The role of functional imaging (PET/SPECT) in radiation therapy

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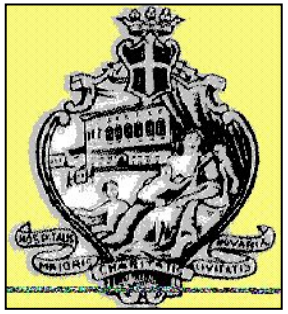


Joint ICTP-IAEA Workshop on Radiation Protection in Image-Guided Radiotherapy (IGRT)

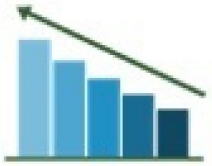
Summary

- Trends in Nuclear Medicine procedures and Distribution of PET/CT scanners
- Radiotracers in PET Imaging
- Role of PET/CT in oncological imaging
- Advances in Positron Emission Tomography (PET)
  - TOF capabilities
  - Digital PET
  - Large FOV cameras
- Advances in Single Photon Emission Computed Tomography (SPECT)

Nuclear Medicine procedures

Growth Drivers

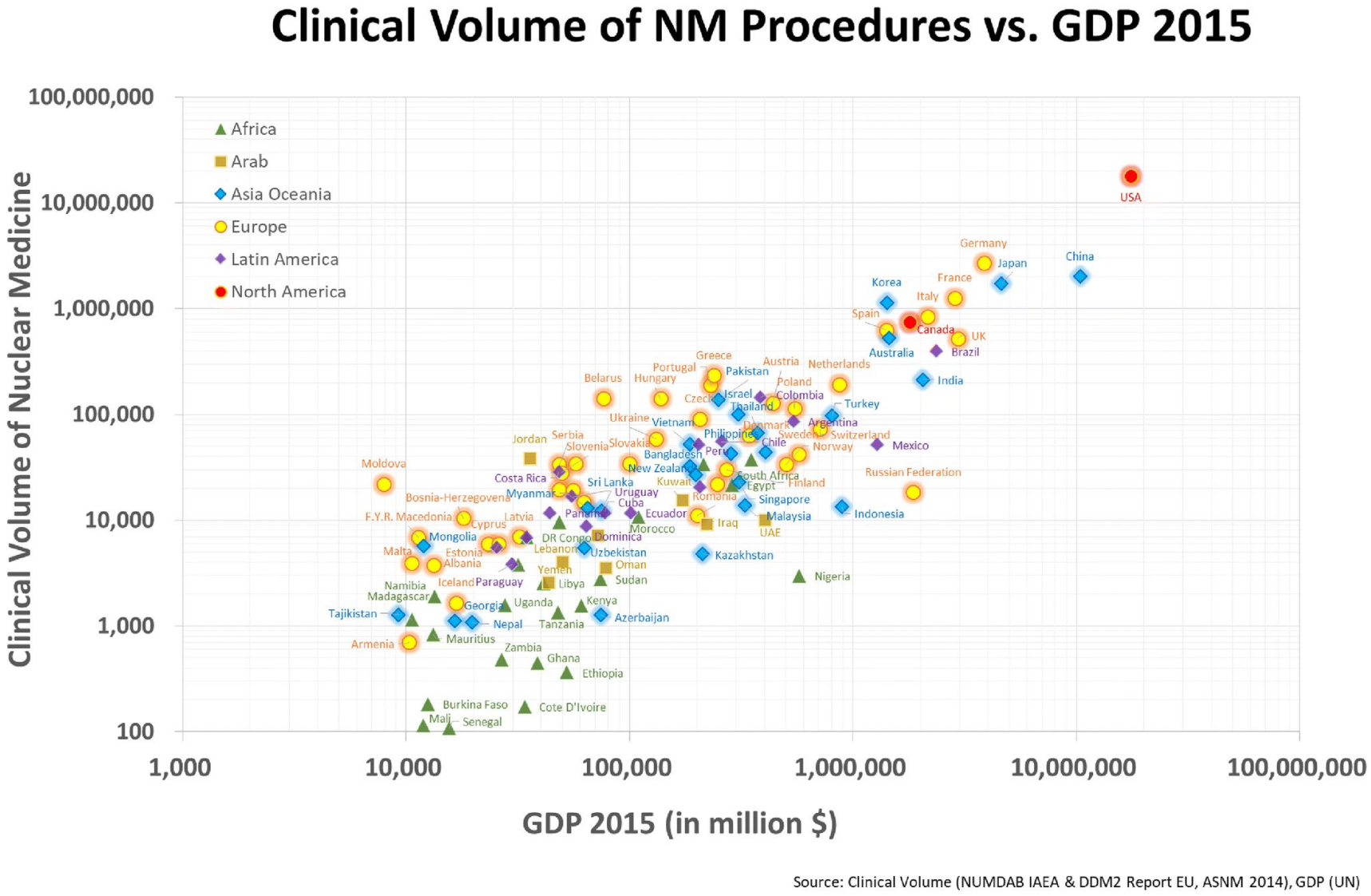
- Upsurge in Neurological disorders
- Worldwide growing prevalence of cancer



Challenges

- High cost Associated with PET or SPECT scanning
- High capital investment
- Procurement of radiopharmaceuticals

- Oncology
- Cardiology
- Brain disorders
- Bone disorders



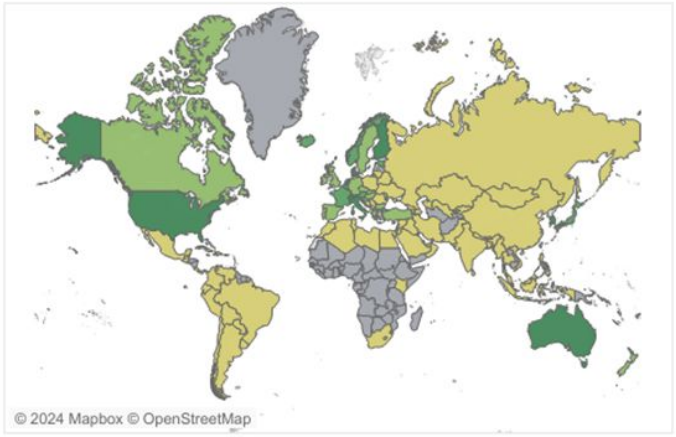
Source: Clinical Volume (NUMDAB IAEA & DDM2 Report EU, ASNM 2014), GDP (UN)

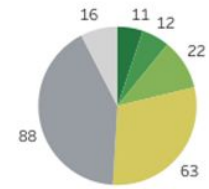
Lee, D.S., Lee, YS., Lee, J.S. et al. Promotion of Nuclear Medicine-Related Sciences in Developing Countries. Nucl Med Mol Imaging 53, 73–82 (2019). https://doi.org/10.1007/s13139-019-00583-0

IAEA
International Atomic Energy Agency

PET scanners (per 1 mil)

Countries	Countries with PET scanners	Regions	Population (mil)	Number of PET scanners	PET scanners (per 1 mil)
212	109	6	7,674M	5,672	0.739





PET scanners ranges
- More than 3
- Between 2 and 3 (inc)
- Between 1 and 2 (inc)
- Between 0 and 1 (inc)
- No PET or PET/CT scann..
- Data not available

Country All

Income Group

Income Group	Countries	Countries with PET sca..	Population (mil)	Number of PET scanners	PET scanners (per 1 mil)
High Income	75	51	1,237M	4,356	3.522
Upper-Middle Income	54	35	2,854M	860	0.301
Lower-Middle Income	50	20	2,913M	451	0.155
Low Income	30	1	669M	3	0.004
Temporary Unclassified	1	1	0M	1	2.751

UN Regions

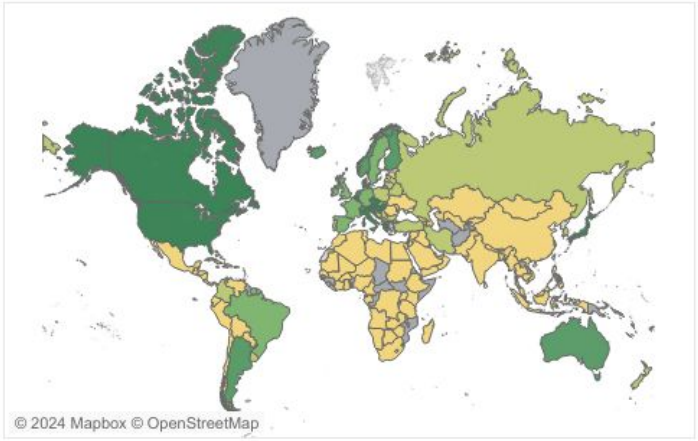
UN Region Name	Countries	Countries with PET sca..	Population (mil)	Number of PET scanners	PET scanners (per 1 mil)
Australia/New Zealand	2	2	30M	85	2.807
Central and Southern Asia	14	9	1,993M	390	0.196
Eastern and South-Eastern Asia	19	12	2,298M	1,011	0.440
Europe and Northern America	48	40	1,110M	3,592	3.235
Latin America and the Caribbean	39	20	647M	313	0.484
Northern Africa and Western Asia	25	21	517M	263	0.509
Oceania (excluding Australia and ..	15	0	12M	0	0.000
Sub-Saharan Africa	49	4	1,066M	17	0.016

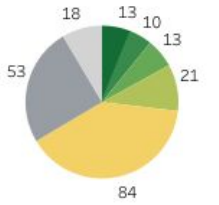
PET/CT Scanners worldwide

Gallach J et al Med Sci Monit, 2020; 26: e926544

SPECT scanners (per 1 mil)

Countries	Countries with SPECT scanners	Regions	Population (mil)	Number of SPECT scanners	SPECT scanners (per 1 mil)
212	141	6	7,674M	27,180	3.542





SPECT scanners ranges
- More than 10
- Between 7.5 and 10 (inc)
- Between 5 and 7.5 (inc)
- Between 2.5 and 5 (inc)
- Between 0 and 2.5 (inc)
- No SPECT or SPECT/CT sca..
- Data not available

Country All

Income Group

Income Group	Countries	Countries with SPECT scanners	Population (mil)	Number of SPECT scanners	SPECT scanners (per 1 mil)
High Income	75	56	1,237M	21,826	17.646
Upper-Middle Income	54	40	2,854M	4,498	1.576
Lower-Middle Income	50	34	2,913M	828	0.284
Low Income	30	10	669M	26	0.039

UN Regions

UN Region Name	Countries	Countries with SPECT scanners	Population (mil)	Number of SPECT scanners	SPECT scanners (per 1 mil)
Australia/New Zealand	2	2	30M	265	8.751
Central and Southern Asia	14	9	1,993M	694	0.348
Eastern and South-Eastern Asia	19	13	2,298M	2,909	1.266
Europe and Northern America	48	43	1,110M	19,912	17.935
Latin America and the Caribbean	39	26	647M	2,388	3.690
Northern Africa and Western Asia	25	24	517M	881	1.704
Oceania (excluding Australia an..	15	0	12M	0	0.000
Sub-Saharan Africa	49	24	1,066M	131	0.123

SPECT Scanners worldwide

https://humanhealth.iaea.org/HHW/DBStatistics/IMAGINEMaps5.html

PET radiopharmaceuticals in Oncology

Medical Field	Radiopharmaceuticals	FDA approval	EMA approval
Oncology	^{18}F-FDG (Fludeoxyglucose)	2000 – cancer applications	2012
Prostate	^{68}Ga/^{18}F-PSMA (prostate specific membrane antigen)	2012	
Prostate	^{18}F-Fluciclovine	2016	2017
Neuroendocrine	^{68}Ga-DOTA-conjugated peptides (DOTA-NOC, DOTA-TOC and DOTA-TATE)	2016	
Pheochromocytoma paraganglioma	^{18}F-FDOPA (Dihydroxyphenylalanine)	NA	2016
Radiotherapy metabolic planning	Hypoxia tracers ^{18}F-FMISO (fluoromisonidazole), ^{18}F-FAZA (fluoroazomycin-arabinozide) and ^{7}Cu-ATSM (diacetyl-bis-methylthiosemicarbazone)	FMISO-1986 ATSM-1997 FAZA –1999	
Tumour proliferation Stratification /prognosis	^{18}F-FLT (Fluorothymidine)	2009	NA

With more than 6000 PET/CT systems and approximately 250 PET/MRI systems operational worldwide, the key application of PET imaging is for oncological indications

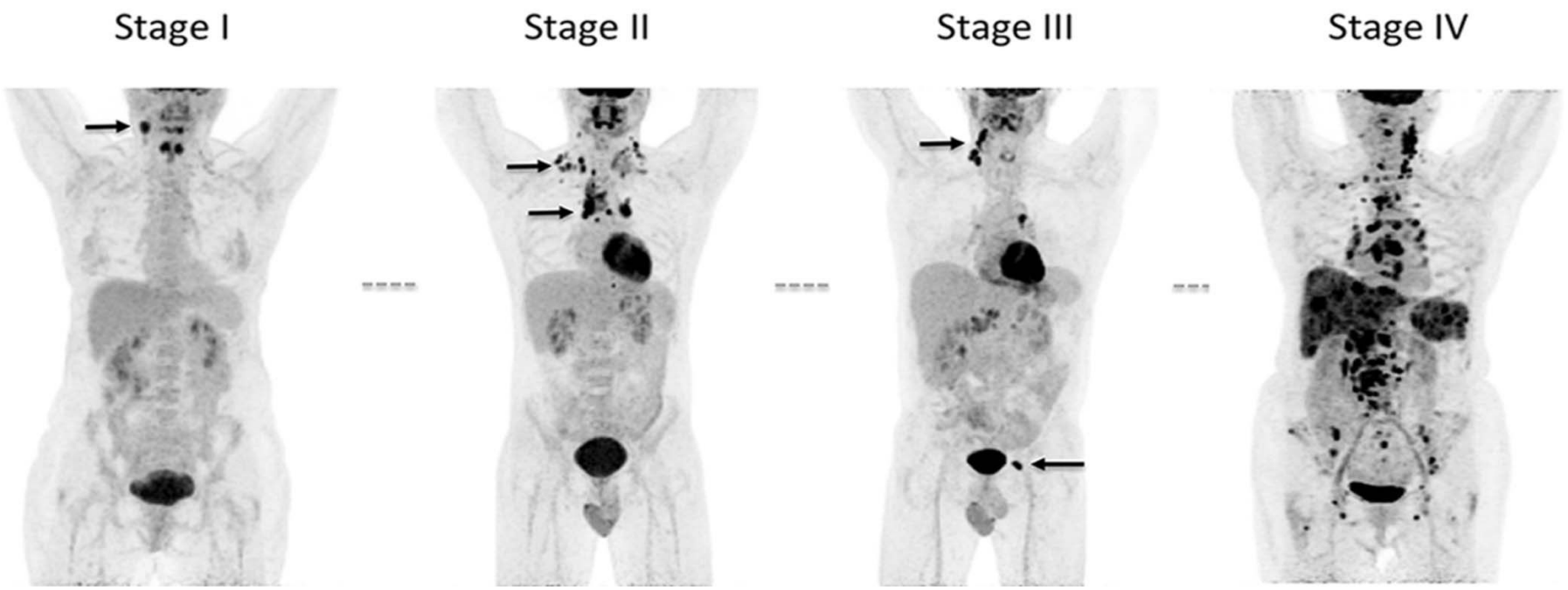
Vaz SC et al BJR 2020 https:// doi. org/ 10. 1259/ bjr. 20200095

The role of ^{18}F-FDG-PET/CT in RT

^{18}F-FDG-PET/CT has three major current applications in RT clinics:

- To identify and stage disease
  - Staging
- To improve delineation of metabolically active target tissue (tumor and nodes)
  - Segmentation
  - Image registration
  - Respiratory gating
  - Treatment Planning
- To assess tumour response to RT
  - Therapy Response Assessment

Ann Arbor Staging of Lymphoma



Stage 1	Stage 2	Stage 3	Stage 4
Involvement of a single lymph node region OR a single extra-lymphatic side	Involvement of ≥2 lymph node regions on the same side of the diaphragm (+/-E lesions)	Involvement of lymph node regions on both sides of the diaphragm (+/-E lesions)	Multiple or disseminated involvement of extra lymphatic organs or tissues

El-Galaly TC et al 2018 Seminars Nucl Med 48: 4-16

https://doi.org/10.1053/j.semnuclmed.2017.09.001

Lugano Classification

Table 5 Lymphoma Staging According to the Lugano Classification[127]

Disease Extent Is Determined by PET/CT for FDG Avid Lymphomas and CT for FDG Non-avid Lymphomas Tonsils, Waldeyer Ring, and Spleen are Considered Nodal Tissues, Not Extranodal Sites

Stage		Nodal Disease	Extranodal Disease
Limited	I	One node or a group of adjacent nodes	Single extranodal lesions without nodal involvement
	II	Two or more nodal groups on either side of the diaphragm	Stage I or II with limited contiguous extranodal involvement
	II bulky	II as above with bulky disease	
Advanced	III	Nodes on both sides of the diaphragm; nodes above the diaphragm with spleen involvement	Not applicable, because nodal stage III plus extranodal involvement constitutes stage IV disease
	IV	Additional noncontiguous extralymphatic involvement	Not applicable

- Several national and regional guidelines recommend PET/ CT as part of routine lymphoma staging workup.
- MRI has diagnostic accuracy equal to that of CT, and MRI is recommended (with or without PET) for the staging of children with lymphoma because of no association with radiation.
- PET/MRI seems to be comparable, but not superior to PET/CT in terms of diagnostic and staging accuracy.
- Contrast-enhanced CT rarely has an impact on patient's management different from that obtained with a PET/CT. Nonetheless, it is still recommended in some guidelines in the initial staging.

El-Galaly TC et al 2018 Seminars Nucl Med 48: 4-16

https://doi.org/10.1053/j.semnuclmed.2017.09.001

Justification and referral guidelines

Country	Type of Lymphoma (guidelines)	Initial workup	Number of examinations during		
			Therapy	Follow-up (5 years)	Refractory disease
Germany	HL	1 Chest X-ray 1 CT Neck/Thorax/Abdomen	2 CTs Neck/Thorax/Abdomen	Only in clinical relapse	1 CT Neck/Thorax/Abdomen
	DLBCL	1 CT Neck/Thorax/Abdomen	1 CT Neck/Thorax/Abdomen, 1 PET/CT or CT Neck/ Thorax/Abdomen	Not in routine follow-up	None
Italy	HL AIOM 2018	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen, 1 PET/CT	1 CT Neck/Thorax/Abdomen,	1 CT Neck/Thorax/Abdomen, 1 PET/CT
	DLBCL AIOM 2018	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen, every six month (2 years)- yearly	
Europe	HL ESMO 2018	1 PET/CT and 1 CT Neck/Thorax/Abdomen	PET/CT	Only if clinical symptoms occur	Not specified
	DLBCL ESMO 2015	1 CT Neck/Thorax/ Abdomen and 1 PET/CT	PET/CT	Not in routine follow-up Option Neck/Thorax/Abdomen, 6,12 and 24 months	1 CT Neck/Thorax/ Abdomen and 1 PET/CT
USA	HL	1 Chest X-ray 1 PET/CT or CT Neck/Thorax/Abdomen	1-2 PET/CTs or CTs Neck/ Thorax/Abdomen	2-4 Chest-X-rays or CTs	1 PET/CT or CT
	DLBCL	1 CT Thorax/Abdomen and/ or 1 PET/CT	2 PET/CTs or 1 PET/CT and 1 CT Neck/Thorax/Abdomen	0-4 CTs Neck/ Thorax/Abdomen	None

Segmentation

- An important utility of [^{18}F]FDG-PET imaging in RT is accurate segmentation of the PET avid region, so it can be included in the target. PET typically informs segmentation of the GTV which is further expanded to create a CTV.
- PET-guidance influence segmentation by changing manual tumor contours drawn only with CT guidance.
- The consequence of not including some portion of the PET avid region is to under dose that region, potentially leading to lower tumor control and higher risk of recurrence.

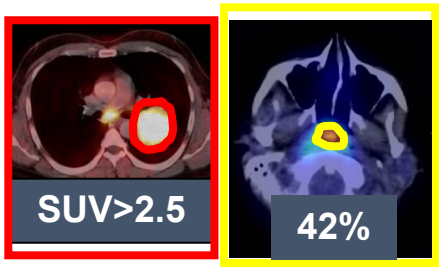
Segmenting PET avid regions is challenging because

- PET detectors have an inherent resolution limitation, on the order of several mm
- Motion of the tumor, as in lung or liver, can blur tumor boundaries and lower SUV
- The time point at which the image is acquired after injection can influence the appearance of the high uptake region relative to background

METHODS FOR TARGET VOLUME SEGMENTATION IN PET

1. Visual contouring of PET scan and definition of contours as judged by the experienced physician

2. Absolute Thresholds: Thresholding by a fixed percentage of the maximum SUV, mean SUV or maximum intensity



3. Adaptive Thresholding algorithms

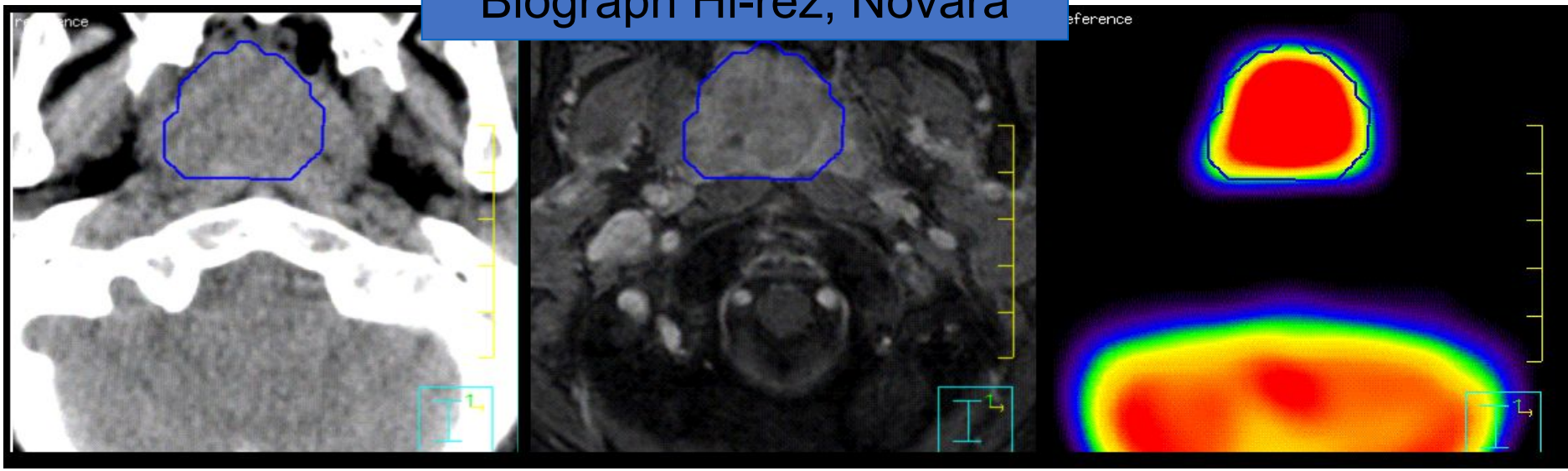
$Th = f(\varnothing_{lesione})$ $Th = f(CNR_{lesione})$

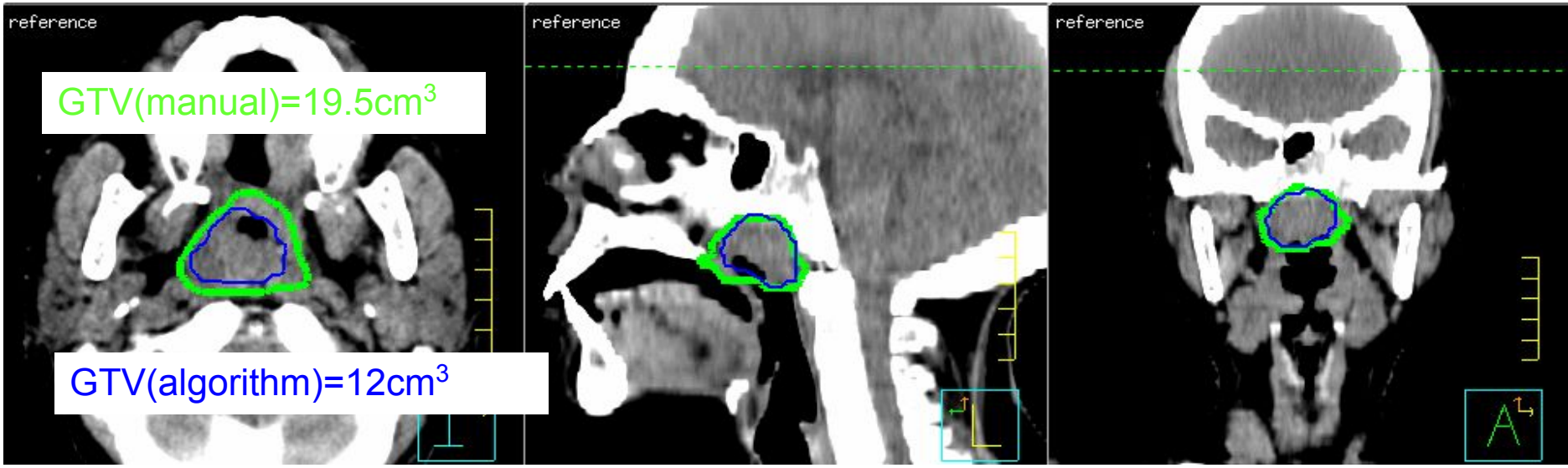
4. Complex algorithms (Gradient- based, Statistical methods)

The 2014 IAEA expert report recommend that ". . . Outside of a clinical trial context, target volumes generated with the use of PET should be delineated using visual interpretation alone or should be visually edited following any automated target volume delineation.

Konert T, Vogel W, MacManus MP, et al. PET/CT imaging for target volume delineation in curative intent radiotherapy of non-small cell lung cancer: IAEA consensus report 2014. Radiother Oncol. 2015;116:27–34.

Biograph Hi-rez, Novara





Novara_orl1

Image Registration

In RT, PET image registration is used for the following purposes:

- better tumor target definition
- propagation of contours from one image set to another.
- adaptive therapy planning/dose painting to selectively increase dose to more PET-avid target regions.
- incorporation of respiratory-gated PET information in treatment planning

Registration techniques

- Rigid
  - Landmark based,
  - surface-based
  - Intensity-based
    - ✔ squared error
    - ✔ Cross correlation
    - ✔ mutual information
- Deformable
  - Despite years of intensive research, a universally accepted deformable registration model still does not exist.

Treatment planning

1. Inclusion of the PET segmented volumes in the GTV –
   - Technically feasible; Established technique

2. **Dose painting**: Delivering nonhomogeneous dose to the target based on [18F] FDG-PET uptake
   - Technically feasible;

An example is a multicenter randomized Phase 2 trial for Stage 2–3 non-small cell lung cancer (PET-boost trial) with the primary endpoint of local progression-free survival at 1 y.

Radiation dose escalation to 150 patients either

- Arm 1 the whole primary tumour, or
- Arm 2 to an 18F-FDG-PET defined sub volume within the primary tumour

Results: The 1-year freedom from local failure was 97% in arm 1 and 91% in arm 2 (difference not significant)

Cooke SA, et al18F-FDG-PET guided vs whole tumour radiotherapy dose escalation in patients with locally advanced non-small cell lung cancer (PET-Boost): Results from a randomised clinical trial. Radiother Oncol. 2023 Apr;181:109492. doi: 10.1016/j.radonc.2023.109492. Epub 2023 Jan 24. PMID: 36706958.

Treatment response assessment

- Response assessment is typically based on images acquired at one or more time points: pre therapy or intra therapy or post-therapy;
- Metrics used are different forms of the Standardized uptake value

$$SUV_{BW} = \frac{Activity\left[\frac{Bq}{ml}\right]}{\left(\frac{InjectedDose[Bq]}{BodyWeight[g]}\right)}\left(\frac{g}{ml}\right)$$

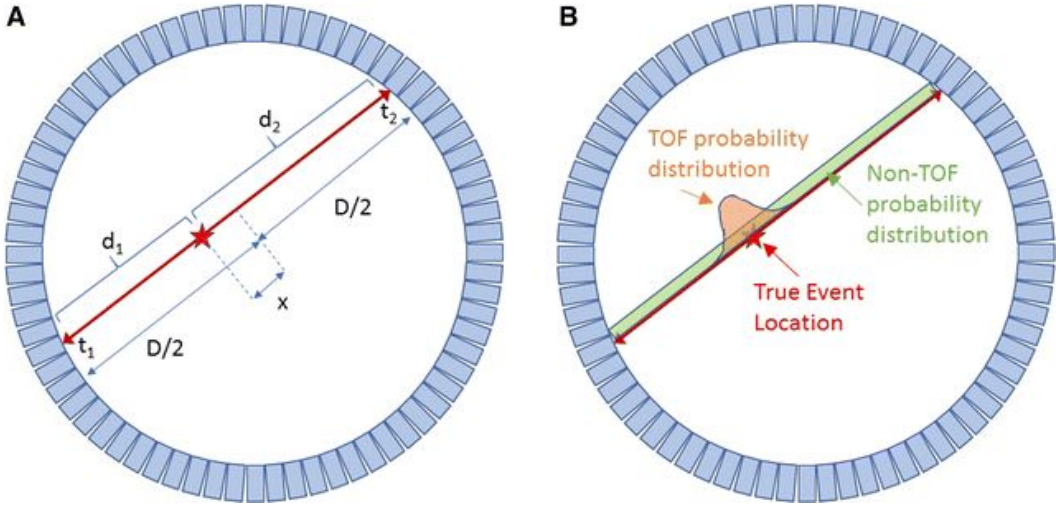
- Both pre-therapy image metrics and the comparison of pre-therapy to intra-therapy (preferably at some early time point during RT) image metrics seek to prognostically separate responders from nonresponders with a view to potentially altering the therapy regimen for nonresponders.
- The comparison of pre-therapy vs post-therapy image metrics seeks to determine the effectiveness of the entire course of therapy and also determine/ predict patients who are likely to have disease recurrence

Head-and neck cancer
Esophageal cancer
Lung cancer,
Uterine/cervix cancer

Advances in PET/CT

Time of Flight Capability

Many modern scanners now possess scintillators and electronics fast and stable enough to include a technique known as time-of-flight (TOF), which works by exploiting the ability to resolve small differences in the arrival times of two valid annihilation photons to further isolate where the annihilation event occurred along a given line of response.



TOF imaging increases the signal-to-noise (SNR) ratio allowing shorter scan times for the same image quality or less noisy images for the same scan time. The extent of improvement **depends on the size of the patient**, with larger cross-section patients deriving greater benefit compared to smaller cross-section patients.

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:

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

Conti, EJNMMI 2011

	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

Physica Medica 80 (2020) 251–258

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/ejmp

Review paper

Update on latest advances in time-of-flight PET

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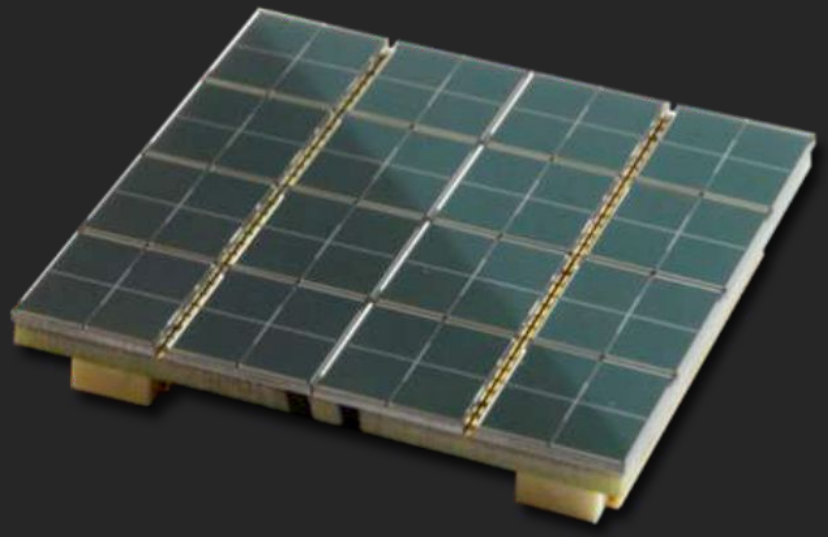


The last five years have seen widespread commercial introduction of silicon photomultiplier (SiPM) based (digital) whole-body TOF PET systems (third generation TOF PET systems) from all major manufacturers.

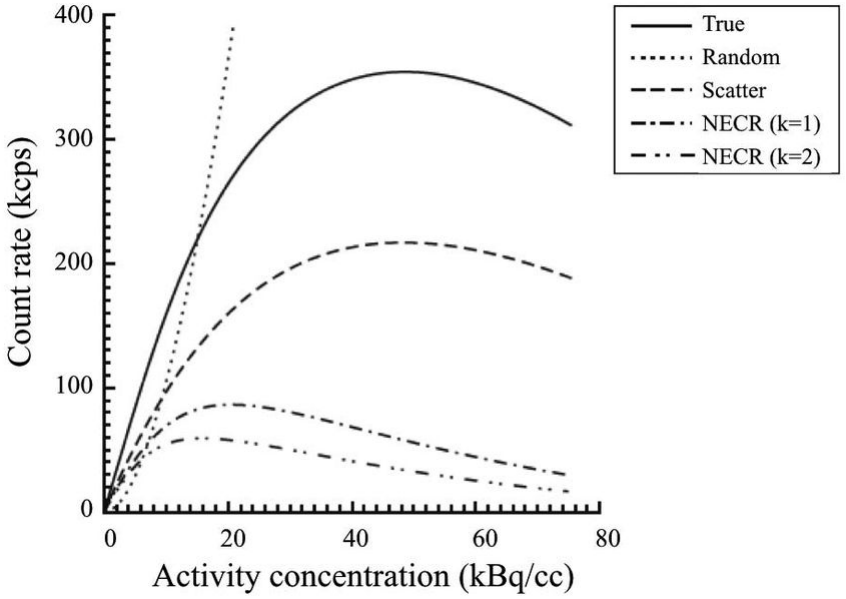
These new scanners not only provide much improved TOF resolution (as good as 214 ps), but also have gains in sensitivity due to longer axial lengths and in some systems improved spatial resolution compared to the second generation of TOF PET systems. Most of these improvements were enabled by the development of compact SiPM photodetectors.

State-of-art in TOF PET scanners

All major commercial vendors of PET/CT systems have transitioned their high-end product to a digital (SiPM-based) system and generally the axial field-of-view has increased to > 20 cm. The TOF resolution of these scanners varies in the range of 214–380 ps while the deadtime is very low compared to the traditional PMT based system due to minimal or no multiplexing

Any differences in NEC performance, at least in the range of activities used for clinical imaging, are primarily determined by the *system sensitivity*.

All of these systems also exclusively use Lu-based scintillators.



GE Healthcare

Fig. 1. (A) Picture of the GE Discovery MI PET/CT. (B) Picture of a 4x3 array of optical blocks coupled to a 4 × 3 array of SiPM chips [52]. Each optical block is a 4 × 3 array of 3.95 × 5.3 × 25 mm^3 Lu-based pixels and each SiPM chip is 3 × 2 pixel array with pixel size of 4 × 6 mm^2.

- Axial lengths of 15 (3 rings), 20 (4 rings), and 25 cm (5 rings)
- The basic crystal element (pixel): Lu-based scintillator 3.95 × 5.3 × 25 mm3.
- A single optical block of 4 × 3 array of crystals.
- A 1 × 3 array of the optical blocks form a detector
- 136 detectors form a single ring of the scanner.
- Detector coupled to a non-contiguous 1 × 3 array of SiPM chips and an analog ASIC is used for signal processing and readout.

- A single scanner ring (15.0 cm axial length) is composed of 136 such detector blocks leading to a scanner ring diameter of 70 cm.
- A closed-loop water cooling system is used to keep the SiPM arrays at a stable temperature of 19◦ C.
- System TOF resolution measured: 382 ps
- Measured NEMA system sensitivity: 13.7 cps/kBq, 4- ring system
  20.8 cps/kBq, 5-ring systems
- Reconstructed NEMA spatial resolution (4-ring): 4.15/4.48 mm @r = 1 cm
  6.22/6.1 mm @r = 20 cm
- Reconstructed NEMA spatial resolution (5-ring): 4.34/5.05 mm @r = 1 cm
  6.20/6.56 mm @r = 20 cm

A new Discovery MI Gen 2 has recently been announced that is similar to the current Discovery MI except for an axial length of 30 cm, leading to even higher system sensitivity.

United Imaging

United Imaging offers two traditional PET/CT with a ring diameter of 76 cm that are identical in design except for the axial length: the uMI 550 (24 cm axial length) and uMI 780 (30 cm axial length)

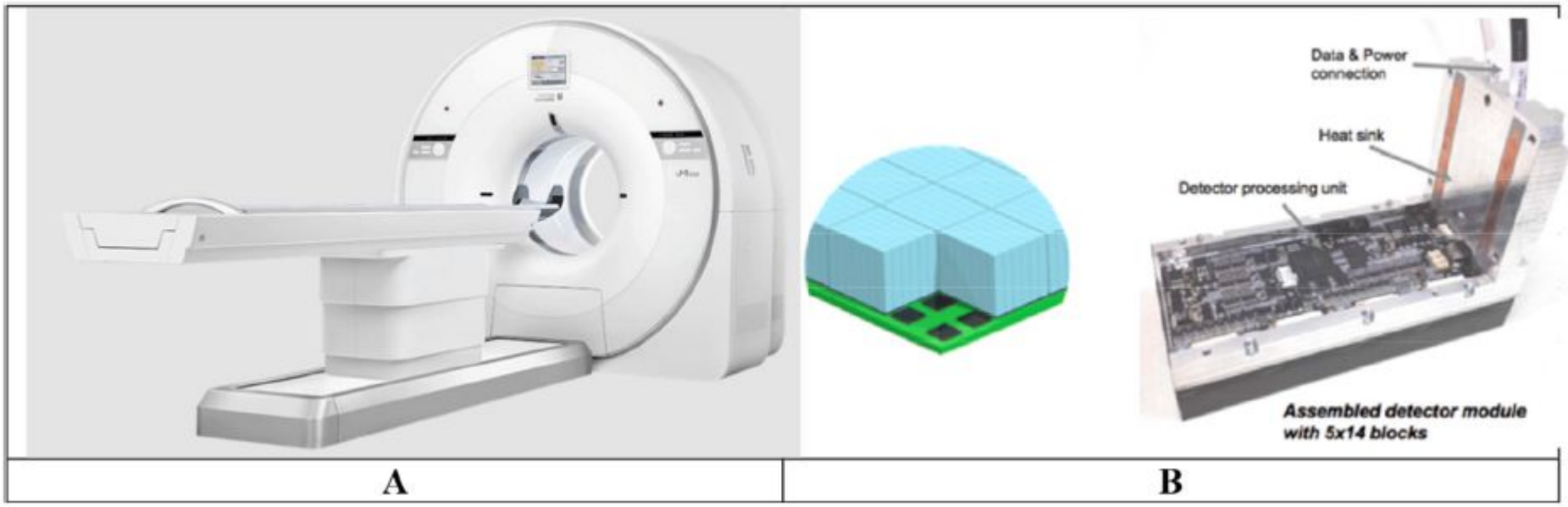
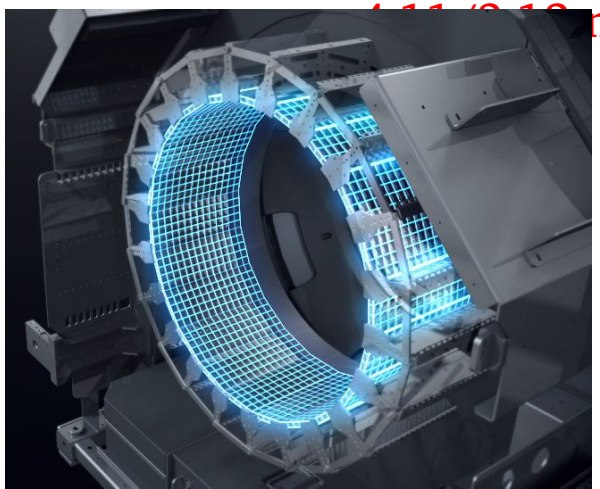


Fig. 2. (A) Picture of the United Imaging uMI 550 PET/CT. (B) Schematic (left) of an array of crystal blocks coupled to SiPMs (courtesy of Dr. Hongdi Li, United Imaging Healthcare America). Each crystal block is a 7 × 6 array of 2.76 × 2.76 × 18 mm^3 LYSO pixels coupled to four non-contiguous 6 × 6 mm^2 single channel SiPMs in a light sharing block readout scheme. Picture of an assembled detector module (right) comprising of a 5 × 14 array of crystal blocks and associated electronics [53].

United Imaging

- Crystal element is a 2.76 × 2.76 × 18 mm3 LYSO pixel
- 7 × 6 array block read-out by 4 non-contiguous 6 × 6 mm2 single channel SiPMs
- The multiplexing ratio is 10.5 crystals per SiPM channel.
- A 5 × 14 array of these blocks leads to a detector module 24.4 cm long (axial direction)
- A scanner ring is composed of 22 of these modules with a ring diameter of 72.2 cm.
- Signal readout electronics are based on traditional discrete circuits – amplification and leading-edge triggering for obtaining timing from the fast SiPM signal, and amplification and digitization
- System TOF resolution: 372 ps
- Measured NEMA system sensitivity: 10.2 cps/kBq for the uMI 550
- Reconstructed spatial resolution (fwhm): 2.95/ 2.97 mm @ r = 1 cm
  mm @ r = 20 cm



Siemens Healthineers

Fig. 3. (A) Picture of the Siemens Biograph Vision PET/CT. (B) Picture of a mini-block (5 × 5 array of 3.2 × 3.2 × 20 mm^3 LSO pixels), a 2 × 2 array of mini-blocks coupled to a 2 × 2 array of SiPMs (each a 4 × 4 array of SiPM channels), a detector block composed of a 4 × 2 array of mini-blocks, and a detector electronic assembly (DEA) of comprising of 2 × 4 array of detectors and associated electronics. Pictures courtesy of Siemens Healthineers.

Siemens Healthineers

- Basic crystal element: $3.2 \times 3.2 \times 20\ mm^3$ LSO pixel.
- A 5×5 array of the individual pixels is coupled to a 4×4 channel SiPM array with full detector coverage to form a mini-block with multiplexing ratio of ~ 1.56 crystals per SiPM channel.
- A 4×2 array of these mini-blocks is packaged into a detector with signal readout performed with two custom-designed ASICs.
- A 2×8 array of these detector modules form a detector electronic assembly (DEA) with readout electronics
- A scanner ring is composed of 19 DEAs leading to a ring diameter of 78 cm and axial length of 26.1 cm.
- The system is water-cooled at room temperature.
- Measured system TOF resolution: 214 ps
- System NEMA sensitivity: 16.4 cps/kBq
- Reconstructed NEMA spatial resolution: 3.55/3.50 mm @ r = 1 cm
  4.65/4.40 mm @ r = 20 cm

Canon Medical Systems

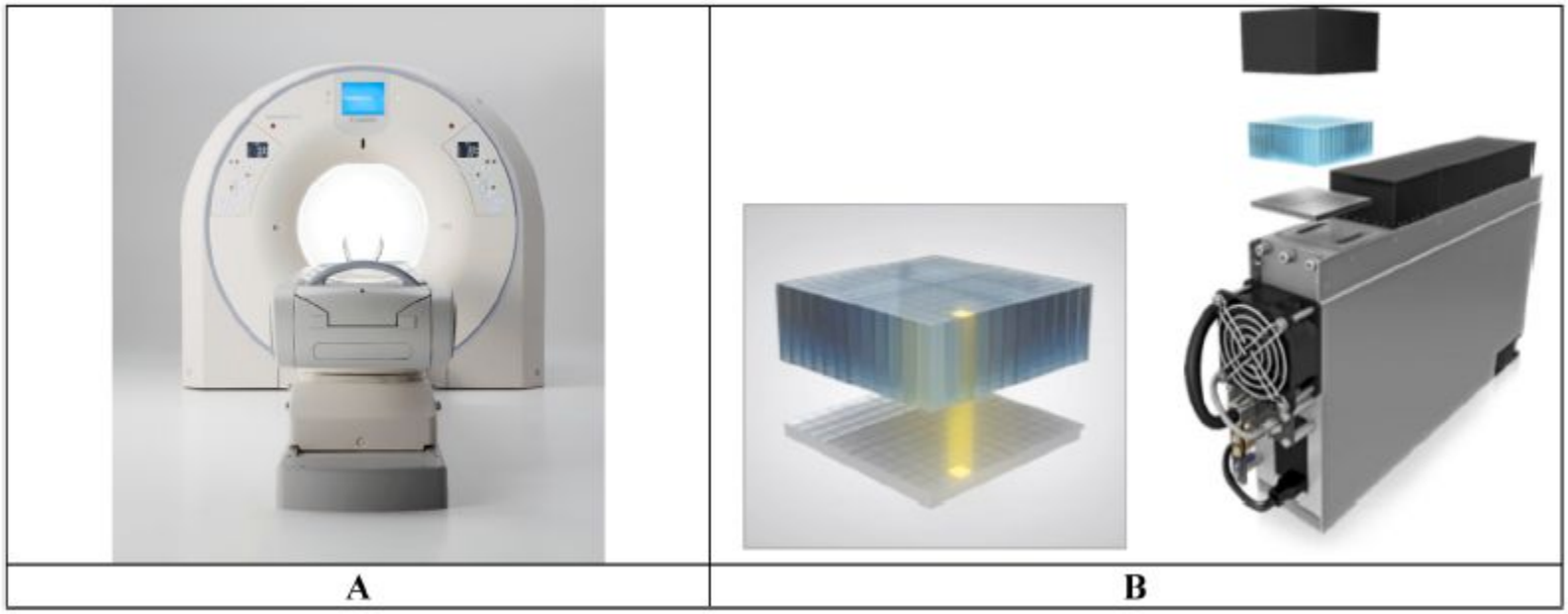
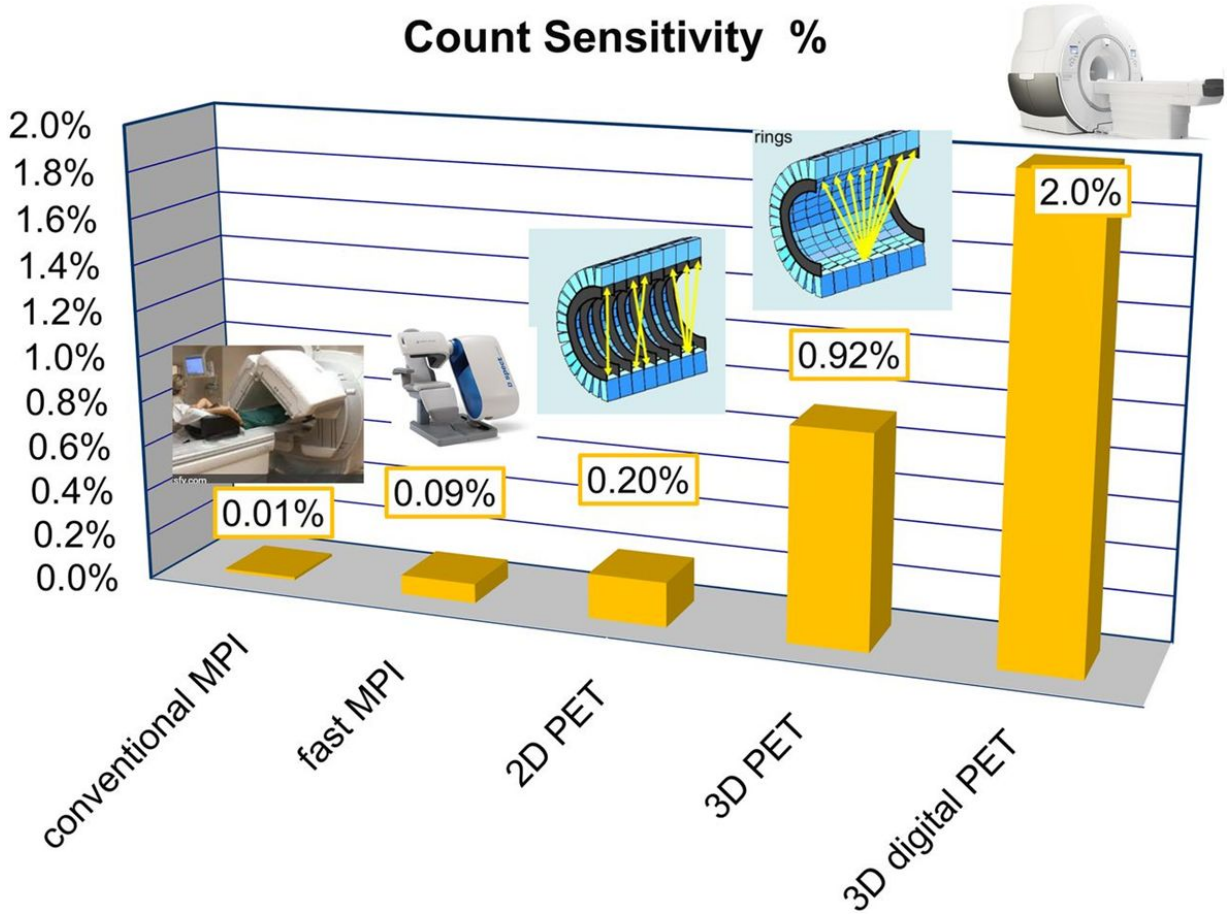


Fig. 5. (A) Picture of the Canon Medical Cartesion Prime PET/CT. (B) Schematic of a detector block (left) comprising a 12 × 12 array of 4.1 × 4.1 × 20 mm^3 LYSO pixels 1–1 coupled to a 12 × 12 array array of SiPMs, and a detector module (right) with a 1 × 5 array of the detector blocks with associated electronics and an air-cooling system. Pictures courtesy of Drs. Jeffrey Kolthammer and Maria Iatrou, Canon Medical Systems, USA.

The new system, Cartesion Prime uses 4.1 × 4.1 × 20 mm3 LYSO pixels. Each detector block is an array of 12 × 12 pixels 1–1 coupled to a 12 × 12 array of SiPMs with complete (100%) detector coverage (Fig. 5B). The scanner ring dimeter is 78 cm with axial length of 27 cm.

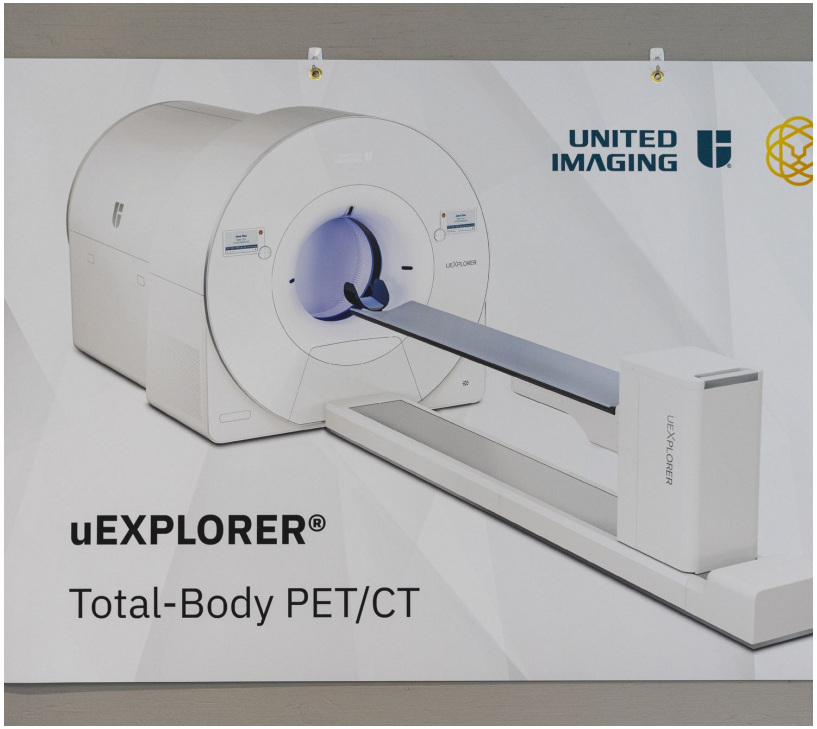
- Measured system TOF resolution: 258 ps
- Measured system sensitivity: 13.5 cps/kBq

Enhanced sensitivity



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

Long axial FOV PET systems



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ORIGINAL ARTICLE

Clinical performance of long axial field of view PET/CT: a head-to-head intra-individual comparison of the Biograph Vision Quadra with the Biograph Vision PET/CT

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LAFOV: Long Axial Field of View
SAFOV: Standard Axial Field of View

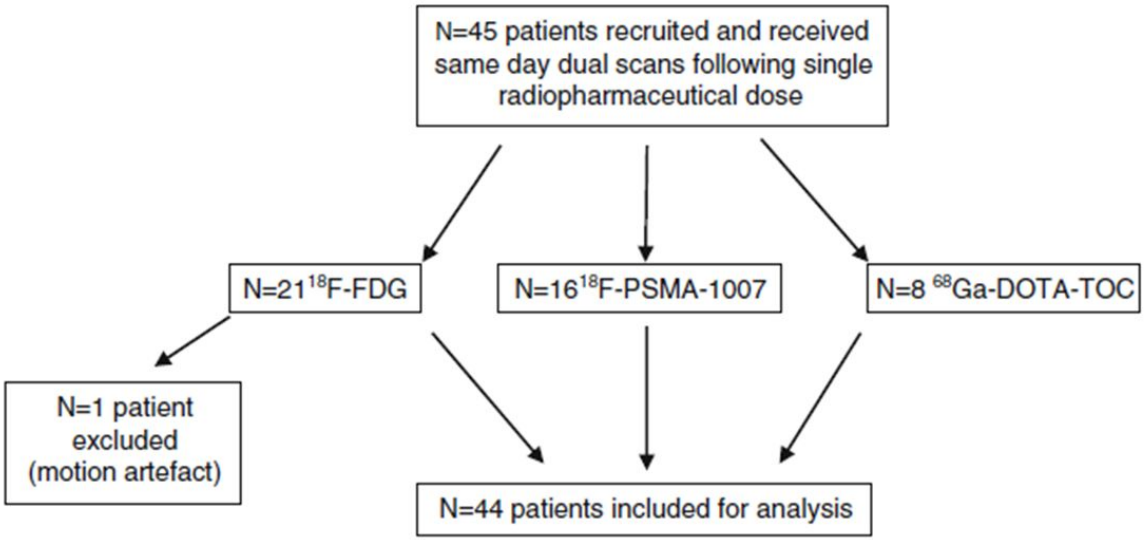


Image quality

The reference SAFOV images were consistently ranked as of inferior quality, with a median ranking of 4th worst (range 3–5), and were largely evaluated as intermediate between the 2 and 0.5 min LAFOV images. Overall image quality on the LAFOV correlated with length of acquisition, with the 10 min being ranked as highest quality in 100% of the cases.

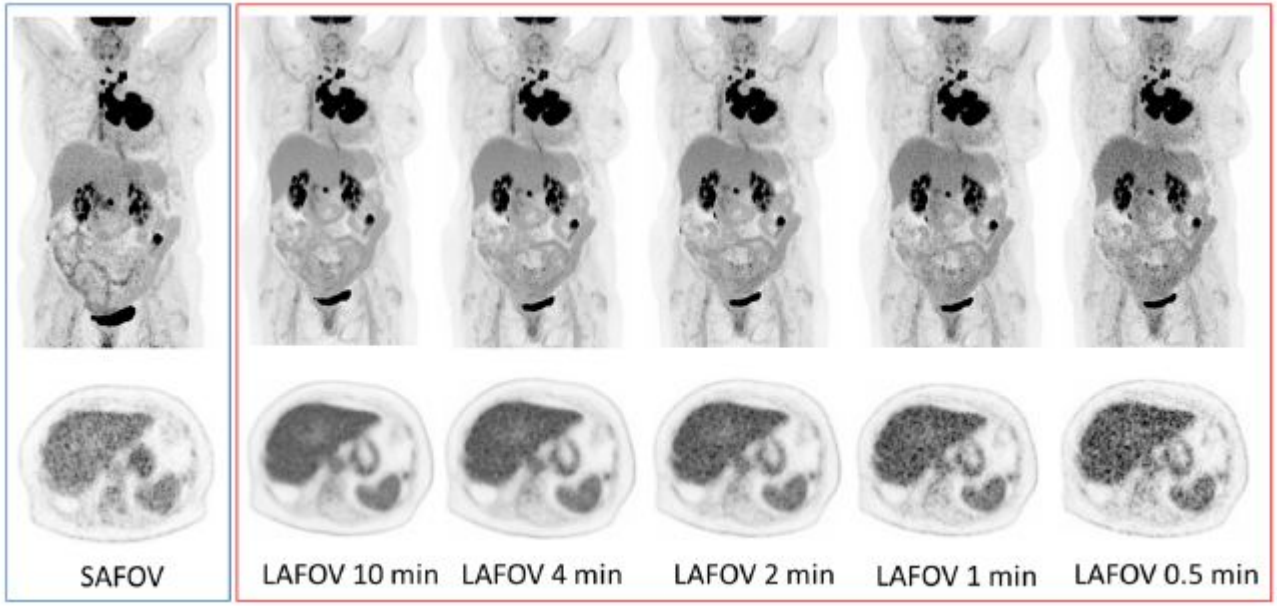
The average scan times for the LAFOV ranked as equivalent to the SAFOV reference acquisitions were as follows:

^{18}F-FDG 1.95 ± 0.86 min

^{18}F-PSMA-1007 1.95 ± 0.86 min

^{68}Ga-DOTA-TOC 1.50 ± 0.48 min

16 min



Equivalent low activity scan and equivalent radiation dose

Table 2 Equivalent acquisition times for equivalent target lesion integral activities obtained for the SAFOV (Vision) and LAFOV (Quadra) systems. Activities (MBq) and corresponding equivalent radiation dose (mSv) giving equivalent target lesion integral activity for examination times on the LAFOV equalling the SAFOV are given

	Examination time (min)		Equivalent activity (MBq)		Equivalent dose (mSv)	
Radiotracer	SAFOV	LAVFOV	SAFOV	LAFOV	SAFOV	LAFOV
^{18}F-FDG	16.06	1.48	265.6	39.3	5.04	0.75
^{18}F-PSMA-1007	16.06	1.59	243.9	38.8	5.37	0.85
^{68}Ga-DOTA-TOC	16.06	2.32	154.1	35.7	3.54	0.82

NOTE: the effective examination time remains longer on the SAFOV scanner, where bed-position overlap is required, whereas the LAFOV offers a single position capture of the head to the thighs for the average adult

Conclusions

- The last five years have seen significant progress made towards improving system coincidence time resolution and currently five major commercial vendors have new digital PET/CT that achieve system TOF resolution in the range of 214–382 ps.
- The primary driver for these improvements has been the full embrace of SiPM photosensors that not only provide improved intrinsic timing performance compared to PMTs but also provide higher flexibility in detector design to reduce any deleterious effects arising from high multiplexing (number of scintillation detectors per photosensor channel).
- An additional advantage of these new detectors has been improved spatial resolution achieved in some of these clinical PET/CT with the use of smaller scintillation pixels.
- Lutetium-based scintillators still provide the best combination of detector properties for use in PET, and benchtop measurements indicate that further improvements in CTR are likely.
- Research efforts are underway to achieve sub-50 ps temporal resolution but these will require further advances in SiPM characteristics that are challenging to achieve, and also utilize non-scintillation mechanisms for better timing performance that may yet come at the expense of some other imaging characteristic of the PET detector.

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

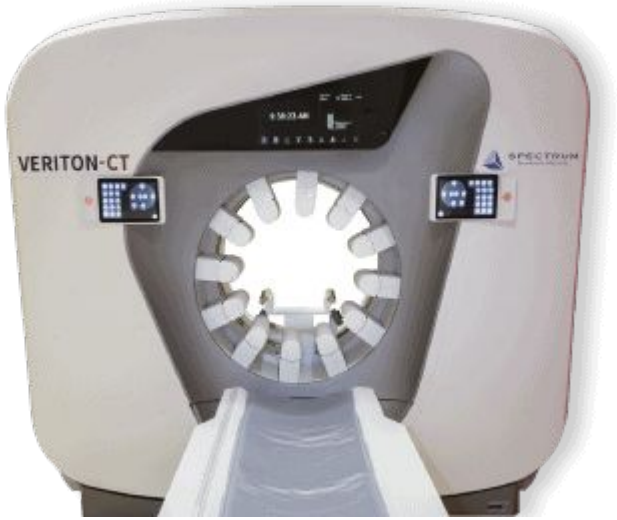
Country	CTDI (mGy)	DLP(mGy cm)	ED (mSv)
Brasil	6.8		
South Korea	6.0	561	
New Zealand	13.7	1319	10.9
Australia	4.4	474	4.7
France	8.0	750	8.6
UK	4.3	400	6.5

SPECT in Oncology

- ^{99m}Tc bone scanning
- Prostate cancer with PSMA ligands
- Thyroid cancer
- ^{99m}Tc sentinel lymphnode mapping
- Radionuclide dosimetry
  - 90Y selective internal radiation therapy
  - progressive metastatic neuroendocrine tumours with 177Lu-DOTA-tyr3-Octreotate

Advances in SPECT

Veriton – Spectrum Dinamics



Design

360° ring shaped gantry design 80 cm bore

Solid state technology

Sensitivity, Energy Resolution

Configuration

Swiveling, high resolution CZT, 12 detectors

Proximity

Adaptive body contouring by each detector

Starguide- General Electric

Sensitivity

8 fold higher than an Anger camera

Energy Resolution

Half (5%) vs (10%) anger camera

Dual isotope imaging

Spatial Resolution

Similar