每千人口/每年
CATH: 2.45次/每千人口/每年
M/C: 1.23

美國65歲以上 (2001)
MPI: 82.4次/每千人口/每年
CATH: 58.6次/每千人口/每年
M/C: 1.41

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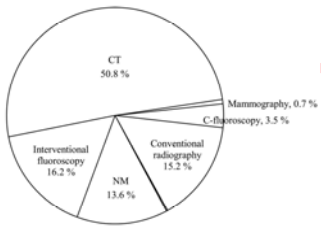

Med Phys. 2011; 38: 3139-3148.

A comparison of the effective dose per individual and the relative dose contribution (in parentheses) for different categories in Taiwan, USA and UK.

	E_{Taiwan} (2008) (mSv)	E_{US} (2006) (mSv)	E_{UK} (2000) (mSv)
CT	0.37 (48 %)	1.47 (49 %)	0.13
R&F	0.16 (21 %)	0.33 (11 %)	0.17
IVF	0.12 (16 %)	0.43 (14 %)	0.02
NM	0.12 (15 %)	0.77 (26 %)	
Total	0.77 (100 %)	3.00 (100 %)	

Radiat Prot Dosimetry. 2011; 146: 248-251

單位：毫西弗/年

類別		UNSCEAR	美國	英國	日本	臺灣
體外輻射	宇宙輻射	0.39	0.28	0.25	0.38	0.26
	地表及建物	0.41	0.28	0.35	0.29	0.54
	小計	0.77	0.56	0.60	0.67	0.80
體內輻射	氡、釷及子體	1.25	2.0	1.30	0.41	0.44
	鉀40等	0.36	0.39	0.30	0.40	0.28
	小計	1.62	2.39	1.6	0.81	0.72
合計		2.4	3.0	2.2	1.48	1.52

UNSCEAR：聯合國原子輻射效應科學委員會

from: 行政院原子能委員會輻射監測中心

15

The use rate (per million population) and longitudinal trend of main nuclear medicine procedures

診療項目	2002	2003	2004	2005	2006	2007	2008
全身骨骼掃描	3,779	3,843	4,317	3,999	4,135	4,767	4,791
壓力與重分布心肌灌注斷層掃描	2,421	2,190	2,376	2,811	2,575	3,509	3,263
心室搏出分率及心室壁活動測定	285	324	298	417	401	500	399
靜態核醫心臟功能檢查	146	96	129	105	167	236	82
碘 -131 治療	112	99	43	149	129	143	163

Nuclear cardiology占所有核醫檢查執行數比例
台灣約30% (2008約貢獻每人0.04 mSv有效劑量)
美國57% (2006約貢獻每人0.65 mSv有效劑量)

斷層掃描	Tl-201 TlCl	88.8	0.121	586	532	579	688	633	866	808
碘-131 治療	I-131 NaI	37	0.062	347	510	471	490	436	578	495
全身骨骼掃描	Tc-99m MDP	888	0.005	378	386	435	404	420	486	490
靜態核醫心臟功能檢查	Tl-201 TlCl	88.8	0.121	35	23	31	26	41	58	20
心室搏出分率及心室壁活動測定	Tc-99m PYP	740	0.005	24	27	25	35	34	42	34

derived from: Ann Nucl Med Mol Imaging. 2014; 27: 12-22.

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Optimization

- Selection of radiotracers
- Stress-first or Stress-only imaging protocols for reduced dose MPI
- Novel reconstruction software, scanners, and collimators for MPI
- Dose reduction with PET

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Recommendations for achieving MPI radiation reduction

J Nucl Cardiol. 2010; 17: 709-718.

Feature	Potential for dose reduction	Recommendation
Patient selection	Significant	Apply appropriate use criteria. Consider alternative modalities with comparable diagnostic accuracy without radiation in younger patients. Consider utilization in the following patients in whom MPI has the most clinical utility: intermediate CAD risk, those requiring prognostic or management information, and those with persistent and unexplained symptoms. Layered or serial testing should be avoided
Protocols, radiotracers and imaging systems	Significant	The clinical indications and physical stature of each patient should be reviewed and the best combination of radiotracers and protocols selected using the following guidelines: use radionuclides with shorter half-life such as Tc-99m and PET tracers, perform stress-only testing, and use weight-based dosing
Reconstruction-FBP	Standard	No recommendation
Reconstruction-iterative	Potential for significant	Strongly recommend
Multi-detector systems	Significant	Strongly recommend minimum of two detectors
New camera geometries	Significant (same effect as multi-detector systems)	Use when available. Consider for new equipment purchase
Solid-state detector systems	Minor unless part of a multi-detector or new geometry system.	No recommendation
Collimators-custom	Unproven, probably minor	Further exploration and research
Energy settings	Probably minor	Further exploration and research
Step and shoot	Minor	No recommendation
Count consistency	Minor	No recommendation

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Table X. Effective Doses for Adults from Myocardial Perfusion Imaging with Various Radiopharmaceuticals.

Radiopharmaceutical	Protocol	Effective Dose (mSv)
^{99m}Tc-sestamibi	One-day rest (10 mCi)/stress (30 mCi)	12.10*
	Two-day stress (30 mCi)/rest (30 mCi)	18.76*
^{99m}Tc-tetrofosmin	One-day rest (10 mCi)/stress (30 mCi)	10.62*†
	Two-day stress (30 mCi)/rest (30 mCi)	16.54*†
^{201}Tl	Stress (2.5 mCi)/redistribution	12.95†
^{82}Rb	Rest (30 mCi)/stress (30 mCi)	7.55*
^{13}N-ammonia	Rest (20 mCi)/stress (20 mCi)	2.96*

*Derived from ICRP publication 80.
†Derived from 4th addendum to ICRP publication 53.
‡Derived from ICRP publication 106.

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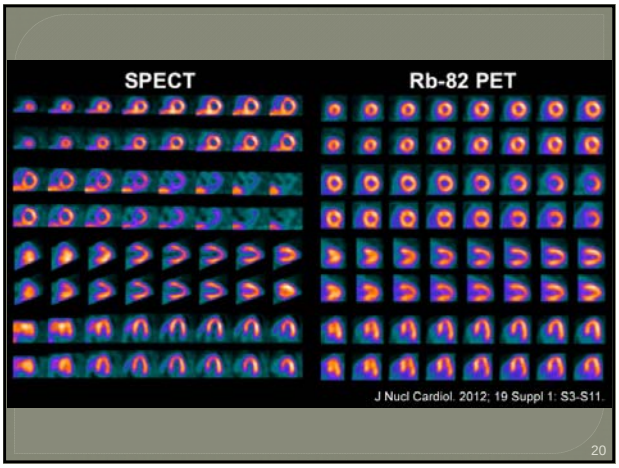

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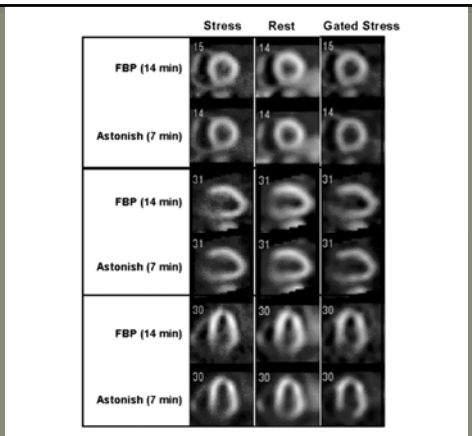
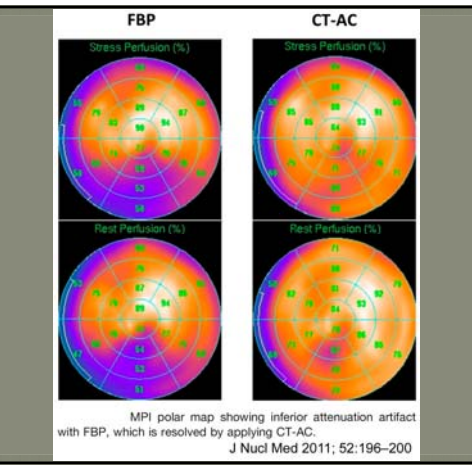


21

General guidelines for CT-based transmission imaging — ASNC imaging guidelines for nuclear cardiology procedures

CT parameter	General principle	Effect on patient dose
Slice collimation	Should approximate the slice thickness of PET (eg., 4-5 min.)	No effect
Gantry rotation speed	Slower rotation speed helps blur cardiac motion (eg., 1 sec/revolution or slower)	Slower gantry rotation increases radiation
Table feed per gantry rotation(pitch)	Relatively high pitch(eg., 1:1)	Inversely related to pitch
ECG gating	ECG gating is not recommended	Decreases without ECG gating
Tube potential	80-140 kVp, depending on manufacturer specification	Increases with higher kVp
Tube current	Because the scan is only acquired for AC, low tube current is preferred (10-20 mA)	Increases with higher mA
Breathing instructions	End-expiration breathhold or shallow free-breathing is preferred (see text)	No effect
Reconstructed slice thickness	Should approximate the slice thickness of PET (eg., 4-5 mm)	No effect

22



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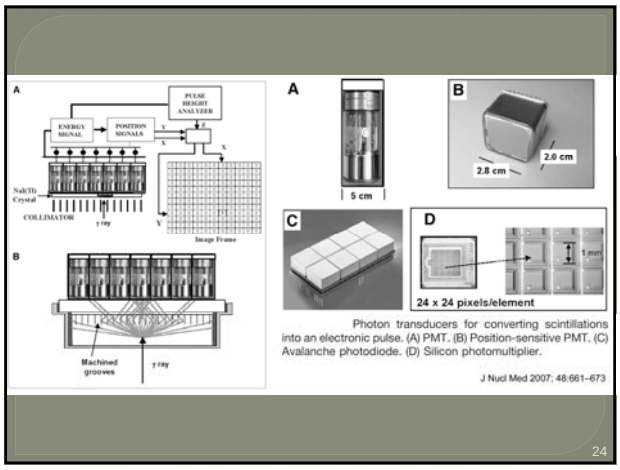

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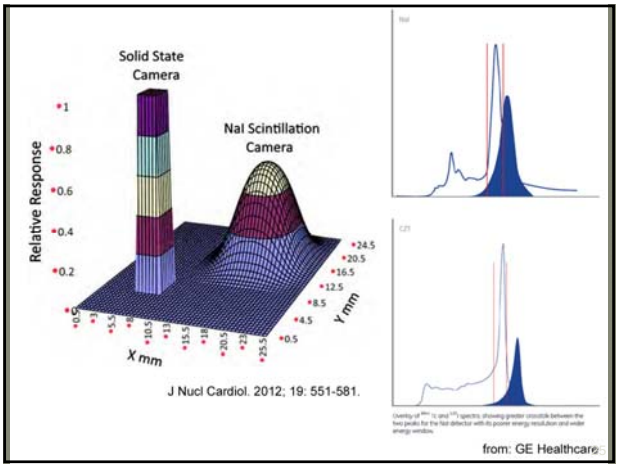
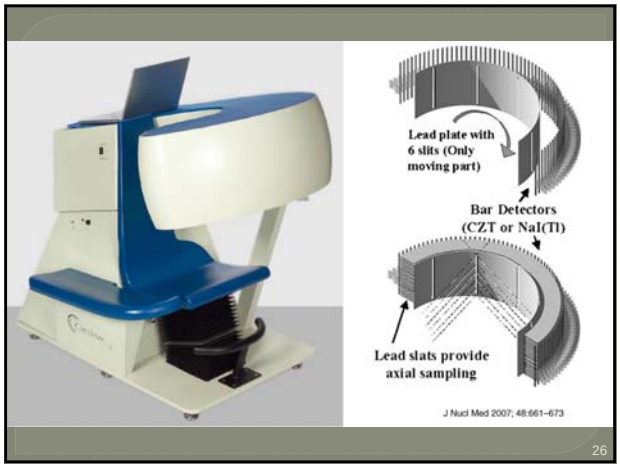
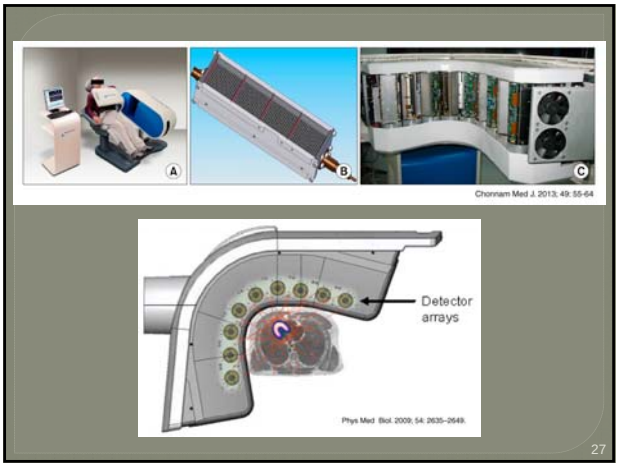
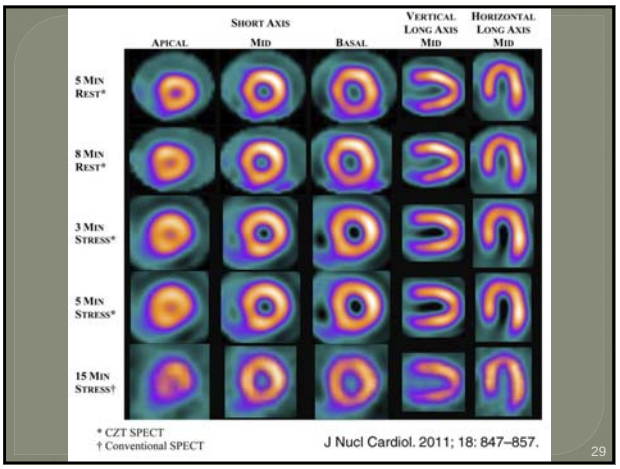
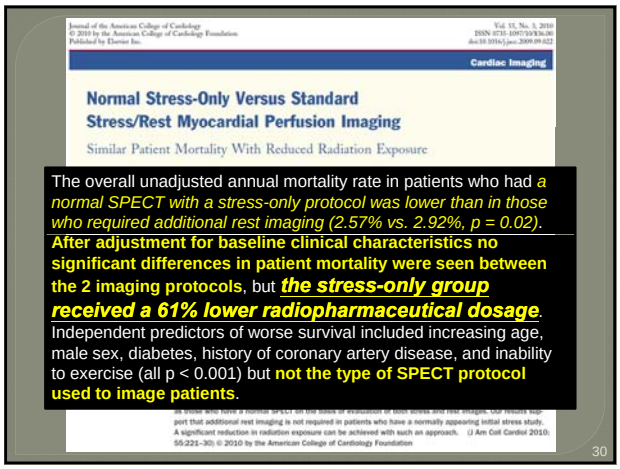

Solid State Camera
NaI Scintillation Camera
Relative Response
X mm
Y mm
J Nucl Cardiol. 2012; 19: 551-581.
from: GE Healthcare

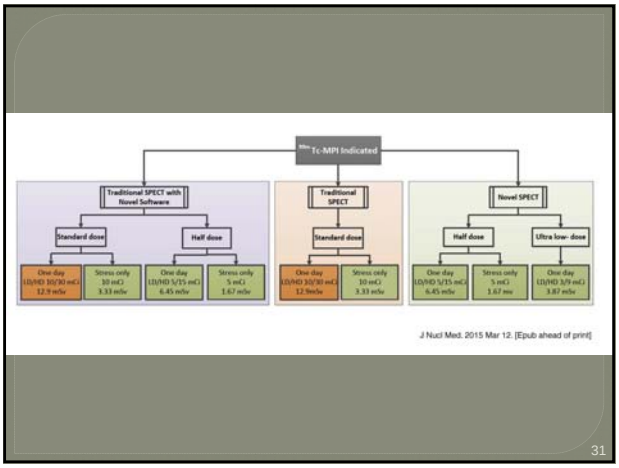

Lead plate with 6 slits (Only moving part)
Bar Detectors (CZT or NaI(Tl)
Lead slats provide axial sampling
J Nucl Med 2007; 48:661–673
26

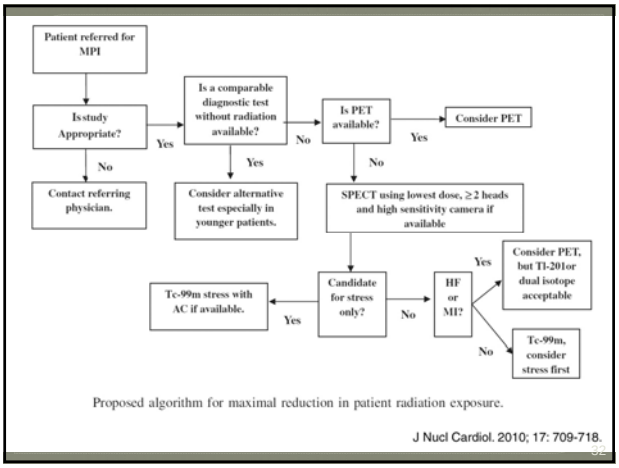

A
B
C
Chonnam Med J. 2013; 49: 55-64
Detector arrays
Phys Med Biol. 2009; 54: 2635–2649.
27


GE Healthcare
28


Short Axis
Apical
Mid
Basal
Vertical Long Axis
Mid
Horizontal Long Axis
Mid
5 Min Rest*
8 Min Rest*
3 Min Stress*
5 Min Stress*
15 Min Stress†
* CZT SPECT
† Conventional SPECT
J Nucl Cardiol. 2011; 18: 847–857.
29


Cardiac Imaging
Normal Stress-Only Versus Standard Stress/Rest Myocardial Perfusion Imaging
Similar Patient Mortality With Reduced Radiation Exposure
The overall unadjusted annual mortality rate in patients who had a normal SPECT with a stress-only protocol was lower than in those who required additional rest imaging (2.57% vs. 2.92%, p = 0.02).
After adjustment for baseline clinical characteristics no significant differences in patient mortality were seen between the 2 imaging protocols, but the stress-only group received a 61% lower radiopharmaceutical dosage.
Independent predictors of worse survival included increasing age, male sex, diabetes, history of coronary artery disease, and inability to exercise (all p < 0.001) but not the type of SPECT protocol used to image patients.
30


Tc-MPI Indicated
Traditional SPECT with Novel Software
Standard dose
Half dose
Traditional SPECT
Standard dose
Novel SPECT
Half dose
Ultra low- dose
J Nucl Med. 2015 Mar 12. [Epub ahead of print]


Patient referred for MPI
Is study Appropriate?
Yes
No
Contact referring physician.
Is a comparable diagnostic test without radiation available?
Yes
No
Consider alternative test especially in younger patients.
Is PET available?
Yes
Consider PET
No
SPECT using lowest dose, ≥ 2 heads and high sensitivity camera if available
Candidate for stress only?
Yes
Tc-99m stress with AC if available.
No
HF or MI?
Yes
Consider PET, but Tl-201or dual isotope acceptable
No
Tc-99m, consider stress first
Proposed algorithm for maximal reduction in patient radiation exposure.
J Nucl Cardiol. 2010; 17: 709-718.