From acquisition to reconstructed images : Steps and corrections

CSG PET workshop

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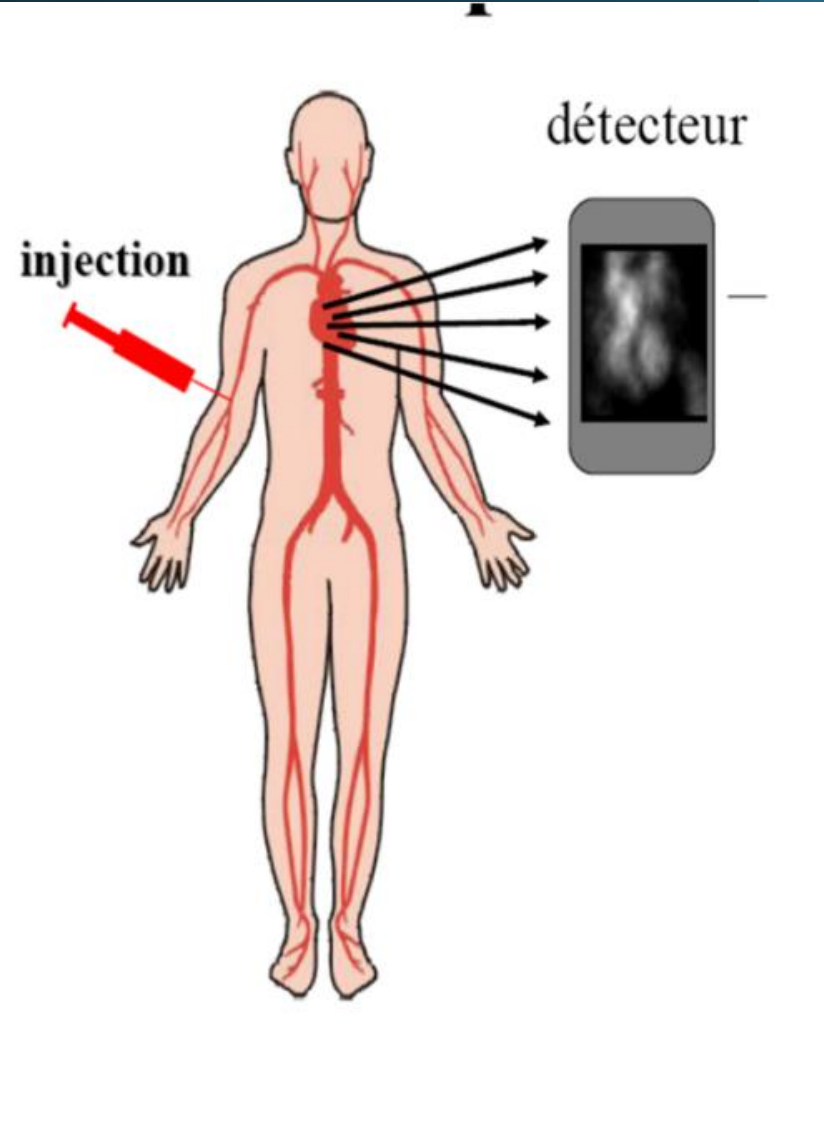
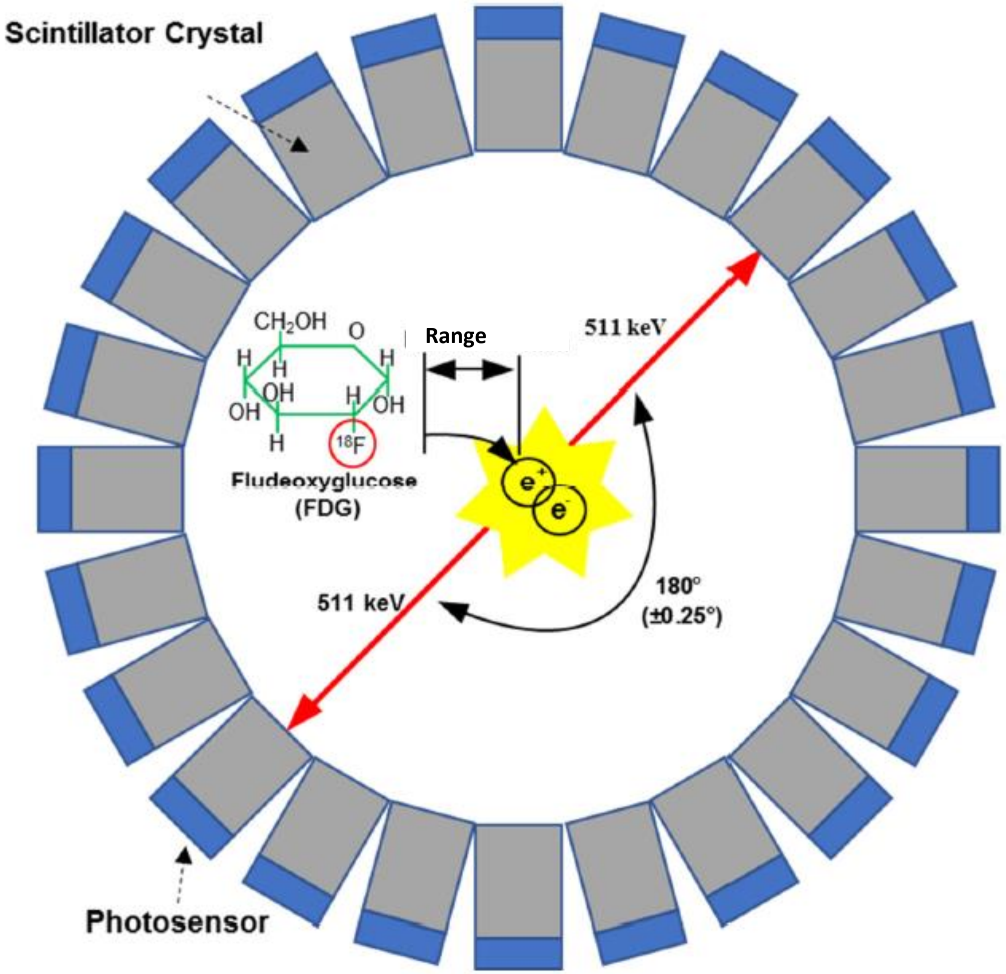
Positron Emission tomography

- Nuclear medicine → Metabolic imaging :
  - Injection, ingestion or inhalation of a radiopharmaceutical – radioactive molecule.
  - Study of the fate of that radiopharmaceutical with images of the radioactivity bounded to the molecule of interest.
  - Functional images.

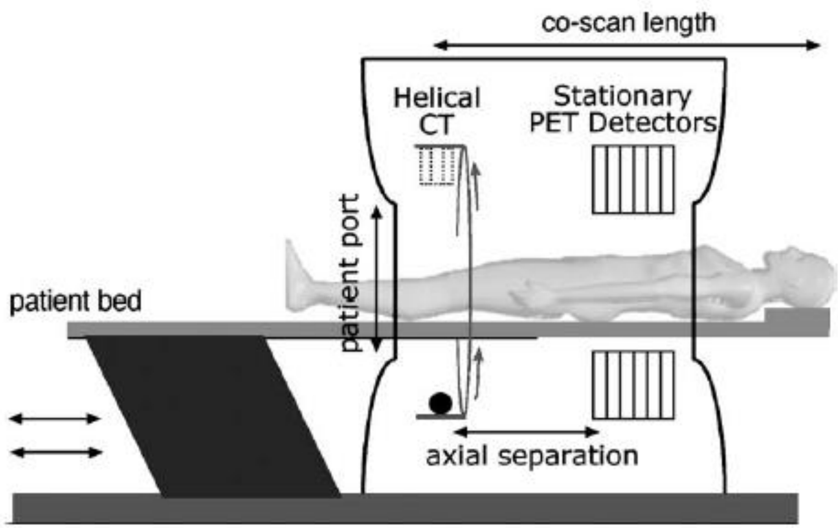


Positron Emission Tomography

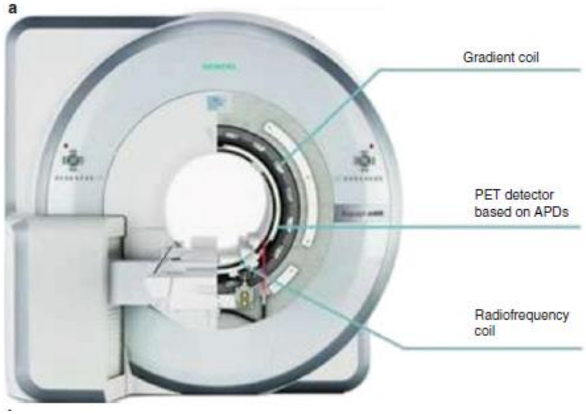
- The radiopharmaceutical is labeled with a radioactive isotope that is a positron emitter.
- Positron or β^+ is like an electron with a positive charge.
  → Annihilation with an electron
- → 2 γ rays of 511 keV emitted in opposite directions 180° (nearly)
- PET scanner is based on the detection of these 2 photons in coincidence.
- → geometry of PET with detectors around the patient.



Jiang, et al. (2019). Sensors for Positron Emission Tomography Applications. Sensors. 19. 5019.

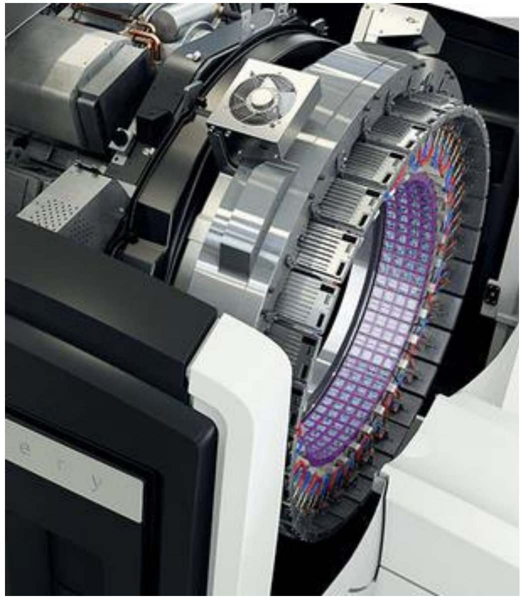


PET-MR

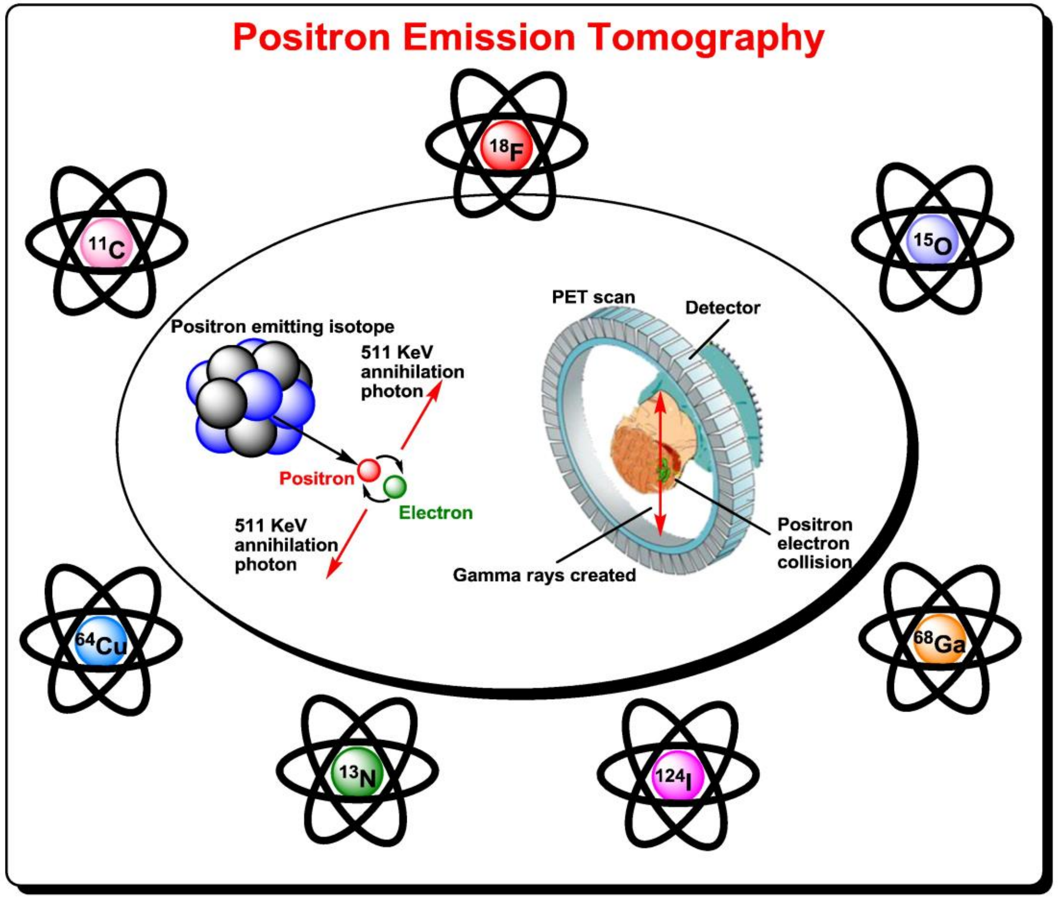


PET-CT

- FOV:
  - Transaxial : 70-78 cm
  - Axial : 15 – 26 cm

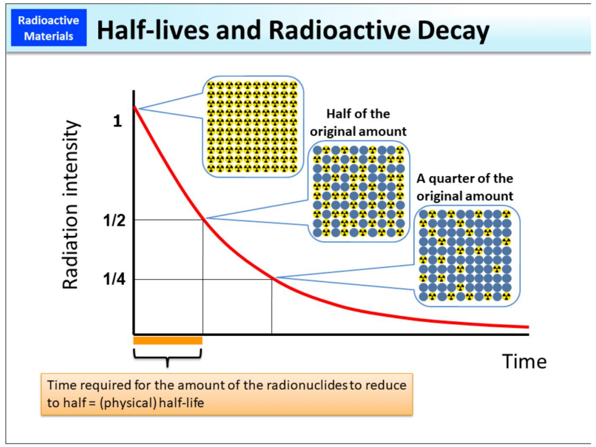


Positron emitter



Zibo et al.(2010),Radiopharmaceutical chemistry for positron emission tomography, Advanced Drug Delivery Reviews,62 (11), 1031-1051,

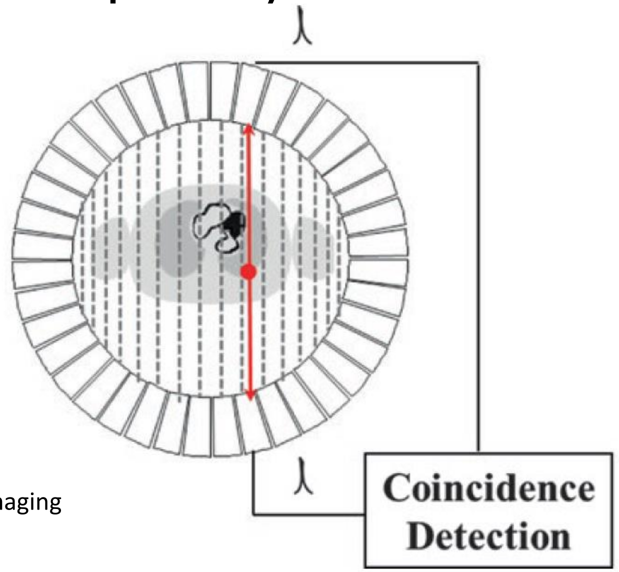
Isotope	Mean range in water (mm)	Half-live T (min)
^{15}O	2,7	2
^{13}N	1,5	10
^{11}C	1,1	20
^{18}F	**0,6**	**110**
^{68}Ga	3,1	68



- Activity unit = Bequerel [Bq]
- 1 Bq = 1 disintegration per second.

PET scanner : process

- Coincidence detection
  → LOR (line of response)



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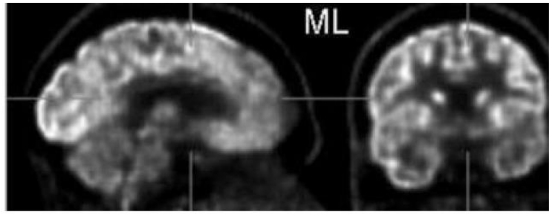
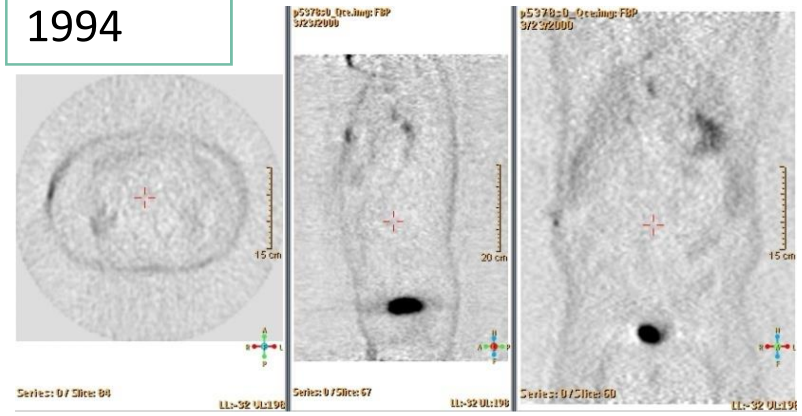
- Reconstruction process
  - Method
  - Corrections applied



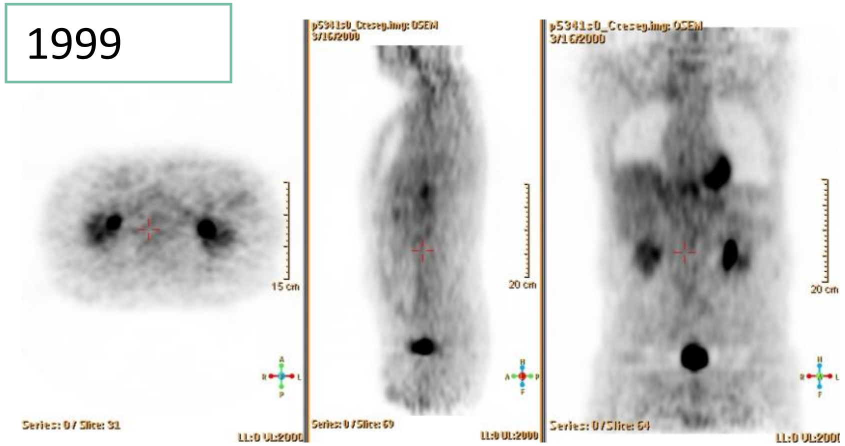
- Differences between scanner (vendor & software version)
  - **Influence images characteristics !**

PET scanner –evolution

1994

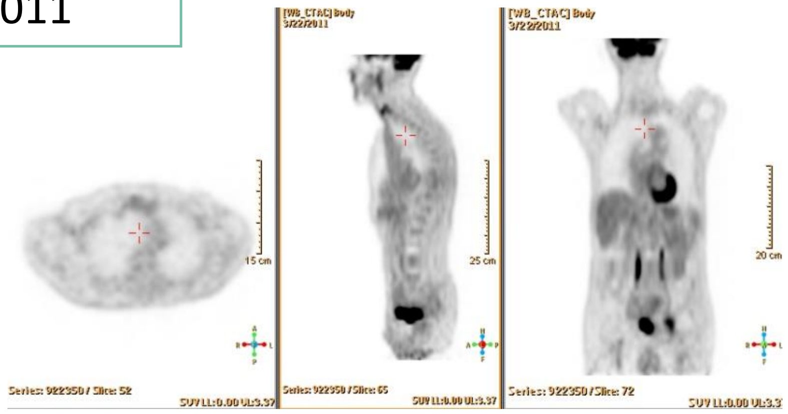


1999

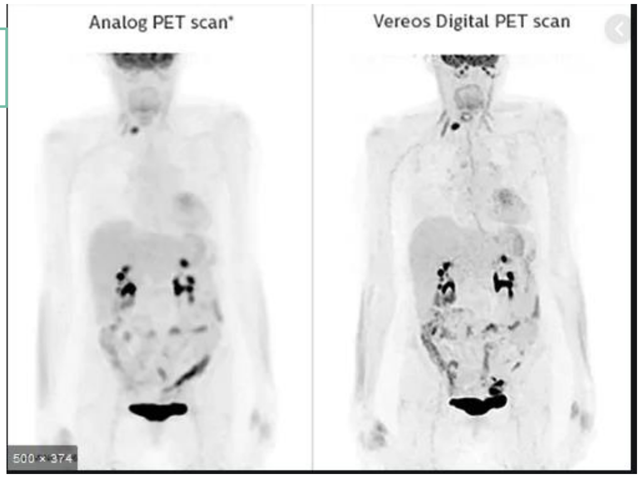


Be careful when comparing images

2011

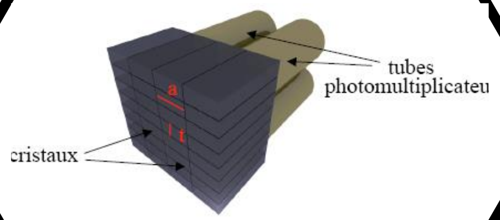


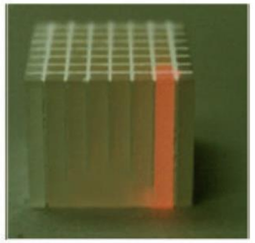
SiPM

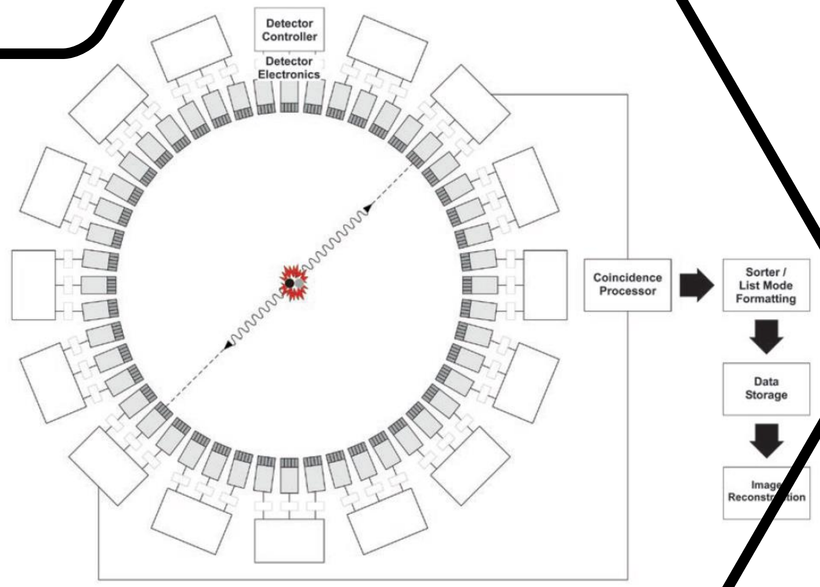


PET scanner - detection system

- Coincidence detection
  - Detector
  - Electronic
- Detector
  - Cristal + photodetector







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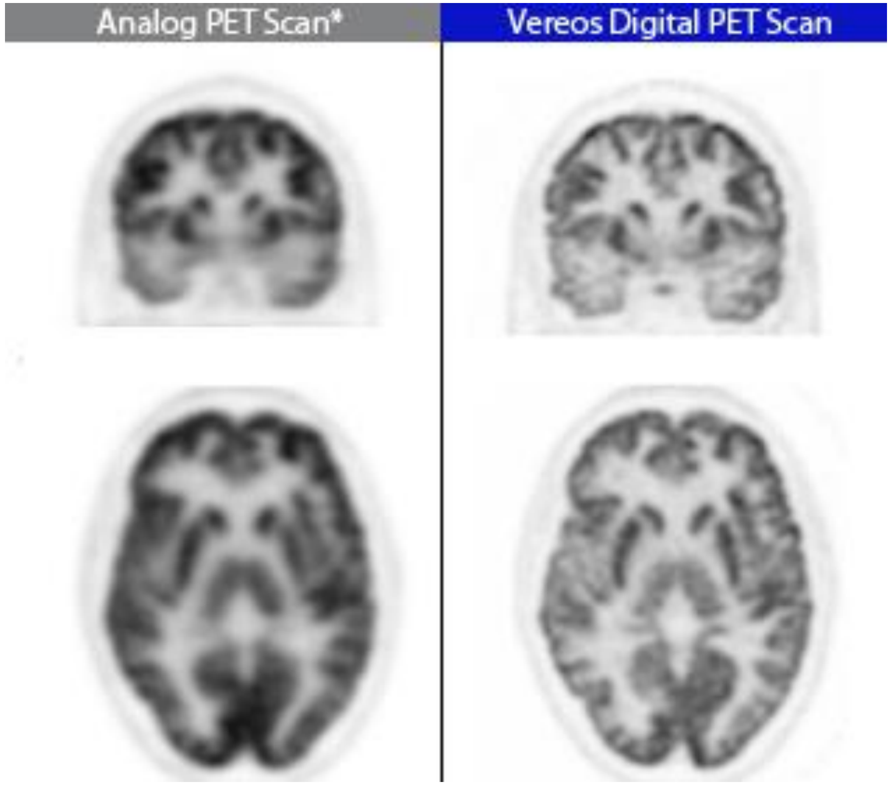
Recent evolution

- PET goes « digital »
  →PMT →SiPM
  → Improve resolution



https://www.peninsulaimaging.com/service/pet-ct/ (20.09.21)

Vrigneaud (2018) 4[ième] JFMN

Images characteristics

Resolution

- Scanner conception (cristal, detector..)
- The recon algorithm (correction, matrix, iteratif process..)

Contrast

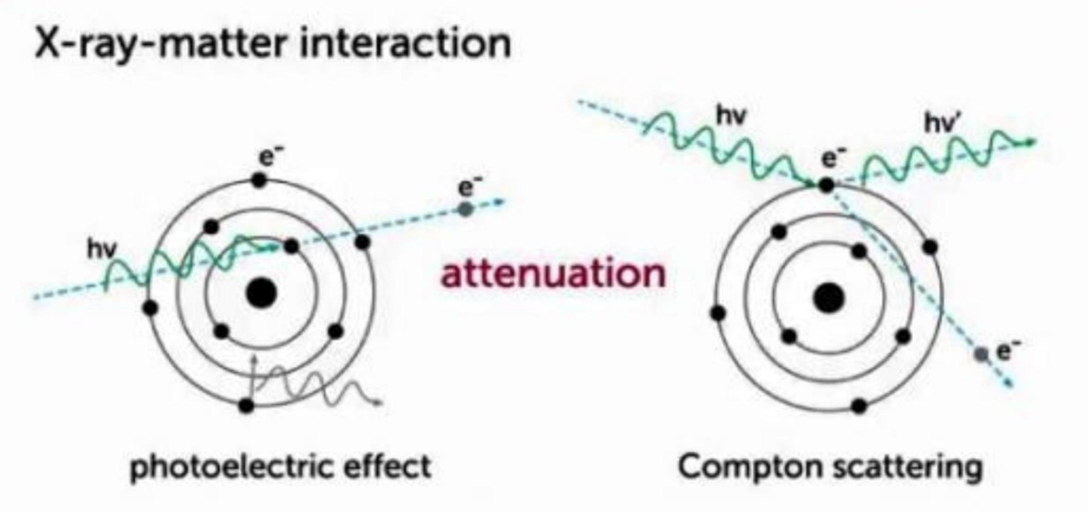
Noise

- Sensitivity of the scanner
- Injected activity
- Time of acquisition

Quantification – SUV

- Resolution, noise , uptake, patient, cross calibration, clock, technologist …

Photon interaction with matter (for PET, 511 keV)



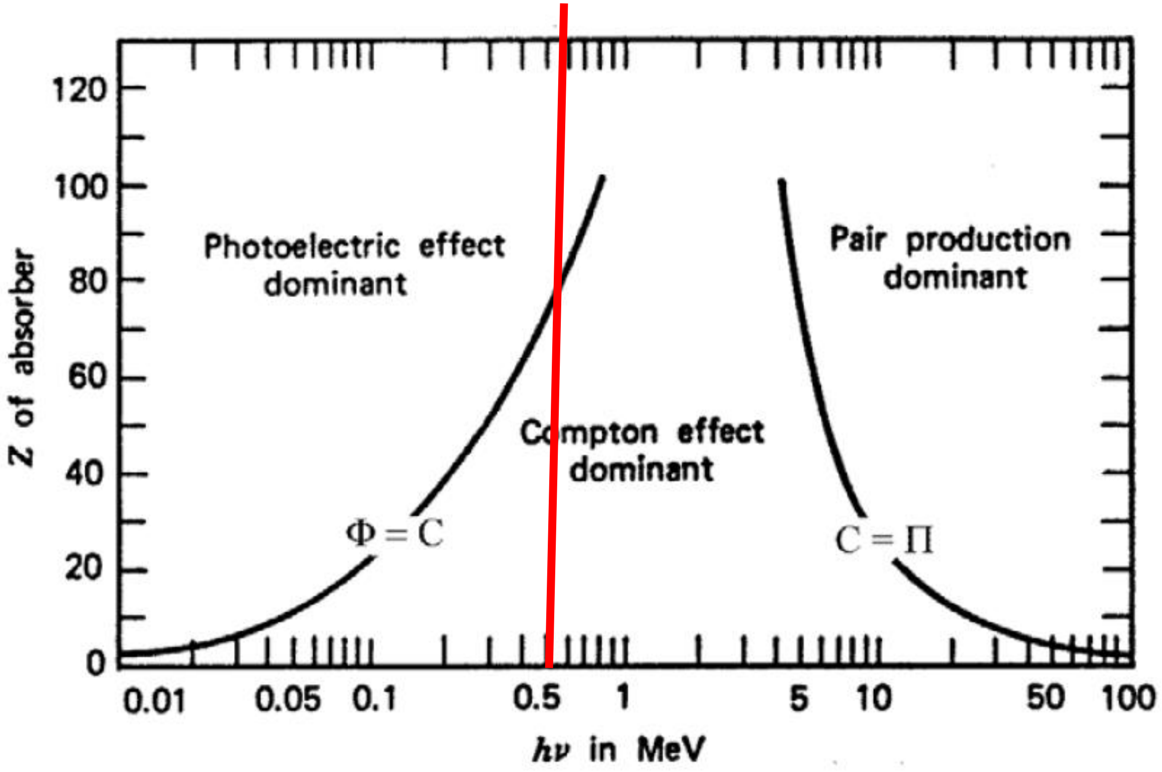
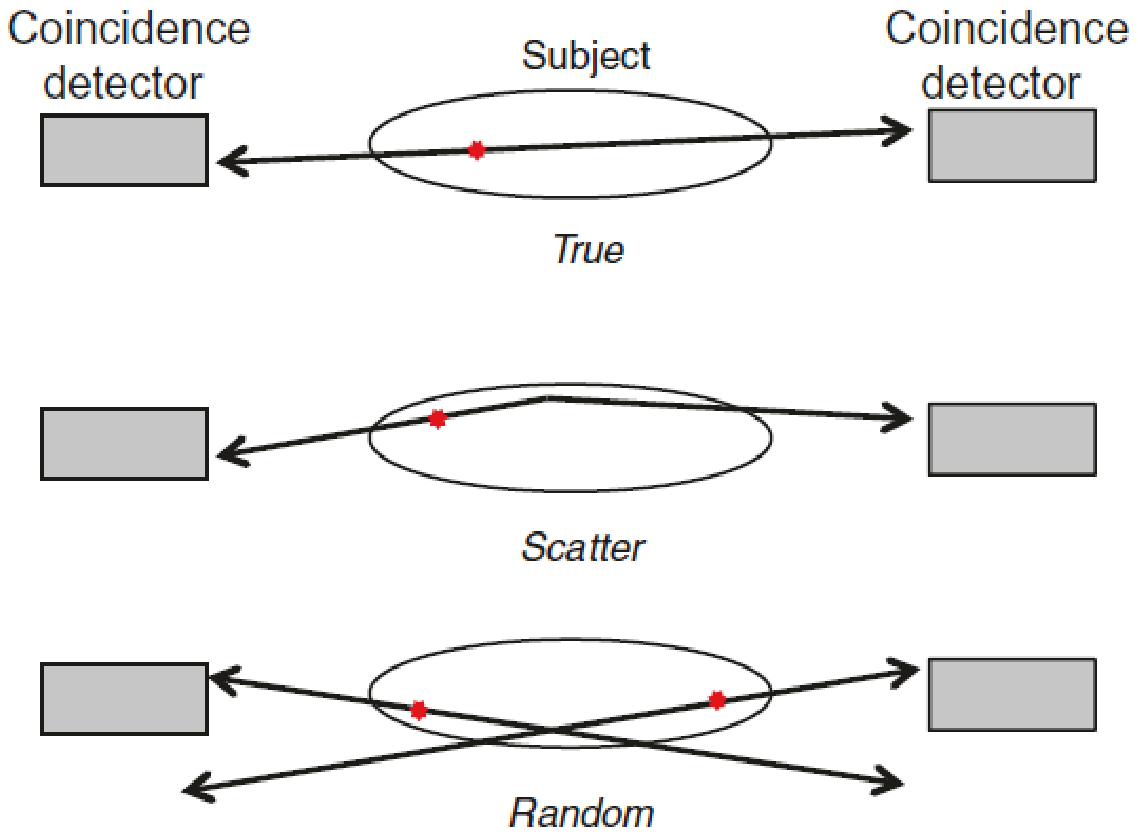


Image degradation

- Events really detected
  - True LOR.
  - Scatter event :
    both photons come from the same decay but one of the γ is slightly scattered.
  - Random event :
    2 photons are detected at the same time but are from 2 different decays.



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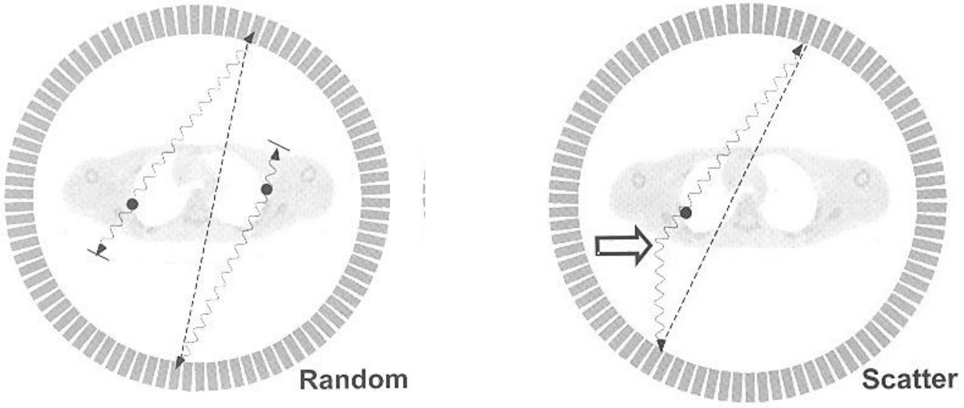
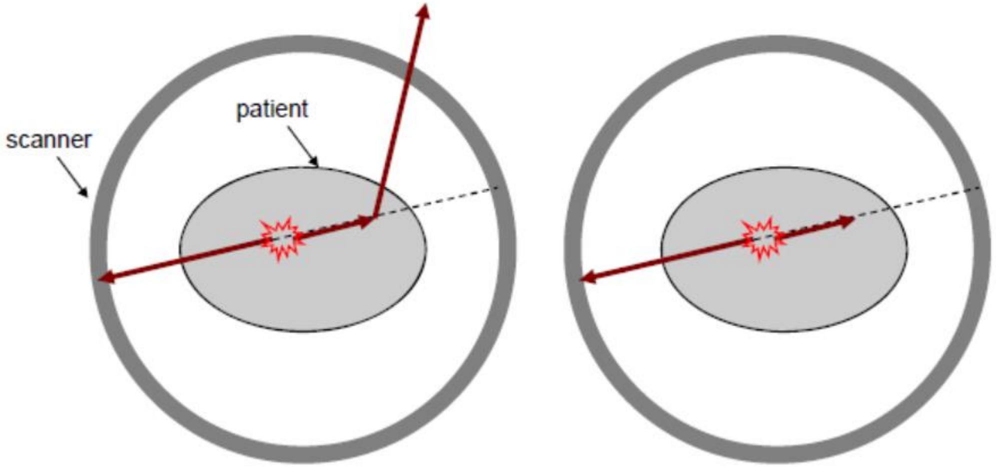
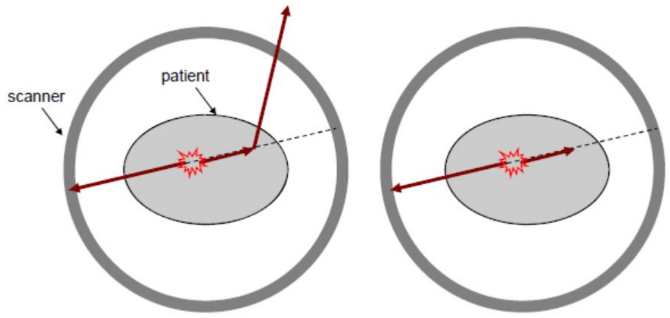
Correction

- Random and scatter events are a big part of the data and have an **impact on contrast and quantification.**
- Corrections are needed.
- They are implemented in all modern scanner in different way which influence image characteristics.





Attenuation map for correction



- ➢PET-CT : → direct measurement with CT.
- ➢PET-MR : → not an attenuation measurement.
  - No signal from bones.
  - Need special sequences and atlas segmentation.
- ➢PET : → for brain, assume uniform attenuation across all tissues.

❖The way the correction is done will influence the quantification of the image and probably the noise added with the correction.

Reconstruction method

Analytic image reconstruction

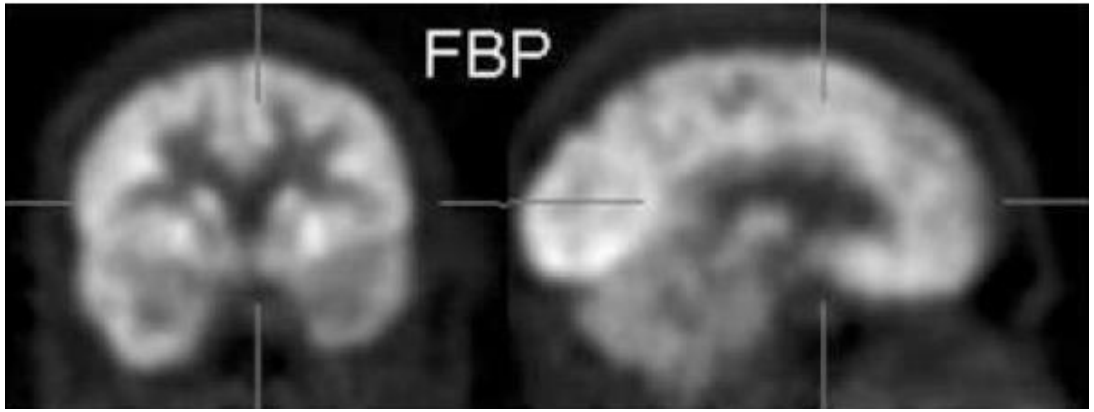
- PET data are modeled as a line integral through the image (Radon transform).
- An analytic solution can be derived and implemented (**FBP** filtered back projection).
- Very fast and not too computer demanding (used until 2000).

Model base statistical reconstruction

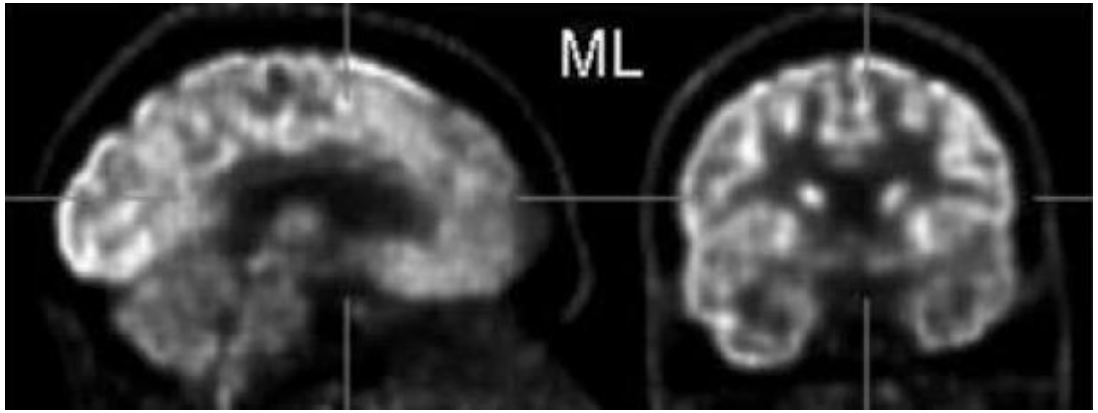
- **Iterative** reconstruction.
- Model the scanner geometry and the data acquisition physics.
- Account the noise in the data.
- Can include correction for resolution (PSF), partial volume (PVC)…

Reconstruction

FBP



Iterative reconstruction



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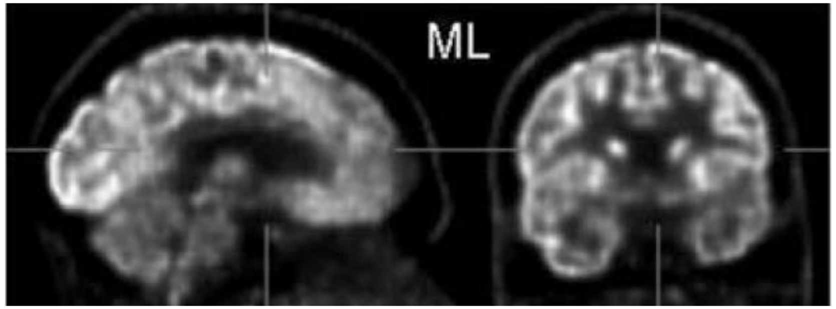
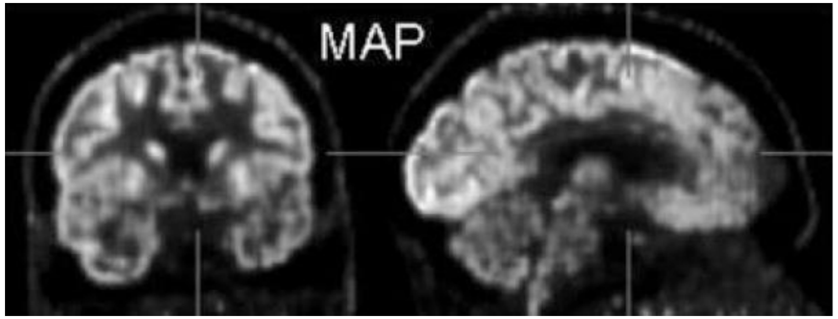
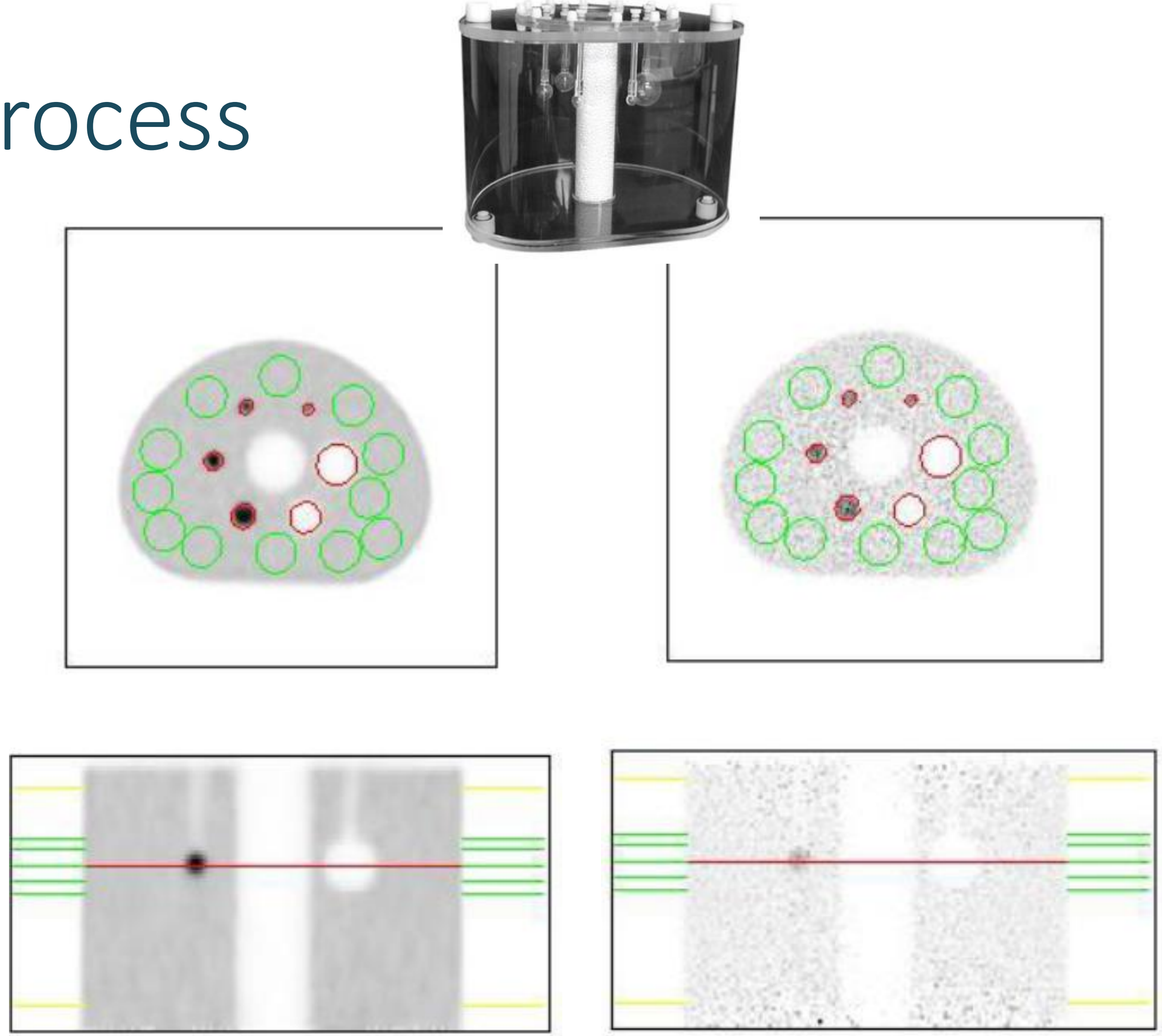
Influence of recon process







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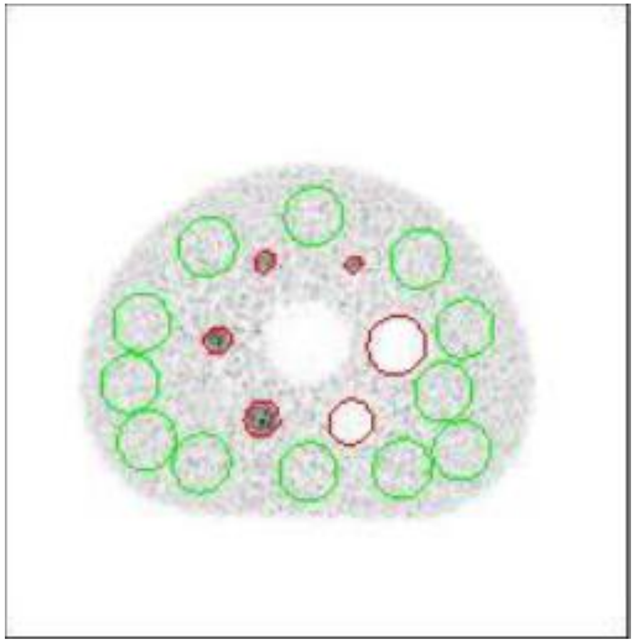
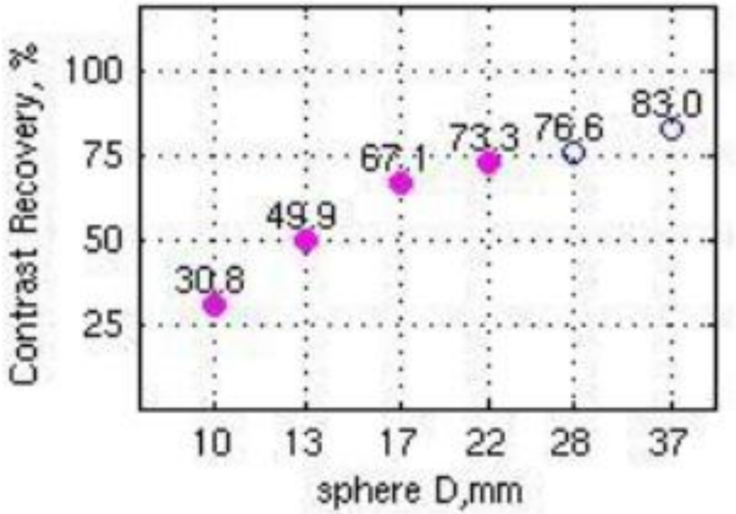
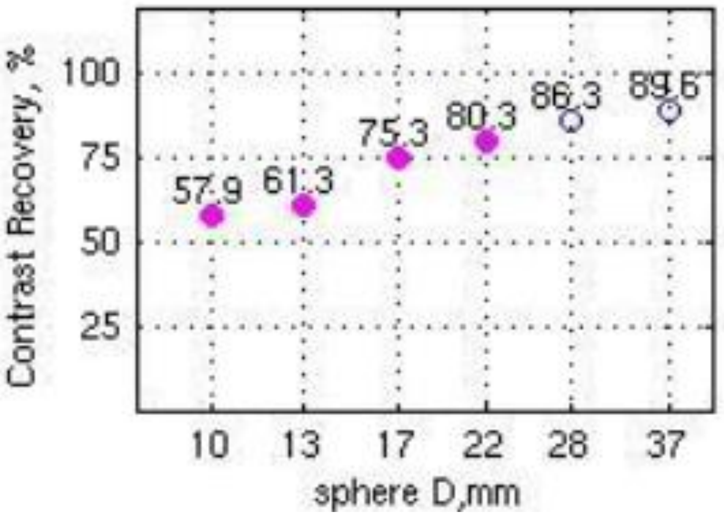
Recon method

Depends on the scanner







Influence of the number of iteration and corrections included.

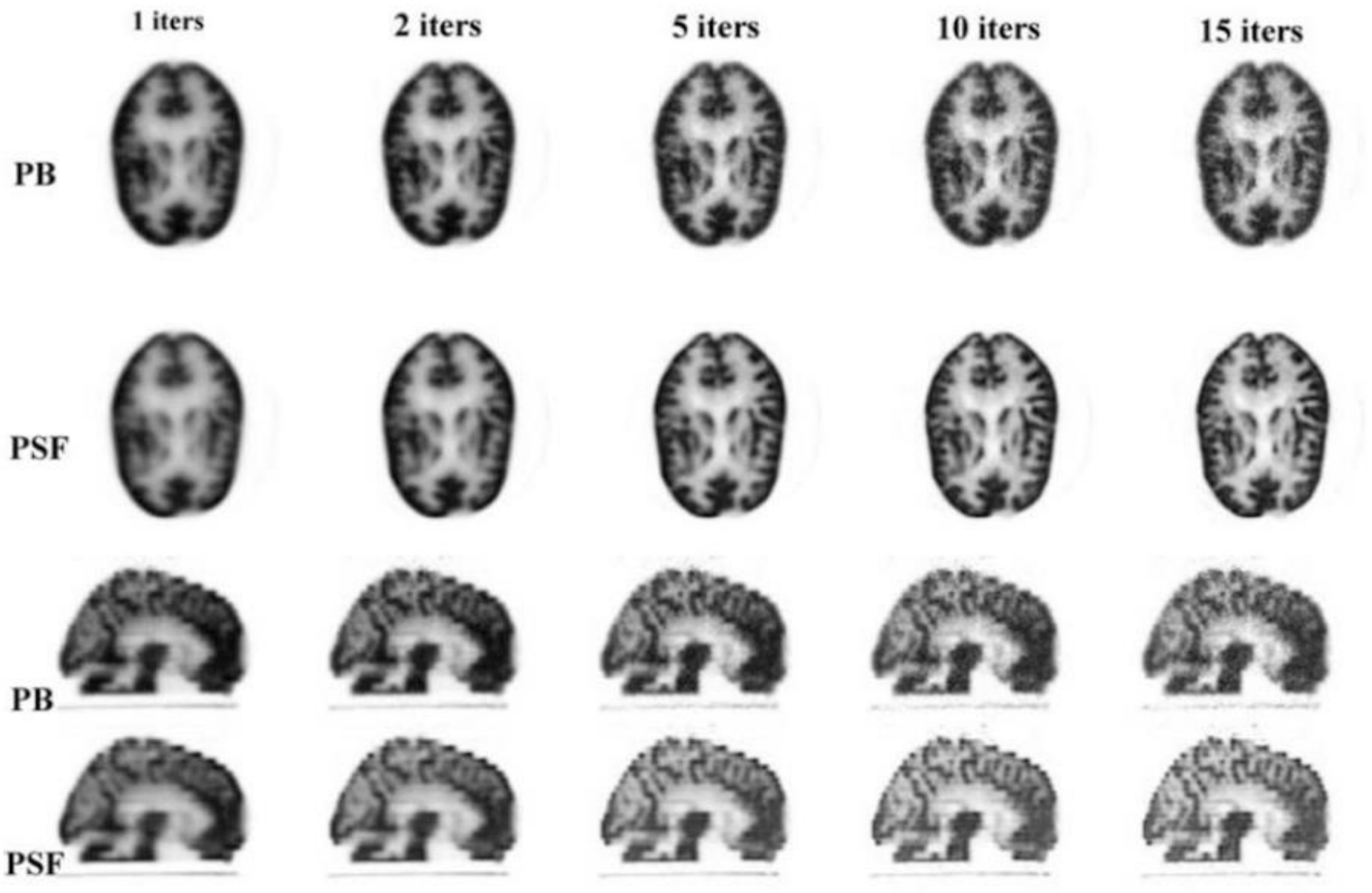


Fig. 11.7 Hoffman brain phantom reconstructions for various numbers of iterations. Upper images are transaxial views, and the lower images are sagittal views. *PB* parallel-beam, non-PSF [22]

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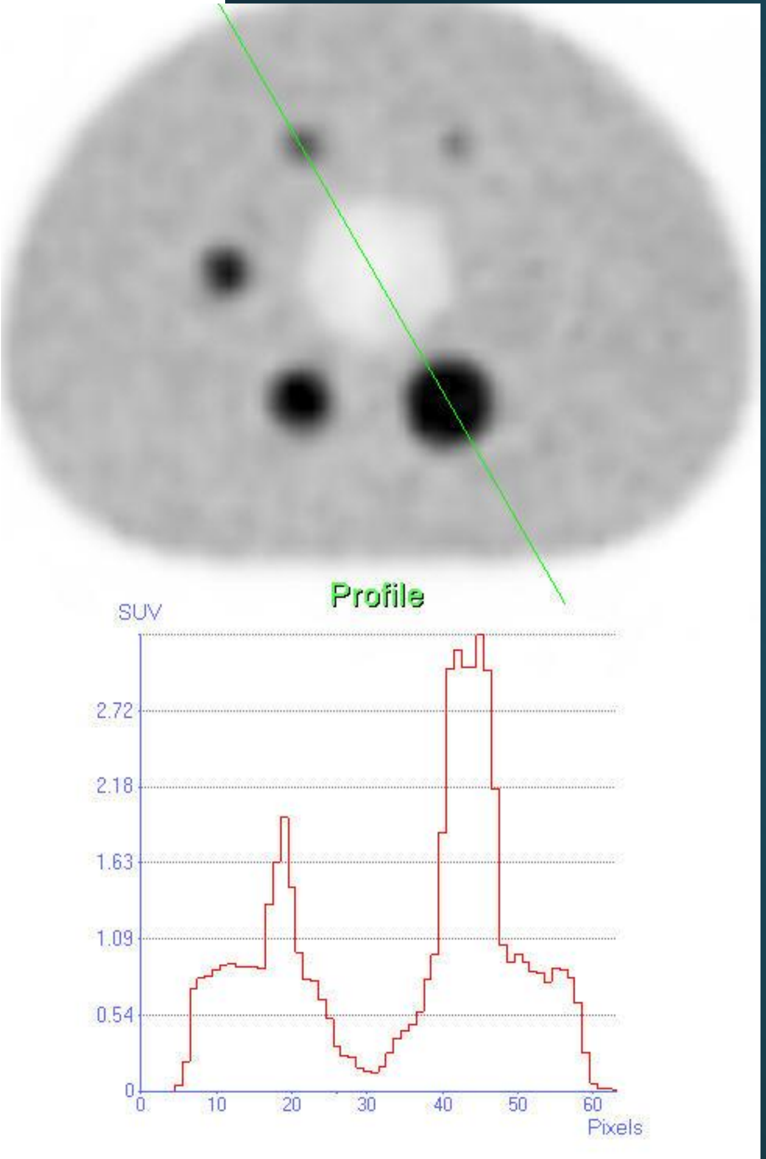
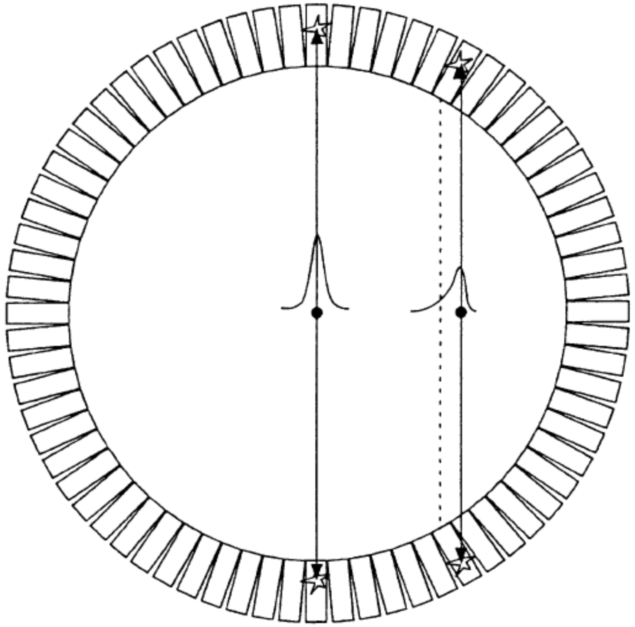
Partial volume

- Under estimation of the concentration for small structures.
- Due to
  - PSF (point spread function) limitation from the system.
  - Tissue fraction effect due to the discretization of image.



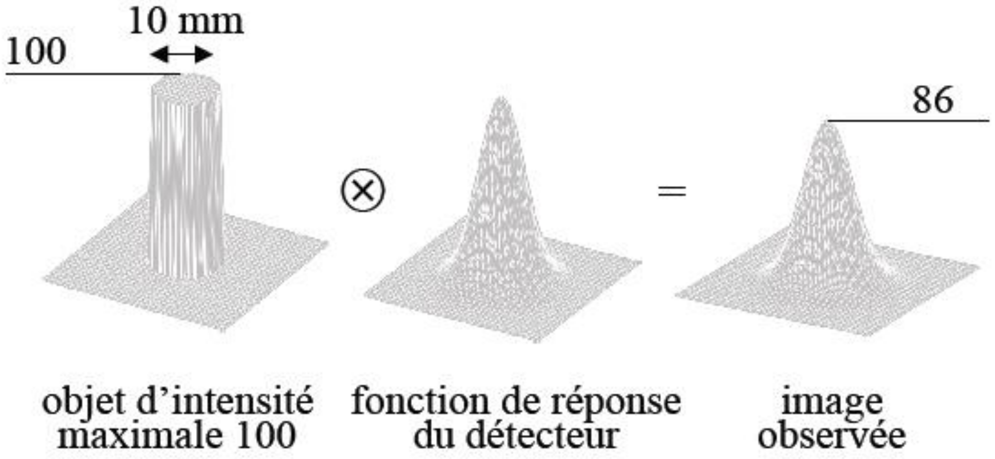
PSF = kind of smoothing

- Not uniform in the FOV.



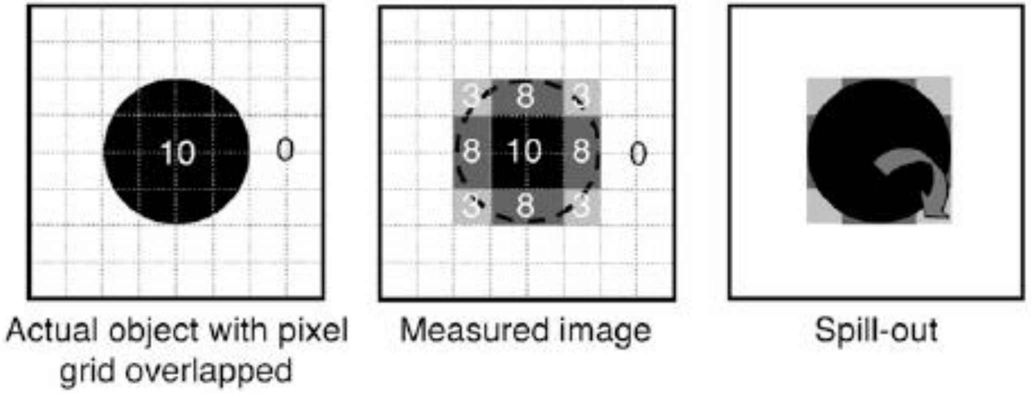
Bailey, Townsend, Valk, Maisey, *"Positron Emission Tomography,"* Springer-Verlag, 2005

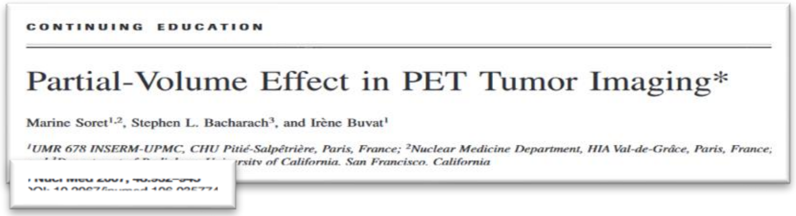
- Often modelled as a Gaussian function assumed to be constant over the FOV.



Tissue fraction effect

- Due to the finite size of image voxels.
- Voxels in boundaries between tissues correspond to a mixture of tissue types.



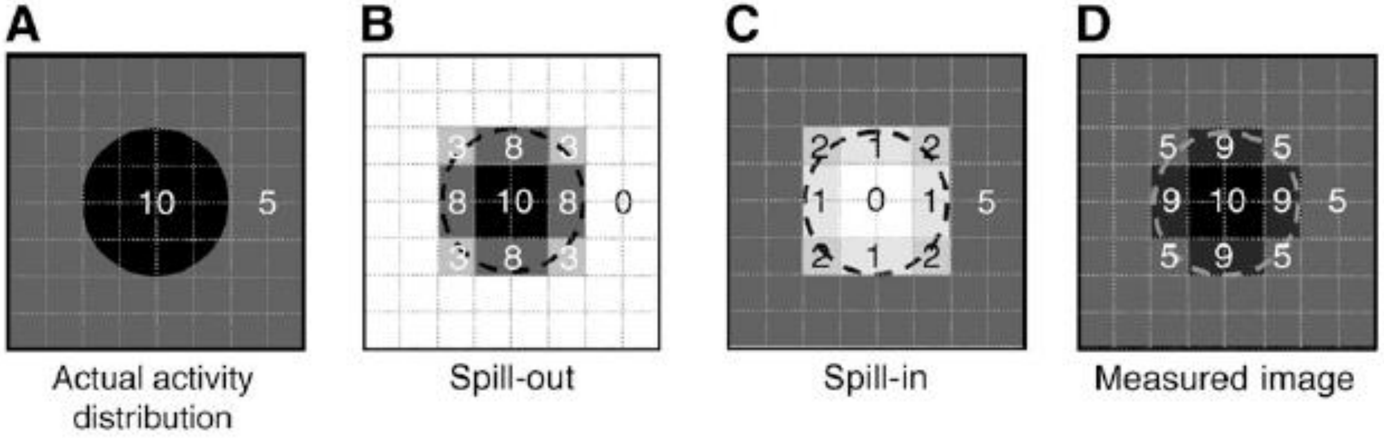


CONTINUING EDUCATION

Partial-Volume Effect in PET Tumor Imaging*

Marine Soret[1,2], Stephen L. Bacharach[3], and Irène Buvat[1]

[1]UMR 678 INSERM-UPMC, CHU Pitié-Salpêtrière, Paris, France; [2]Nuclear Medicine Department, HIA Val-de-Grâce, Paris, France; …rsity of California, San Francisco, California

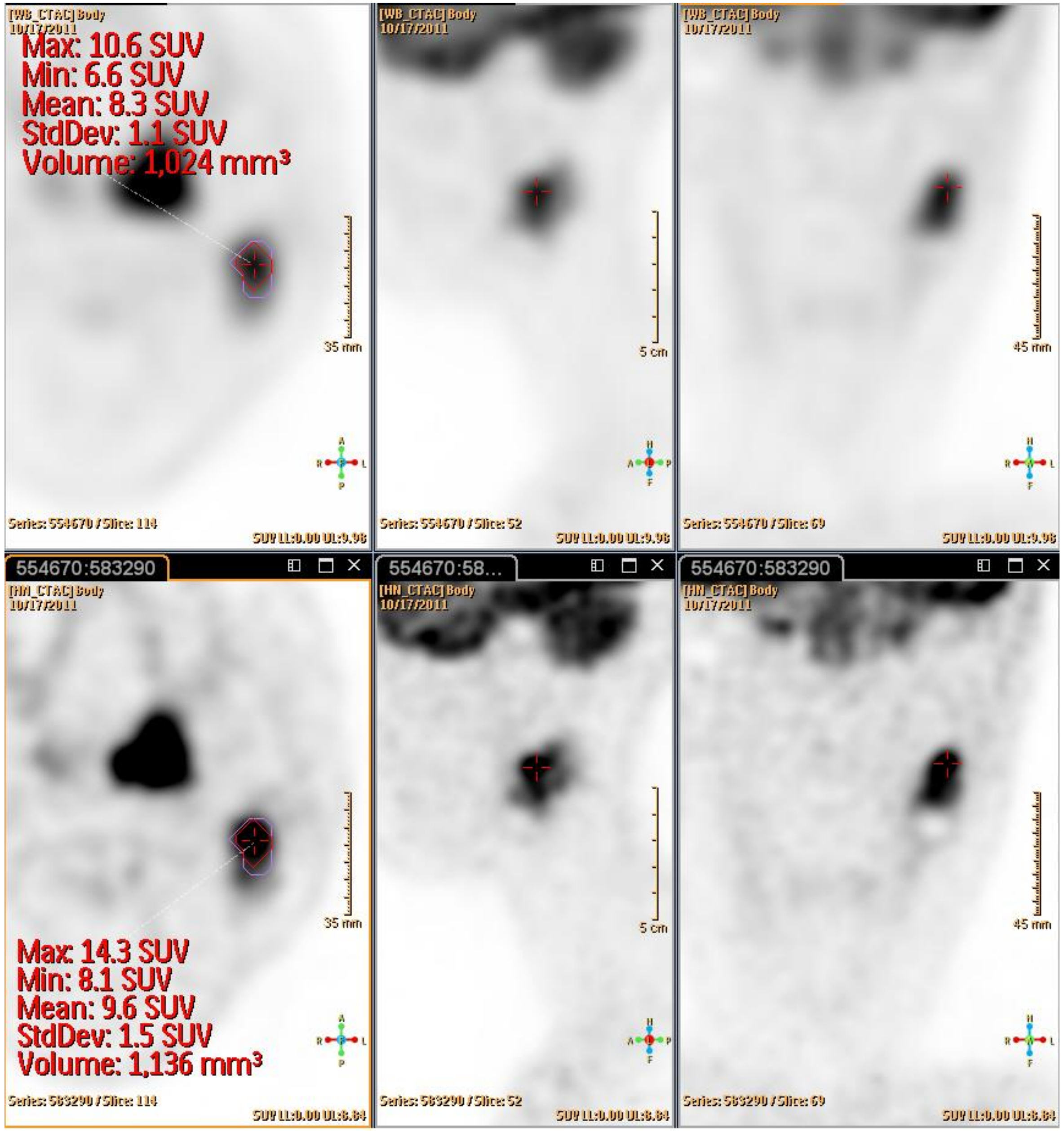


Example

cubic voxel of side size

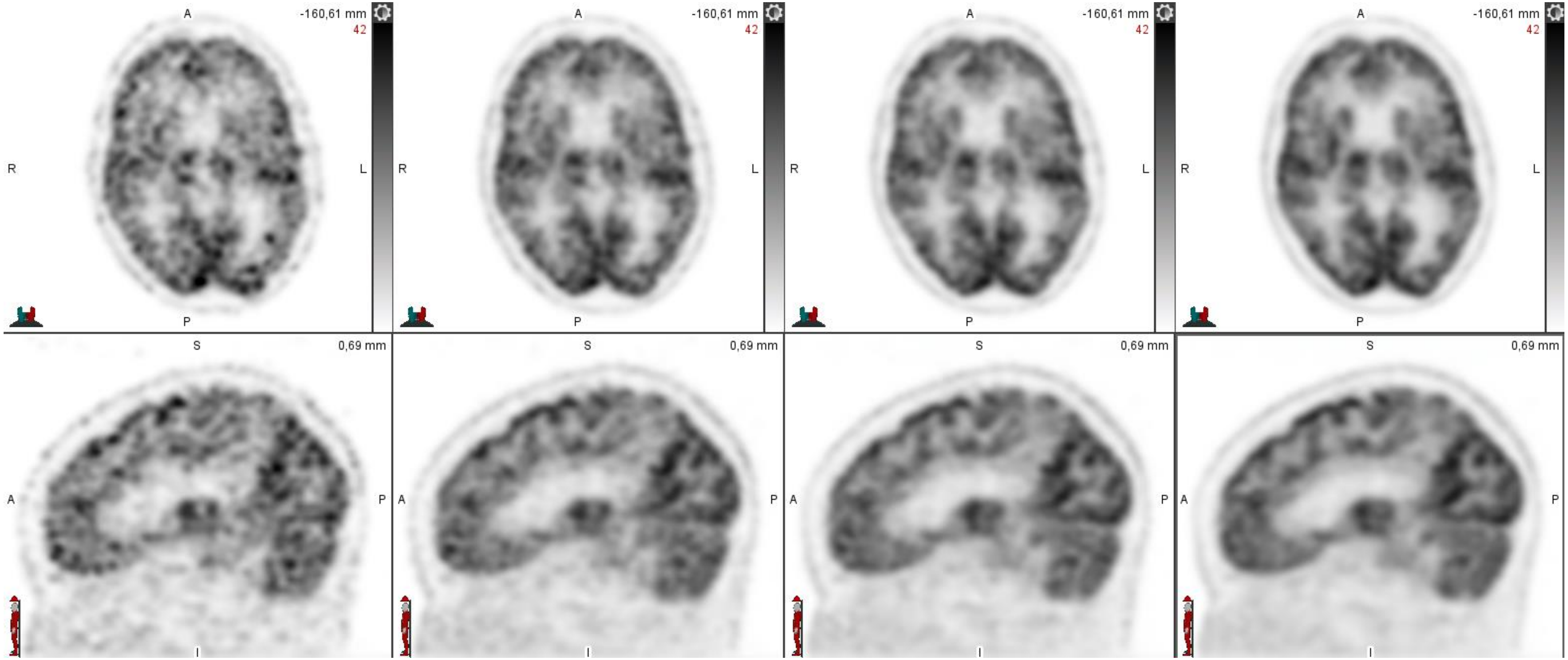
Top : 4 mm

Bottom : 2 mm



Influence of statistics

1 min 3 min 6 min 12 min



Partial volume correction

- PSF can be introduced in the projection model of the iterative process.
- PVC : use structural CT or MR information.
    - Region based.
    - Voxel based.

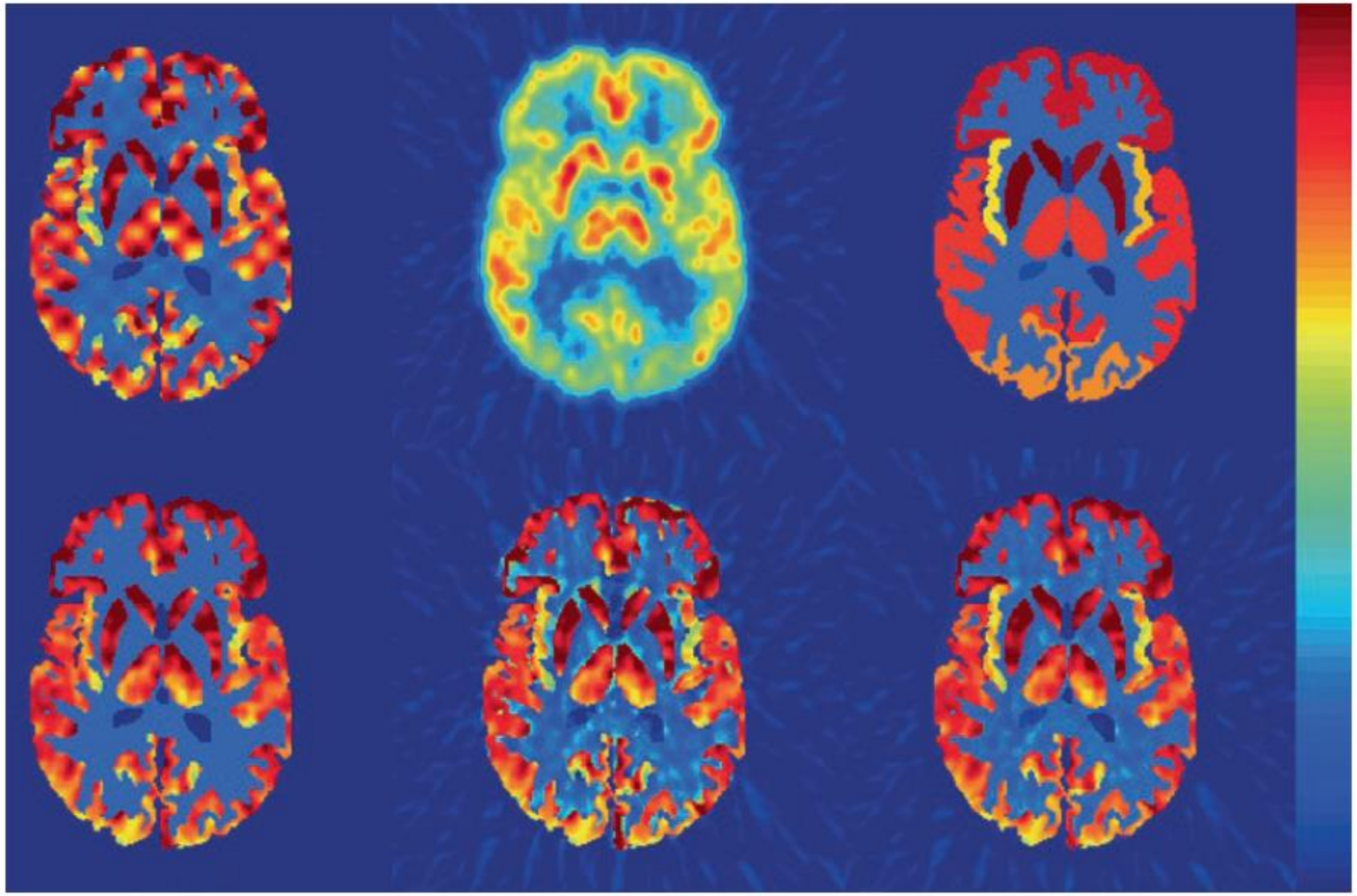


Fig. 15.12 Results of the brain phantom experiment, from *left to right* and *top to bottom*: the true activity distribution, the uncorrected image and images corrected using the GTM, MG, MTC and RBV methods

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Quantification - SUV

Quantification

The number contained in the voxel is proportional to quantities of interest

Activity concentration (Bq/ml)	SUV

Needs calibration of the imaging device

SUV standardised uptake value

- SUV expresses the uptake related to an uniform distribution of the activity in the volume of the patient.

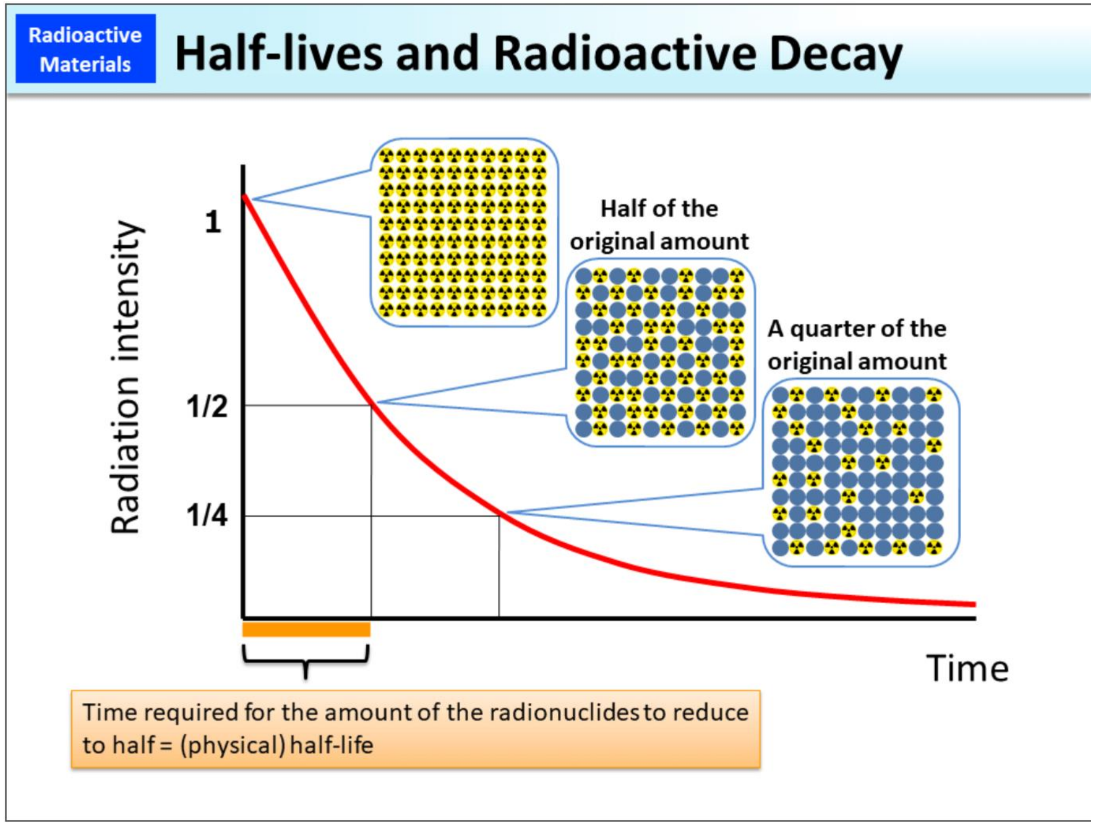
$$SUV = \frac{VOI\ concentration\ [{}^{Bq}/_{ml}]}{Injected\ activity\ [Bq]\Big/_{Volume[ml]}} \qquad [No\ unit]$$

Injected activity and concentration are expressed at same time.

- Volume usually estimated by the weight

$$SUV = \frac{Uptake\ \ [Bq/ml]}{A_{inj}[Bq]} \cdot Weight[g] \qquad [g/ml]$$

Radioactive decay



- A_0 : activity at time t_0
- A_t : activity at time t
- $\Delta t = (t - t_0)$ time delay
- T : half live of the radioisotope (T=110 min for ^{18}F)

- $A_t = A_0 \cdot e^{-0,693 \cdot \frac{\Delta t}{T}}$
- Times expressed is same unit!

Sources of error JNM 2009 : R. Boellaard

- Residual activity in the syringe : 5 %
- Clock synchronisation : 10 %
- Paravenous injection : 50 %
- Uptake period : 15 %
- Patient movement : 30 %
- Blood sugar : 15 %
- …

Thank you!

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