Sources of DRL's variability in Hybrid Imaging

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Summary

- DRL’s variability in PET
- Why DRL’s in PET vary?
- Why DRL’s in Nuclear cardiology vary?

DRL’s variability in PET

Administered Activity and Radiation dose (USA)

Effective Doses for Adults from Various Nuclear Medicine Examinations

Examination*	Effective Dose (mSv)	Administered Activity (MBq)†	Effective Dose (mSv/MBq)‡
Tumor (^{18}F-FDG)	14.1	740	0.019

* DMSA = dimercaptosuccinic acid, DTPA = diethylenetriaminepentaacetic acid, ECD = ethyl cysteinate dimer, ^{18}F = fluorine 18, FDG = fluorodeoxyglucose, HMPAO = hexamethylpropyleneamine oxime, ^{111}In = indium 111, MAA = macroaggregated albumin, MAG3 = mercaptoacetyltriglycine, MDP = methylene diphosphonate, ^{99m}Tc = technetium 99m.

† Recommended ranges vary, although most laboratories tend to use the upper end of suggested ranges.

‡ From reference 74.

FA Mettler *et al* Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog Radiology 2008

"Typically many departments use activities near or at the high end of suggested activity ranges to optimize patient throughput and image quality."

This roughly corresponds to a weight-based injection protocol of:

8 MBq/kg

with an upper limit of 740 MBq of ^{18}F-FDG injected.

Halpern BS *et al* Optimizing inaging protocols for overweight and obese patients… J Nucl Med 2005; 46:603-607
Everaert H et al Optimal dose of 18F-FDG required for whole body PET using an LSO PET camera EJNM 30: 1615-19

Administered Activity and Radiation dose (Germany)

TABLE 2

Summary of Representative Protocols Used Routinely for Whole-Body ^{18}F-FDG-PET/CT Examinations at 4 German Hospitals Equipped with the Dual-Modality Tomographs Characterized in Table 1

Hospital	Scan		Effective dose (mSv)	
	Type	Abbreviation	Per scan	Per examination
H1	2 Topograms*		0.8	
	Diagnostic CT with CA	H1-D-CT	18.6	
	PET, 370 MBq ^{18}F-FDG	H1-PET	7.0	26.4
H2	Topogram		0.1	
	Low-dose CT	H2-LD-CT	4.5	
	PET, 300 MBq ^{18}F-FDG	H2-PET	5.7	
	Diagnostic CT with CA	H2-D-CT	14.1	24.4
H3	Low-dose protocol			
	Topogram		0.2	
	Low-dose CT	H3-LD-CT	1.3	
	PET, 370 MBq ^{18}F-FDG	H3-PET	7.0	8.5
	High-quality protocol			
	Topogram		0.2	
	Diagnostic CT with CA	H3-D-CT	17.6	
	PET, 370 MBq ^{18}F-FDG	H3-PET	7.0	24.8
H4	Topogram		0.2	
	Low-dose CT	H4-LD-CT	2.4	
	PET, 370 MBq ^{18}F-FDG	H4-PET	7.0	
	Diagnostic CT with CA	H4-D-CT	14.1	23.7

*In anteroposterior and lateral direction; dose indicated represents the dose sum from both topograms.
CA = intravenous CT contrast agent administered for most examinations.

Brix G et al FH *J Nucl Med* 2005; 46:608-613

This would roughly corresponds to a weight-based injection protocol of:

5,4 MBq/kg

Administered Activity and Radiation dose (EANM)

Recommended administered activities for most radiopharmaceuticals are generally calculated from a reference administered activity for each radiopharmaceutical for a 70 kg patient and a table or formula that decreases the reference administered activity according to age or body mass.

Gelfand MJ Dose reduction in pediatric hybrid and planar imaging *Q J Nucl Med* 2010 ;54:379-388.

The implied reference administered activities in the 2007 EANM Pediatric Dose card for a 70 kg patient are an ^{18}F-FDG administered activity of:

196 MBq when a 3D PET scanner is used

Jacobs F et al FH *Eur J Nucl Med* 2005 ;32:581-8.

This would roughly corresponds to a weight-based injection protocol of:

2,8 MBq/kg

Variations in PET/CT Methodology for Oncologic Imaging at U.S. Academic Medical Centers: An Imaging Response Assessment Team Survey

128 responses were collected between November 2009 and April 2010

- ^{18}F-FDG administration was based on patient weight on 44% of the sites.
- The average dose for oncologic studies was 5.2 MBq/kg (range 1.5-7.8 MBq/kg)
- This translates into an average activity of 390MBq (range 113-585 MBq injected in a 75 kg patient.
- Sites that did not use a weight-based activity injection (56%) had established maximum activity limits averaged across sites: 465 MBq (range 370-666 MBq) for 3D PET
- The average emission acquisition time per bed position was 3.2 min (min=1 min; max=10 min)
- Emission acquisition times dependent on patient weight at 34% of sites.

Graham MM et al *J Nucl Med* 2011;52:311-317.

Variations in Clinical PET/CT operations: results from an International survey of active PET/CT users

15 institutions surveyed

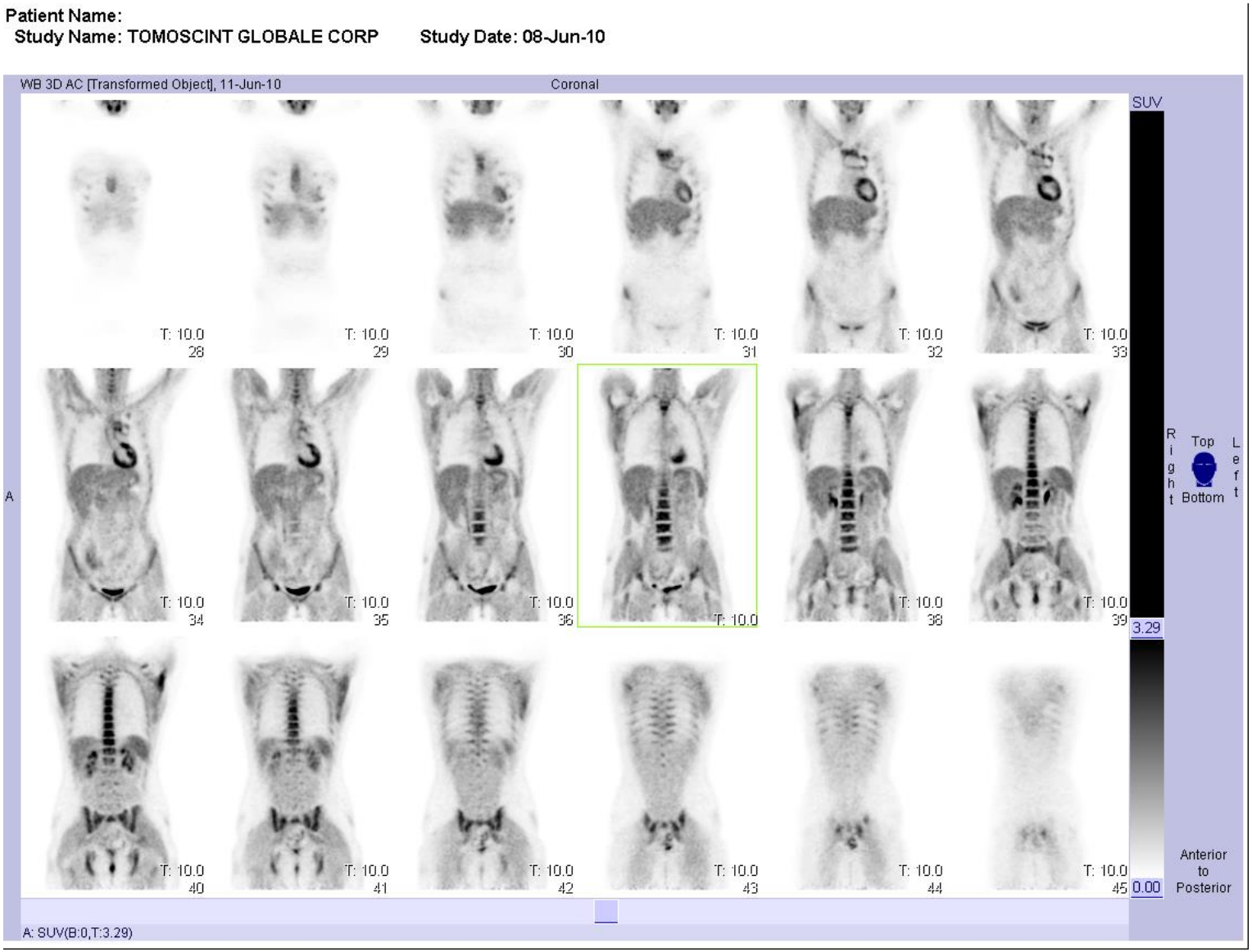
- The average administered ^{18}F-FDG dose for adult varies from 259 to 740 MBq. At least two institutions gives as much as 925 MBq.

- For those sites (only 3) that reported dose per kilogram, the range is 5.2-8.1 MBq

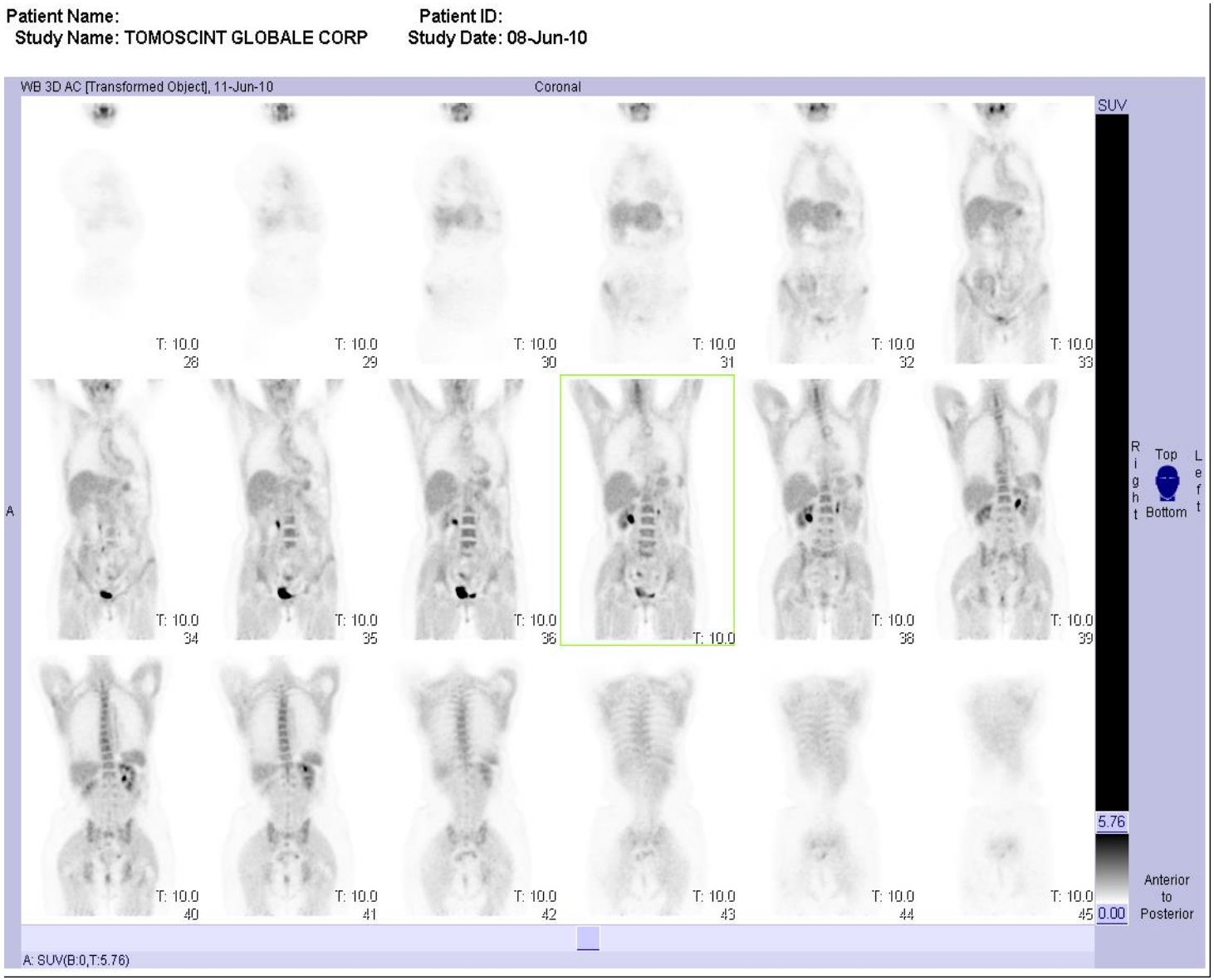
- The acquisition was 3D for 8 systems (Siemens) and 2D for 13 systems (GE)

- Duration of the emission acquisition per bed position for whole-body scans ranges from 2 min to 7 min.

Beyers T et al *J Nucl Med* 2011 ;52:303-310.



BMI 22.5, weight 65 kg, A_{inj} =198 MBq (3 MBq/kg), Hour_inj=10:20,
ESD= 7 min A_{acq}= 56 Mbq (0.9 Mbq/kg), Hour_acq =13:56



BMI 23.4, weight 60 kg, A_{inj} =203 MBq (3.4 MBq/kg), Hour_inj=10:00,
ESD = 7 min A_{acq}= 41 MBq (0.7 Mbq/kg), Hour_acq=14:35

Effective Dose in Nuclear Medicine Studies and SPECT/CT: Dosimetry Survey Across Quebec Province

DRL= 444 MBq

= 8.4 mSv

vey results

Study	T	Factor (mSv/MBq)	Dose (mSv) Mean	SD	DRL (mSv)
Oncology					
Glucose metabolism	^{18}F-FD(	0.0190	7.7	1.9	8.4

Charest M H et al *J Nucl Med Tech* 2018

Suggestion of a national diagnostic reference level for 18F-FDG/PET scans in adult cancer patients in Brazil

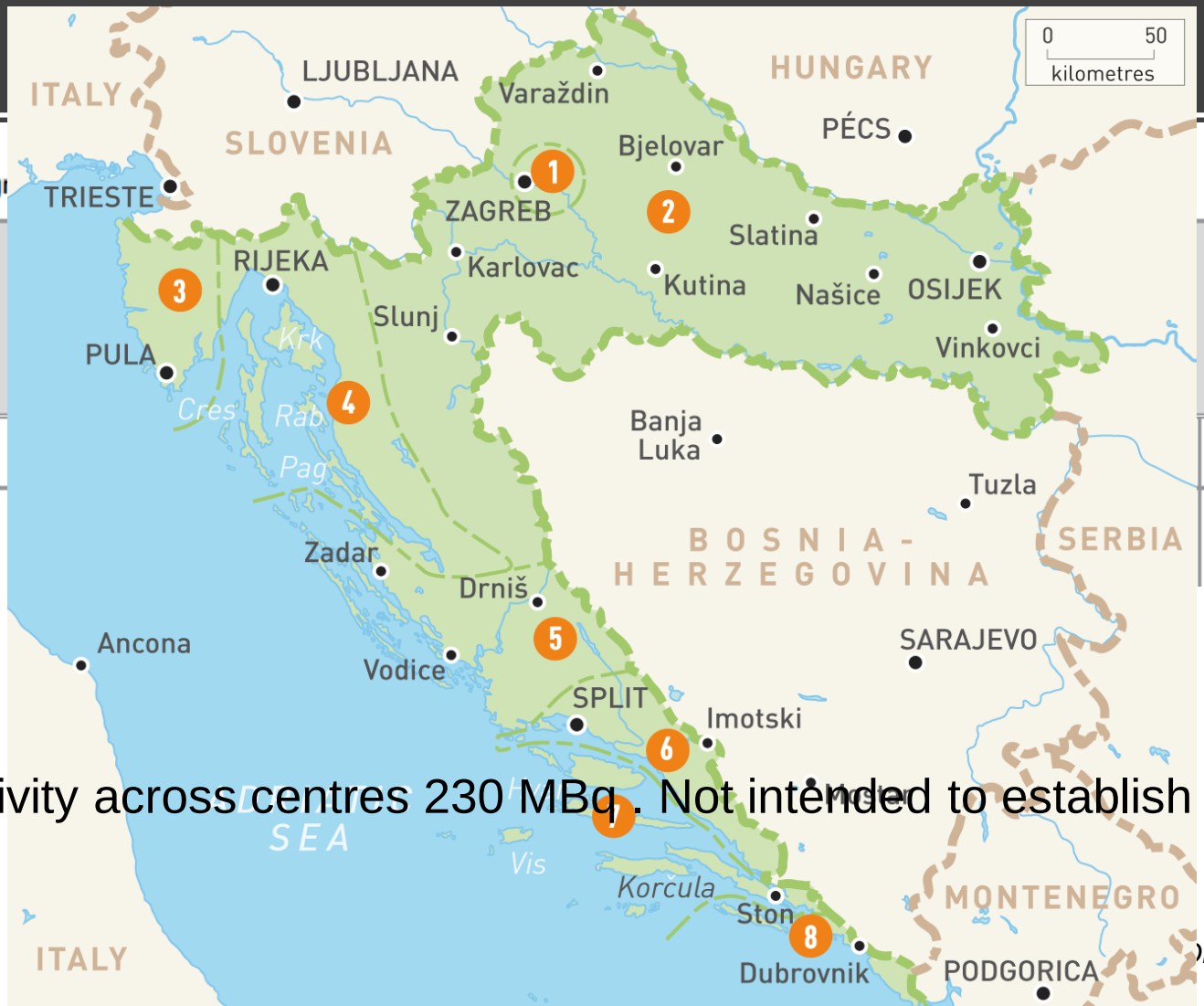
Figure 1. A

Oliveira CM Radiol Bras. 2013

Estimated collective effective dose to the population from nuclear medicine diagnostic procedures in Croatia

Table 1. Data of NM diagr

	Examination	Collective effective dose (manSv) 2010	Collective effective dose (manSv) 2015
7.	Tumor imaging (PET)	0	16,58
8.	Tumor imaging (PET) + Diagnostic CT	0	21,52



Mean Activity across centres 230 MBq. Not intended to establish DRLs

One 2017

Original article

Nuclear Medicine Communications 2017, 38:459–470

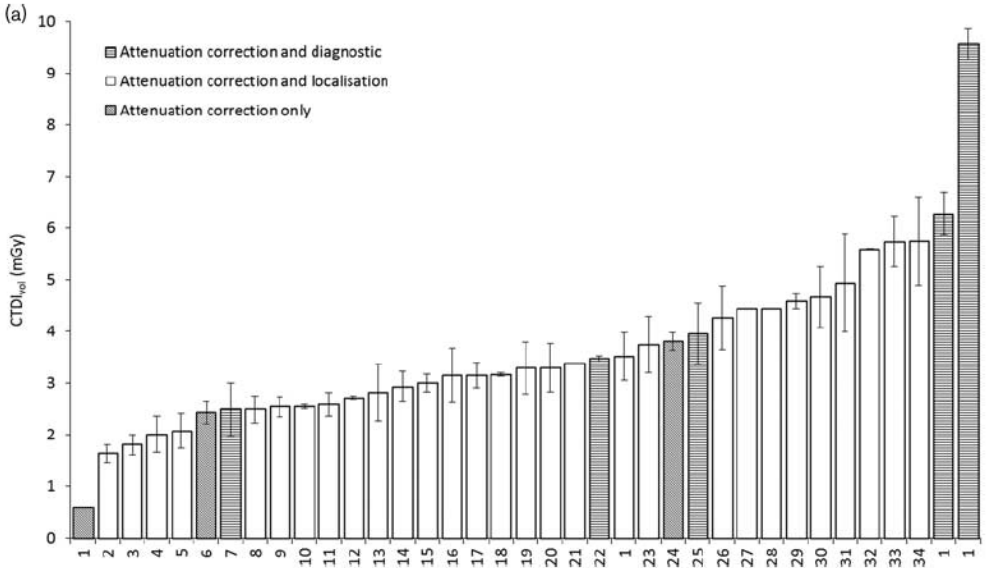
Nuclear Medicine Communications

A national survey of computed tomography doses in hybrid PET-CT and SPECT-CT examinations in the UK

Gareth R. Iball[a], Natalie A. Bebbington[b,c], Maria Burniston[d], Sue Edyvean[e], Louise Fraser[f], Peter Julyan[g], Nasreen Parkar[f] and Tim Wood[h,i]

Table 4 Effective doses for radiopharmaceutical and computed tomography exposures for the six examinations with achievable doses presented in Table 3

Examinations	Radiopharmaceutical	Typical administered activity (MBq)	Radiopharmaceutical effective dose (mSv)	CT effective dose (mSv)
PET-CT				
Half body	^{18}F-FDG	400	7.6	6.5



Radiation Dose from Whole-Body F-18 Fluorodeoxyglucose Positron Emission Tomography/computed Tomograhy: Nation wide Survey in Korea

Kwoon H et al *J Kor Med Sci* 2016

Radiation Dose from Whole-Body F-18 Fluorodeoxyglucose Positron Emission Tomography/computed Tomograhy: Nation wide Survey in Korea

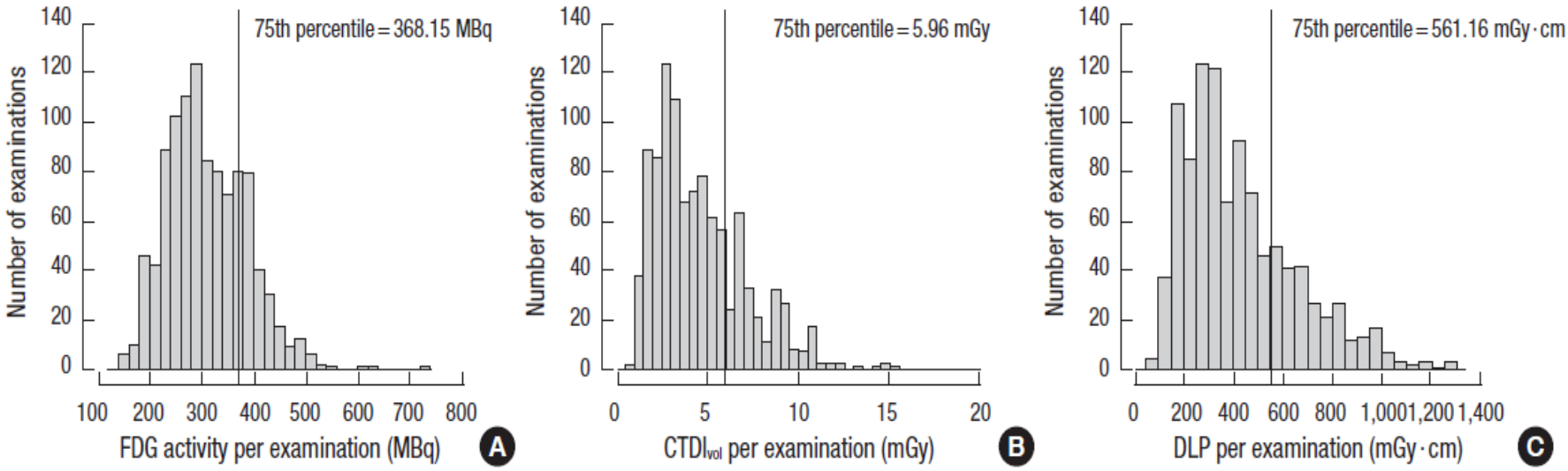


Fig. 3. Distribution of injected FDG activity (**A**), $CTDI_{vol}$ (**B**), and DLP (**C**) of each PET/CT examination.

Kwoon H et al *J Kor Med Sci* 2016

Report of a nationwide survey on actual administered radioactivities of radiopharmaceuticals for diagnostic

Procedure an	DRLs (MBq)[a]
Lymphatic sy	950
Sentinel lym	120
Sentinel lym	120
RI angiograp	1000
Tumor: ^{18}F-F	240
Tumor: ^{18}F-F	240
Brain: ^{18}F-FI	240
Brain: ^{18}F-FI	240
^{15}O-CO_2 gas	8000
^{15}O-O_2 gas:	6000
^{15}O-CO gas:	3000
^{15}O-CO_2 gas	2900
^{15}O-O_2 gas:	7000
^{15}O-CO gas:	7500
Myocardial r	240
Myocardial r	240
Myocardial p	720

[a] Adult dosa

Hiroshi Watanabe Annals of Nuclear Medicine 2016

Diagnostic reference levels for 18 F-FDG whole body PET/CT procedures: Results from a survey of 12 centres in Australia and New Zealand

DRL_A= 333 MBq
DRL_{ED}= 5.6 mSv
DRL_{CTDI}=4.4 mGy
DRL_{DLP}= 474 mGy cm
DRL_{EDCT} = 4.7 mSv

DRL_A= 332 MBq
DRL_{ED}= 5.6 mSv
DRL_{CTDI}=13.7 mGy
DRL_{DLP}= 1319 mGy cm
DRL_{EDCT} = 10.9 mSv

Alkhybari E et al *J Med Imaging Rad Oncol* 2019

Current Australian diagnostic reference levels for nuclear medicine

DRLs for general nuclear medicine, PET and the CT component of SPECT/CT and PET/CT

https://www.arpansa.gov.au/research-and-expertise/surveys/national-diagnostic-reference-level-service/current-australian-drls-update/nm

FDG scanning in PET is one of the few nuclear medicine procedures where weight correction is used routinely at the majority of Australian imaging facilities. However, there were a number of the submissions to the NDRL survey from facilities that clearly didn't conduct weight correction. As a result, two DRLs for whole body FDG scans have been issued.

Category	Pharmaceutical	25th percentile (MBq)	Median (MBq)	DRL (MBq)
Body	F-18 FDG	225	250	310
Body (weight corrected)	F-18 FDG	2.5 x kg + 75	2.5 x kg + 100	2.5 x kg + 125
Brain	F-18 FDG	200	220	250

Current Australian diagnostic reference levels for nuclear medicine

DRLs for general nuclear medicine, PET and the CT component of SPECT/CT and PET/CT

https://www.arpansa.gov.au/research-and-expertise/surveys/national-diagnostic-reference-level-service/current-australian-drls-update/nm

CT scans

The DRLs below are for CT scans conducted for the purposes of attenuation correction or localisation in conjunction with a PET scan.

Region	25th percentile (mGy.cm)	50th percentile (mGy.cm)	DRL (mGy.cm)
Head/Brain	75	125	325
Whole body (Eyes - Thighs)	325	430	540
Whole body (Vertex - Toes)	495	655	985

Table 2. Summary of hybrid PET/CT DRL methods.

Authors (Country & Year)	Procedure	Clinical indication	Radiotracer	Scan range	Characteristic of patient sample	DRL dosimetry value		E (mSv)		
						A(MBq) [MBq/kg]	$CTDI_{vol}$ (mGy) and DLP (mGy.cm)	A	CT	Total
Kwon *et al*[15]. (KO, 2016)	Whole body	–	^{18}F-FDG	Base of skull-upper thigh	10 per each exam	370 [5.89 ± 1.46]	5.96 and 560	5.89	6.26	12
Etard *et al*[27]. (FR, 2012)	Whole body	–	^{18}F-FDG	At least neck-thigh	20 (50–100 kg)	350 [4.3] 250 [3.5 TOF]	8 and 750	5.7	8.6	14
Iball *et al*[18]. (UK, 2017)	Half body	Tumour Infection/ Inflammation	^{18}F-FDG	Base of brain-mid thigh	30 per each exam	–	4.3 and 400	7.6	6.5	14
Roch *et al*[20]. (FR, 2017)	Whole body	–	^{18}F-FDG	–	30 per each exam	350	–	–	–	–
						260 [3.6 TOF]	–	–	–	–
Watanabe *et al*[21]. (JP, 2016)	Tumour	Tumour	^{18}F-FDG HP	–	–	235 [2–5]	–	–	–	–
	Tumour	Tumour	^{18}F-FDG (Delivery)	–		252 [2–5]	–	–	–	–
	Tumour	Tumour	^{18}F-FDG HP	–		227	–	–	–	–
	Brain	–	^{18}F-FDG (Delivery)	–		255	–	–	–	–
		–	^{15}O-CO_2 g: 2D	–		7500	–	–	–	–
		–	^{15}O-O_2 g: 2D	–		4500	–	–	–	–
		–	^{15}O-CO g: 2D	–		3000	–	–	–	–
		–	^{15}O-CO_2 g: 3D	–		2888	–	–	–	–
Watanabe *et al*[21]. (JP, 2016)	–	–	^{15}O-O_2 g: 3D	–	–	6600	–	–	–	–
	–	–	^{15}O-CO g: 3D	–	–	7125	–	–	–	–
	Myocardial/ Metabolism	–	^{18}F-FDG H	–	–	221	–	–	–	–
	Myocardial/ Metabolism	–	^{18}F-FDG D	–	–	251	–	–	–	–
	Myocardial/ Perfusion	–	^{13}N-NH3	–	–	718	–	–	–	–
Jallow *et al*[23]. (US, 2016)	Oncology	–	^{18}F-FDG	–	2010–14: 35, 65, 76, 42 and 14 cases	–	9.8, 9.8, 10.2, 9.7 and 9.7	–	–	–

Alkhybari E et al Determining and updating PET/CT and SPECT/CT diagnostic reference levels: A systematic review. Rad Prot Dosim 2018

Authors (Country & Year)	Procedure	Clinical indication	Radiotracer	Scan range	Characteristic of patient sample	DRL dosimetry value		E (mSv)		
						A(MBq) [MBq/kg]	$CTDI_{vol}$ (mGy) and DLP (mGy.cm)	A	CT	Total
Willegaignon *et al*[22]. (BR, 2015)	Oncology/ inflammation	Tumour/ Inflammation	^{18}F-FDG	–	–	370	6.76 ± 1.08	–	–	–
	Brain	–	^{18}F-FDG	–		350	5.11 ± 1.52	–	–	–
	Bone	–	^{18}F-NaF	–		370	7.30 ± 0.30	–	–	–
Alessio *et al*[19]. (USA, 2015)	Whole body	–	^{18}F-FDG	–	1–5 (4.3 ± 1.3) cases	592	–	–	–	–
Oliveria *et al*[26]. (BR, 2013)	^{18}F-FDG PET	Cancer	^{18}F-FDG	–	–	387.7 [5–5.4]	–	–	–	–
Roch *et al*[25]. (FR, 2013)	^{18}F-FDG PET	–	^{18}F-FDG	–	20 (60–80 kg)	350 and 337 [5]	–	–	–	–
Botros *et al*[28]. (AU & NZ, 2009)	Whole body	Tumour	^{18}F-FDG	–	20 per exam or	385	–	–	–	–
	Brain	–	^{18}F-FDG	–	facility guidance	385	–	–	–	–
	Myocardial Viability	–	^{18}F-FDG		level for 70–80 kg	370	–	–	–	
Hart *et al*[29]. (UK, 2005)	Tumours PET	Tumour	^{18}F-FDG	–	–	400	–	7	–	–
Brix *et al*[30]. (DE, 2002)	Oncology	–	^{18}F-FDG	–	–	370 (2D)	–	7	–	–
	Neurology	–				200 (3D)	–	3.8	–	–
	Cardiology	–								
	Other application	–								

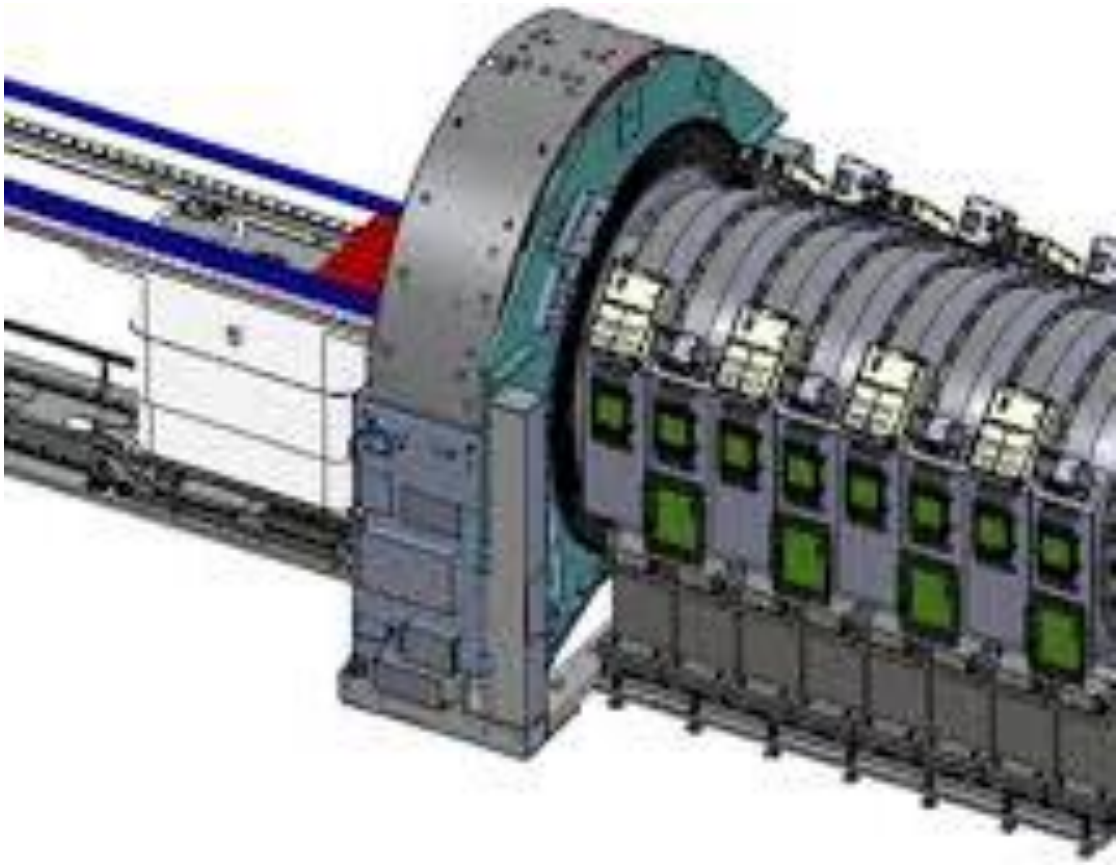
Note: TOF = Time of flight, ^{15}O-CO_2 = Oxygen-15 carbon dioxide, ^{15}O-CO = Oxygen-15 carbon monoxide, HP = hospital product, g = gas, ^{13}N-NH_3 = Nitrogen-13 ammonia, NaF = Sodium Fluoride, A = administered activity.

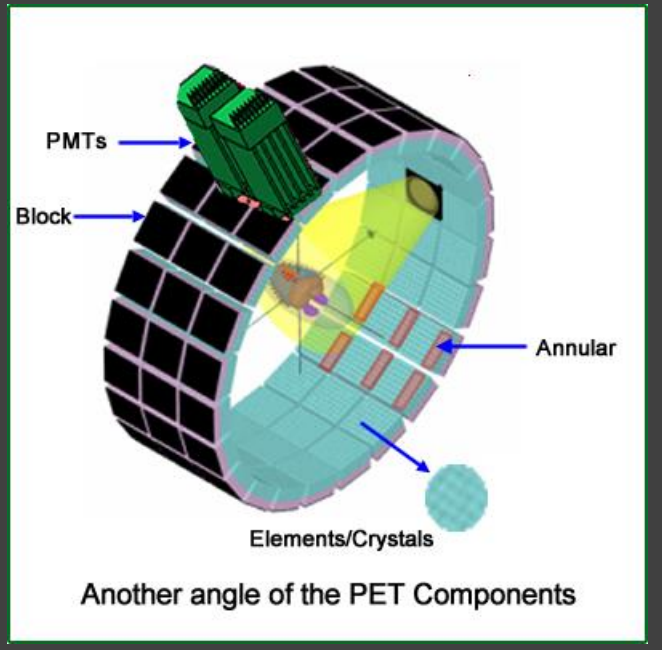
Summary DRLs PET

Country	Activity (MBq)	Act Conc. (MBq/kg)	ED (mSv)
Quebec	444	6.3	8.4
Brasil	371	5.3	7.0
Croatia	232	3.3	4.3
South Korea	368	5.6	7.0
Japan	240	3.4	4.6
New Zealand	333	4.8	5.6 (6.3)
Australia	300	2.5 x kg+100	5.7
France	350	4.3	6.6
	250	3.5	4.8

Summary DRLs CT

Country	CTDI (mGy)	DLP(mGy cm)	ED (mSv)
Brasil	6.8		
South Korea	6.0	561	
New Zealand	13.7	1319	10.9
Australia	4.4	474	4.7
France	8.0	750	8.6
UK	4.3	400	6.5





Another angle of the PET Components

WHY DRLs vary?

Installation Year

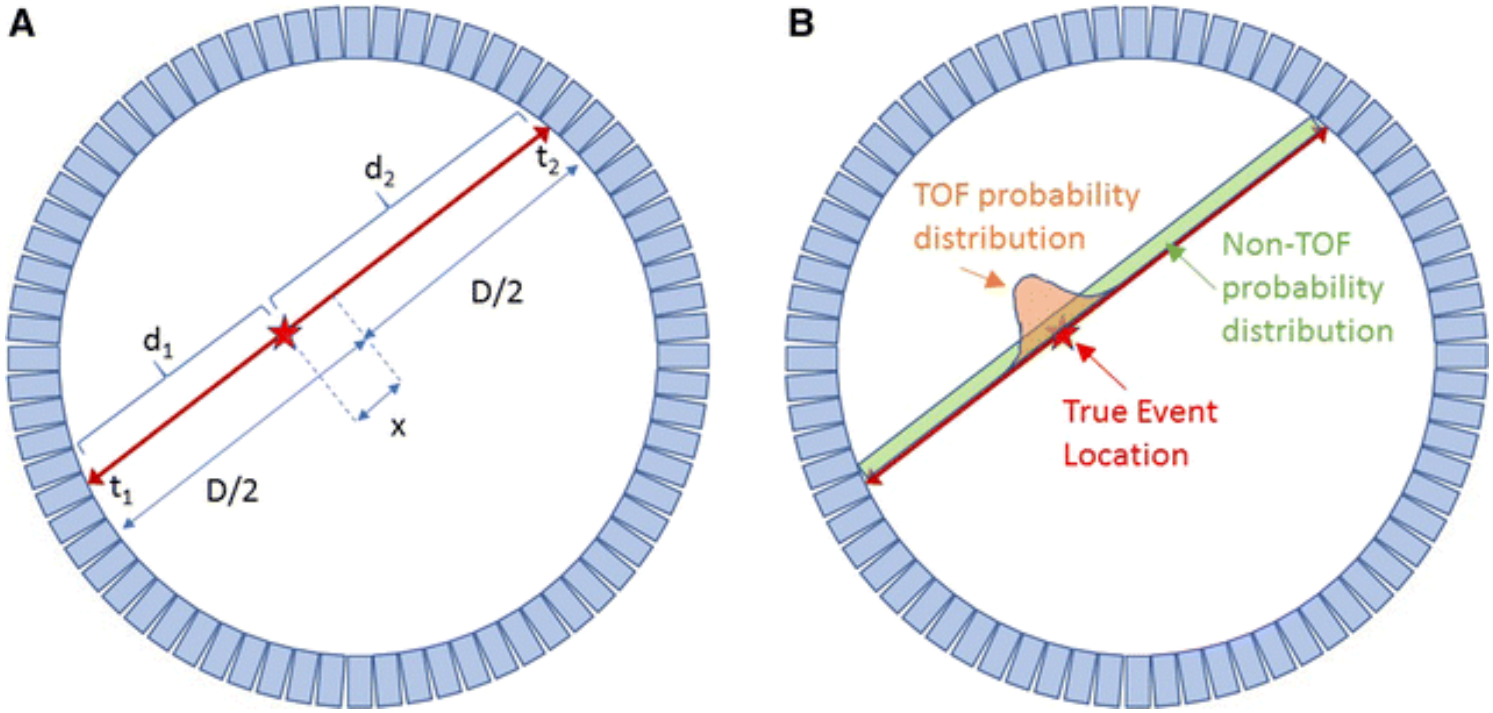
Table 3. Radiation dose of FDG PET/CT according to installation year

Installation year	No.	FDG activity, MBq/kg	$CTDI_{vol}$, mGy	DLP, mGy·cm
2000-2005	13	6.10 ± 1.19	6.04 ± 2.58	514.5 ± 246.5
2006-2010	50	5.30 ± 1.22	4.87 ± 2.85	460.7 ± 241.2
2011-2015	42	4.60 ± 0.85	3.95 ± 1.97	369.6 ± 185.4
P value		< 0.001	< 0.001	< 0.001

$CTDI_{vol}$, volume computed tomography dose index; DLP, dose-length product; FDG, F-18 fluorodeoxyglucose.

Kwoon H et al *J Kor Med Sci* 2016

TOF capability



TOF capability

There are different ways to use the improved SNR associated with TOF PET and additional advantages associated with TOF reconstruction that derive from the time and spatial information carried by TOF data:

1. TOF can provide better image quality and improved lesion detection,
2. the scan time can be shortened while keeping the same image quality with better clinical workflow and added comfort for the patient,
3. the dose to the patient can be reduced with the same scan time and image quality.

Conti, EJNMMI 2011

TOF capability

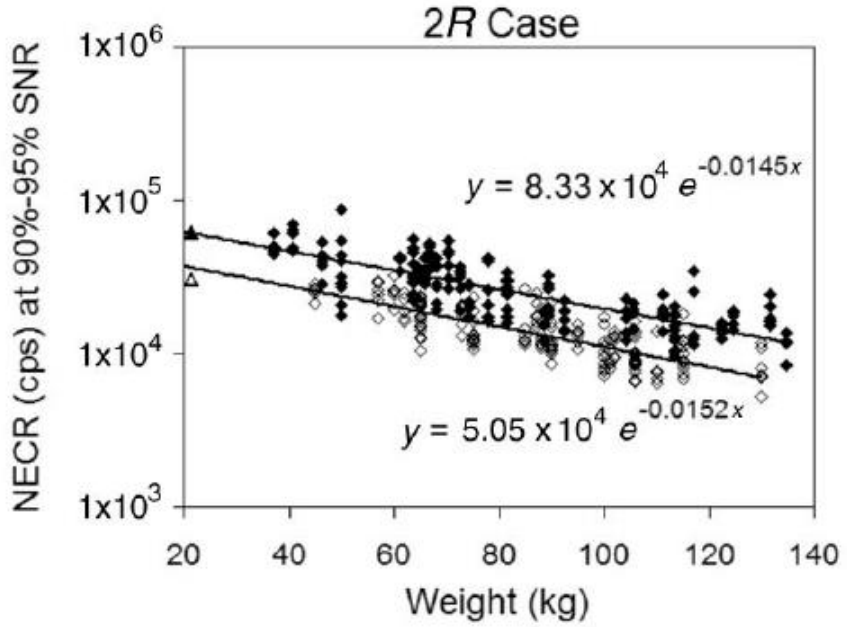
	DRL dosimetry value	
	A (MBq)	A (MBq/Kg)
Non TOF	350	4.3
TOF	250	3.5

Etard C National survey of patient doses from whole-body FDG PET-CT examinations in France in 2011. Rad Prot Dosim 2012

Managing weight: Activity vs time

Optimizing Injected dose in clinical PET by accurately modeling the counting rate response functions specific to individual patient scans

Patient NECR versus weight



Plots of estimated NECR values at 90% or 95% of peak SNR, versus patient weight, for all scans.

Optimal NECR decreases rapidly (1,4%/Kg) with increasing weight.

The only solutions for heavier patients is to scan them longer!!!

Watson CC J Nucl Med 2005; 46:1825-1834

Optimizing Injected dose in clinical PET by accurately modeling the counting rate response functions specific to individual patient scans

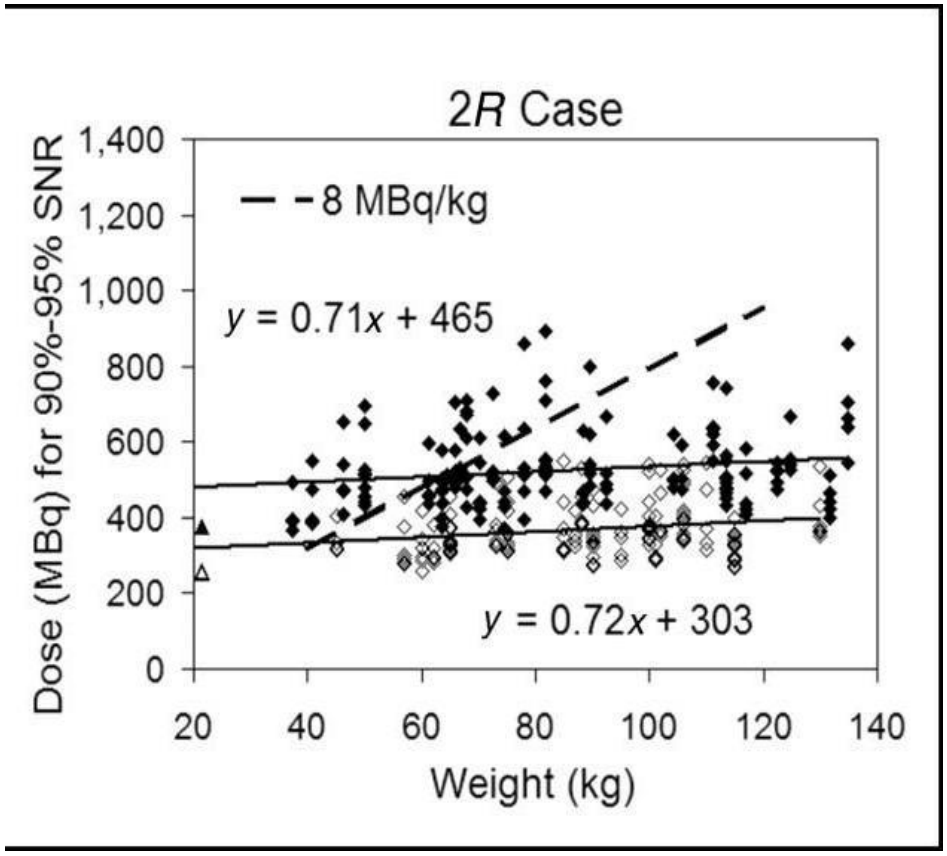


Fig.5 Plots of estimated optimal dose vs patient weight standardized at 60 min

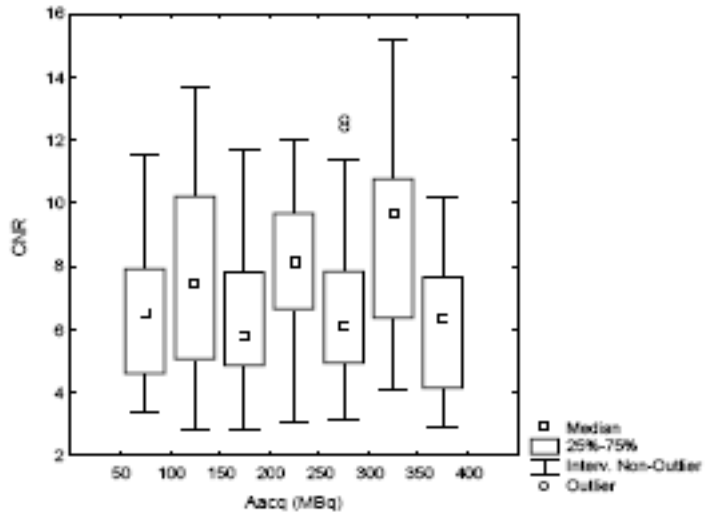
It appears that the average optimal dose increases only slightly (0.7-1.1 MBq/kg) with weight, suggesting that poorer image quality in larger patients generally cannot be overcome by increasing D_{inj} significantly in proportion to patient weight.
The common (8 MBq/kg) recipe wastes dose for heavier patients!!!

Optimal dose for LSO Pico-3D scanner at 70 kg = 524 MBq

Watson CC J Nucl Med 2005; 46:1825-1834

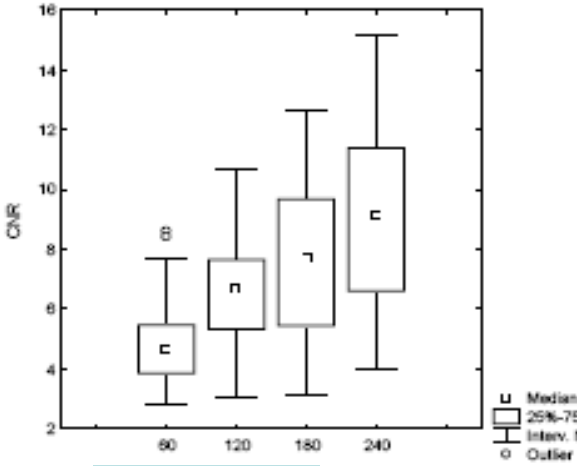
Impact of target-to-background ratio, target size, emission scan duration, and activity on physical figures of merit for a 3D LSO-based whole body PET/CT scanner

Brambilla M et al Med Phys 2007

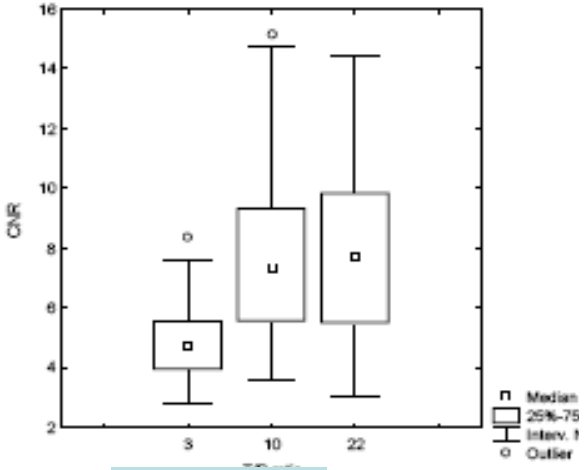


The dependence of CNR on A_{acq} appears to be slight in the range explored (from 92.3 to 370.5 MBq)

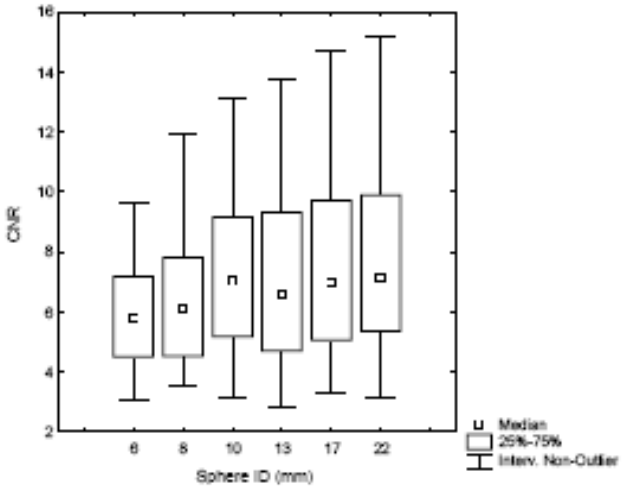
CNR increases more quickly with increasing ESD, T/B ratio and sphere ID



ESD (sec)



T/B ratio



Sphere ID (mm)

Example

A sphere of 10 mm ID with a T/B ratio of 10 imaged with emission scan duration (ESD) of 120 s and a global activity at the start of acquisition Aacq of 185 MBq.

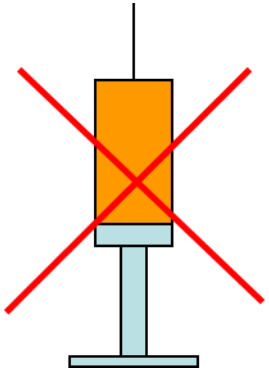
According to regression equation, we will expect a CNR of 5.78.

Doubling the *A*acq to 370 MBq will move up CNR to 7.17 a 24% increase.

Doubling ESD to 240 s will move up CNR to 8.33 a 44% increase.

To increase CNR

Is much more effective to increase ESD



Than injecting an higher activity of ^{18}FDG

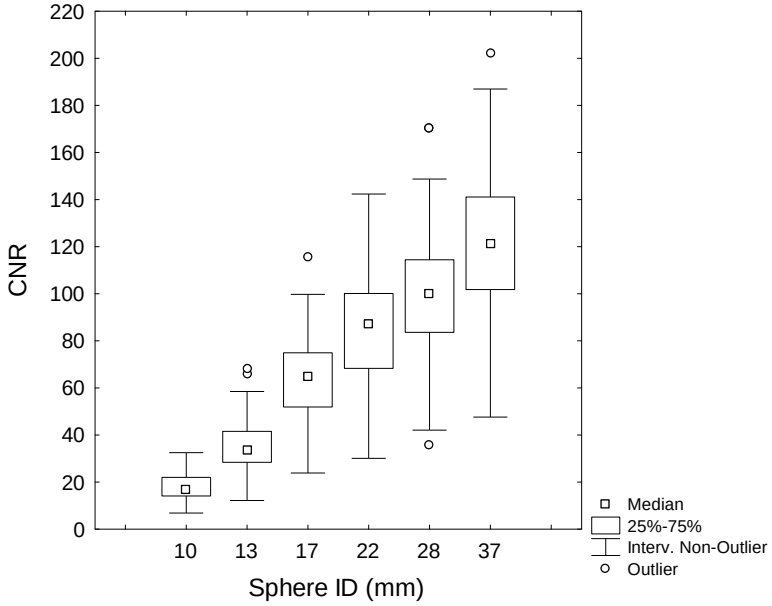
The effect of activity outside the field of view on image quality for a 3D LSO-based whole body PET/CT scanner

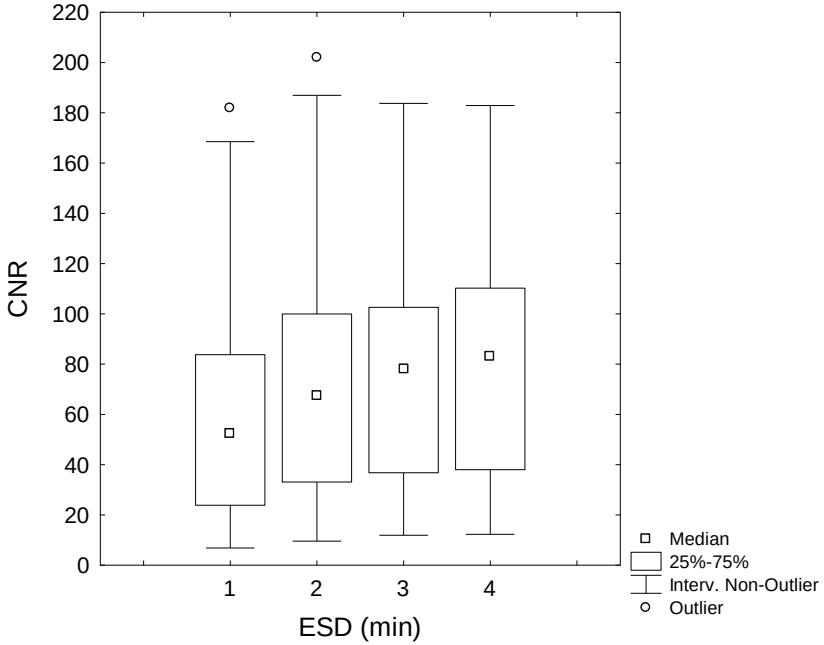
R. Matheoud et al Phys Med Biol 2009 54:5861-5872

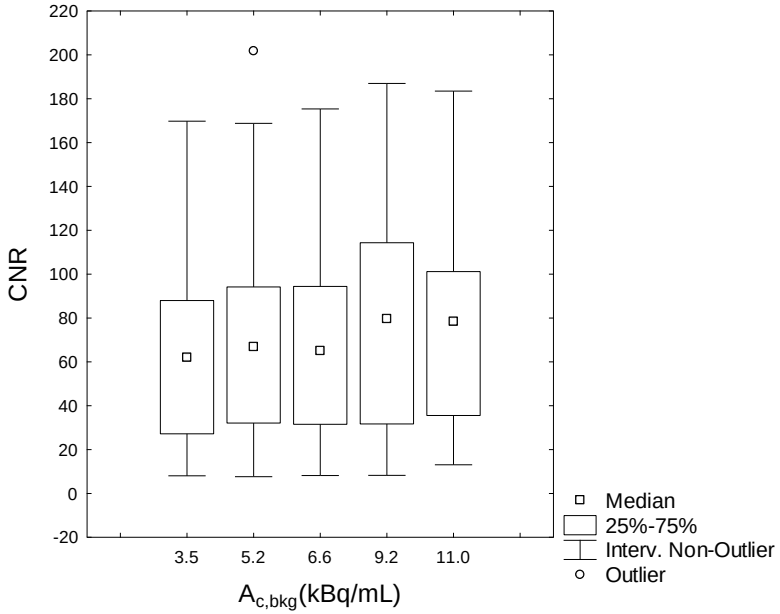
Image quality in whole-body PET imaging might be affected by presence of activity outside the field of view (FOV). Outside FOV activity might results in increased dead time and random and scatter fractions, thereby influencing noise equivalent count rate (NECR) and image quality

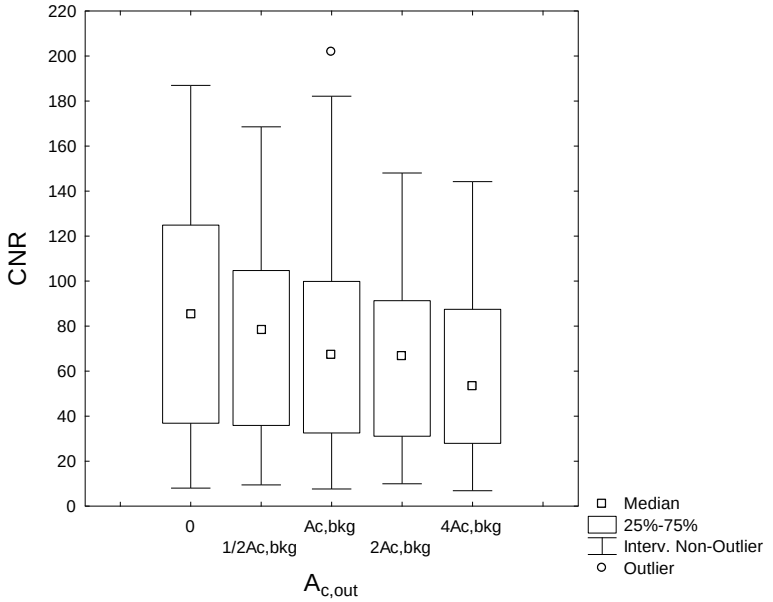
The purpose of this study was to investigate and quantify the influence of outside FOV activity on image quality of a 3D LSO whole-body PET/CT scanner. Contrast-to-noise ratio (CNR) was the figures of merit used to characterize image quality and quantitative accuracy of PET scans.

Contrast-to-noise ratio (CNR)









DISCUSSION AND CONCLUSIONS

- There is a significant decrease of CNR with increasing outside FOV activity in the range explored.
- Noteworthy ESD and $A_{c,out}$ convey a similar explanatory power on CNR variance
- This suggests the possibility of counterbalancing the effect of elevated outside FOV activity by modulating ESD in individual bed positions.
- Intuitively ESD and $A_{c,bkg}$ should have similar effects on CNR. Both of them increase the total number of events although in different ways.
- Nevertheless it must be recognized that increasing $A_{c,bkg}$ do not appear to be a valid strategy in order to raise CNR, since an increment in $A_{c,bkg}$ is likely to be accompanied by a corresponding increment in $A_{c,out}$ and these two variables act in opposite direction with respect to CNR.

Count rate analysis from clinical scans in PET with LSO detectors

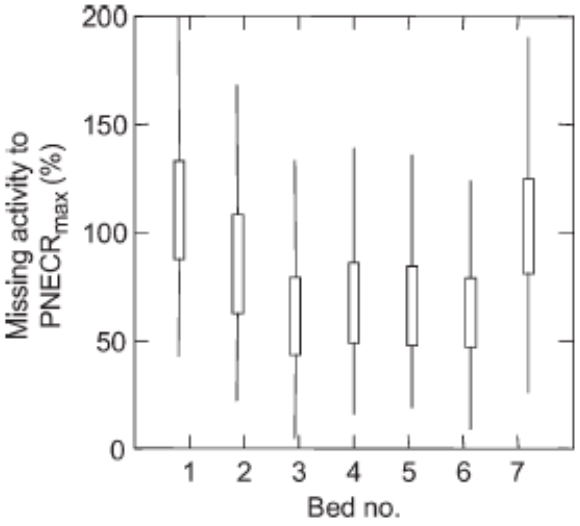


Figure 2. Percentage missing activity to get the maximum PNECR value for various bed positions.

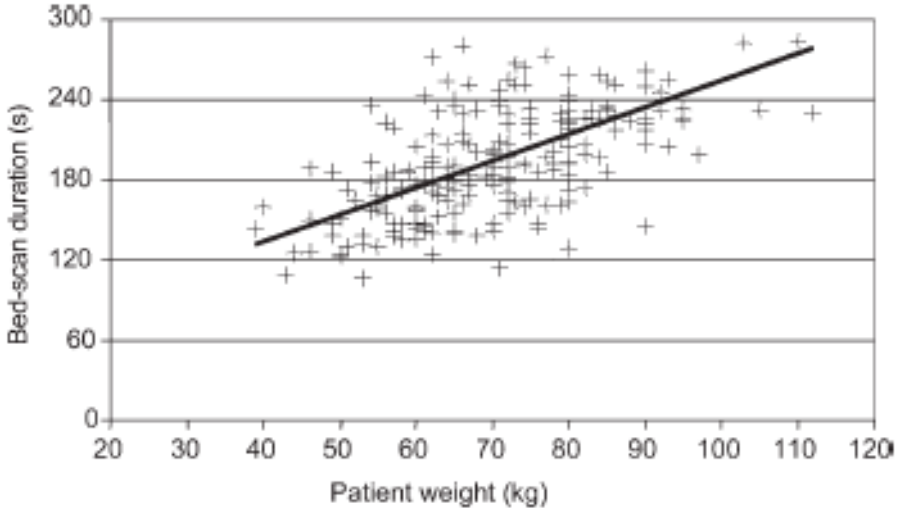


Figure 3. Dependence of the duration of single bed-scan on patient weight.

Normalizing the counts at PNECR(max) for the 70 kg patient, the bed duration for a 90 kg patient should be 230s which is approximately 30% longer.

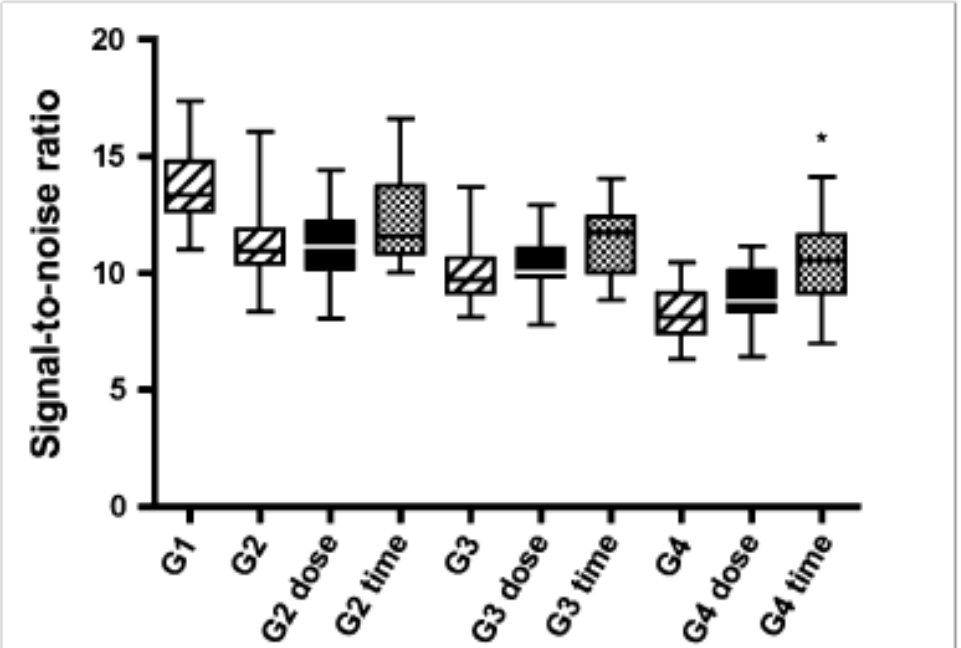
Although the analysis indicated that the fast scanner electronics allow using higher administered activities, this would involve poor improvement in terms of NECR. Instead, attending to higher bed duration for heavier patients may be more useful.

Since the gain in terms of PNECR is so low, from the patient exposure point of view it could seem unjustified to inject higher activities than those currently administered.

Bonutti F Radiat Prot Dosim 2008; 129:288-290

Comparison of Imaging Protocols for 18F-FDG PET/CT in overweight patients: Optimizing Scan duration versus administered Dose

Masuda et al *J Nulc Med* 2009 50: 844-848



Signal-to-noise ratio

	G1	G2	G2 dose	G2 time	G3	G3 dose	G3 time	G4	G4 dose	G4 time
Mean	13.8	11.1	11.0	12.4	10.0	10.3	11.5	8.2	9.0	10.5
SEM	0.41	0.40	0.34	0.25	0.34	0.23	0.34	0.25	0.26	0.43

The major finding of this study was that an extended acquisition time effectively maintained the quality of 18F-FDG PET/CT images of overweight patients.
In contrast, an increased dose of up to 2.5 fold higher than 3.7 MBq/kg did not improve image quality.
Our findings suggest that only scanning for prolonged periods can maintain the quality of images of heavier patients.

G1 (<or=59 kg), G2 (60-69 kg), G3 (70-84 kg), and G4 (>or=85 kg)

G2 dose (5.59 ± 0.19 MBq/kg), G3 dose (7.29 ± 0.33 MBq/kg), G4 dose (8.88 ± 0.43 MBq/kg.)

G2 time (3 min/bed position), G3 time (4 min/bed position), and G4 time (5 min/bed position).

Impact of phantom size on variance/noise

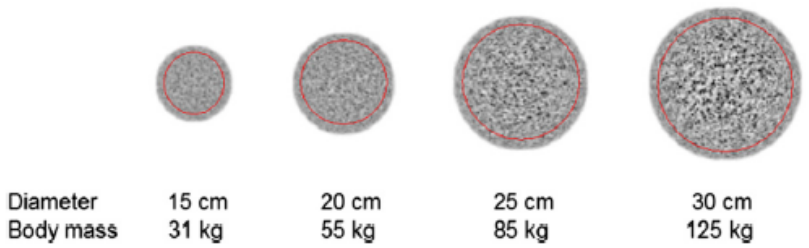
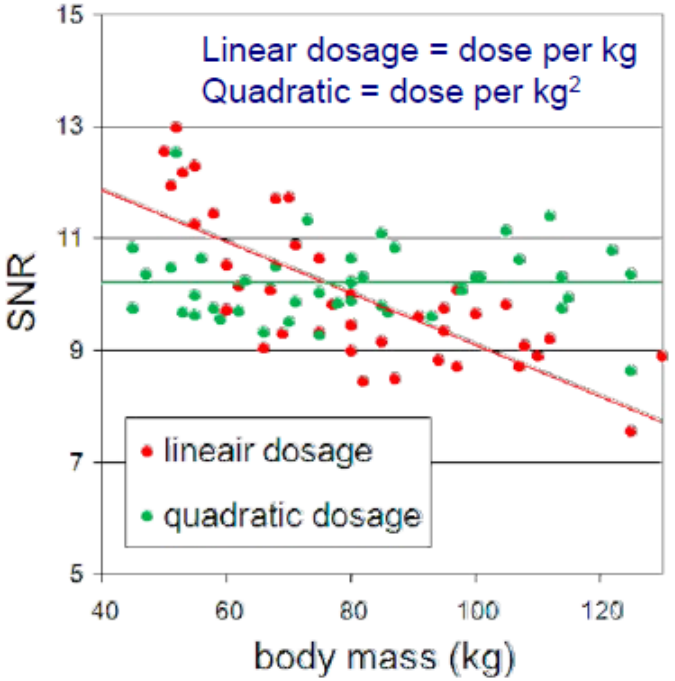


Figure 6 Axial slices of the simulated mathematical phantom. Representative axial slices of the simulated mathematical phantom with various diameters. Images were taken from the simulation applying a linear relationship between weight and administered activity. The region of interest to derive SNR is indicated by the red contour.



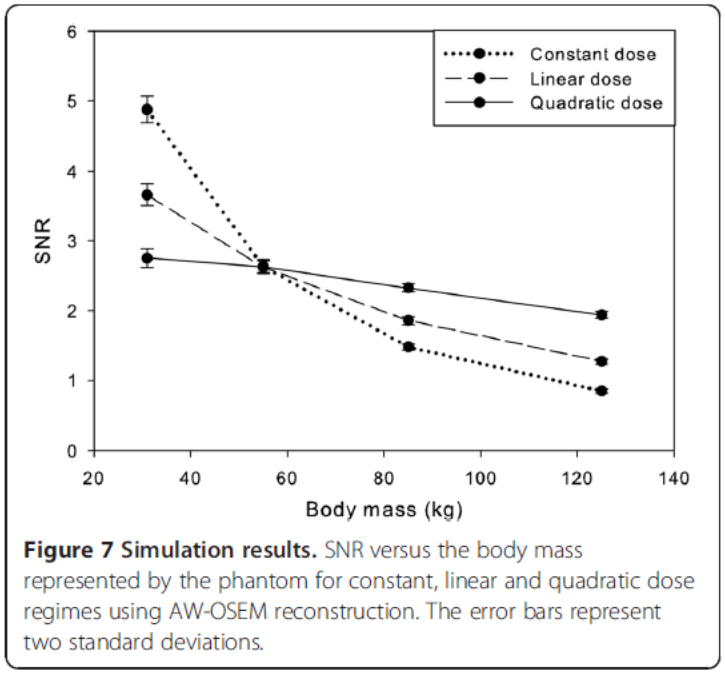


Figure 7 Simulation results. SNR versus the body mass represented by the phantom for constant, linear and quadratic dose regimes using AW-OSEM reconstruction. The error bars represent two standard deviations.

$$A = c/t * m^2$$

At 'low' activities image noise (or SNR) approximately varies quadratically with body weight, thus by quadratically adaption activity with weight the image quality remains approximately constant.

$$A = 0.023\ m^{2.047}\ MBq$$

80 kg 180MBq
120 kg 414 MBq

De Grooth EH EJNMMI Res 2013;

Optimization of acquisition protocols in PET Conclusions

•There are no experimental evidence of the fact that raising the administered activity linearly with body weight brings a significant improvement of the figures of merit more related with Image quality such as NECR or CNR.

•The role of emission scan duration and of administered activity in the increase of CNR are not equivalent.

•An increase of ESD, in the range of activities clinically administered, brings to a significant improvement in the image quality, in particular for obese patients.

•It seems reasonable to adopt protocols of administered activity which stay on the inferior range of international guidelines (Fixed activity of 250 MBq) and adjust the ESD according to the body weight (BMI>30 ESD=4-5 min Non TOF, ESD 2 min TOF).

SNR – weight relation seems independent of TOF vs non TOF and use of resolution modeling in reconstruction

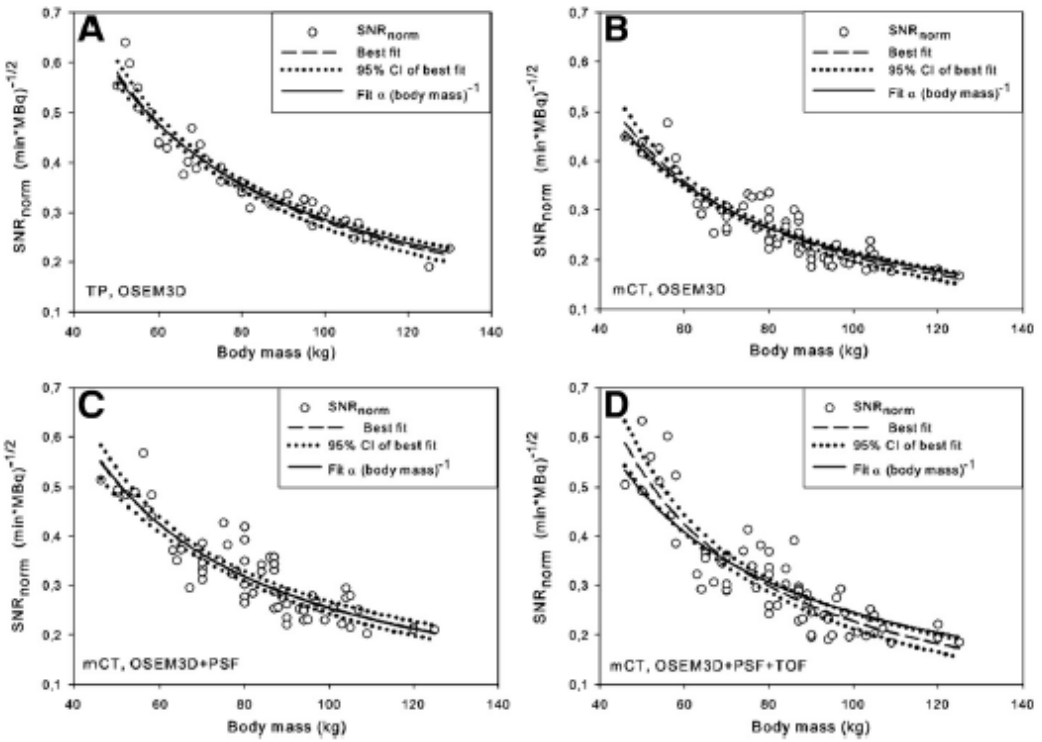


Figure 4 SNR_{norm} versus body mass. Signal-to-noise ratio normalized for the administered FDG dose and scan time per bed position (SNR_{norm}) versus body mass. Besides the best fits through the data, also their 95% confidence intervals are shown, and the best fit with the value of the parameter *d* fixed to 1 for **(A)** the Biograph TruePoint (TP) and for the Biograph mCT for three different reconstructions: **(B)** OSEM3D, **(C)** OSEM3D + PSF and **(D)** OSEM3D + PSF + TOF. The fit with the parameter *d* fixed to 1 corresponds to the situation where SNR_L can be kept constant by a quadratic relation between dose and body mass.

De Grooth EH EJNMMI Res 2013;

DRL’s variability in Nuclear Cardiology

2009

Nuclear Medicine

Table 5

Effective Doses for Adults from Various Nuclear Medicine Examinations

Examination*	Effective Dose (mSv)	Administered Activity (MBq)†
Cardiac rest-stress test (^{99m}Tc-sestamibi 1-day protocol)	9.4	1100
Cardiac rest-stress test (^{99m}Tc-sestamibi 2-day protocol)	12.8	1500
Cardiac rest-stress test (Tc-tetrofosmin)	11.4	1500
Cardiac ventriculography (^{99m}Tc-labeled red blood cells)	7.8	1110
Cardiac (^{18}F-FDG)	14.1	740

Mettler et al. Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog. Radiology 2009

Summary

- **Reconstruction Algorithms for Fast Imaging with Standard MPI Systems**
  - Astonish (Philips Healthcare)
  - Evolution for Cardiac, EfC (GE Medical Systems)
  - Flash3D (Siemens Medical Solutions)
  - Wide-beam reconstruction, WBR, by a third-party vendor (UltraSPECT)

- **New hardware for optimized MPI.**
  - Spectrum Dynamics - D-SPECT
  - General Electric Discovery NM 530 c
  - Siemens IQ•SPECT

D-SPECT gamma camera

- **Solid state design**
  - Semi conductor: Cadmium Zinc Telluride (CZT)
- **Square tungsten parallel hole collimator**
  - 2.46 mm on its side -large in comparison to conventional collimators
- **9 independently addressable detectors**
  - Region of interest (ROI) centric scanning
  - Wide solid angle tungsten collimators
- **No perceivable motion**
  - No need to rotate the camera around the patient
  - No need to rotate patient in front of the camera
- **Acquisition**
  - 1-min scout scan for the 9 detectors
  - each detector assembly fanning within the limits determined by the scout scan.

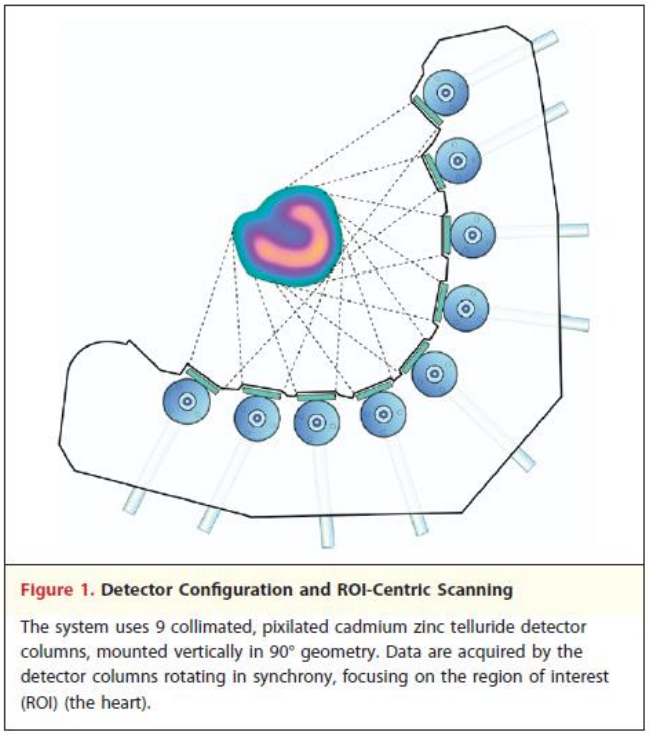
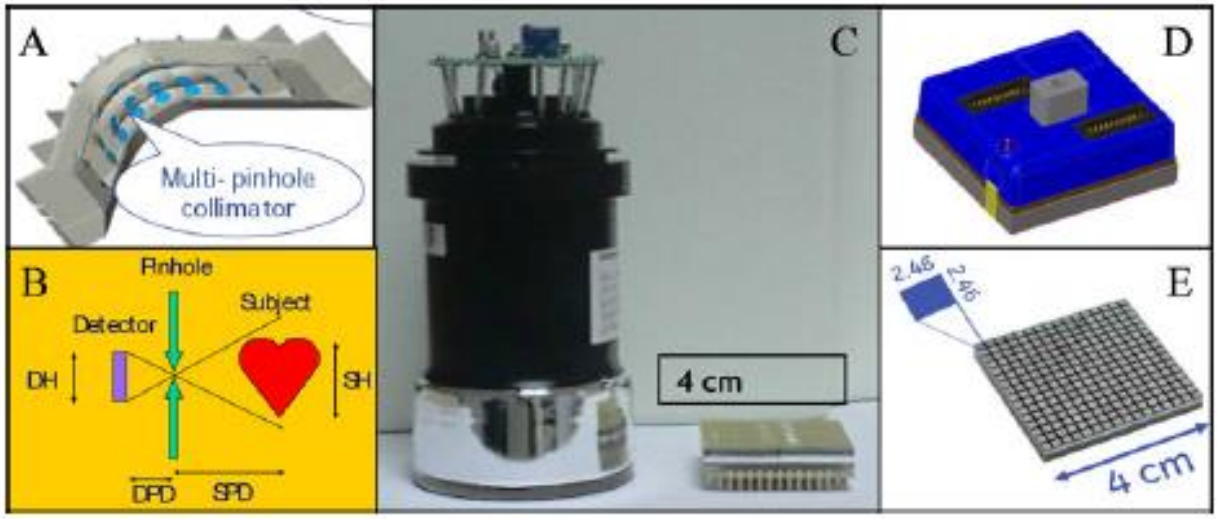


Figure 1. Detector Configuration and ROI-Centric Scanning

The system uses 9 collimated, pixilated cadmium zinc telluride detector columns, mounted vertically in 90° geometry. Data are acquired by the detector columns rotating in synchrony, focusing on the region of interest (ROI) (the heart).

Discovery NM 530c – General Electric

- **Solid state design**
  - Semi conductor: Cadmium Zinc Telluride (CZT)
- **Array of 19 pinhole detectors**
  - The detector assembly is mounted on a gantry that allows for patient positioning in the supine or prone position
- **No motion**
  - All the 19 pinholes simultaneously imaging the heart with no moving parts during data acquisition



Pinhole collimation and miniaturization of the detector enable proximity to the heart with minification of the heart image, utilizing most of the detector surface to cover the heart projection.

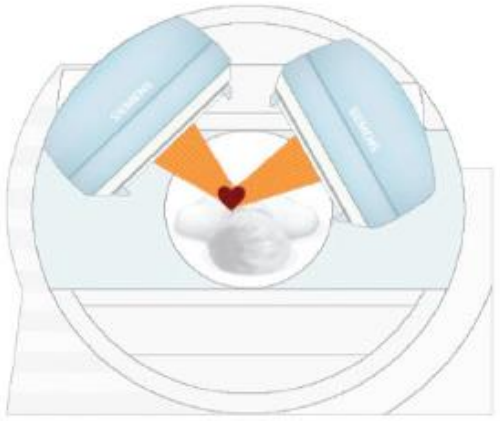
Bocher M Eur J Nucl Med Mol Imaging (2010) 37:1887–1902

Multiple Confocal Collimator Design (IQ-SPECT)

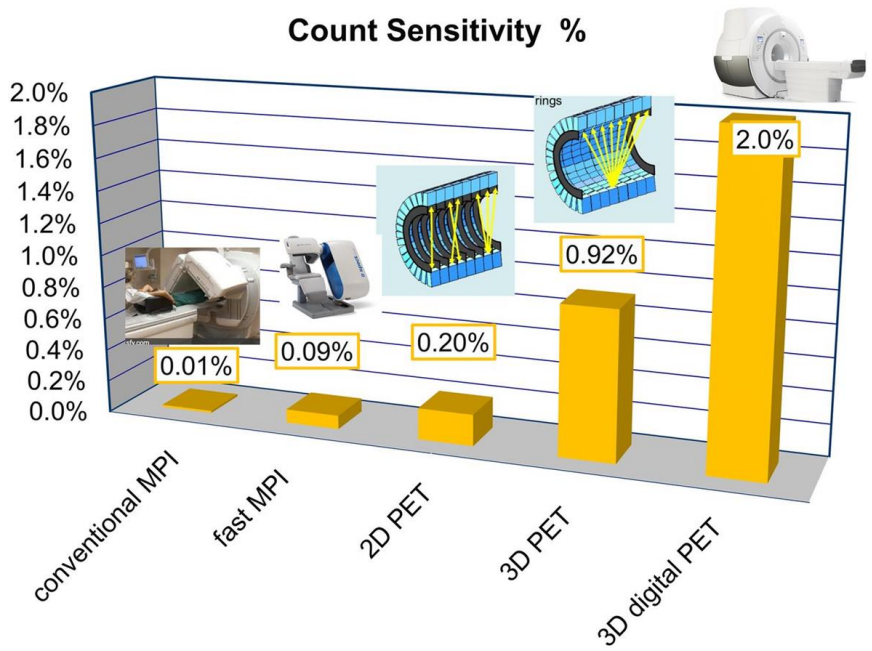
Siemens has introduced to the field the use of confocal collimators with dedicated reconstruction software: It uses a combination of converging collimators, modified cardio-centric acquisition and special reconstruction methods, with scan times as low as 4 minutes per acquisition. For increased sensitivity and resolution, the fields of view of these collimators are most convergent at their center, whereas the convergence is relaxed toward the edge of the field of view. The advantage of this approach is that it can be used by Siemens' existing dual-detector systems.

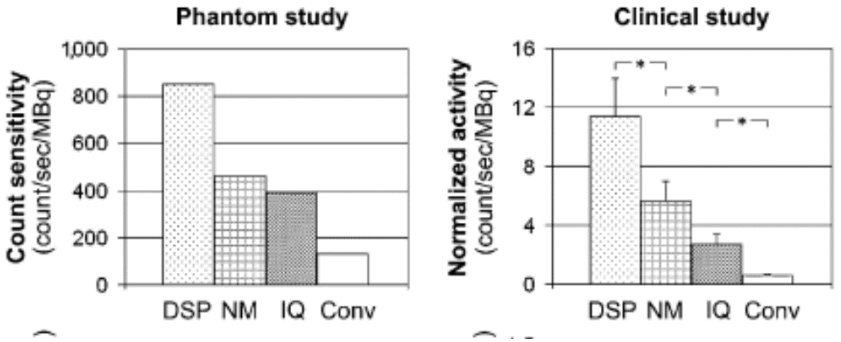
Confocal collimators

Cardio-centric acquisition



Enhanced sensitivity

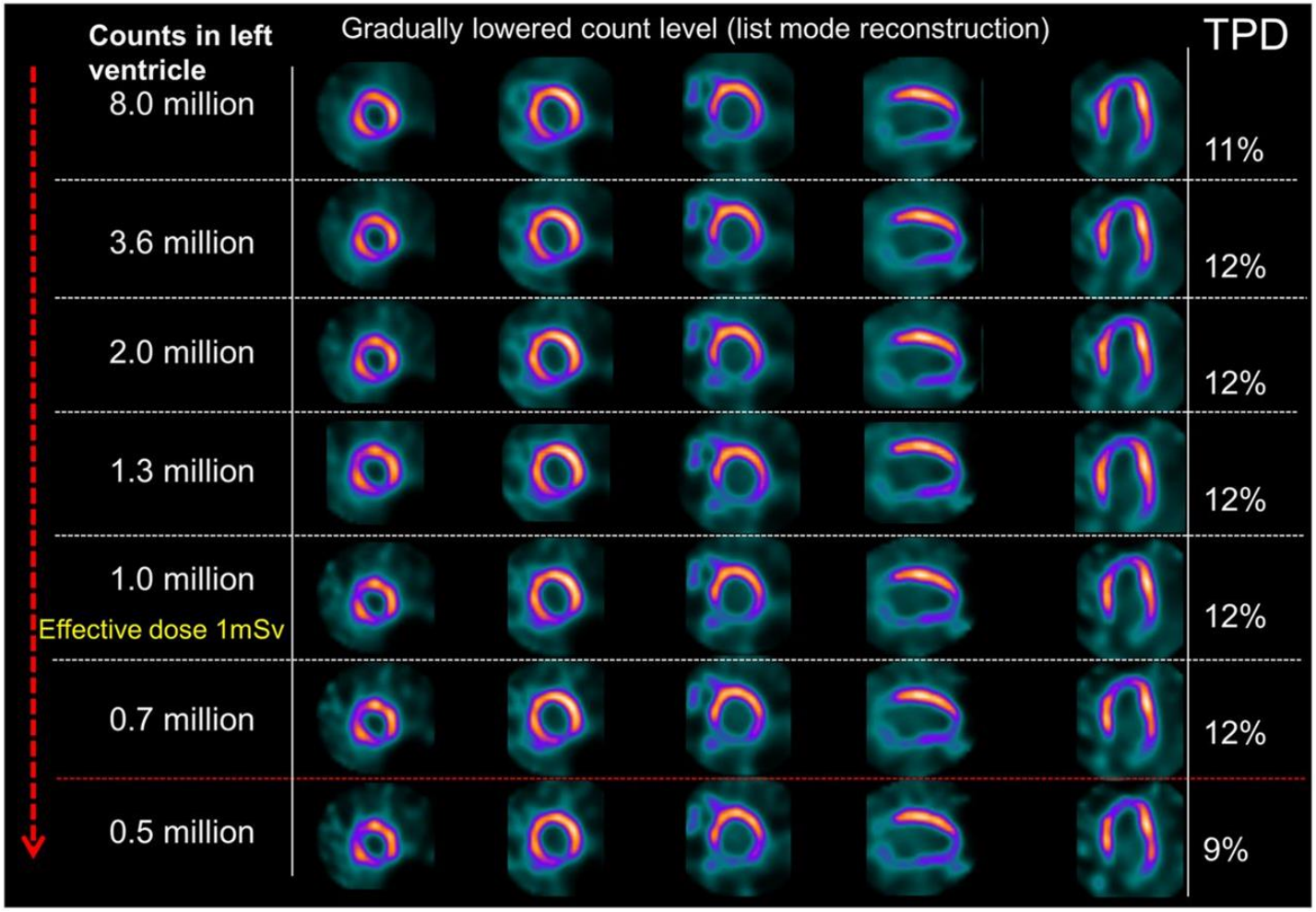




Slomka et al. J Nucl Med 2019;60:1194-1204

L. Imbert et al J Nucl Med 2012

Dosimetry in MPI



A study simulated reduced radiation protocols in 79 patients, who were imaged with a solid-state scanner for 14 min with 802.9 ± 199.8 MBq (21.7 ± 5.4 mCi) of 99mTc injected at stress (18). There was no significant difference in quantitative perfusion or functional measurements even with simulated activity corresponding to an effective radiation dose of less than 1 mSv, as outlined in Figure.

Patient with abnormal perfusion in low-dose simulation study performed by Nakazato et al. Piotr J. Slomka et al. J Nucl Med 2019;60:1194-1204

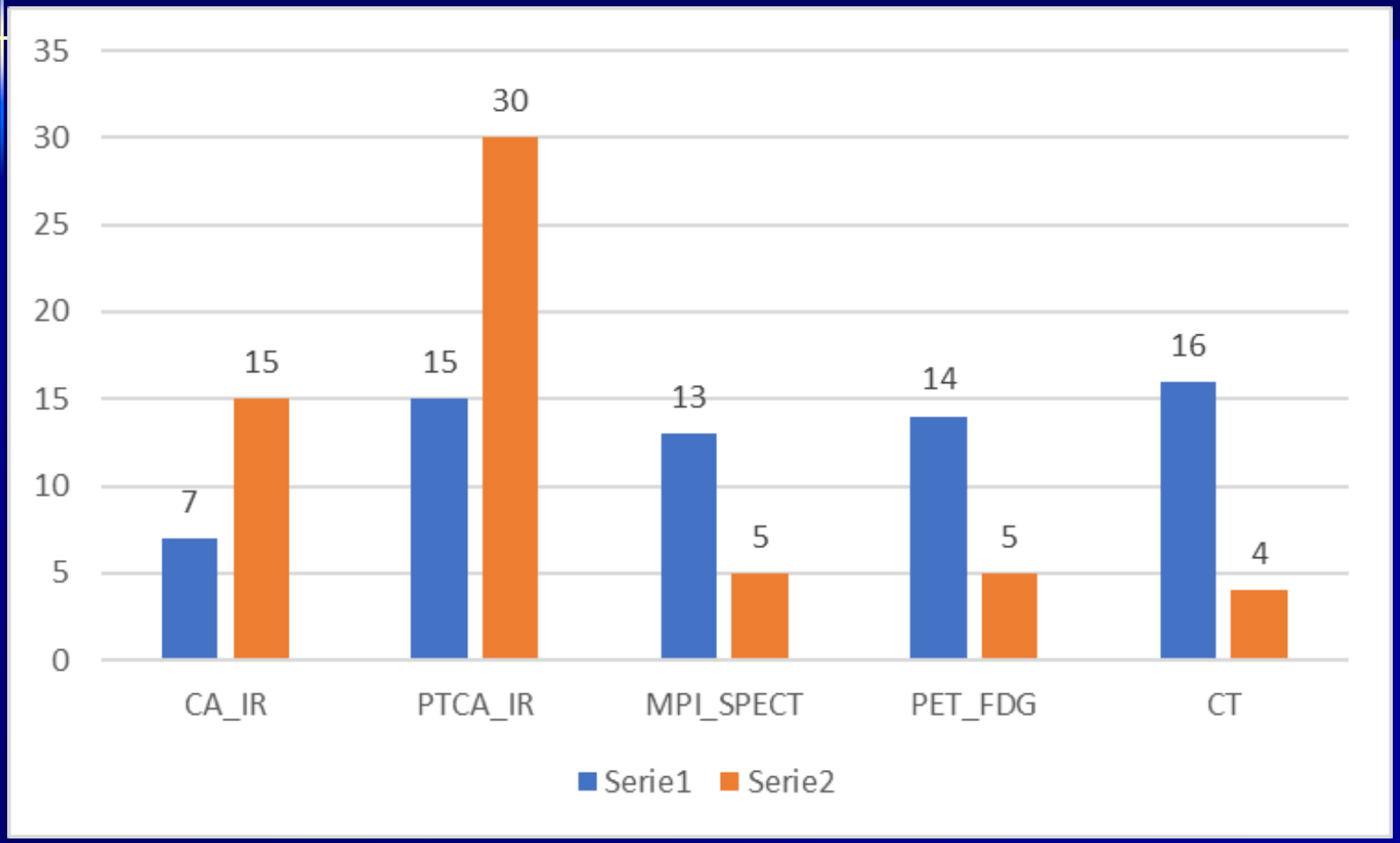
Dosimetry in MPI

The lowest total radiation exposure with current SPECT MPI (~1 mSv) can be accomplished clinically by performing stress-only imaging with a solid-state camera system.

stress-only protocols dramatically shorten total study times to as low as 30–45 min,

Patient with abnormal perfusion in low-dose simulation study performed by Nakazato et al. Piotr J. Slomka et al. J Nucl Med 2019;60:1194-1204

Evolution of typical Effective doses in Cardiology procedures 2009-2019



Conclusions

- Despite nearly 30 years of existence, DRLs for adults have been confined to representative standard patient or phantom. Larger fractions of patients are currently non-standard.

- DRLs were developed for a defined technology, and it was envisaged that they would be updated when technology changes. The point is that different technologies can coexist for a certain time period providing DRL's which can be different for an order of magnitude or even more.

- Many administration schemed in NM are weight based. This introduce a source of variation in DRLs depending on the weight composition of the sample.