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HU
de Liège

**What are the technological advances that
made PET such a major player in clinical
medicine?**

What to expect next?

**THE
HIKE
GUIDE
TO THE
GALAXY**

DOUGLAS ADAMS
Based on the famous Radio series

Roland HUSTINX

Division of Oncological Imaging and Nuclear Medicine

GIGA-CRC *in vivo* imaging

Disclosures

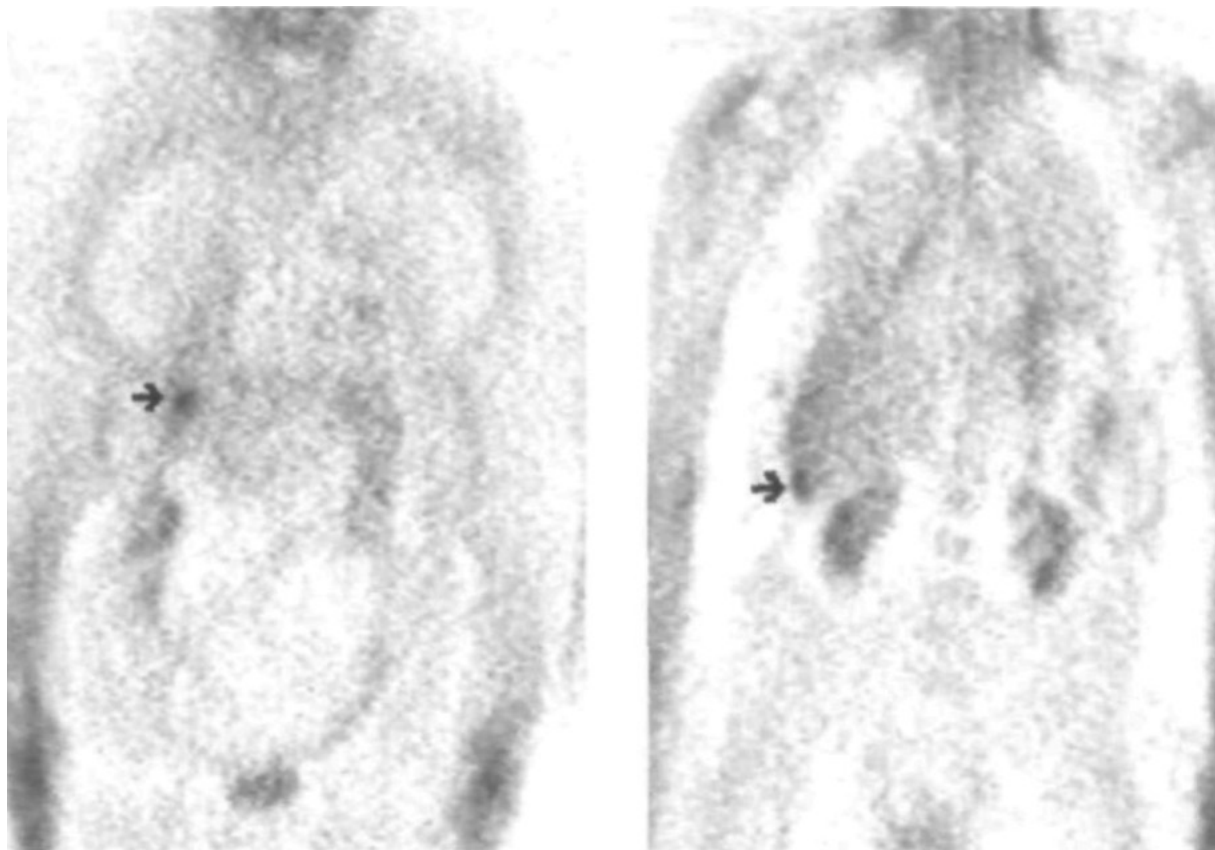
- The Department of NM received speaker's fees from Siemens Healthineers in 2022
- RH is co-founder of Nuclivision

Original article

Clinical evaluation of whole-body ^{18}F -fluorodeoxyglucose positron emission tomography in the detection of liver metastases*

R. Hustinx,¹ P. Paulus,¹ N. Jacquet,² G. Jerusalem,³ T. Bury⁴ & P. Rigo¹

Divisions of ¹Nuclear Medicine, ²Abdominal Surgery, ³Oncology-Hematology, ⁴Pneumology, University Hospital, Sart Tilman, Liege, Belgium



“Eight to 11 overlapping steps extending from the neck to the pelvis were obtained during a total scanning time of 32 to 44 minutes (4 min/step)”

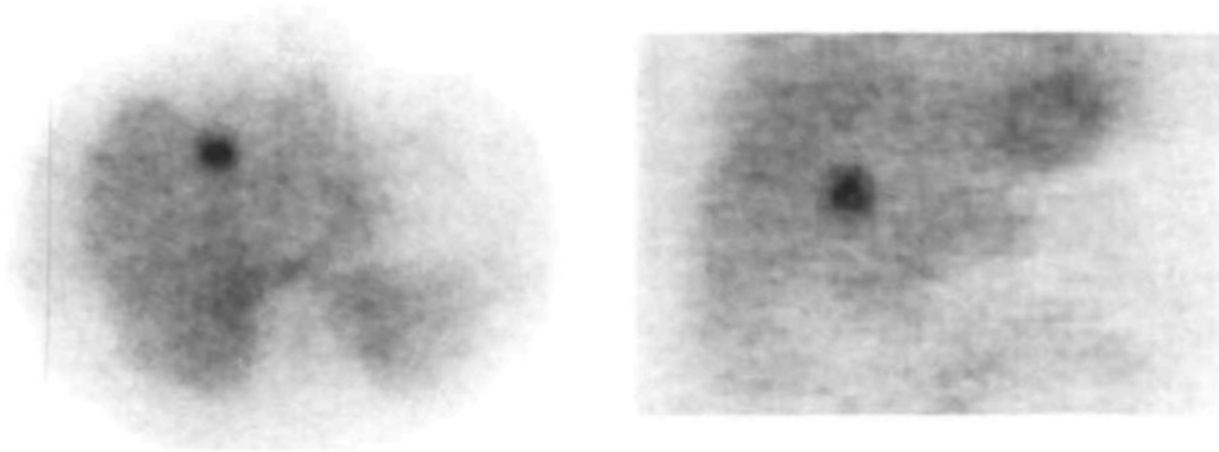


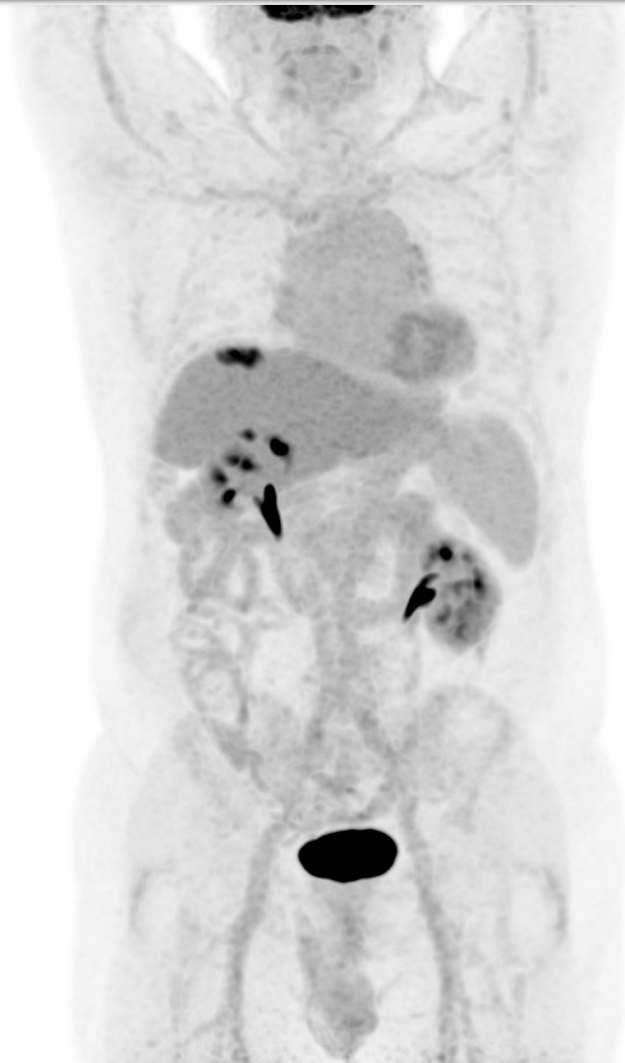
Figure 3. Sixty-eight-year-old man with a previous history of rectal carcinoma. A single liver metastasis is demonstrated by contrast enhanced CT and FDG-PET (left: transverse slice; right: coronal slice). Note the high quality of the attenuation corrected images.

$[^{18}\text{F}]$ FDG PET/CT



Acquisition: 38 minutes

1994 → 2023



Acquisition: 9 minutes

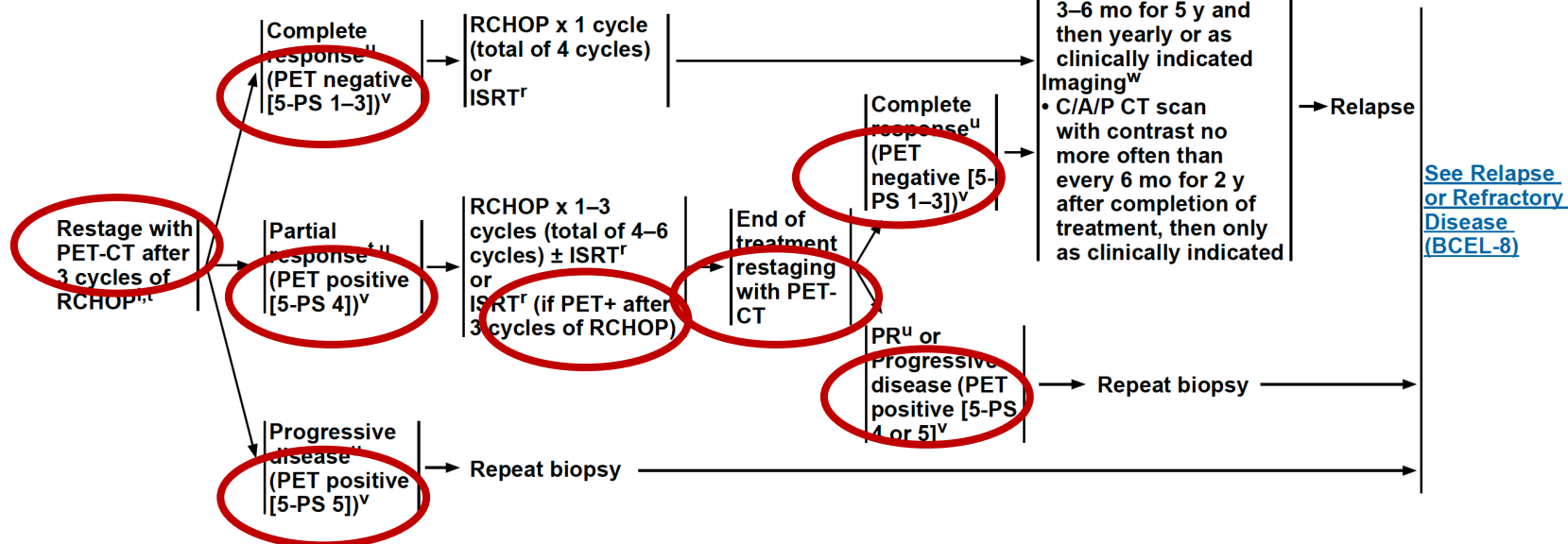


NCCN Guidelines Version 2.2023 Diffuse Large B-Cell Lymphoma

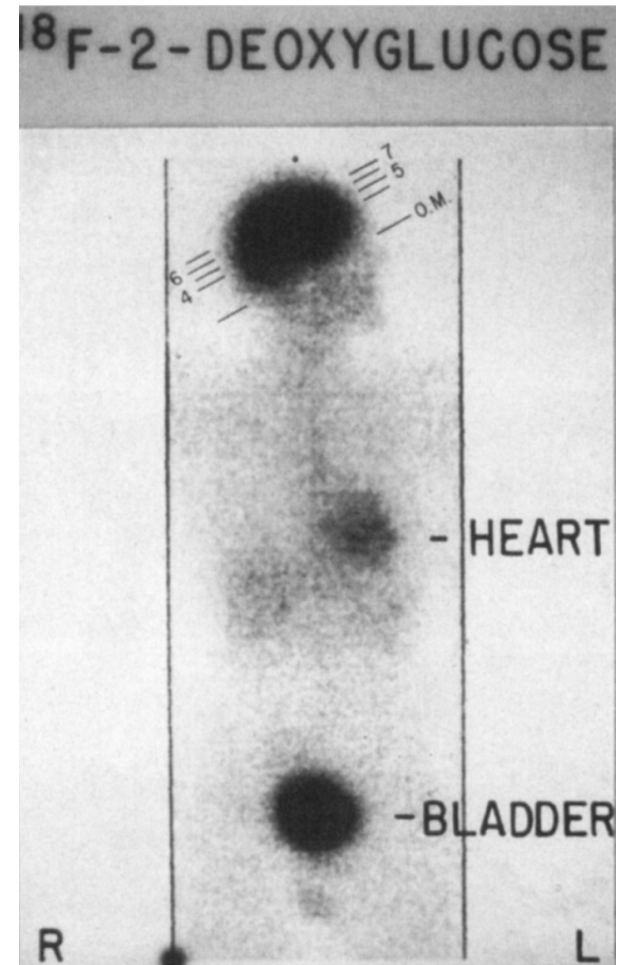
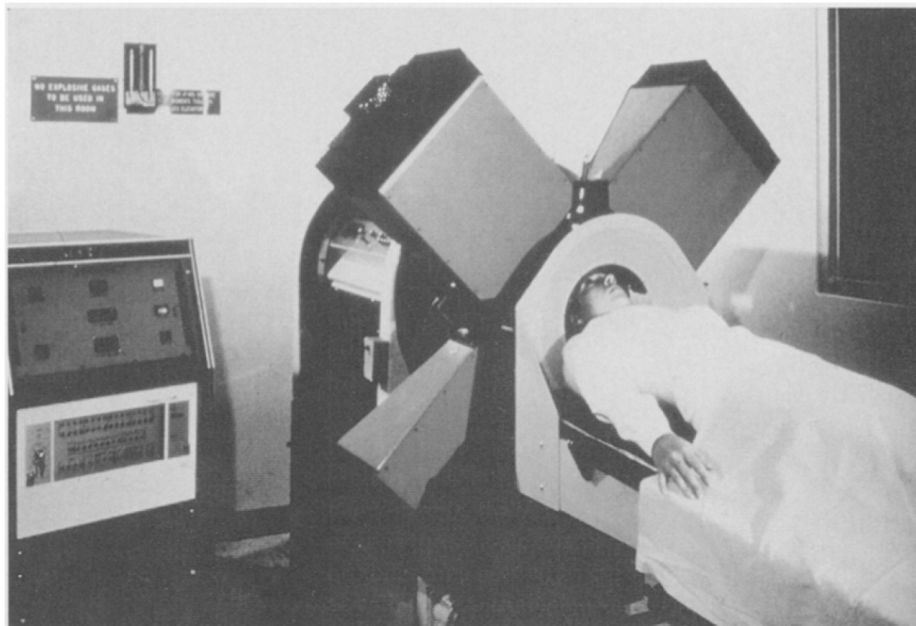
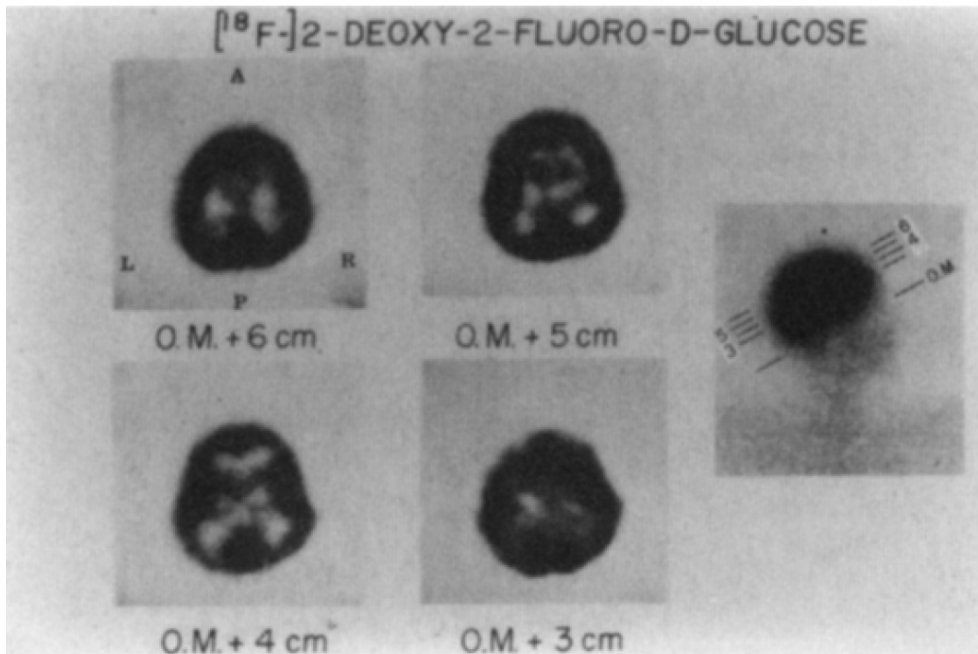
STAGE I–II (NON-BULKY; <7.5 CM)
(EXCLUDING STAGE II WITH
EXTENSIVE MESENTERIC DISEASEⁱ)
INTERIM RESTAGING
AND ADDITIONAL THERAPY

END-OF-
TREATMENT
RESPONSE

FOLLOW-UP

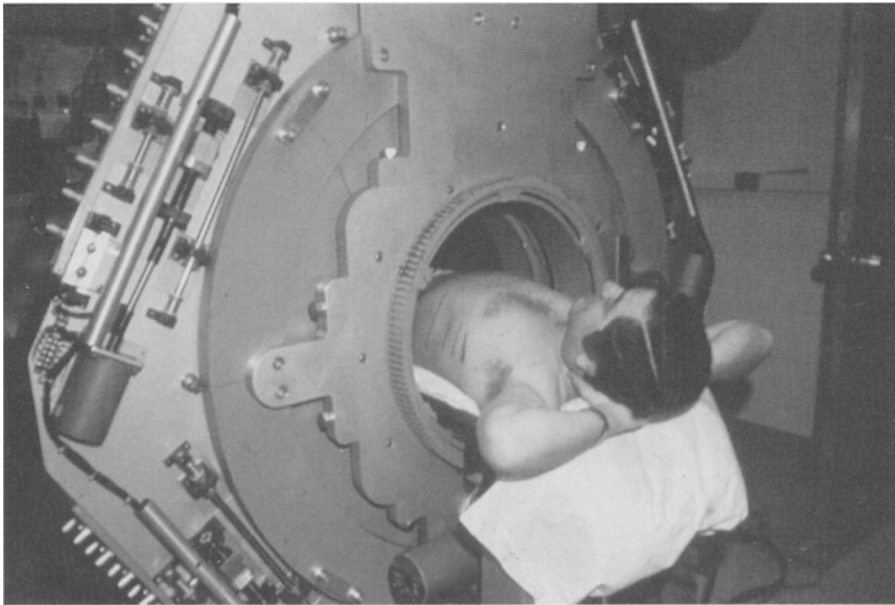


1976: 1st [¹⁸F]FDG study



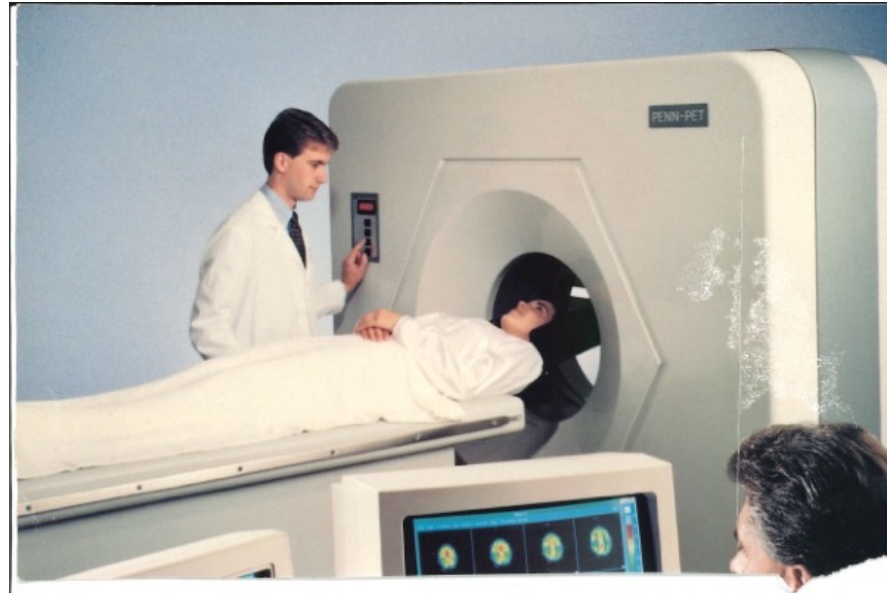
Alavi & Reivich, Seminars in Nuclear Medicine, Vol XXXII, No 1, 2002: pp 2-5

1975: 1st PET device
(PETT Scanner)



Wagner HN, Seminars in Nuclear
Medicine, Vol XXVIII, No 3, 1998: pp 213-
220

1994: 1st clinical
PET Scanner in
Liège

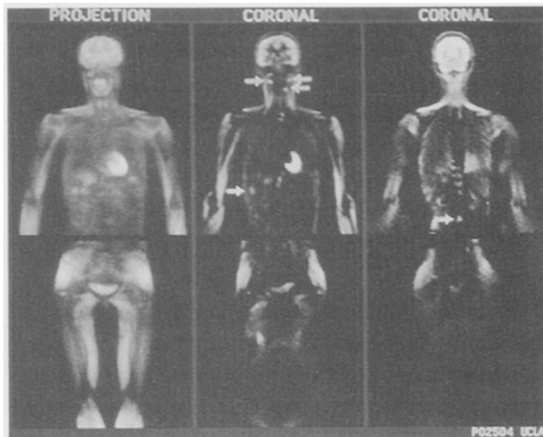


Clinical PET

The Journal of Nuclear Medicine

JNM

Volume 32, Number 4 • April 1991



***Clinical PET:
Its Time
Has Come***

Page ... 561

1. Whole-body capability
2. Indications with a clinical impact: cancer imaging
3. Clinically-oriented NM physicians

PET imaging: The secret of its success

Visual Diagnosis

So our central point is this. **It is time for PET to emerge from behind the veil of mathematics and models into the real world of clinical imaging.** Our direct experience with brain tumors bears witness to this. We have seen, in over 500 studies, that FDG-PET imaging has a striking superiority over *any other* diagnostic method, including MRI and, in some cases, even histology, in regard to the fundamental issue, i.e., assessment of malignancy. Attempts to quantitate FDG uptake or glucose utilization in brain tumors have not been helpful, and can even lead to diagnostic error. **Unsurprisingly, the trained human eye has once again triumphed over computers in the interpretation of anatomic images.** Our (GDC) extensive experience

INVENTORS & INVENTIONS

a winning combination

Two Americans working in the Alps come up with a plan to merge two widely used scanning devices—the PET and the CT—into one

BY LEON JAROFF

THE IDEA CAME OUT OF LEFT field. Electrical engineer Ronald Nutt and physicist David Townsend, working at the University of Geneva in Switzerland, had just taken the cover off their newly developed metabolic-imaging machine and were admiring its innards when an oncology surgeon happened by. "You have a lot of space between those detectors," he offered. "You ought to try to put something in there that would be useful."

At the time, eight years ago, PET (positron emission tomography) machines, which can reveal subtle metabolic processes such as tumor growth, and CT (computerized tomography) scanners, which show precise anatomical details, were already in widespread medical use. But doctors, especially cancer surgeons, were often frustrated in their attempts to match the two different scans to determine, for example, the precise location of a tumor in relation to an organ or to the spinal column. There seemed to be no better way than simply "eyeballing" the two separate images.

That is, until Nutt and Townsend had their epiphany in the Alps. Last October the U.S. Food and Drug Administration approved the marketing of a combination PET/CT machine, the first medical-imaging device that simultaneously and clearly reveals both anatomical details and metabolic processes

within the body. By early next year the new scanners will be installed at Manhattan's Memorial Sloan-Kettering Cancer Center, Indiana University, the University of Iowa and other medical facilities.

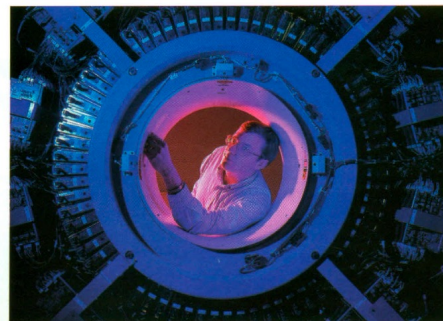
Others had attempted, with little success, to match the two different images by using computer algorithms as a way to unify data from CT and PET scans made at different times and in different settings. "The problem is that the body is kind of a flimsy structure," says Nutt, co-founder of CTI, the Knoxville, Tenn., imaging company that is gearing up to produce the new scanning combine. "If you lay it on the bed one time for a CT scan and another time for a PET scan, just a small difference in body position will result in all of the organs shifting about a bit, so it's very difficult to do that matching."

After refining their combined PET and CT concept for three years, Nutt and Townsend, who had transferred from the University of Geneva to the University of Pittsburgh, received a three-year, \$1.5 million grant from the National Cancer Institute in 1995 that enabled them to complete a prototype machine. Installed at the University of Pittsburgh medical center in 1998,

Carolyn Cidis Meltzer, who with Townsend is a co-director of the University of Pittsburgh PET facility, the use of the PET/CT machine has resulted in decisions to modify or change treatment. In one case a standard CT scan had detected a tumor on the left side of a patient's neck but none elsewhere. "When CTs are read and you look for a spread of tumor to the lymph nodes," Meltzer explains, "all you're able to look at is the size of the lymph node."

If a CT shows that a lymph node is less than one centimeter in size, it is considered to be normal. But on the PET/CT, Meltzer says, "we saw a very small lymph node in the right side of the neck that we thought was involved with the tumor." A biopsy that otherwise would not have been performed confirmed her suspicion.

The Pittsburgh machine has also made a difference in the diagnosis and treatment of cervical and ovarian cancers. Blood tests of some women who had already been successfully treated

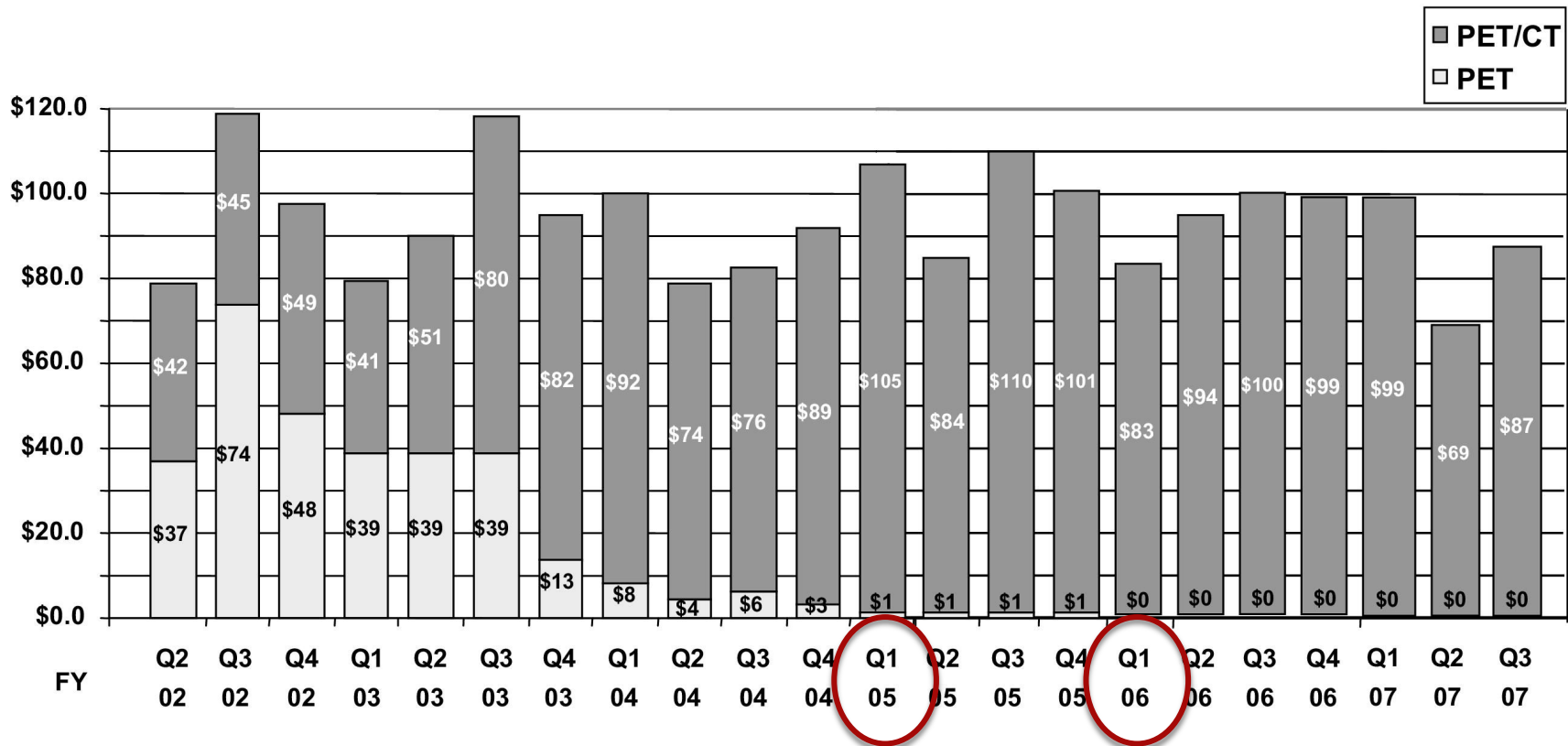


for these malignancies began to show markers suggesting that tumors were recurring. CT scans showed nothing amiss, but PET/CT surveys revealed the precise locations of small new tumors in the pelvic area that surgeons were able to remove before they metastasized.

Despite the limitations of a standard CT, it does a superb job of picturing the internal anatomy of the body. "The CT shines a fan beam of X rays through the human body," Nutt explains, "and makes a series of slices. Al-

INVENTIONS

PET Vs PET/CT: Market shares



1st PET/MR: Jan 2010



Mt. Sinai Medical Center in New York

PET MRI Market

Global Market Study on PET MRI: Hybrid Imaging Systems to gain Traction, thereby driving the Market

PET MRI Market Segmented By Integrated, Separate, Insert, Hybrid Product Type in Conventional, Time of Flight PET Imaging Technology for Sequential, Simultaneous Image Acquisition

Market Bytes

Companies

FAQ

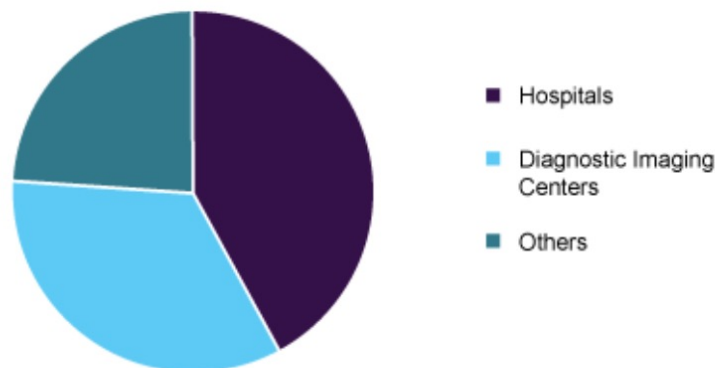
View ToC

PET MRI Market Outlook (2022-2029)

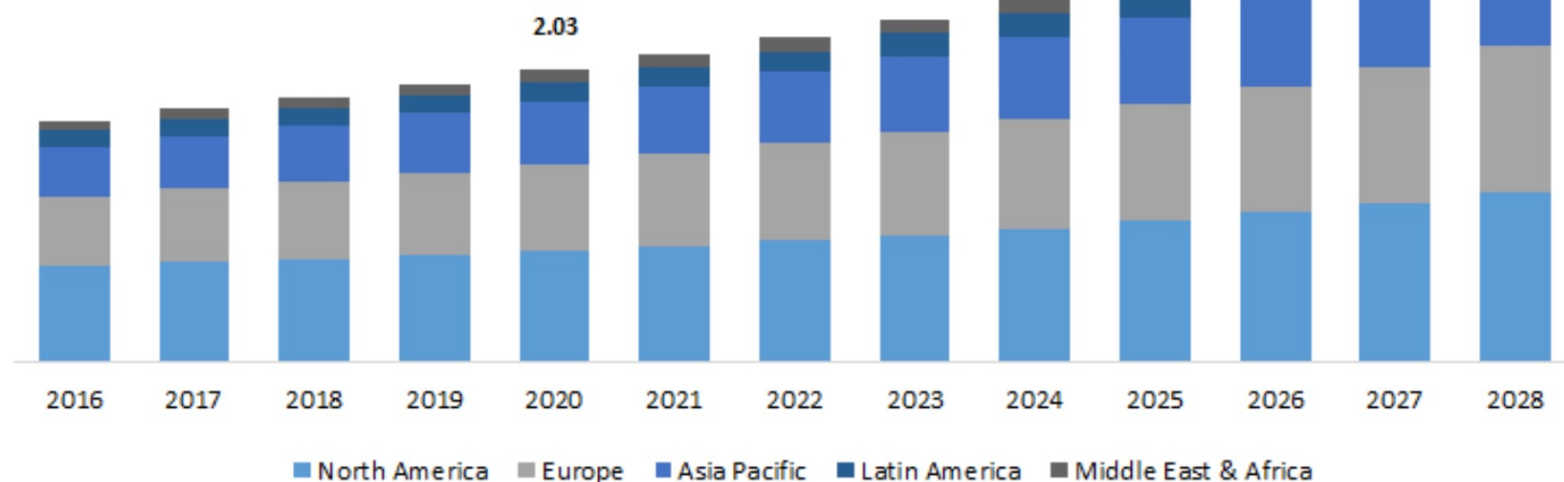
The global PET MRI market is slated to witness a remarkable CAGR of 9.8% between 2022 and 2029, reaching US\$ 338.9 Mn by the year 2029.

PET MRI Market (2022)	US\$ 176.3 Mn
Projected Market Value (2029)	US\$ 338.9 Mn
Global Market Growth Rate (2022-2029)	9.8% CAGR
Share in Medical Imaging Equipment Market	0.4%

systems market share, by end use, 2019 (%)



PET-CT Scanner Device Market Size, By Region, 2016 - 2028
(USD Billion)



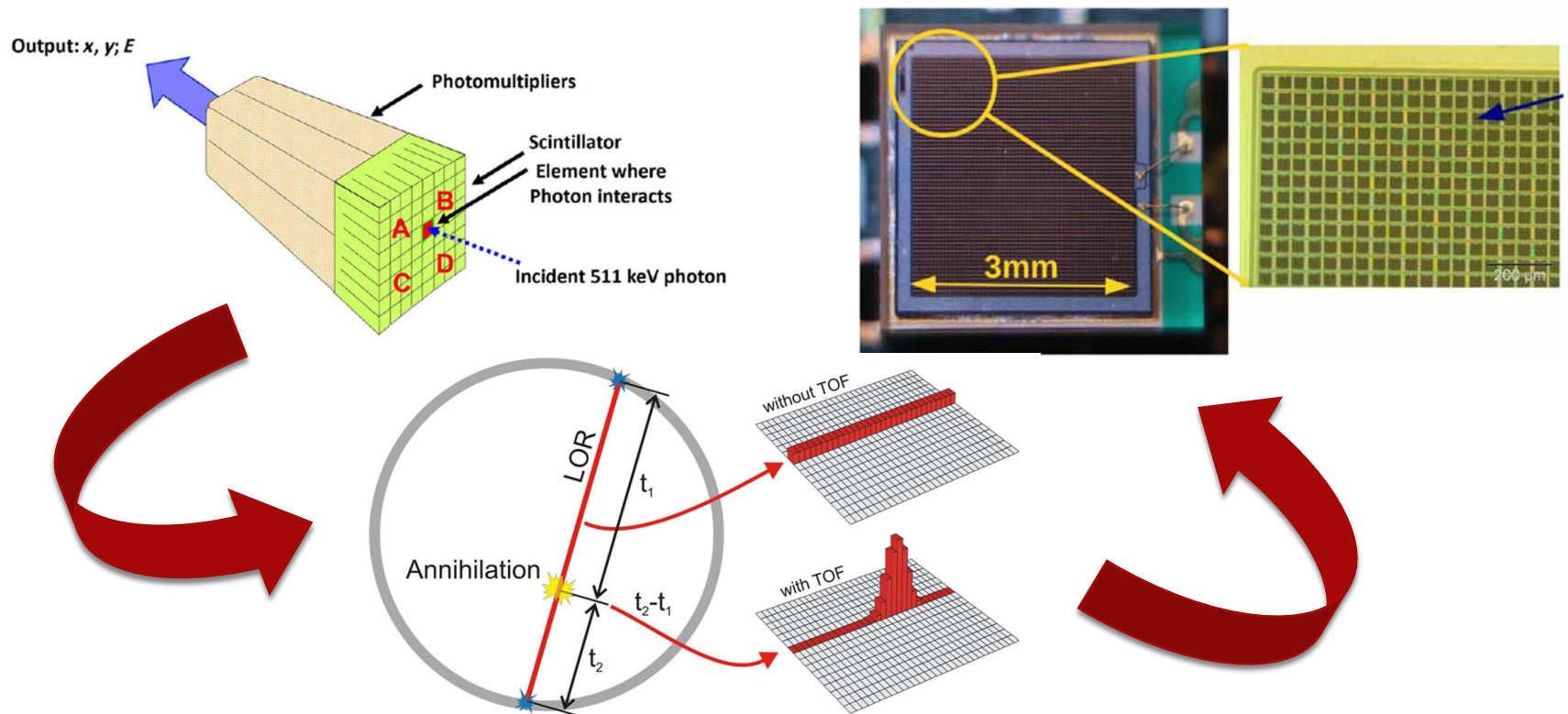
Source: Polaris Market Research Analysis

PET/CT Vs PET/MRI

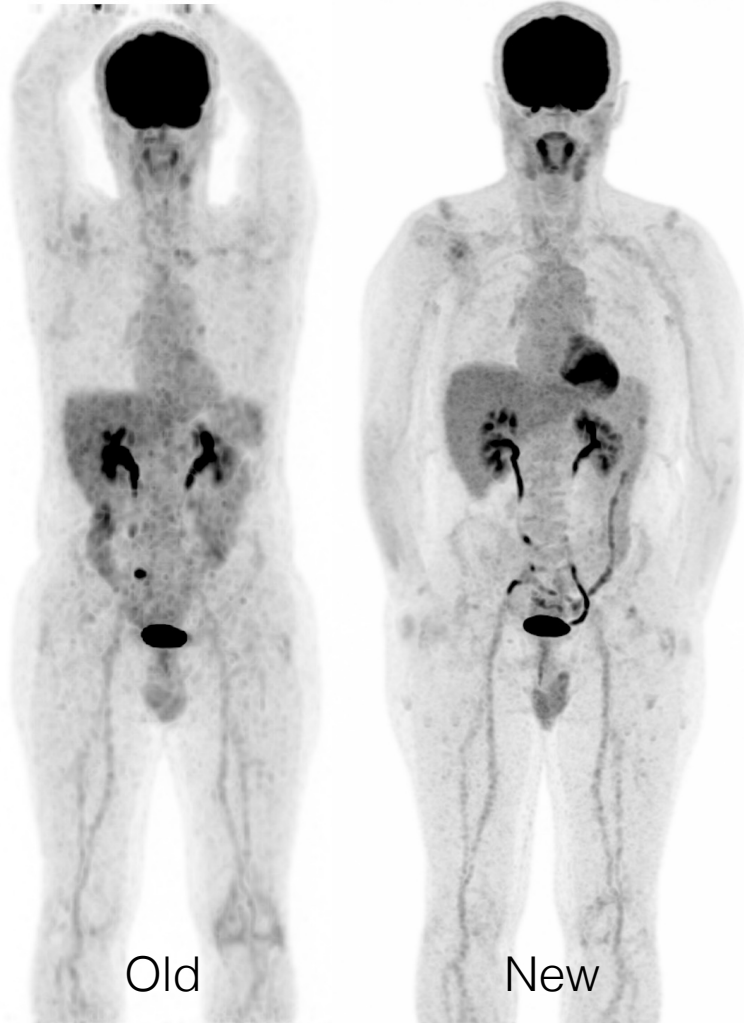
- From PET to PET/CT:
 - Additional information, immediately actionable
 - Higher PET image quality
 - Higher throughput
- From PET/CT to PET/MRI:
 - Additional information (sometime less: lungs)
 - Durability (7T ?)

Time of Flight (ToF) + Silicon photomultipliers (SiPM)

- Sensitivity – time resolution



BMI 25,3 - 68 kg - 1,64 m



Old

New

201 MBq
18'

169 MBq
11'

Old

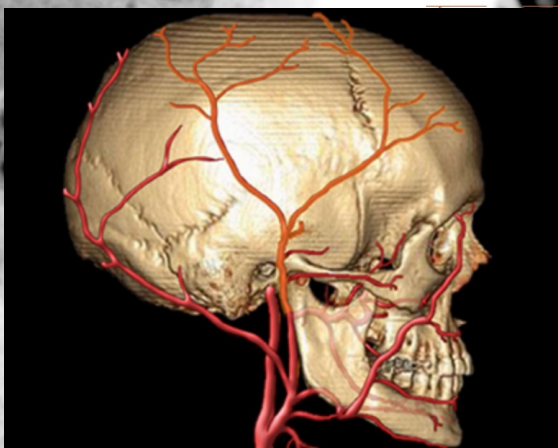
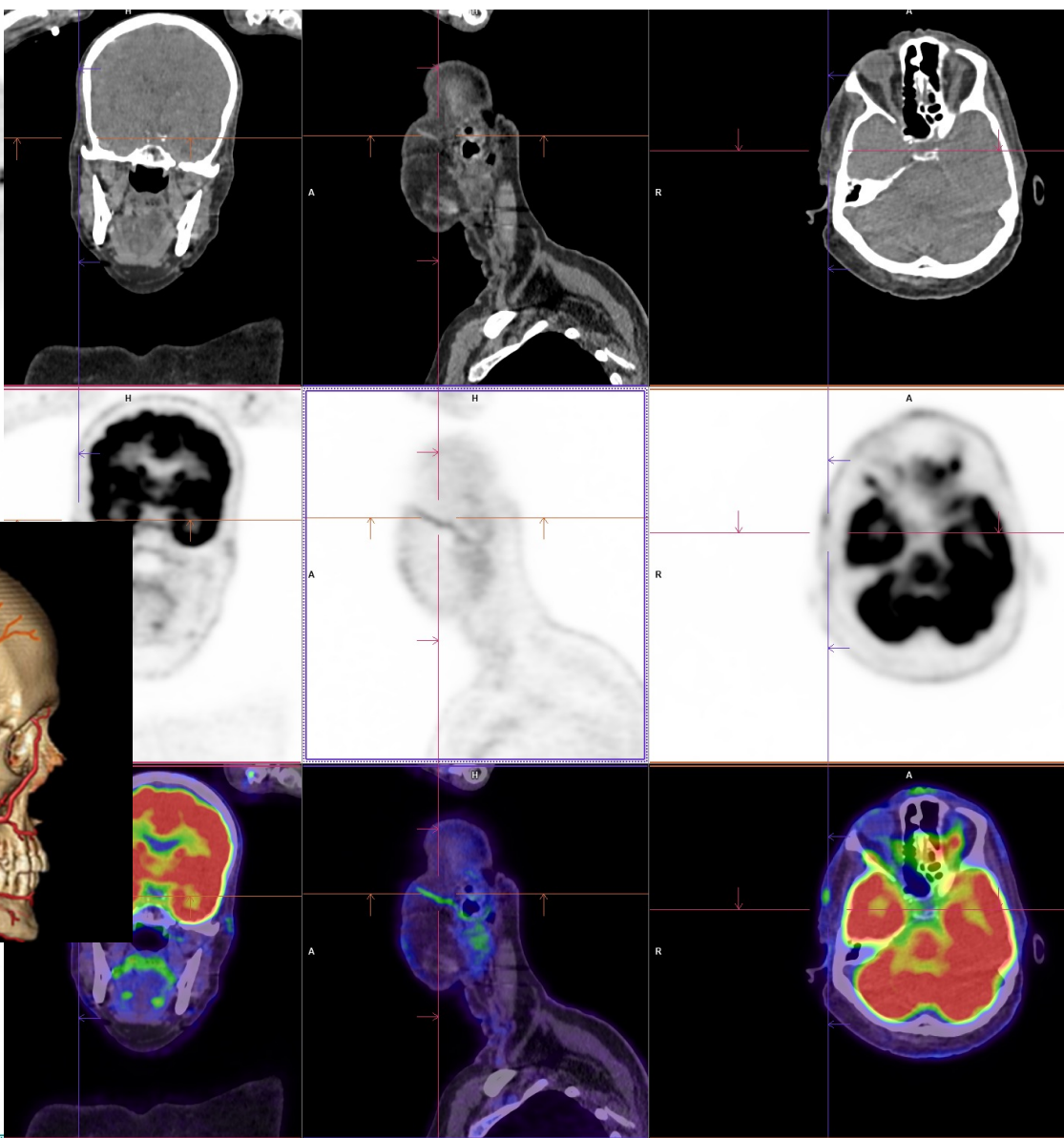
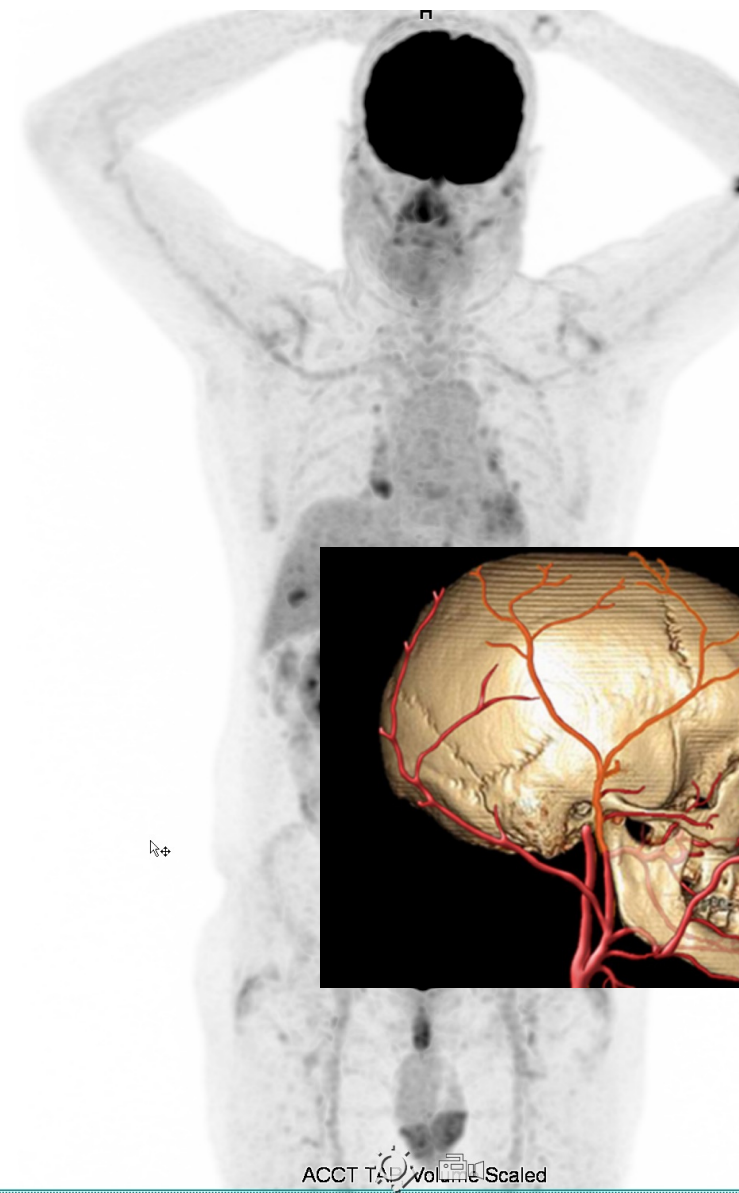
R



New

R





Acquisition protocols

- Increase speed and/or
- Reduce injected activity
 - [^{18}F]FDG: 2,5 MBq/kg (max 370)
 - [^{68}Ga]Ga-PSMA-11: 1 MBq/kg (60-100)

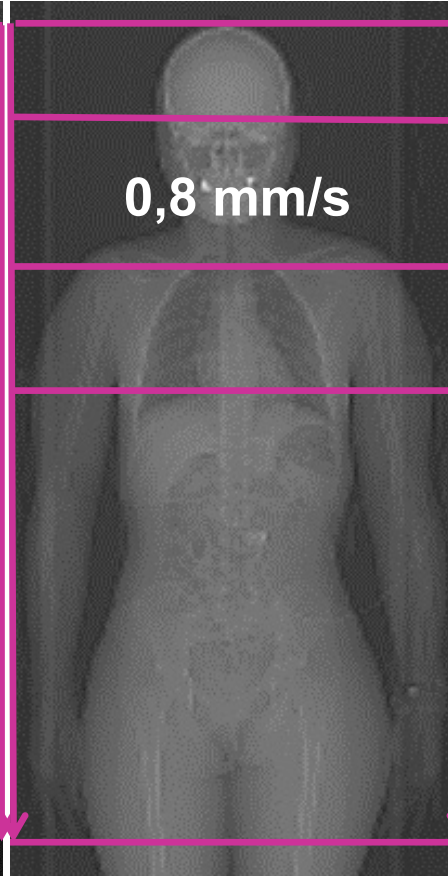
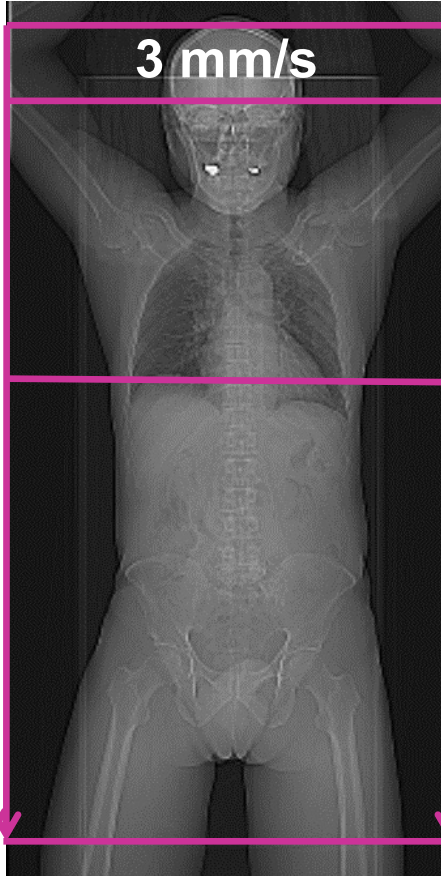
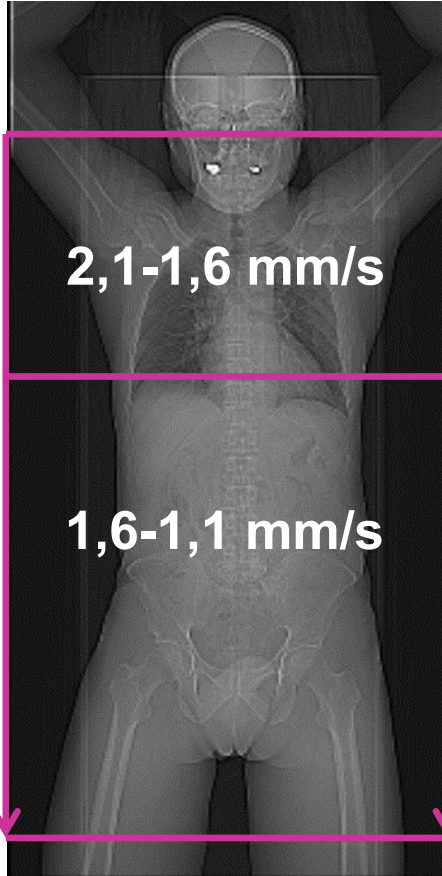
Continuous flow motion: Zones rather than bed positions

Conventional
WB: 2 zones

WB incl. brain:
3 zones

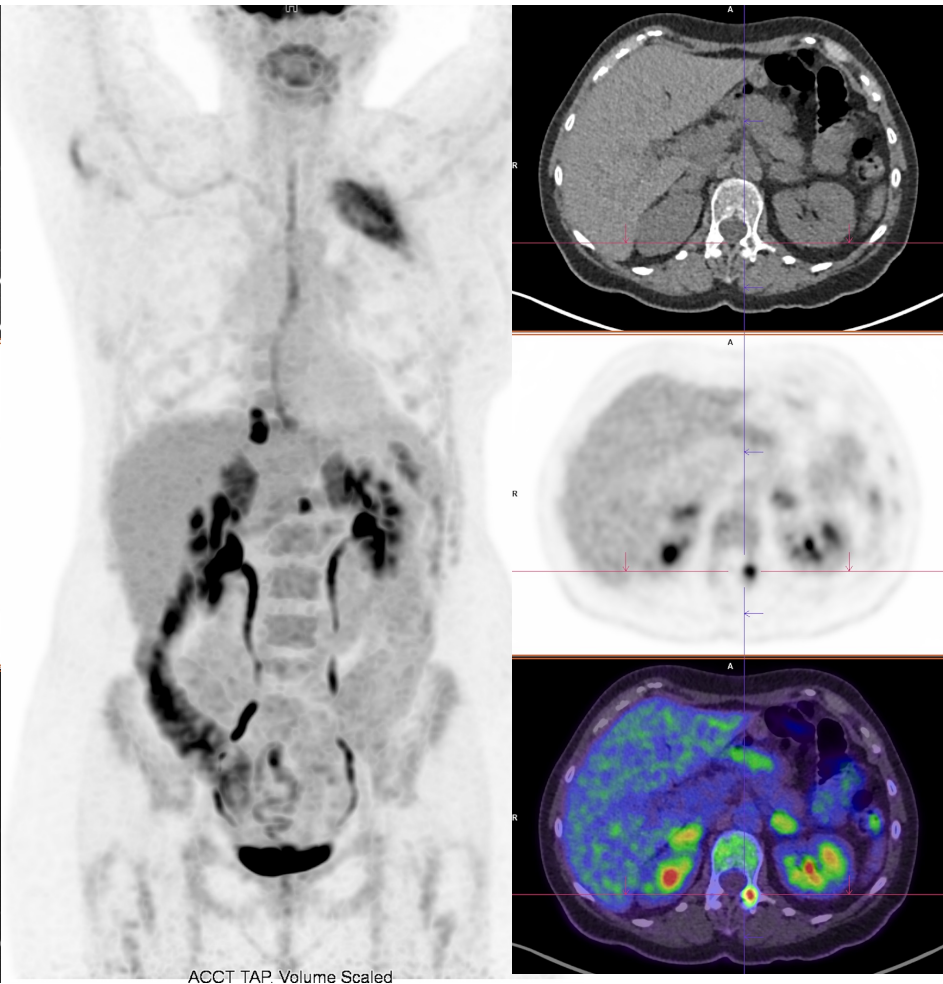
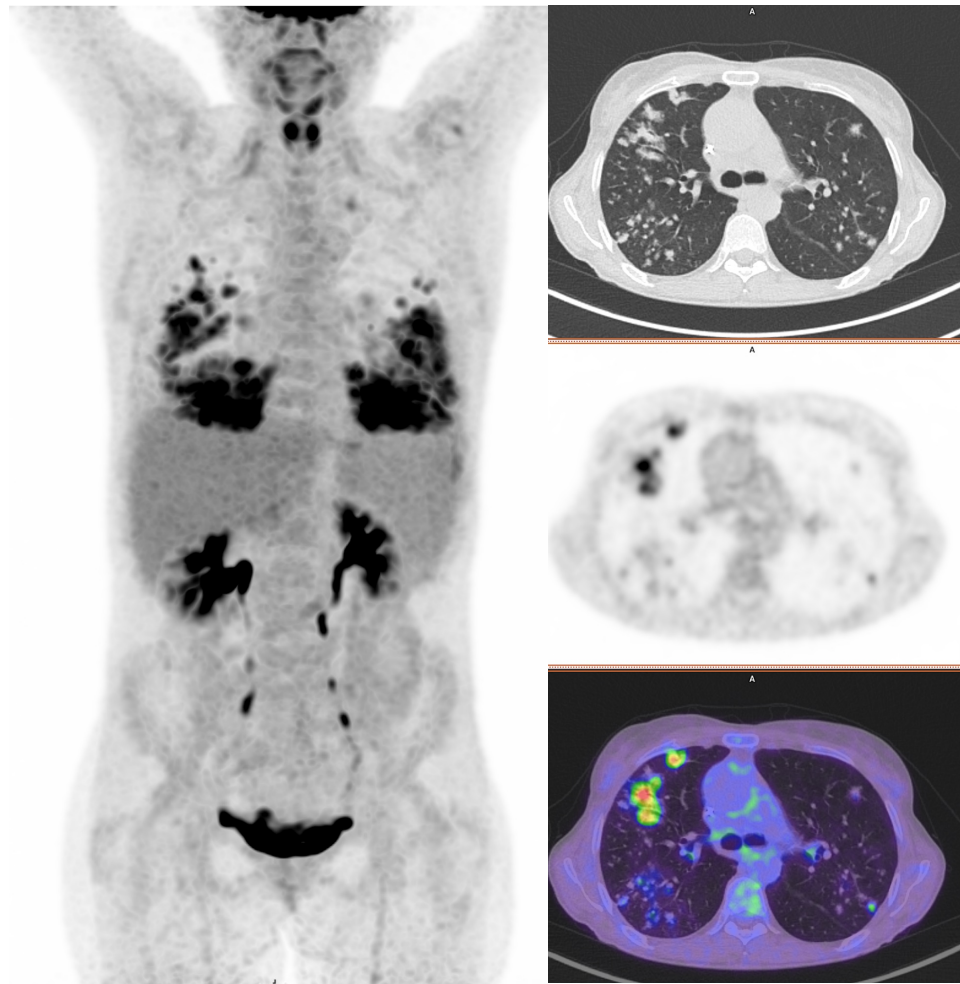
Head & Neck:
4 zones

Total body: 4 zones

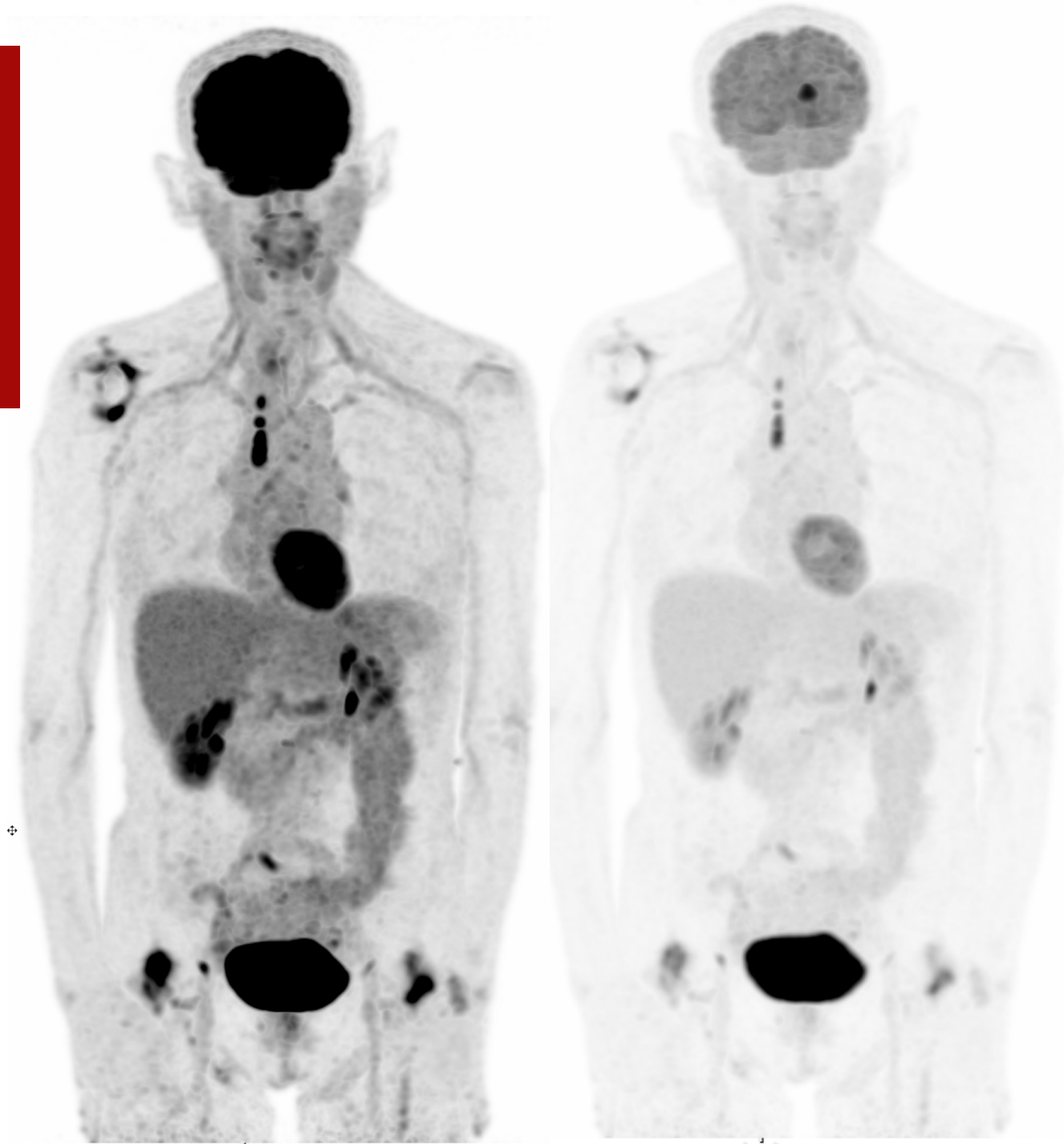


BMI 17,5 - 50 kg - 1,69 m -126
MBq - 7'35"

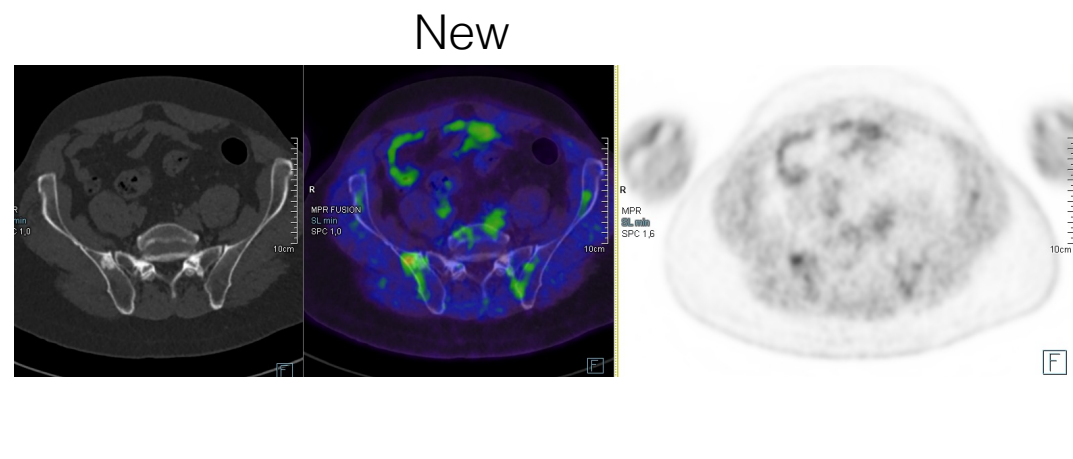
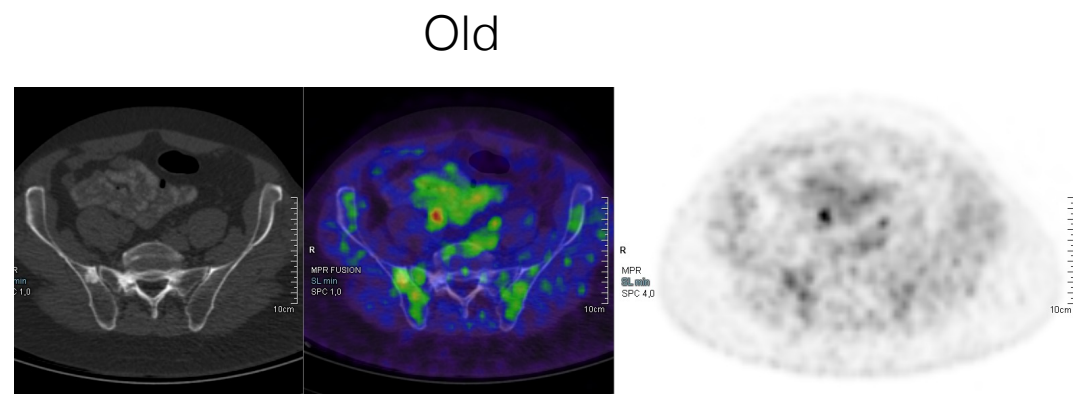
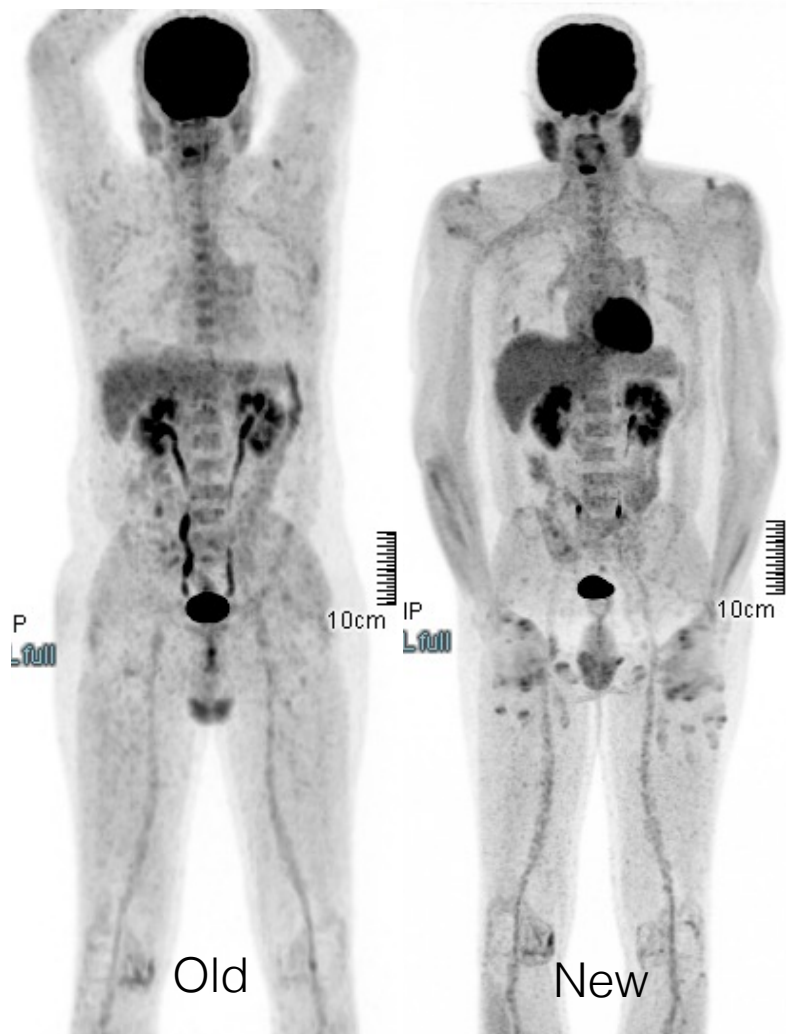
BMI 24 - 70 kg - 1,70 m -174 MBq
- 6'36"



BMI 16,4 - 42 kg -
1,60 m -105 MBq -
8'20"



BMI 27,5 - 89 kg - 1,80 m

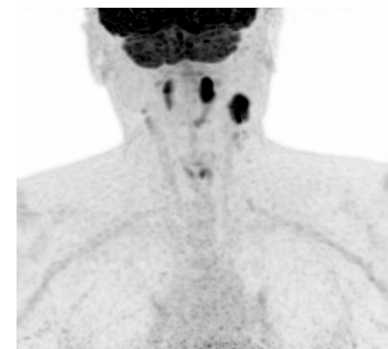
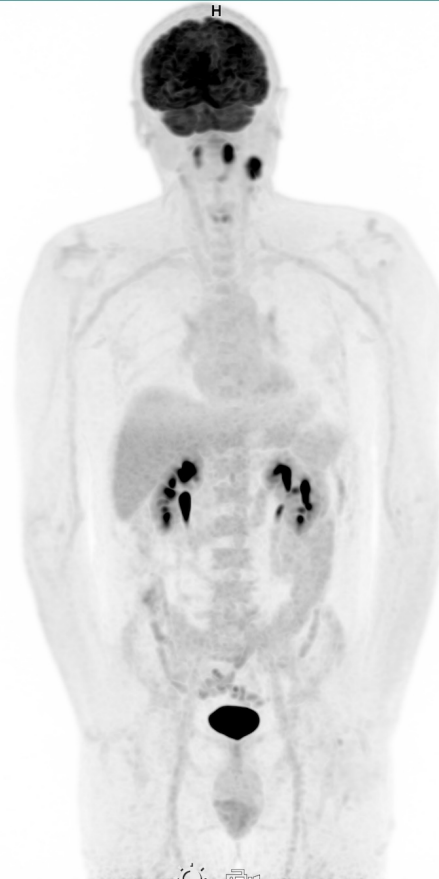
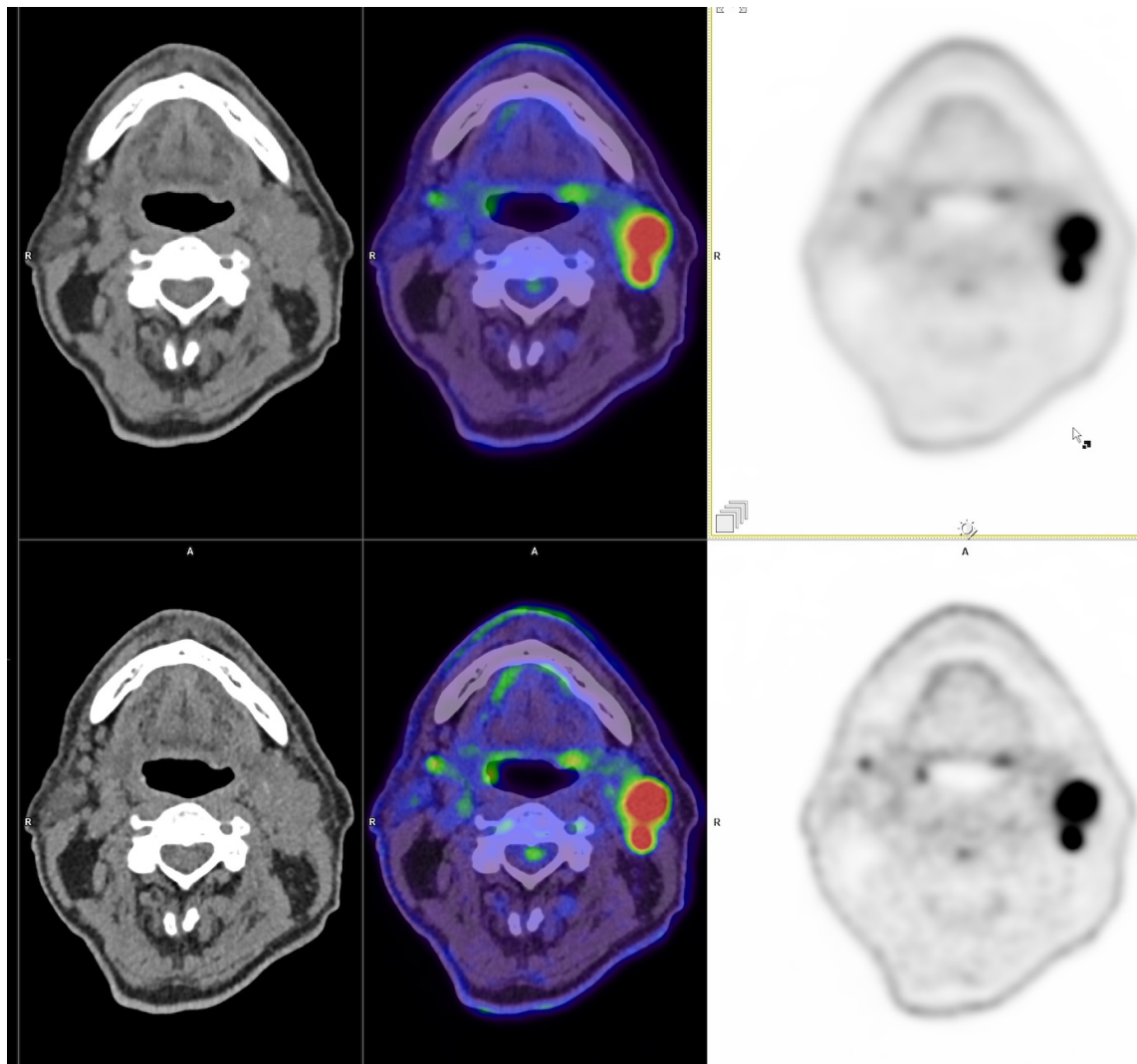


262 MBq
20'

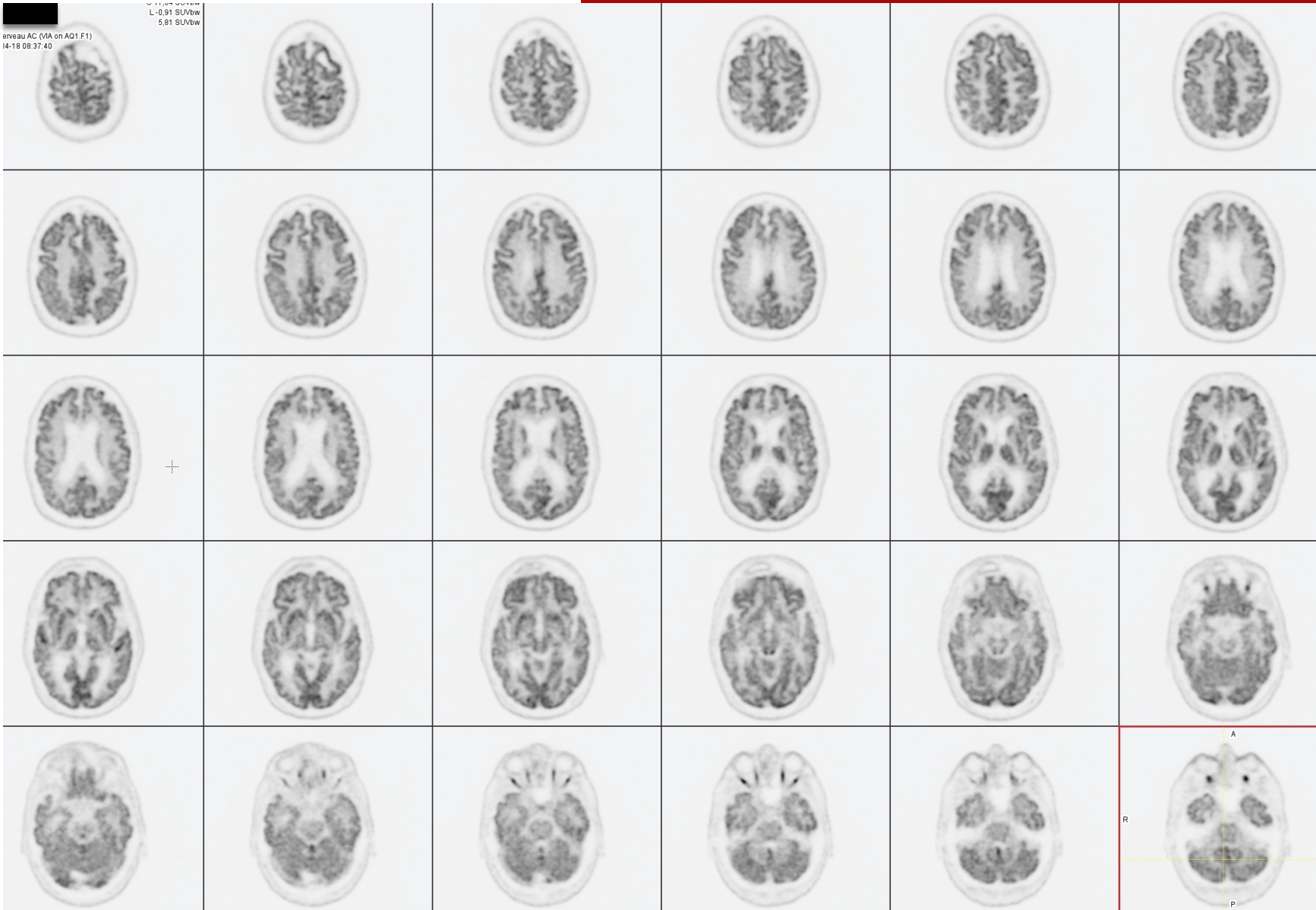
224 MBq
14'

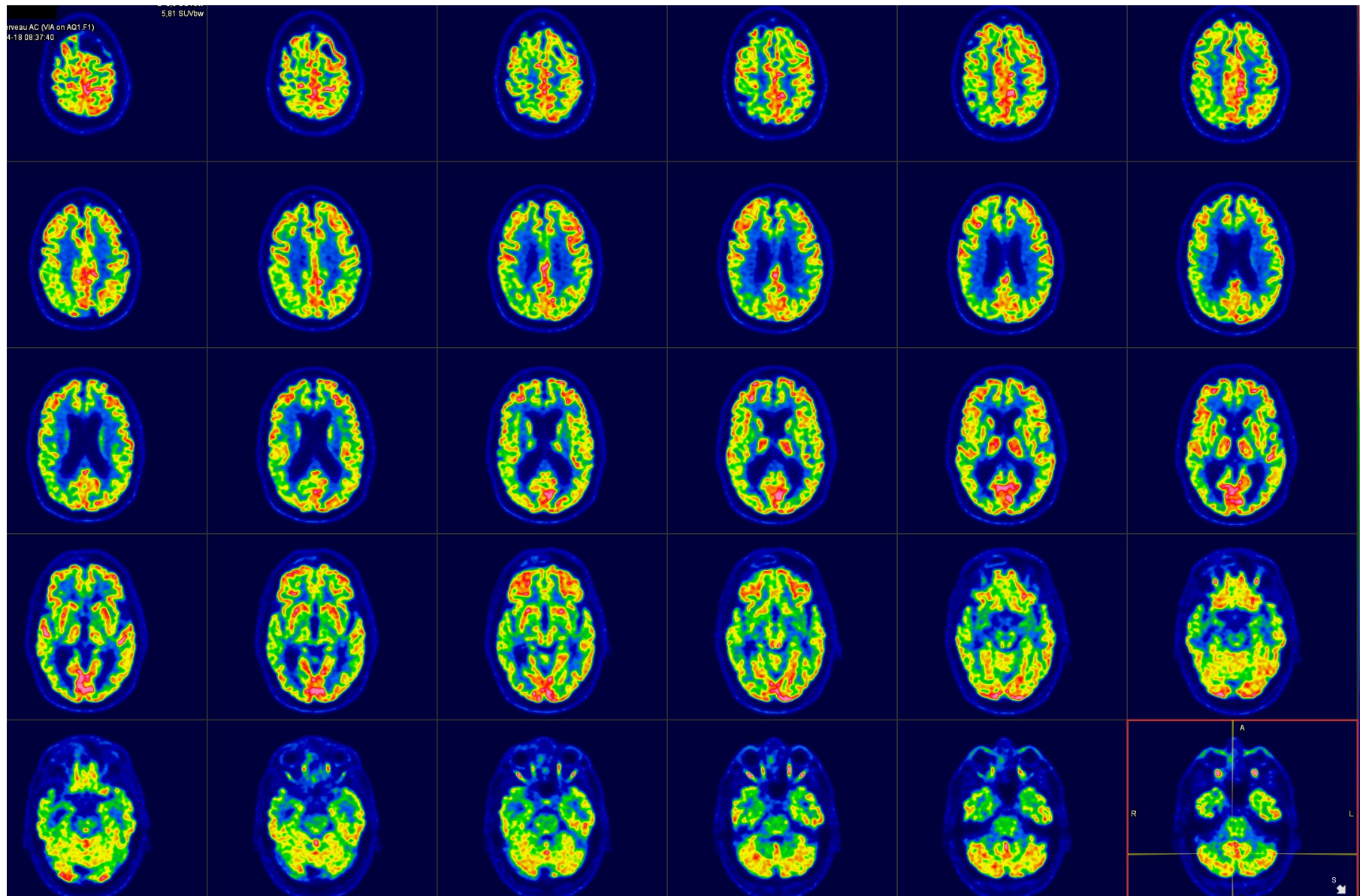
AC CT CE, Volume Scaled

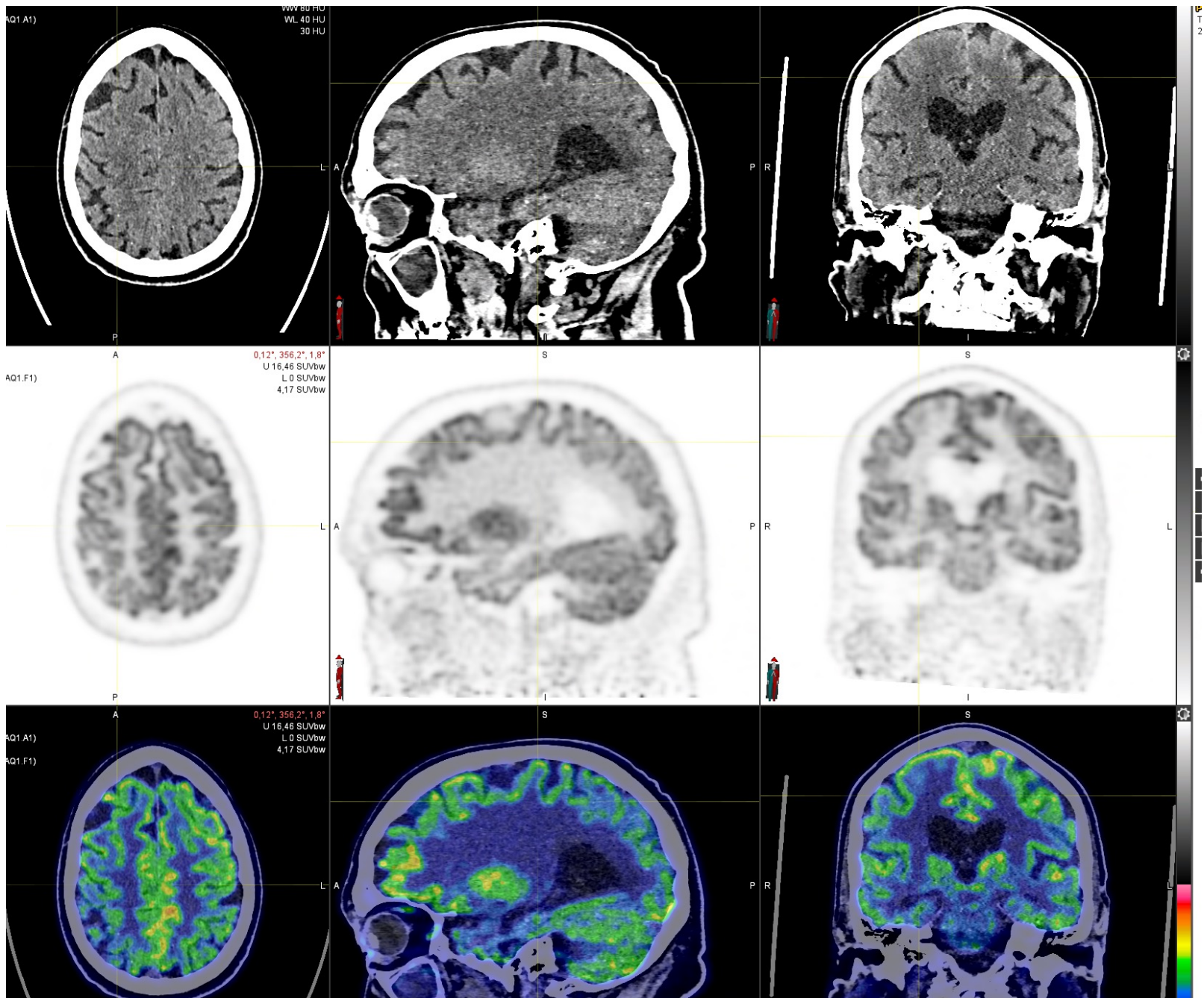
BMI 24 - 81 kg - 1,83 m - 215 MBq – 12'



79-year-old male - 10' acquisition



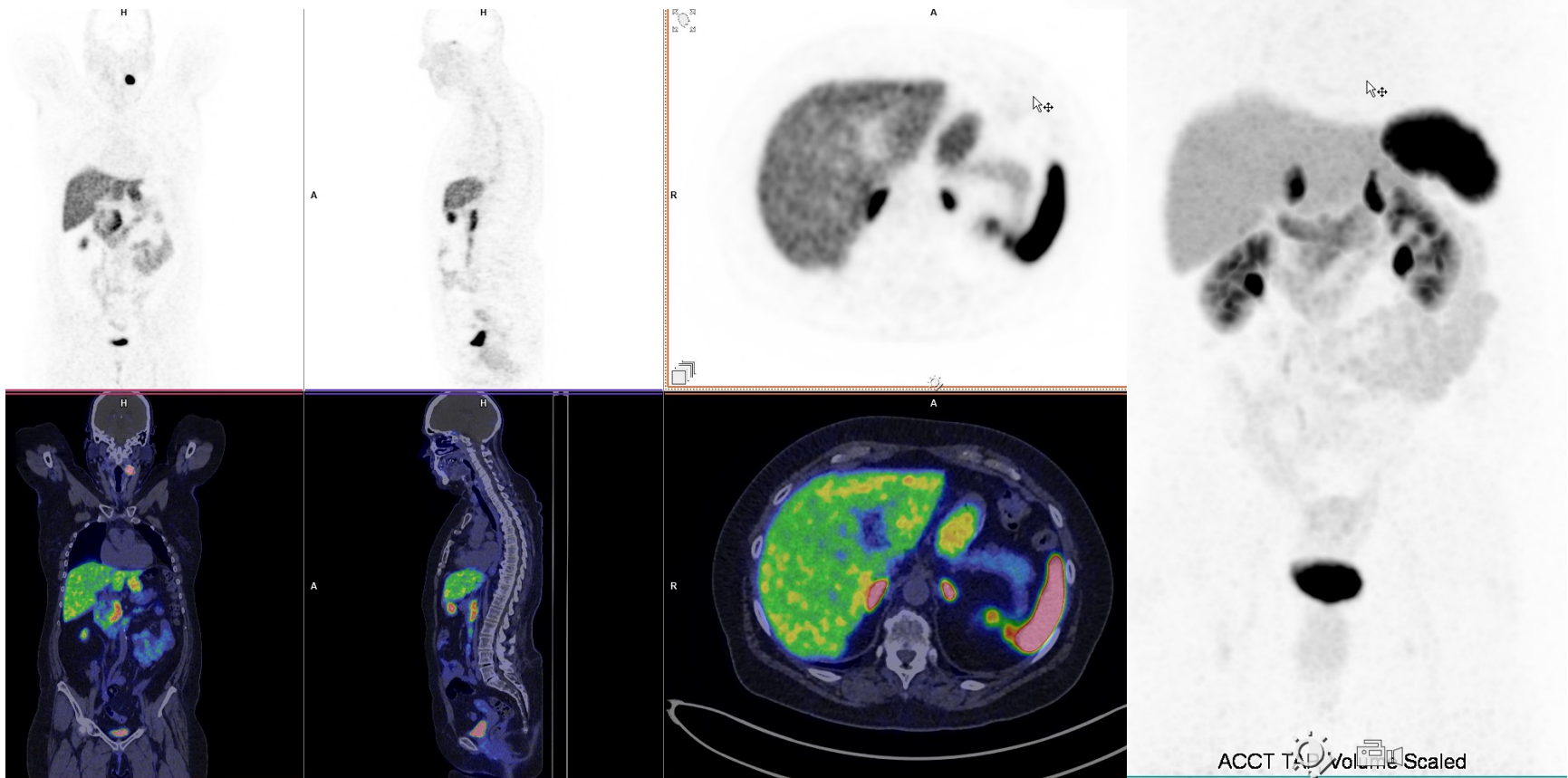




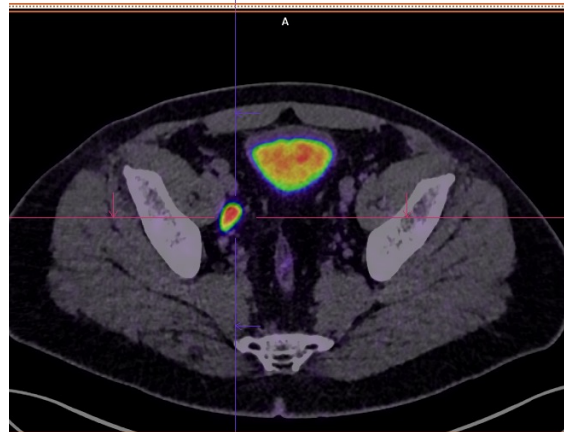
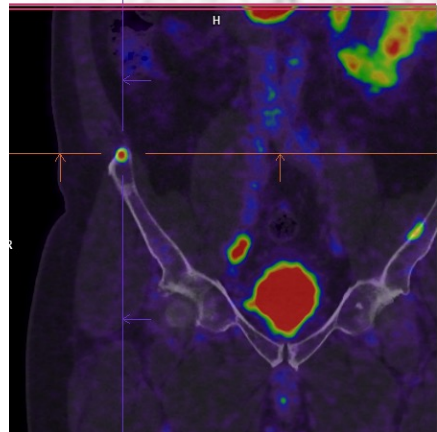
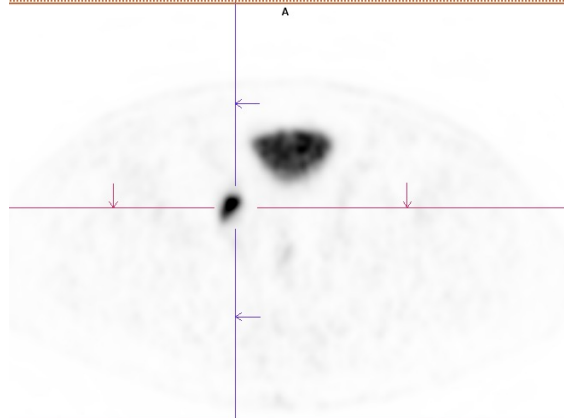
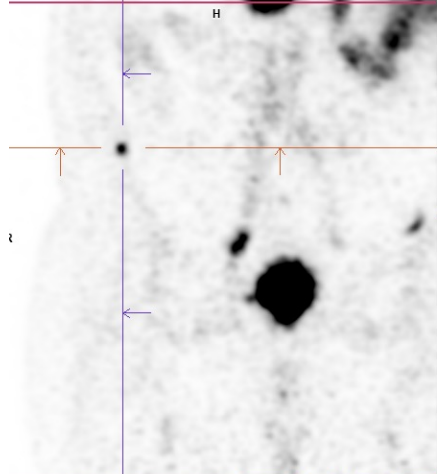
What's the goal?

- As fast as possible?
- As low activity as possible?
- As many patients as possible?
- The main benefit is flexibility

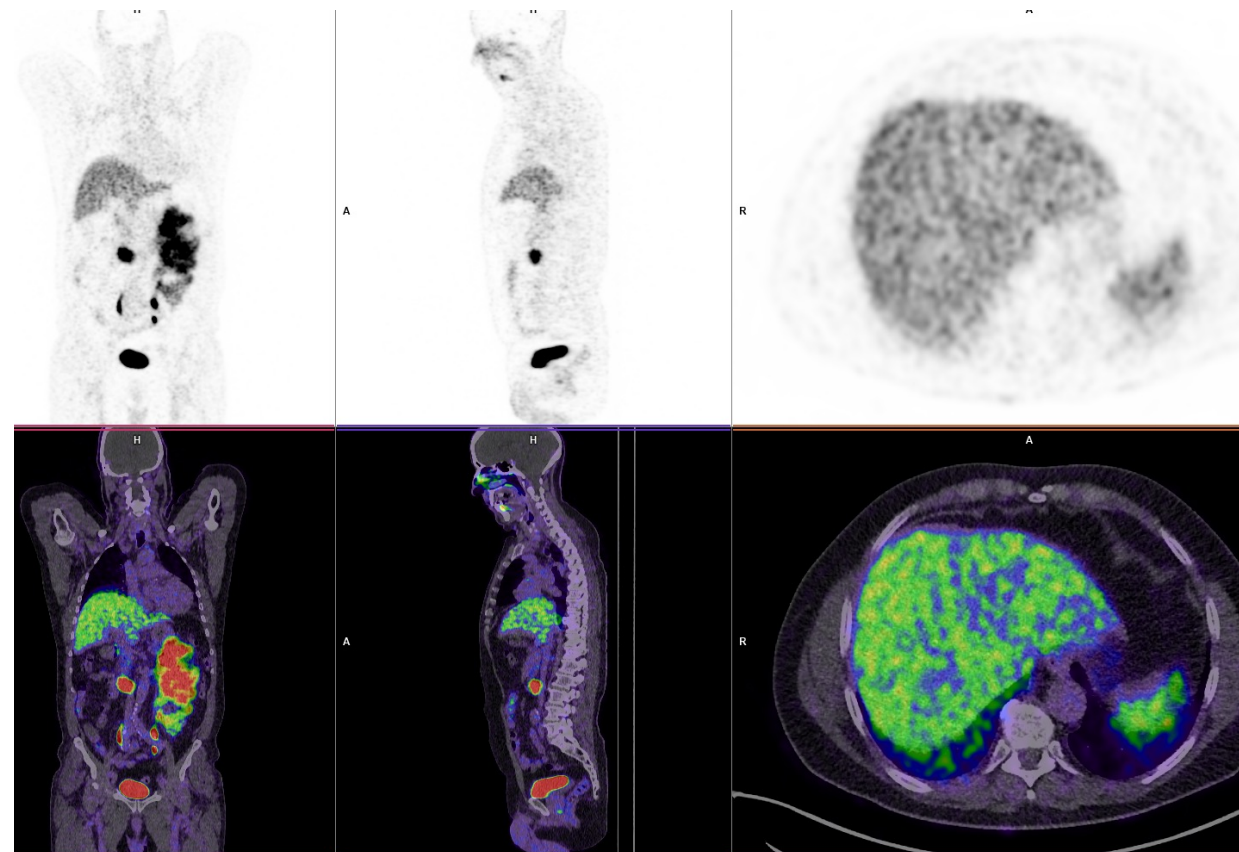
$[^{68}\text{Ga}]\text{DOTANOC}$
BMI 32,7 - 89 kg - 1,65 m - 96 MBq – 11' –
1h12 post injection



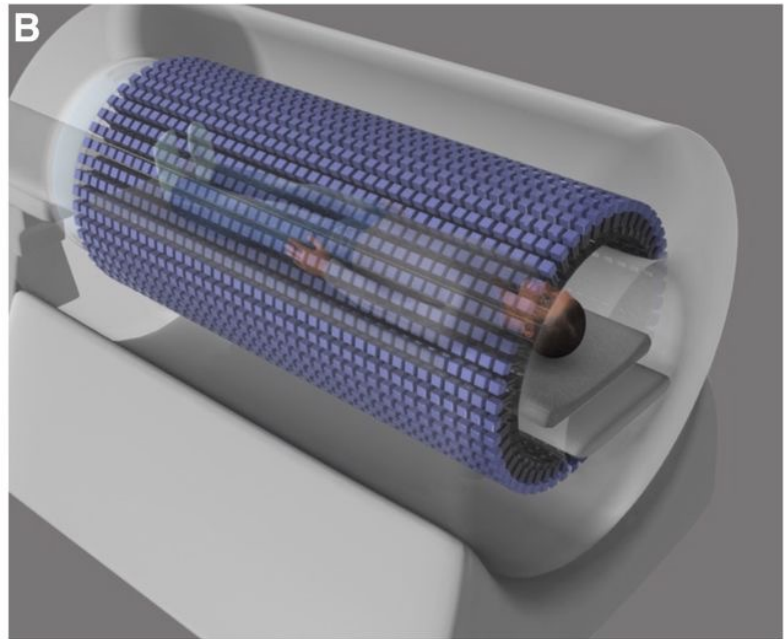
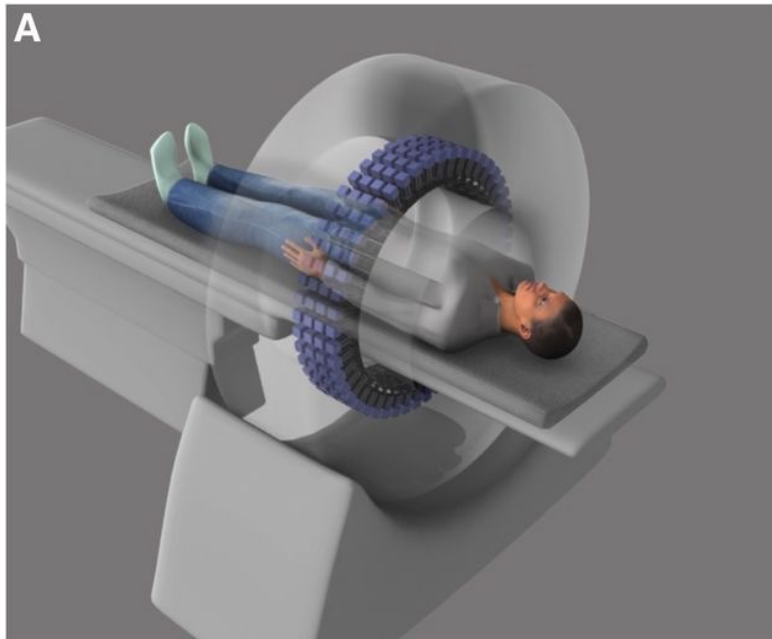
$[^{68}\text{Ga}]\text{Ga-PSMA-11}$
BMI 32,5 - 94 kg - 1,70 m - 96 MBq – 12'



$[^{68}\text{Ga}]\text{Ga-PSMA-11}$
BMI 27,3 - 78 kg - 1,69 m - 52 MBq – 15' –
1h34 post injection



Long-axial FOV PET “Total-Body” PET



Cherry et al. J Nucl Med 2018; 59:3–12

REVIEW

Open Access



So, you want to get into “total-body” PET/CT scanning? An installation guide for beginners!

Rodney J. Hicks^{1,2*} 

Challenge #1 - Financing

They are more than twice as expensive as the next-best standard FOV digital PET/CT, and closer to 3–4 times the price of most of the installed base of analog PET/CTs in clinical use globally. Would it not be more cost-effective to just buy 2 or 3 conventional PET/CT devices?

The financial case for ultra-extended FOV PET/CT must lie, at least partially, in greater throughput. This is made possible by the very substantial gain in sensitivity provided by greater coverage of the body by detector material. For example, the Siemens Biograph Vision Quadra has been shown to be 8–tenfold more sensitive, depending on the radionuclide, than the Biograph Vision 600, a standard FOV PET/CT with otherwise identical digital detector technology with time-of-flight capability [10]. Without changing the administered activity, equivalent signal-to-noise ratios, which are critical to lesion contrast and therefore detectability, can be achieved in imaging from head to pelvis in 2 min or less. Accounting for time to get patients on and off the scanner bed, 6 patients per hour is feasible with upwards of 40 patients per day possible. For standard photomulti-

Let's do the math

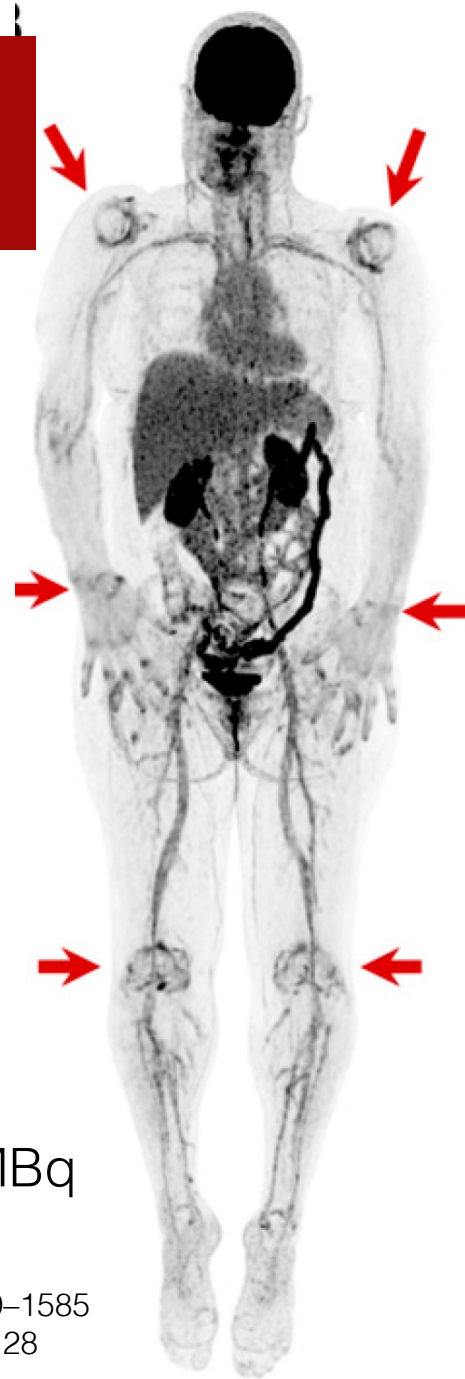
- One Total Body PET is more expensive than 2 Vision 600
- One TB PET scanner images 6 patients/hour
- Two Vision 600 scanners image 8 patients/hour
- 8 patients/hour is more than 6 patients/hour
 - *Higher throughput for less money*
- Case closed: Visions 600 win!

Not so fast!
Inject less activity and reduce the cost of the
radiopharmaceutical!



Quadra, 20 MBq

Acquisition:
20 minutes



μExplorer, 75 MBq

Total 40 patients heure calibration

/

l

48,7 GBq

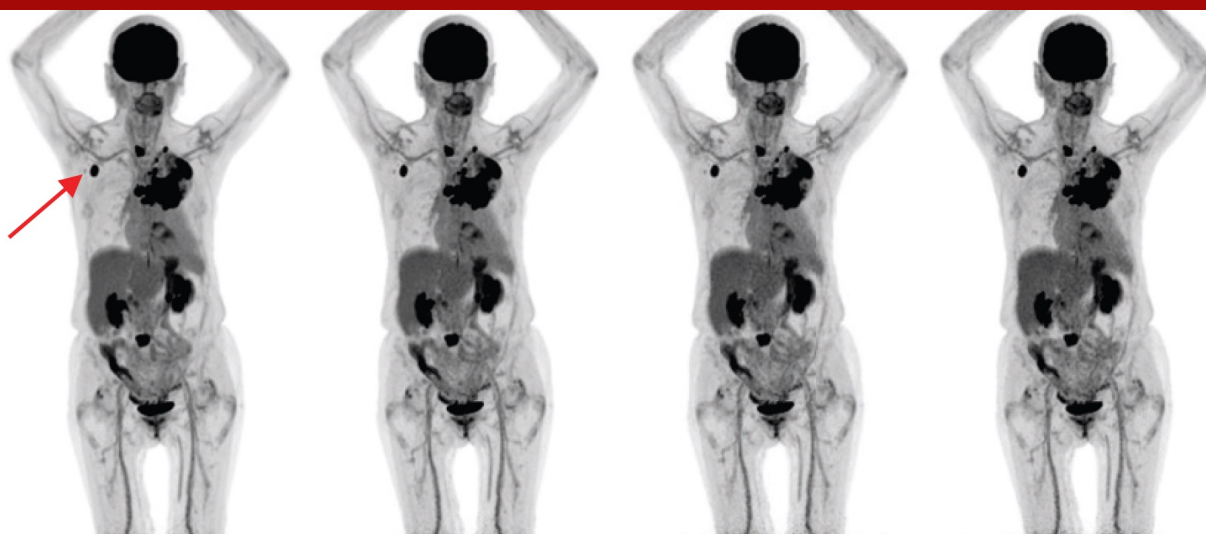
36,2 GBq

	Heure injection	d'injection	calibration	
1	08:00	20	42,6	
2	08:20	20	48,3	
3	08:40	20	54,8	
4	09:00	20	62,2	
5	09:20	20	70,5	
6	09:40	20	80,0	
7	10:00	20	90,7	
8	10:20	20	102,9	
9	10:40	20	116,8	
10	11:00	20	132,4	
11	11:20	20	150,2	
12	11:40	20	170,4	
13	12:00	20	193,3	
14	12:20	20	219,3	
15	12:40	20	248,7	
16	13:00	20	282,1	
17	13:20	20	320,0	
18	13:40	20	363,0	
19	14:00	20	411,7	
20	14:20	20	467,0	
21	14:40	20	529,8	
22	15:00	20	600,9	
23	15:20	20	681,6	
24	15:40	20	773,2	
25	16:00	20	877,0	
26	16:20	20	994,8	
27	16:40	20	1128,4	
28	17:00	20	1280,0	
29	17:20	20	1451,9	
30	17:40	20	1646,9	
31	18:00	20	1868,1	
32	18:20	20	2119,0	
33	18:40	20	2403,7	
34	19:00	20	2726,5	
35	19:20	20	3092,7	
36	19:40	20	3508,1	
37	20:00	20	3979,3	
38	20:20	20	4513,7	
39	20:40	20	5120,0	
40	21:00	20	5807,7	

Number of PET
studies: +11%

[¹⁸F]FDG bill: -19%

Quadra: BMI 22,3 160 cm 57 kg 191 MBq

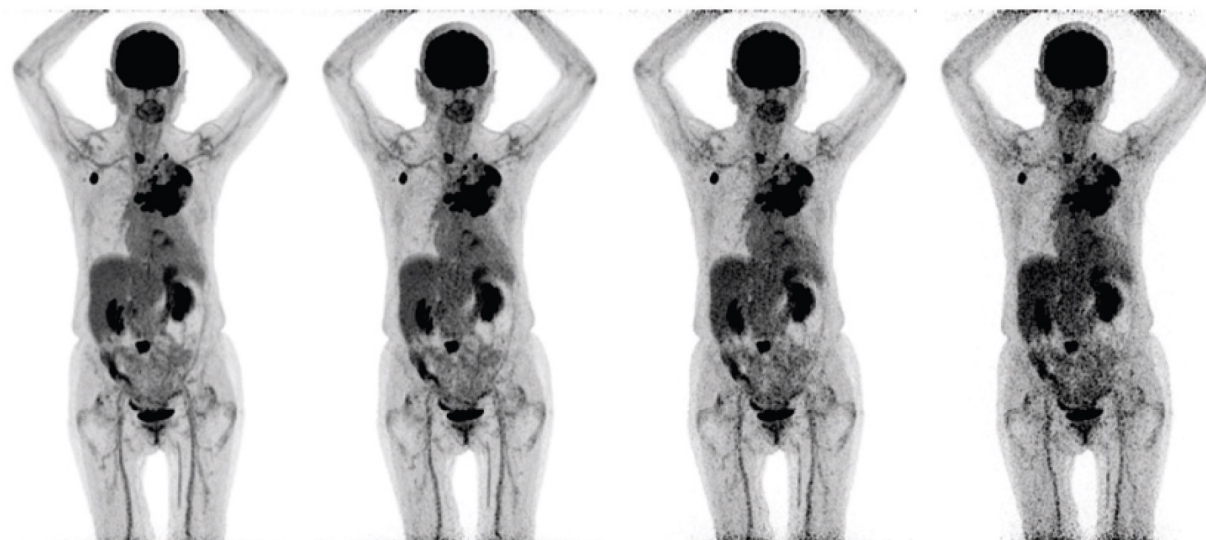


10 min

6 min

4 min

3 min



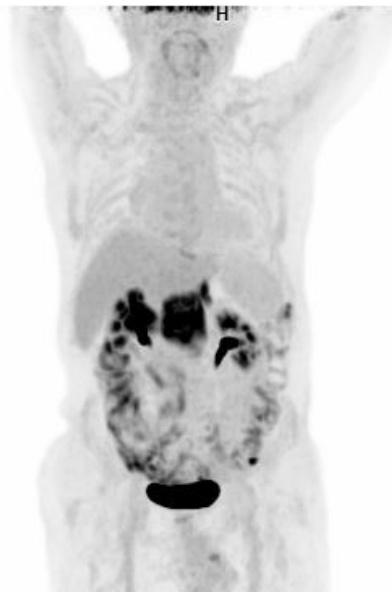
2 min

1 min

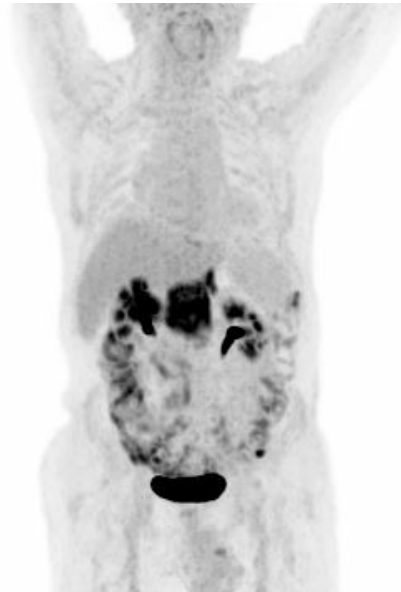
30 s

30 s

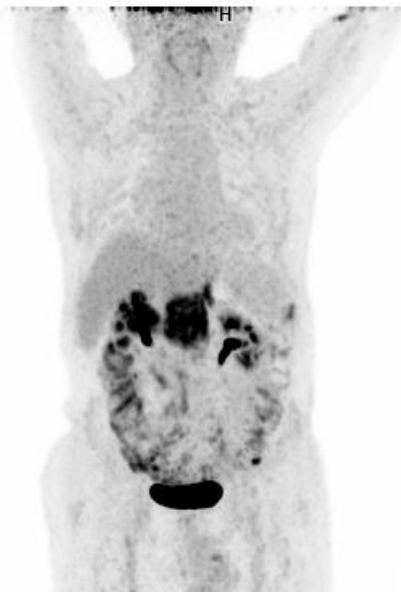
Vision 600: BMI 23,8 160 cm 61 kg
List-mode acquisition



100%
8'
157 MBq



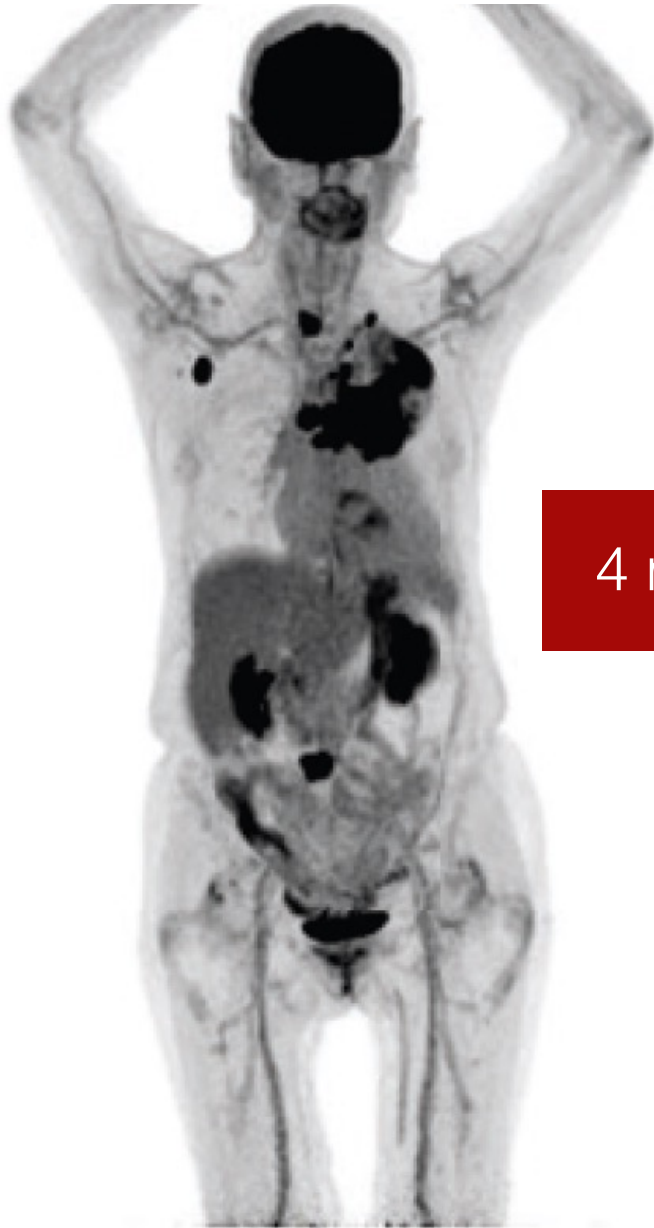
50%
4'
79 MBq



25%
2'
39 MBq



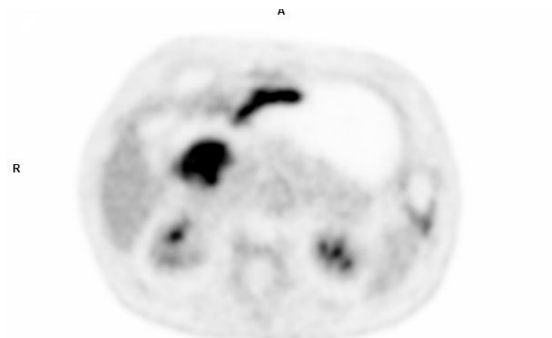
10%
1'20
16 MBq



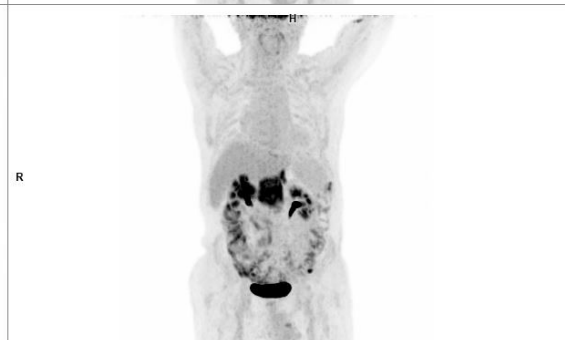
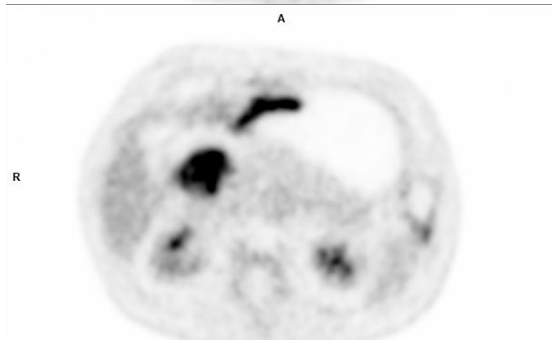
4 minutes



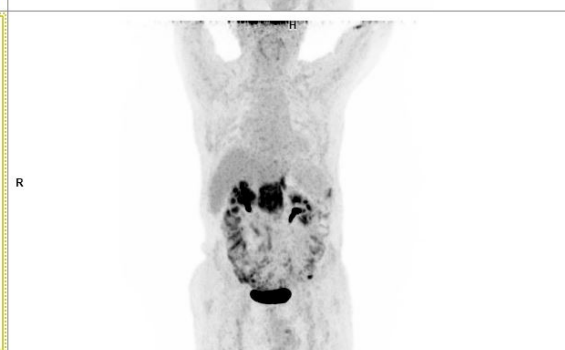
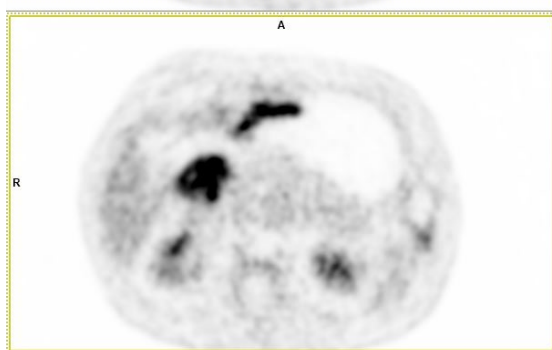
100%
8'
157 MBq



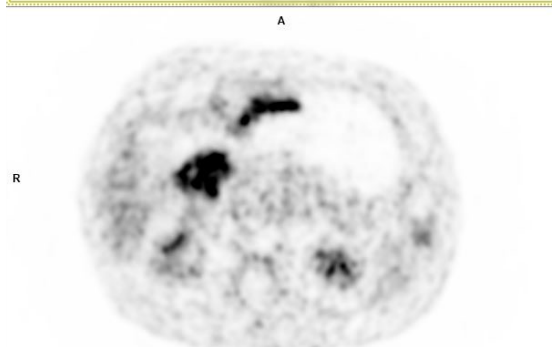
50%
4' or
79 MBq



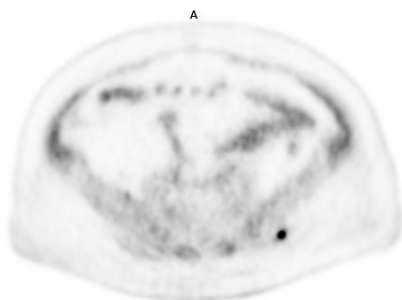
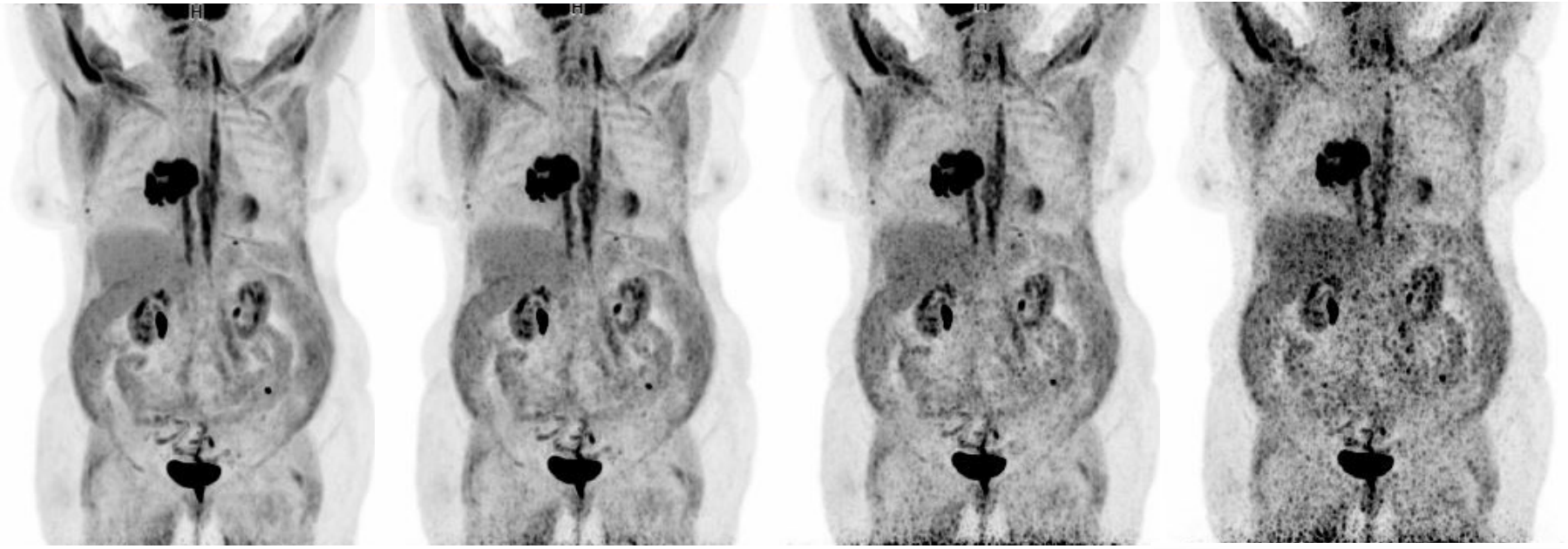
25%
2' or
39 MBq



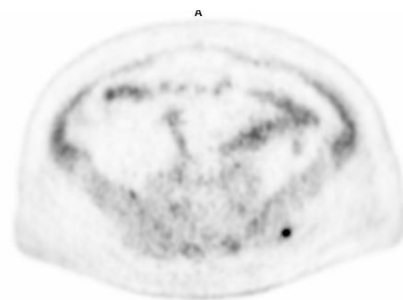
10%
1'20 or
16 MBq



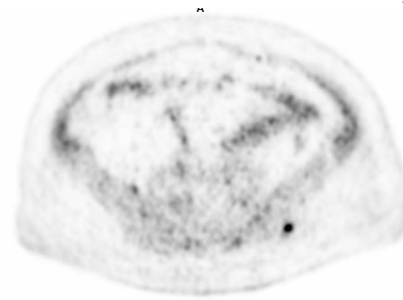
BMI 39,8 160 cm 102 kg



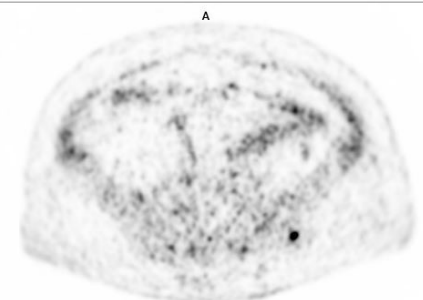
100%
10'24" and
257 MBq



50%
5'12" or
129 MBq

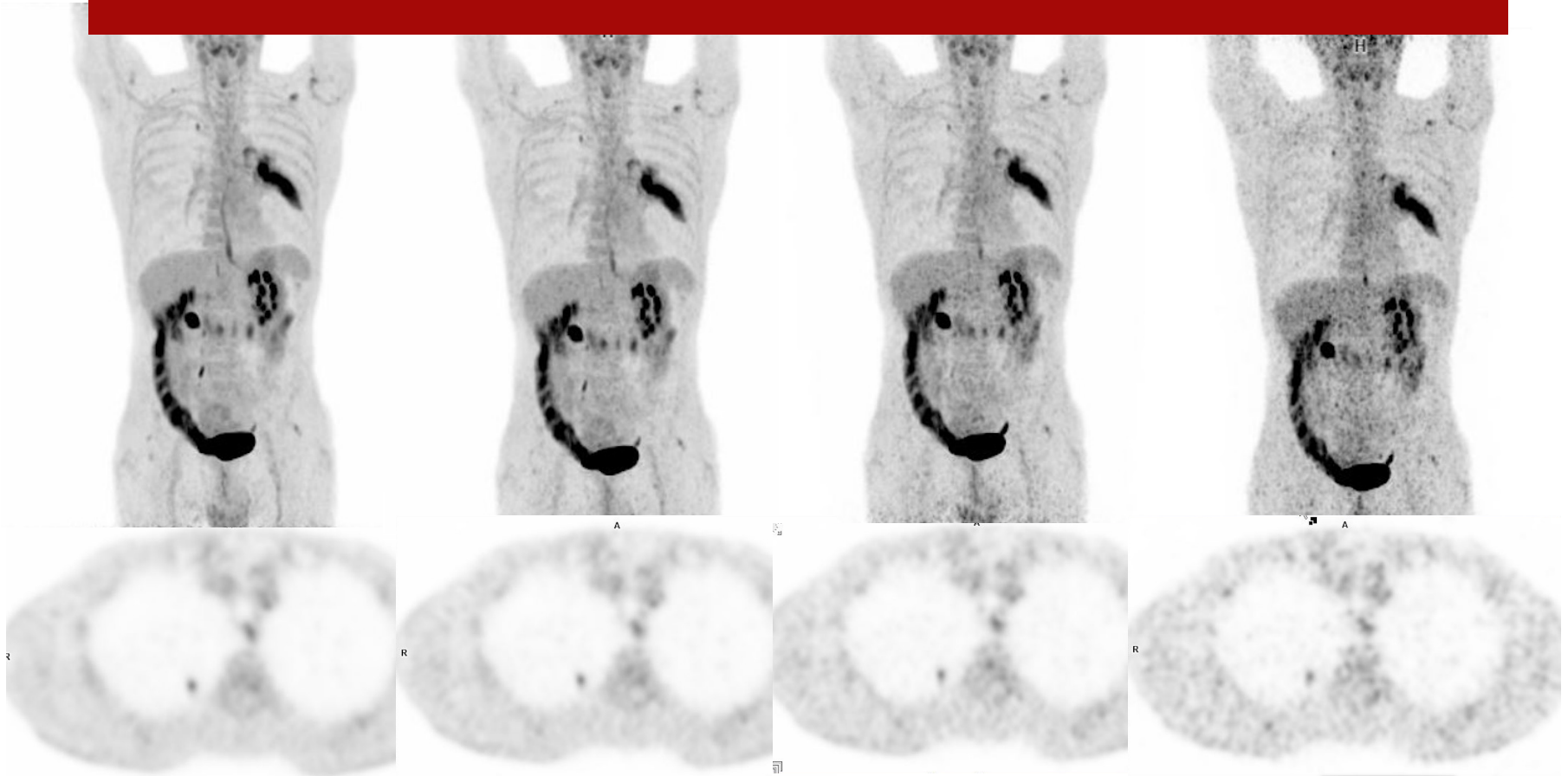


25%
2'36" or
64 MBq



10%
1'20" or
26 MBq

BMI 16,3 175 cm 50 kg



7'52"
118 MBq

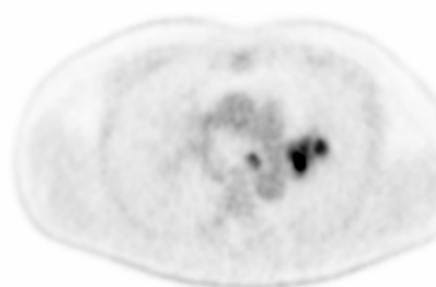
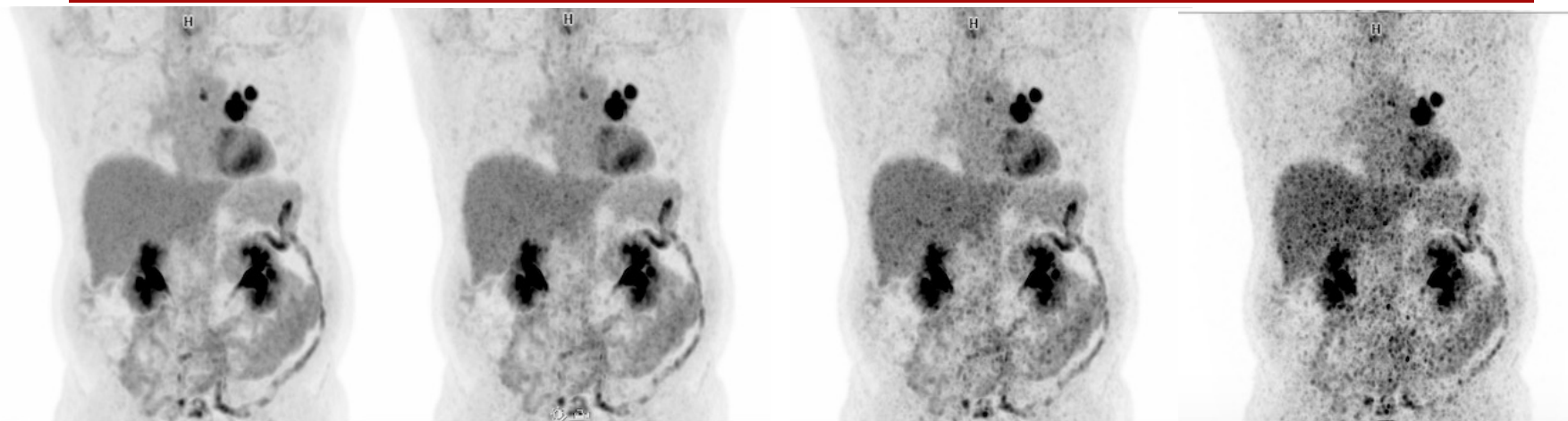
3'56" or
59 MBq

1'58" or
30 MBq

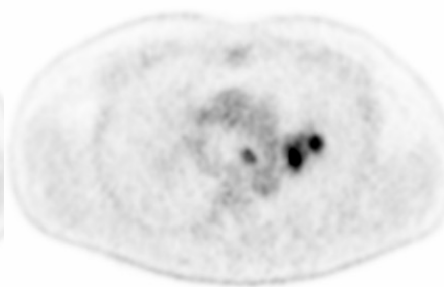
52" or
12 MBq



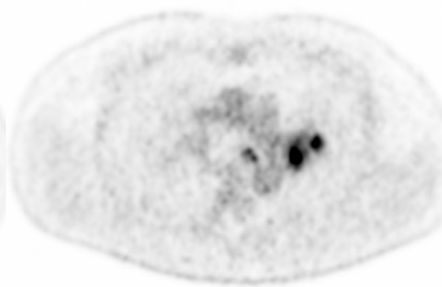
BMI 33,4 179 cm 107 kg



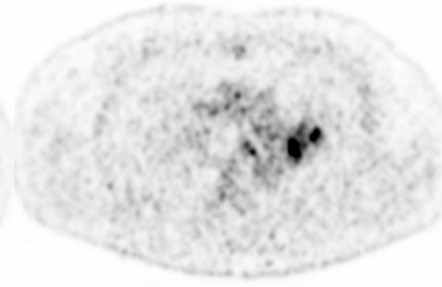
8'
258 MBq



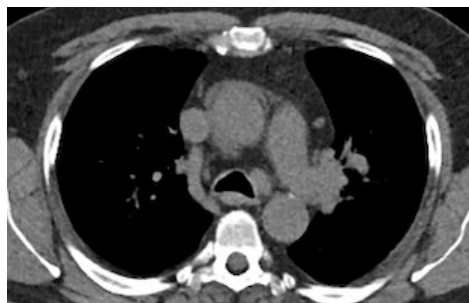
4' or
129 MBq

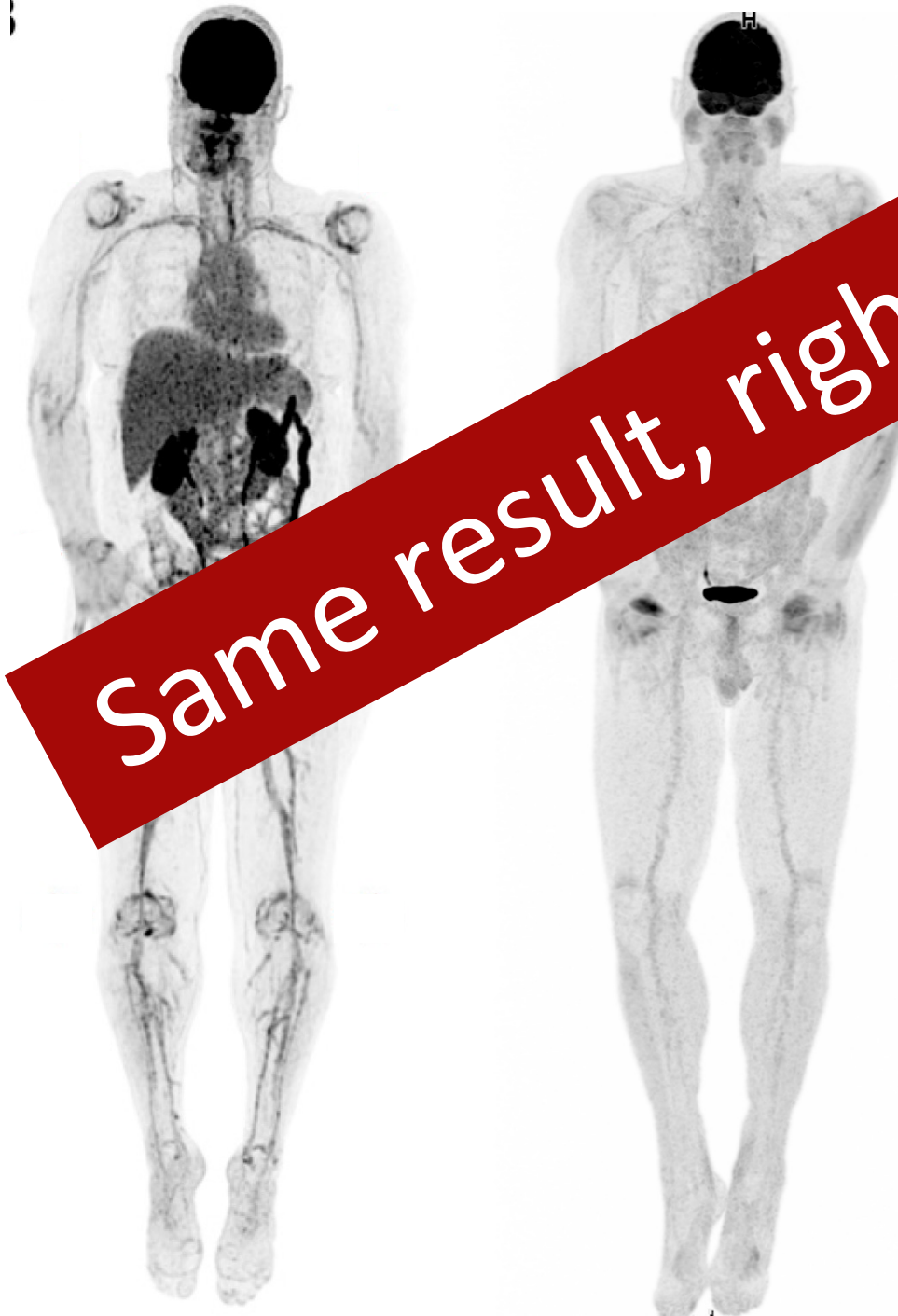


2' or
65 MBq



48" or
26 MBq





Same result, right?

μ Explorer
70 MBq
20 minutes

Vision 600
BMI 24
187 cm
84 kg
209 MBq
12 minutes

PET IS QUANTITATIVE

European Journal of
**Nuclear
Medicine**

Original article

Fluorine-18 deoxyglucose uptake in sarcoidosis measured with positron emission tomography

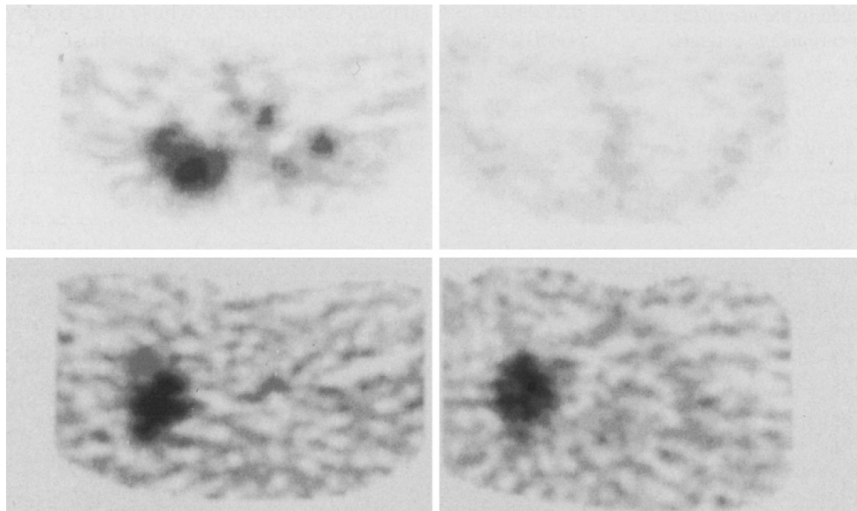
Lars H. Brudin^{1*}, Sven-Olof Valind¹, Christopher G. Rhodes¹, Charles F. Pantin², Martin Sweatman², Terry Jones¹, J.M.B. Hughes¹

¹ MRC Cyclotron Unit and Department of Medicine, Royal Postgraduate Medical School, Hammersmith Hospital, Ducane Road, London W12 0HS, UK

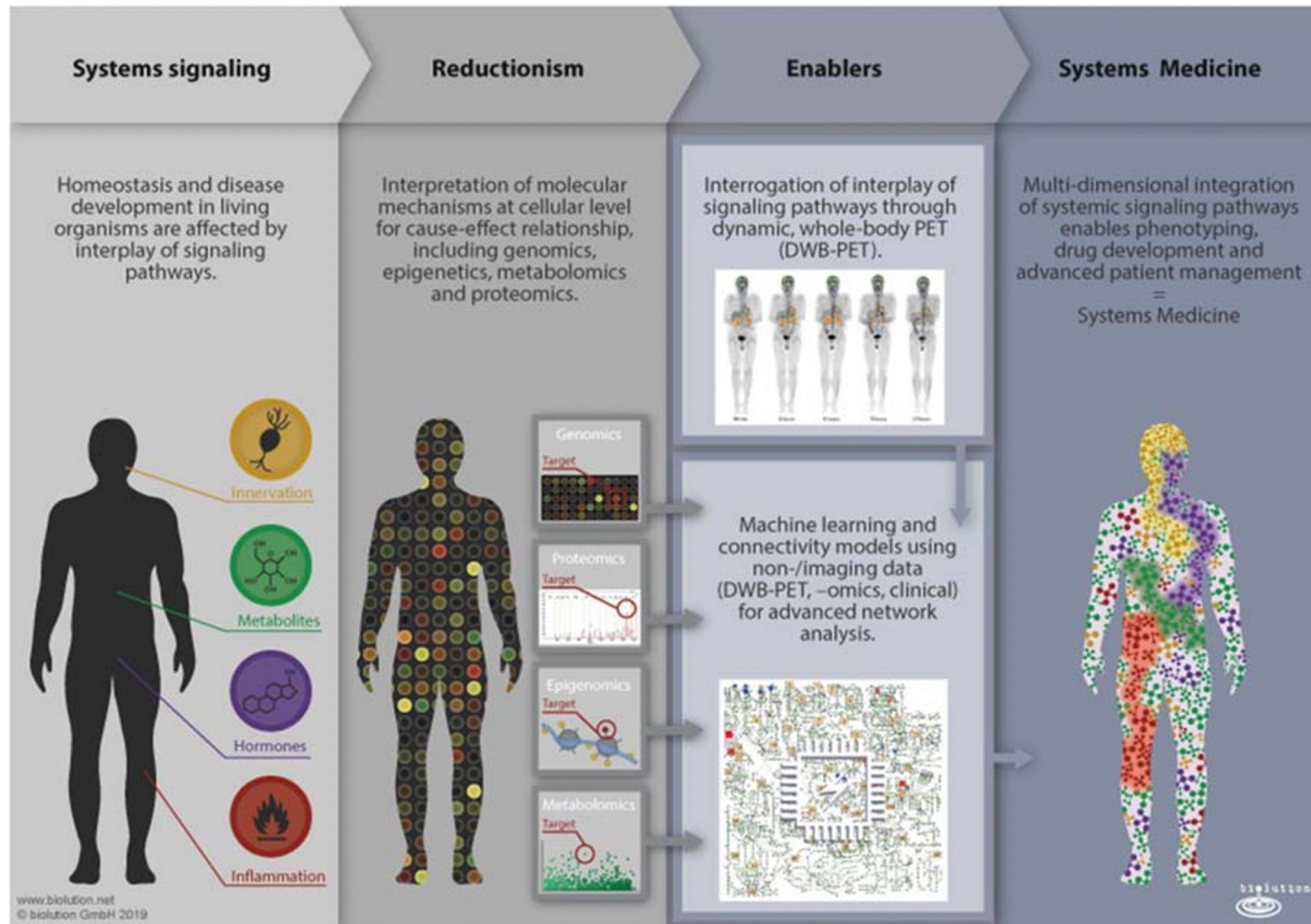
² Cardiothoracic Institute, Brompton Hospital, Fulham Road, London SW3 6HP, UK

Received 2 September and in revised form 27 November 1993

MRglu :
absolute
quantification of
glucose
metabolism

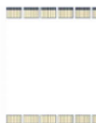


Dynamic whole-body imaging

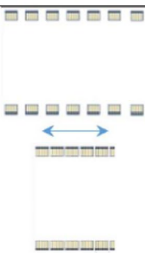
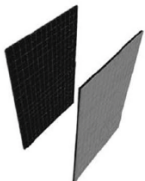


Quantification has always held a pervasive allure for nuclear medicine. There is a sense that anything that can be quantified should be. Once we have the numbers in hand, there is a mysterious tendency to accord them special value. Why this should be the case is unclear. Perhaps it is because of the functional nature of nuclear medicine studies, which seem as if they should be quantified. Perhaps it is because it is so easy to extract numbers from our studies. Whatever the cause, the phenomenon has been particularly strong in PET, in which we hear at every turn that PET is “quantitative.”

What's next?

Configuration	Design	Detector	Expected performance
Medium axial FOV Axial: 50–60 cm, 100% detectors		LYSO + SiPMs	200–400 ps 4–6 more sensitive
Split axial ring PET Axial: 100–120 cm 50% detectors		LYSO + SiPMs	200–400 ps 4–6 more sensitive
Thin crystal Axial: 100–120 cm 50% thickness		LYSO + SiPMs	150–300 ps 4–6 more sensitive

- Medium cost long axial FOV PET?

Thick lower cost crystal Axial: 100–120 cm 100% thickness		BGO + SiPMs	No TOF 400–600 ps (Cherenkov + optimal SiPMs) 8–20 × more sensitive
Adaptive PET Axial (top): 100–120 cm Axial (top): 50–60 cm 100% thickness Axial sparse PET and/or transverse gaps		LYSO/BGO + SiPMs	200–400 ps 4–6 × more sensitive
Flat panel PET Axial: 100–120 cm 100% thickness		LYSO/BGO + SiPM	200–400 ps (LYSO) 400–600 ps (BGO) 8–20 × more sensitive

Vandenberghe et al. Eur J Nucl Med Mol Imag (2023) 50:652–660

What's next? A.I.!

- Acquisition: lower counts
- Resolution: effect of acolinearity and positron range
- Processing: reconstruction, attenuation correction
- Interpretation: segmentation, quantification, lesion recognition and characterization

European Journal of Nuclear Medicine and Molecular Imaging (2022) 49:4452–4463
<https://doi.org/10.1007/s00259-022-05891-w>

REVIEW ARTICLE



Application of artificial intelligence in nuclear medicine and molecular imaging: a review of current status and future perspectives for clinical translation

Dimitris Visvikis¹ · Philippe Lambin^{2,3} · Kim Beuschaus Mauridsen^{4,5} · Roland Hustinx⁶ · Michael Lassmann⁷ · Christoph Rischpler⁸ · Kuangyu Shi^{5,9} · Jan Pruim¹⁰

European Journal of Nuclear Medicine and Molecular Imaging (2022) 50:61–66
<https://doi.org/10.1007/s00259-022-05947-x>

ORIGINAL ARTICLE



An EANM position paper on the application of artificial intelligence in nuclear medicine

Roland Hustinx¹ · Jan Pruim² · Michael Lassmann³ · Dimitris Visvikis⁴

Conclusions



« Don't panic! »

The past has been fun

The present is fascinating

The future is going to be wild

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