Partial volume correction in emission tomography imaging : from theory to clinical application

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Plan

- Quantification in emission tomography
- What is partial volume effect ?
- Why do we correct this effect ?
- State of the art of correction methods.

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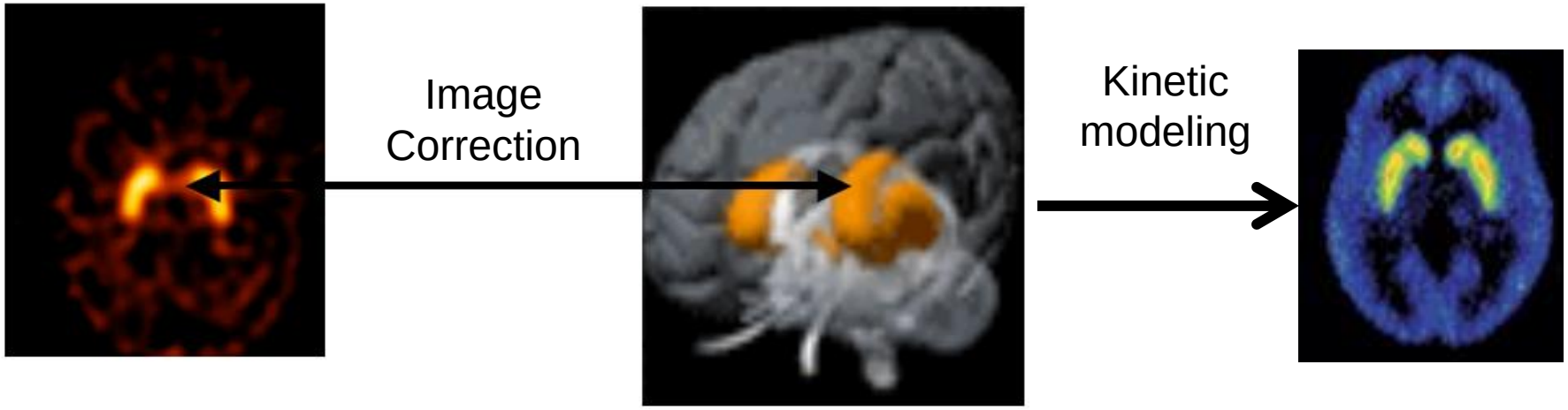
Image analysis

- 2 ways :
  - Qualitative : visual assessment of the pathology, subjective characterisation of the observation
  - Quantitative : measuring one or several parameters in the image characterizing the pathology, objective characterisation of the observation
- Quantitative measurement is an **additional** information for the radiologist in order to make the best diagnostic
- It can enhance:
  - Differential prognosis
  - Prognosis
  - Therapeutic follow-up
  - Radiotherapy treatment

What is quantification in Emission Tomography?

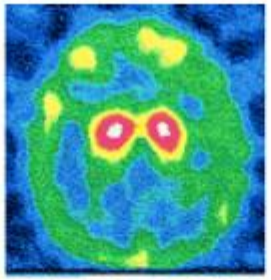


Signal intensity in the image (counts in a pixel)

True radiotracer concentration (kBq/ml) in the region

Estimation of physiological parameters (BP, SUV,etc...)

Parkinson disease

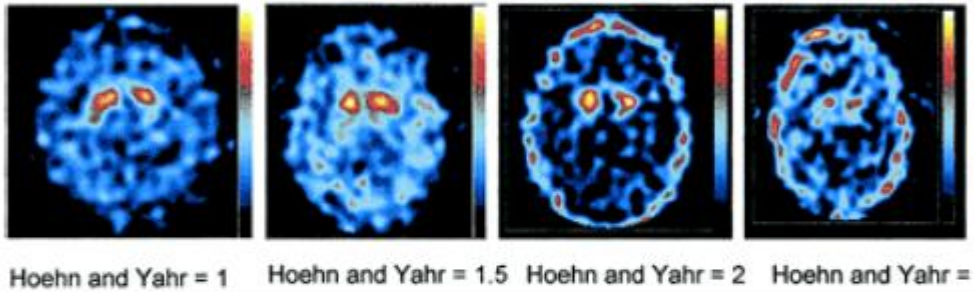


Healthy volunteer

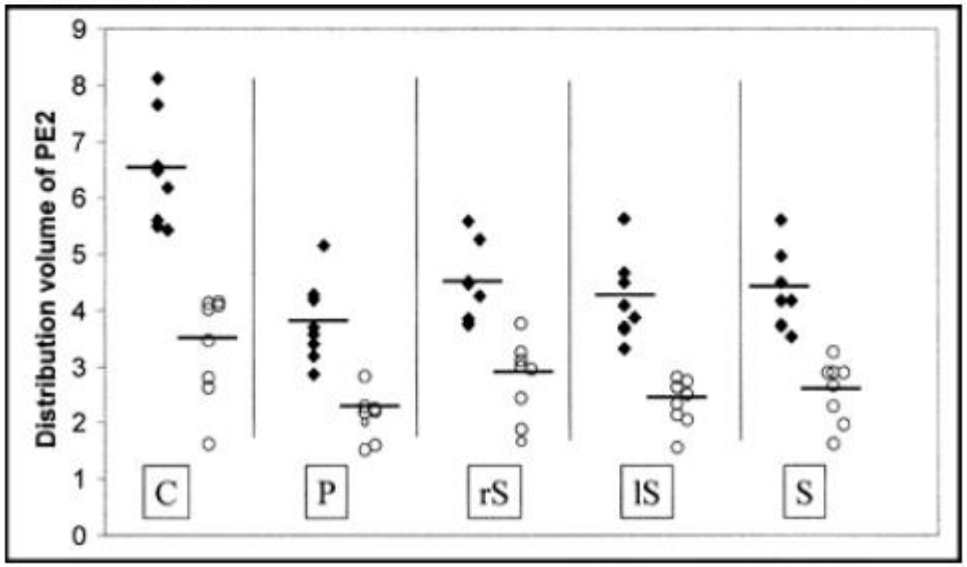
Uptake of (*E)-N-(3-iodoprop-2-enyl)-2-carbomethoxy-3-(4-methylphenyl)* nortropane (123I-**PE2I**) (cocaine analog)

↓

Imaging dopamine transporter



Hoehn and Yahr = 1 Hoehn and Yahr = 1.5 Hoehn and Yahr = 2 Hoehn and Yahr = 2.5



♦ Healthy

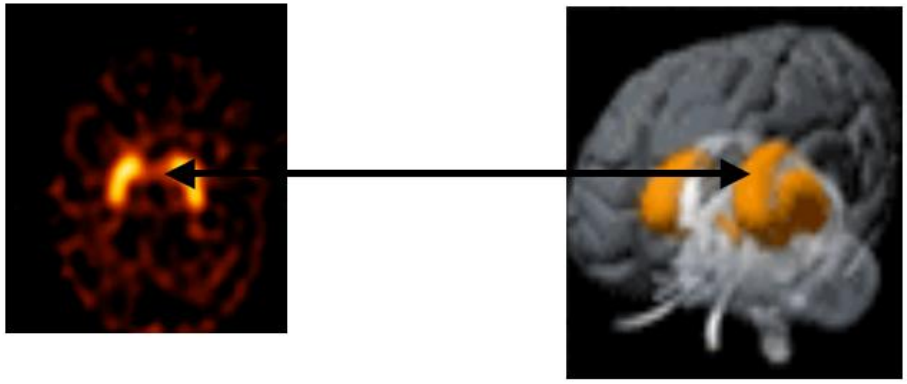
○ Parkinsonian

C : caudate
P : putamen
rS : right striatum
lS : left striatum
S: striatum

Prunier et al, J Nucl Med 2003

Quantification challenges

N: number of counts in a pixel
C: radiotracer concentration



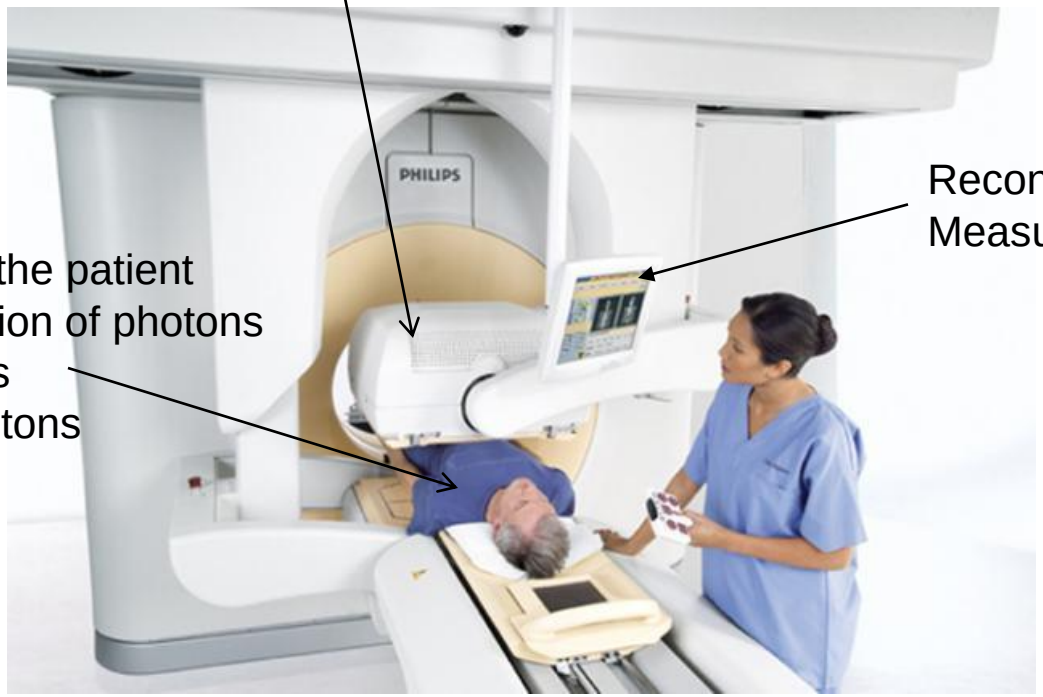
Objective : N=k.C <- estimate k <- find C

BUT

No linear relation between pixel value and tracer concentration

From photon emission to pixel value

CAMERA
- Limited spatial resolution
- Non-detected photons



PATIENT
- Mouvement of the patient
- Random emission of photons
- Scatter photons
- Attenuated photons

POST-PROCESSING
- Reconstruction algorithm
- Measurment tool (ROI)

Every measure is <u>biaised</u> and this bias is <u>dependent on the machine</u> you are using

Bias sources

- Attenuation in the patient:
  - Any photon emitted from inside the patient has a certain chance to be stopped by the tissues / bones on its path towards the detectors (photoelectric interaction with matter)
    - PET: single events, loss of events in regions with bones
    - SPECT: loss of events in regions with bones
- Scatter in the patient:
  - Any photon emitted from inside the patient has a certain chance to be deviated by the tissues / bones on its path towards the detectors (Compton interaction with matter)
    - PET: single and random events
    - SPECT: loss of events (collimator), mislocalized events.

Plan

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- Why do we correct this effect ?
- State of the art of correction methods.

Glucose metabolism in normal aging

- Moeller, 1996, *The metabolic topography of normal aging* : decrease in glucose metabolism with normal aging

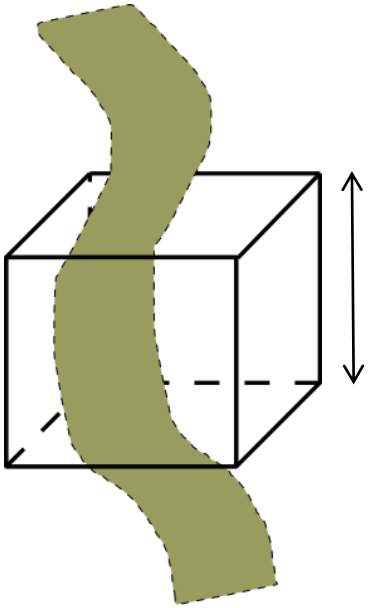
- Measure decrease in metabolism can be causedcaused by :
  - age -> include it in the statistical analysis
  - atrophy of the cortex-> ?

- Ibanez, 2004 : *Resting state brain glucose metabolism is not reduced in normotensive healthy men during aging, after correction for brain atrophy*
  - age -> include it in the statistical analysis
  - atrophy of the cortex -> partial volume correction

- NO REDUCTION IN GLUCOSE METABOLISM WITH NORMAL AGING

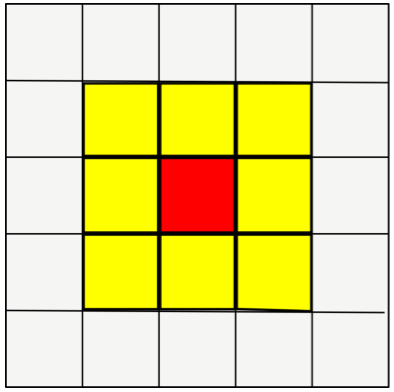
Definition

- Partial volume effect (PVE) is a term gathering two effects introducing bias in the measure :
  - Tissue fraction effect



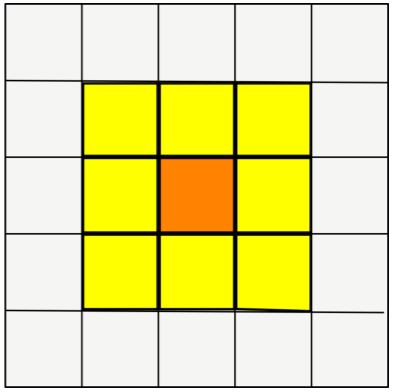
Voxel size : 2.66 x 2.66 x 2 mm (PET in Radium)

Cortex thickness: ~1-4mm



Physiological ratio uptake
GM/WM : 4/1

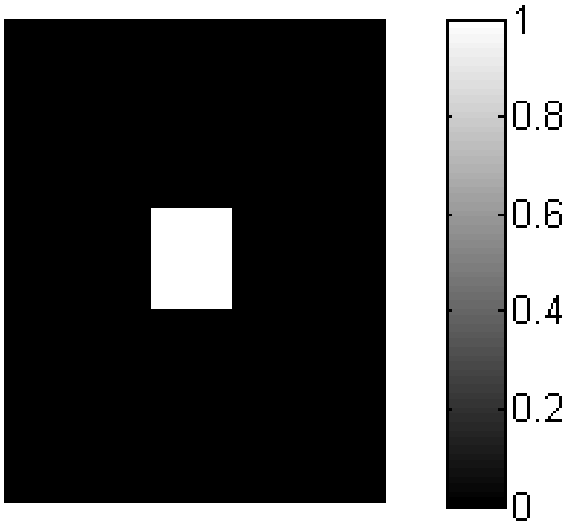
but



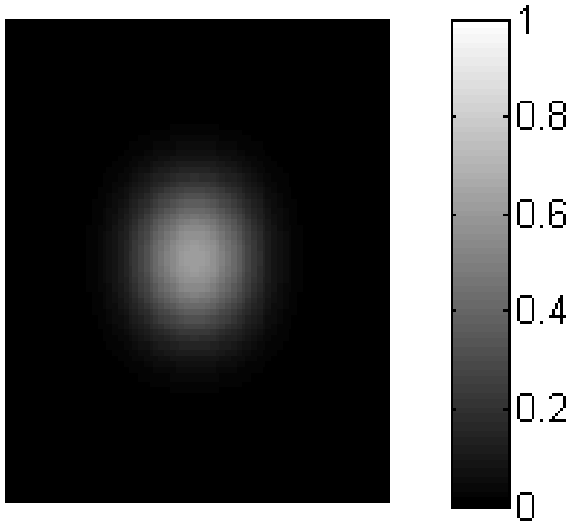
Measured ratio uptake
GM/WM : 2~2.5/1

Definition

- Partial volume effect is term gathering two physical effects introducing bias in the measure :
  - Intensity blurring



Want to see



Really see

Underlying causes of intensity blurring

- **Limited spatial resolution**
  - Physical:
    - Positron range, non-colinearity (PET)
    - Scattered radiation
  - Instrumental:
    - Crystal size
    - Detection efficiency and geometrical arrangement
    - Collimator geometry (SPECT)
  - Methodological:
    - Parameters for image acquisition
    - Reconstruction process

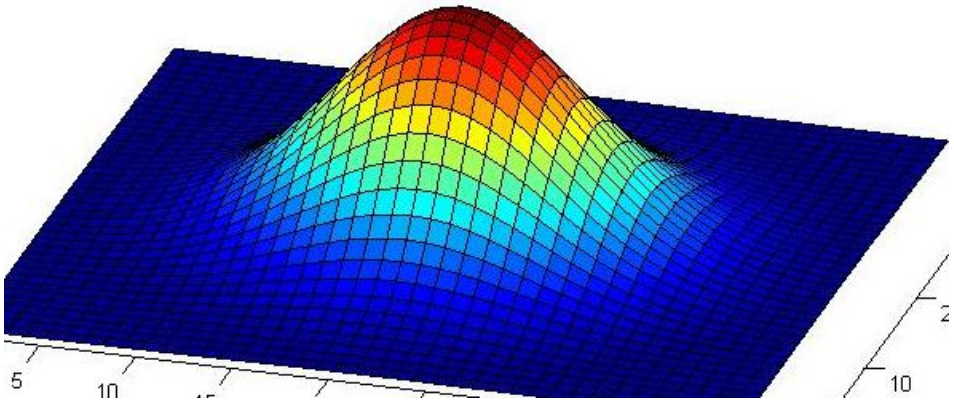
Problem formulation

g: measured image

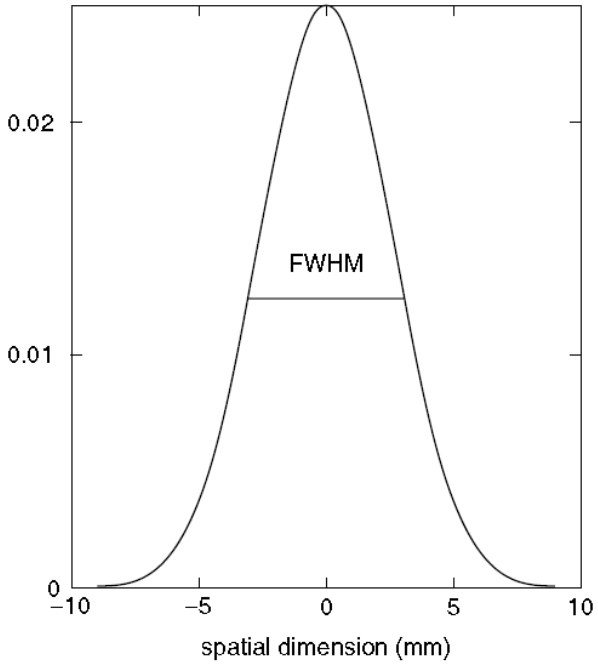
f : concentration distribution in the body

$$g(x,y) = h(x,y) \otimes f(x,y)$$

h: all the possible source of bias, model by a point spread function (PSF)

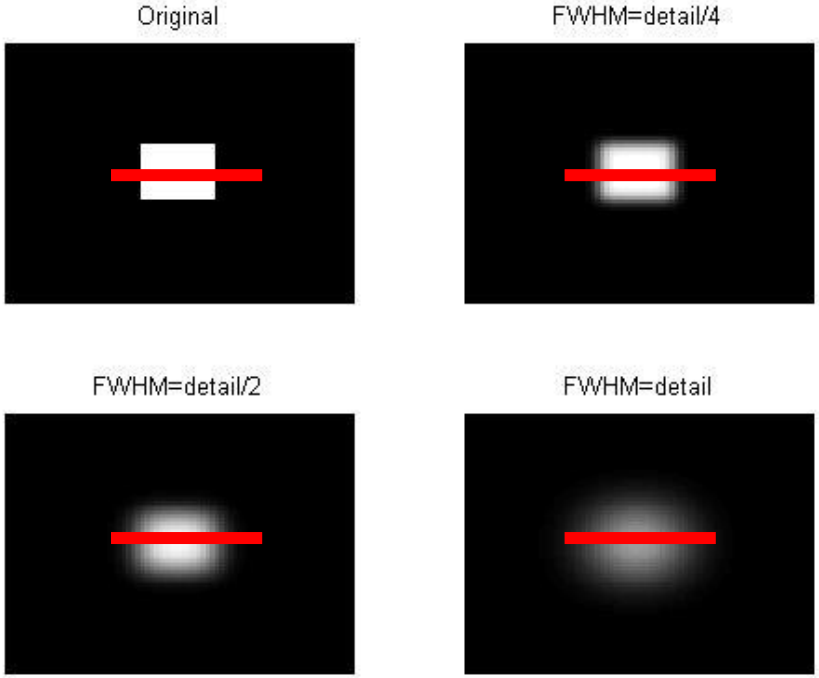


2D

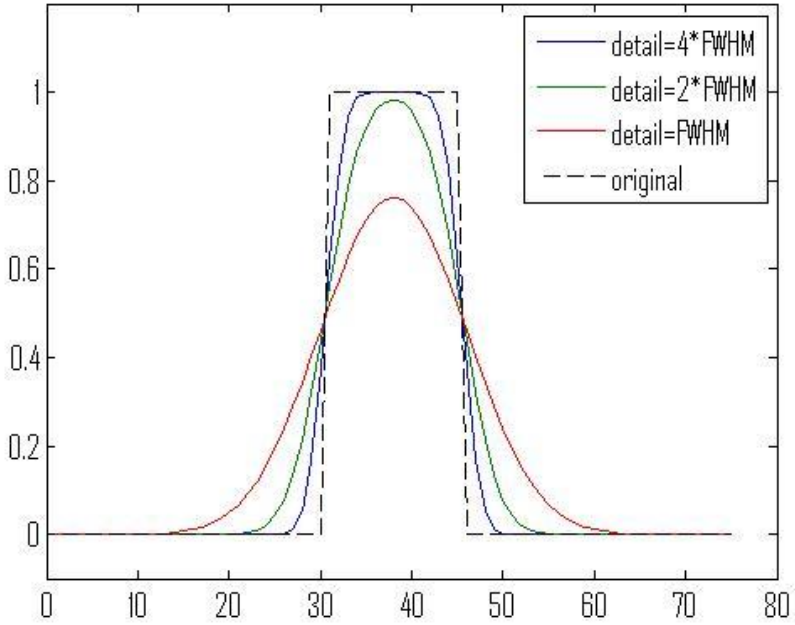


1D

Relation btw details and FWHM



2D



1D

Consequence

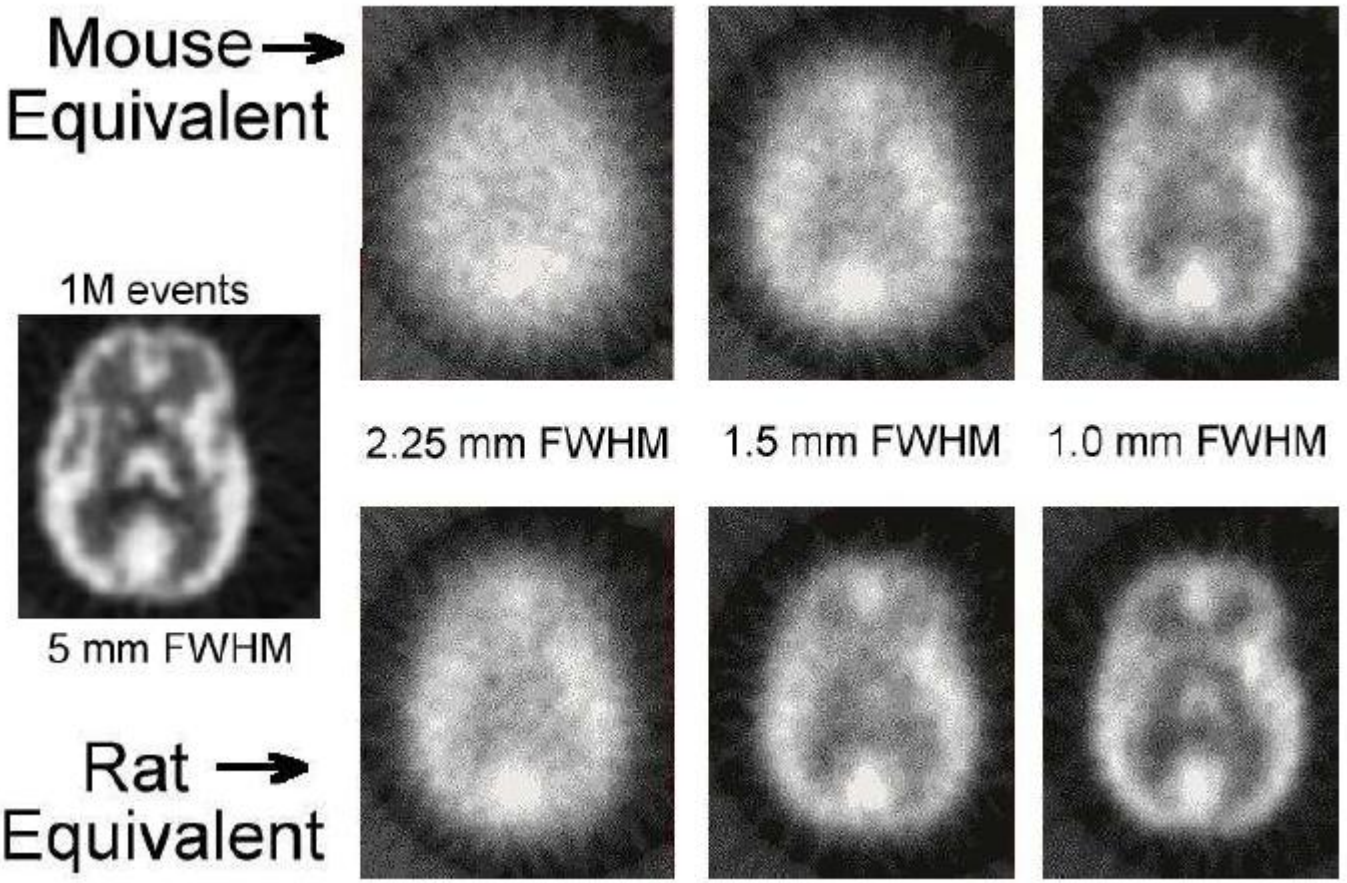
100% of the original true activity

↓

Size of the detail > 2 x FWHM

- PET in Radium:
  - FWHM of 5.9 x 5.9 x 5.1 mm -> details > 1.2cm are without bias
- SPECT in Ahus:
  - Brightview XCT : (annonced) FWHM of
    - 3D-FBP : 8.3mm -> details > 1.7cm
    - OSEM: 5.8mm -> details > 1.2cm
- Small animal PET in CMBN, UiO :
  - MicroPET Focus 120 : FWHM of
    - 3D-FBP: 2.1mm -> details > 4.2mm
    - Iterative: 2.8mm -> details > 5.4mm

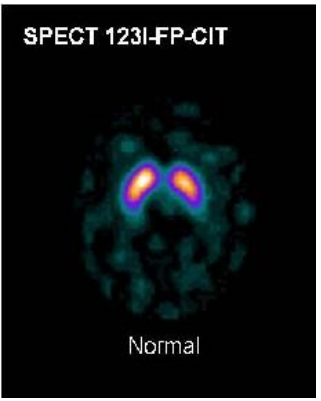
Preclinical better resolution ?



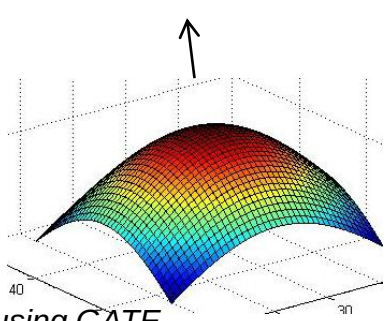
Miller et al., Proceedings IEEE, 2003

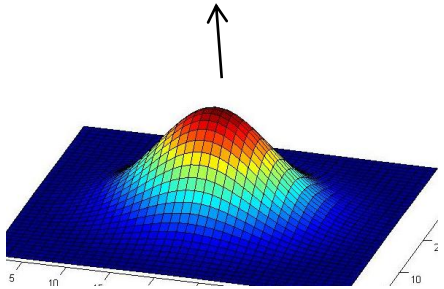
Correction of biases

- Scatter, attenuation and partial volume effect are the three main sources of bias, and they are independant : correct separetly

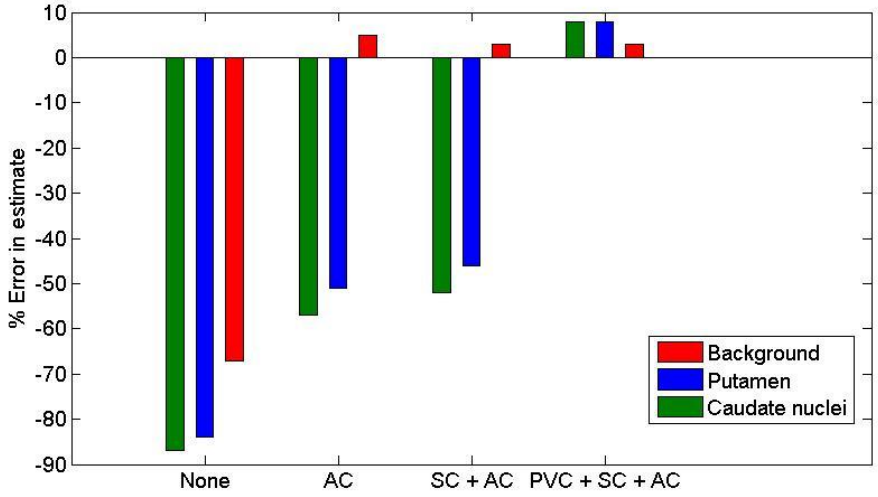


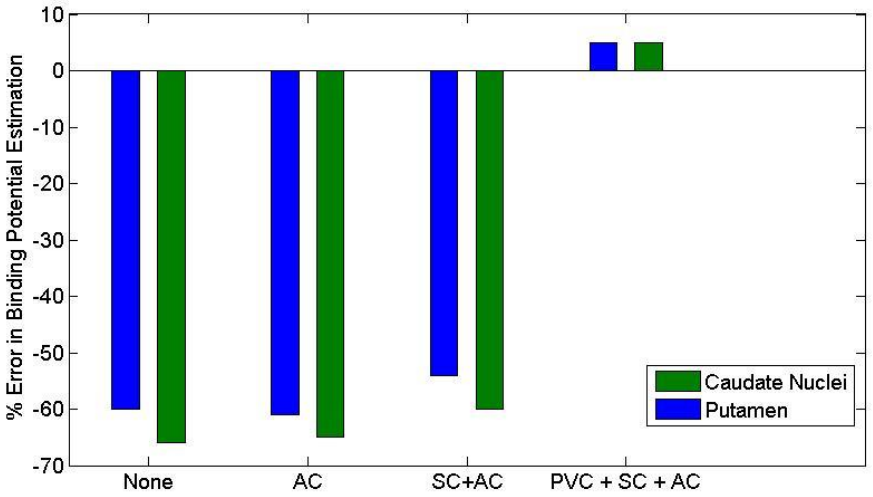
$$h(x,y) = h_{scatter}(x,y) + h_{att}(x,y) + h_{pve}(x,y)$$





Soret, JNM, 2003 *Simulation and phantom study using GATE*





Partial volume correction

- Which approach to choose ?
- Depends on the a-priori information we have on the uptake localisation and the hypothesis we accept to do to simplify the problem:
  - Recovery coefficent technique -> easy but inaccurate
  - Embeded in the reconstruction
  - Post-recontruction
    - Pixel based :
      - with anatomical a-priori
      - wihtout anatomical a-priori
    - Region based

More accurate but not straightforward

Tumor imaging

Hypothesis

Existing methods

TABLE 1
Summary of Main Properties of 8 PVE Correction Approaches*

Property	RC	GTM	Deconvolution	Partition based	Multiresolution	Fitting	Anatomic maximum a posteriori	Kinetic modeling
Assumes tumor is spheric?	**No**	**No**	**No**	**No**	**No**	Yes	**No**	**No**
Assumes known tumor volume?	Yes	Yes	**No**	Yes	**No**	Yes	Yes	**No**
Assumes uniform tumor uptake?	Yes	Yes	**Not necessarily**	Yes	**No**	Yes	**No**	**No**
Assumption(s) regarding tissues surrounding tumor	Locally uniform, known uptake	Piecewise constant, unknown uptake	**No**	Piecewise constant, known uptake	Gray levels correlated with those of anatomic data	Locally uniform, unknown uptake	Partially known	**No**
Needs anatomic data?	**Not necessarily**	Yes, registered	**No**	Yes, registered	Yes, registered	**No**	Yes	**Not necessarily**
Mode of action	**After reconstruction**	**After reconstruction**	**After reconstruction**	**After reconstruction**	**After reconstruction**	**After reconstruction**	During reconstruction	After reconstruction, time series required
Type of results	Tumor uptake value	Tumor average uptake value	Tumor average uptake value	**Image of tumor compartment**	**PVE-corrected image**	Tumor average uptake value	**PVE-corrected image**	Kinetic parameters compensated for PVE
Reference(s) for PET tumor imaging	*7,17,18,22,23,50,51,53,54*		*30*		*37*	*38*		*47,50*

Apriori information

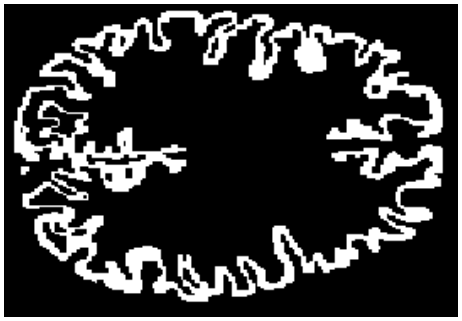
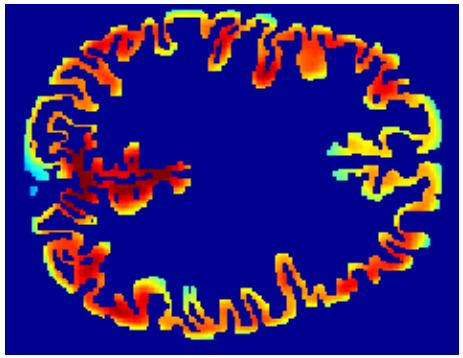
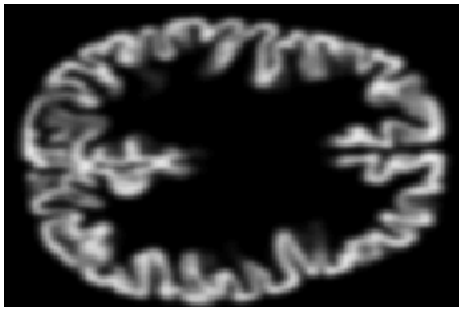
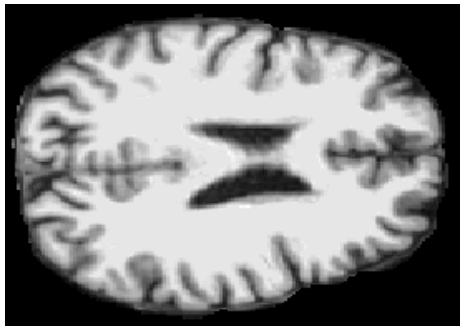
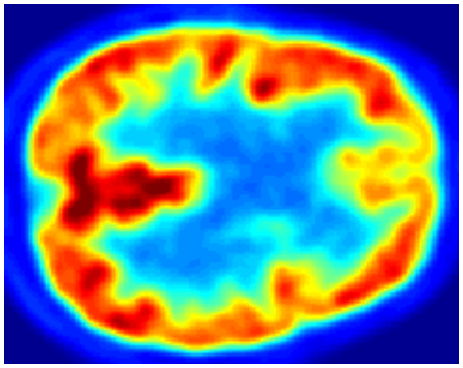
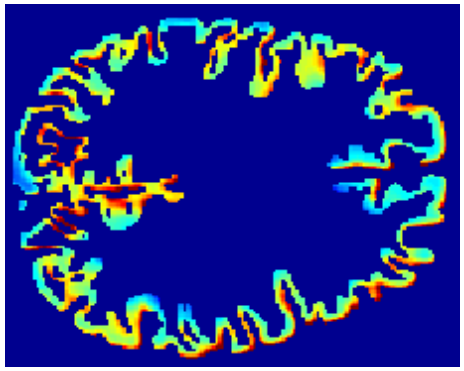
Format of the result

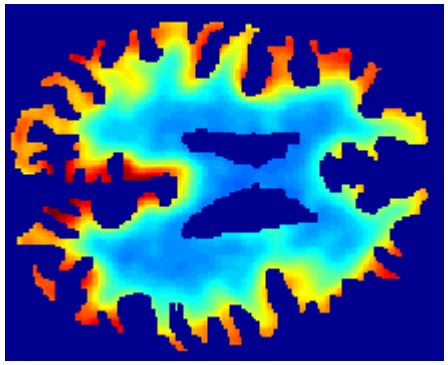
Soret JNM, 2007

Pixel based with anatomical information

- True activity distribution : N non overlapping compartments with a known uniform uptake except for the compartment of interest.
- Brain application : N=2 (GM, WM), N=3 (GM, WM and CSF)
- Hypothesis : uptake in the whole WM is constant
- A-priori information needed : segmented MRI to define the GM and WM binary maps
- Type of result : PV-corrected image

Pixel based method

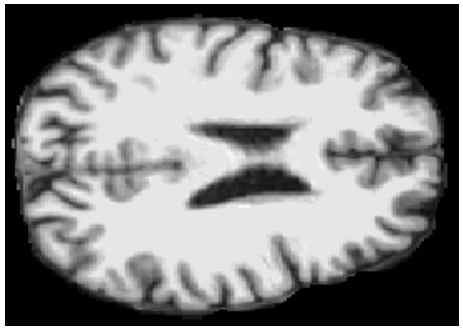



ROI based with anatomical information

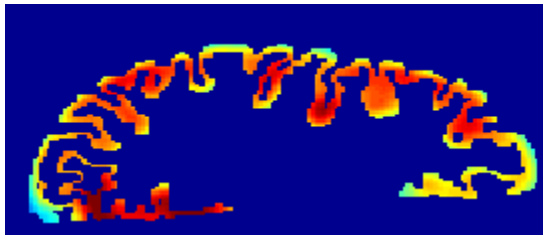
- True activity distribution : N non overlapping compartments with a unknown uniform uptake in the defined regions.
- Brain application : N=3 (GM, WM), N=6, N=32,…
- Hypothesis : uptake is constant in the defined regions
- A-priori information needed : region delineation (MRI)
- Type of result : corrected uptake value in the regions.

ROI based

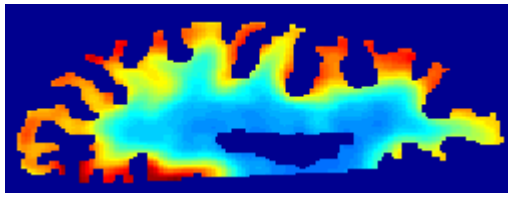
exemple with N=4

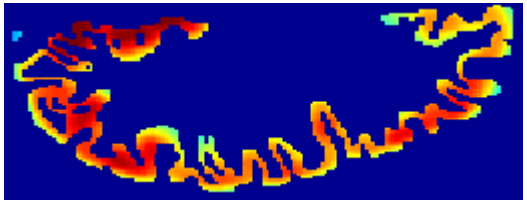


ROI 1 : left cortical GM

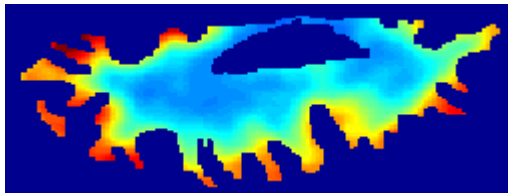


ROI 2 : left sub-cortical WM





ROI 3 : left cortical GM



ROI 4 : left sub-cortical WM

On 96 subjects

	Ratio Left GM / Left WM	Ratio right GM / right WM
Before correction	1.28	1.24
After correction	5.58	4.22

ROI CT based _ Tumor imaging

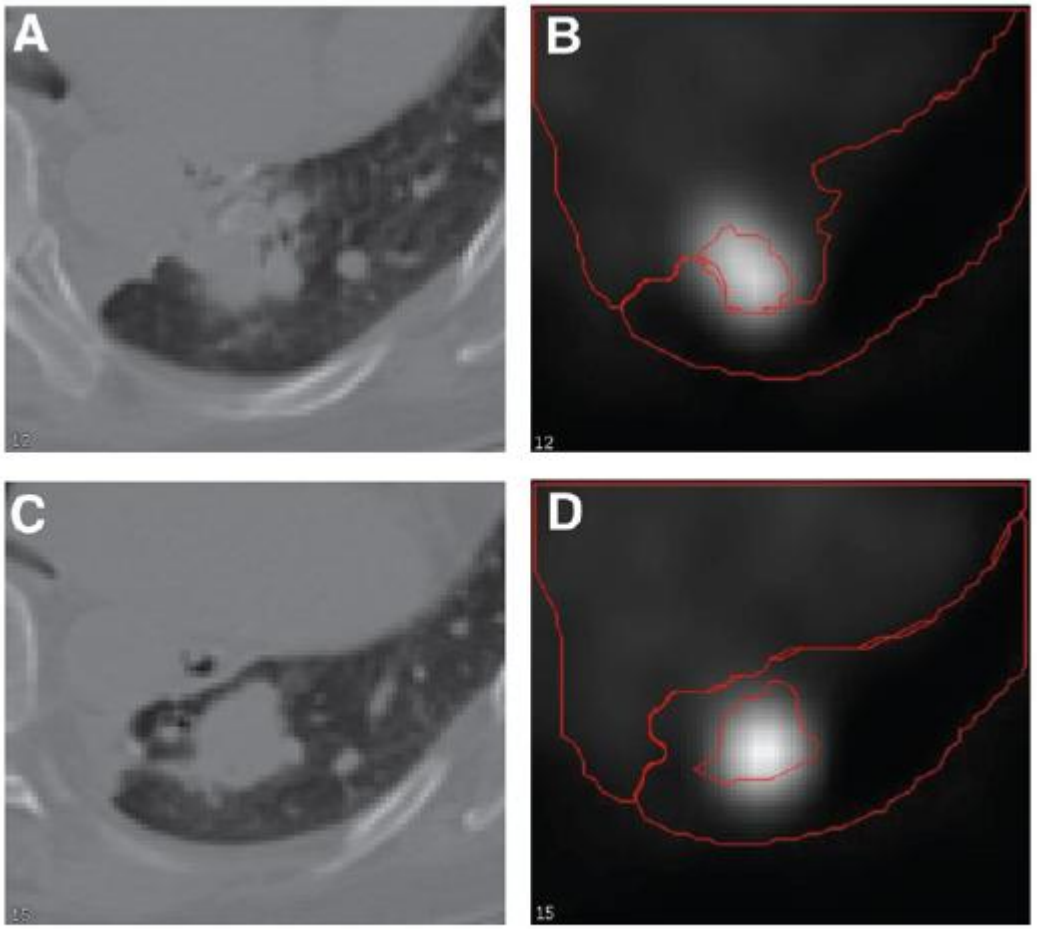


FIGURE 13. CT (A and C) and PET (B and D) images corresponding to 2 slices through lung tumor. Compartment contours as drawn from CT are shown in red on PET images.

Soret JNM, 2007

What about clinical routine

...

Feasibility of Automated Partial-Volume Correction of SUVs in Current PET/CT Scanners: Can Manufacturers Provide Integrated, Ready-to-Use Software ?

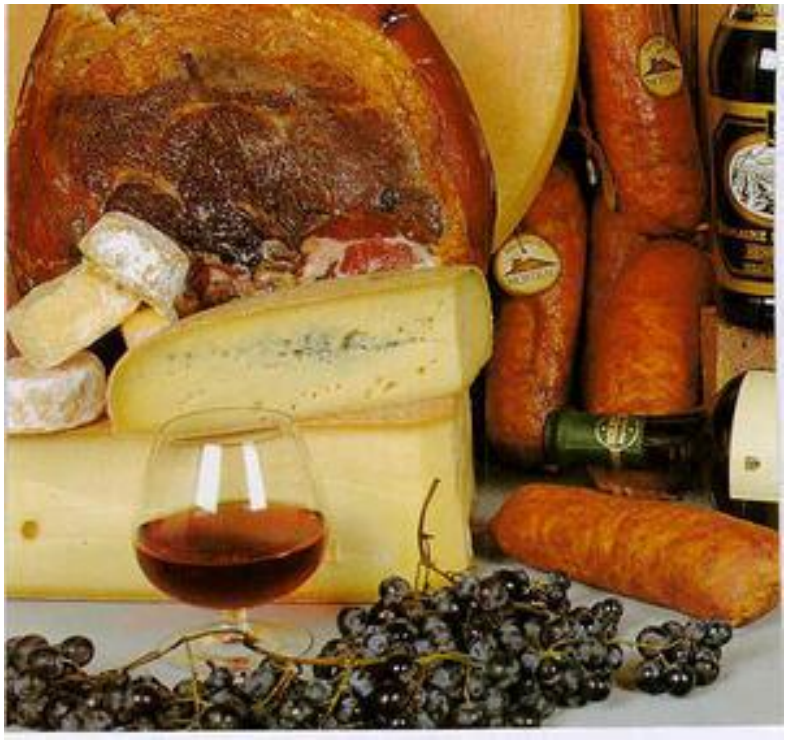
The availability of integrated algorithms would likely improve reproducibility and reduce operator-dependent errors on SUV calculation.

S.Basu, JNM 2008

Oasis (Segami) provides a recovery coefficient correction for partial volume effect

End

THANKS FOR YOUR ATTENTION



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