Quantification in emission tomography: challenges, solutions, performance and impact

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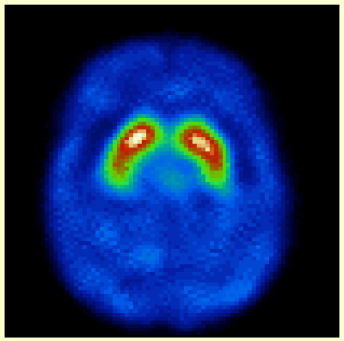
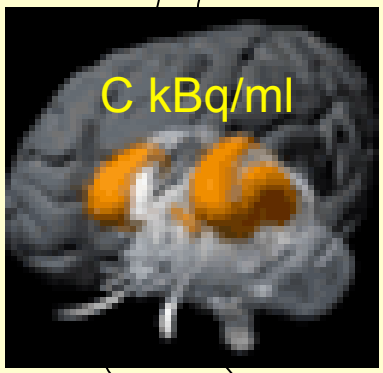
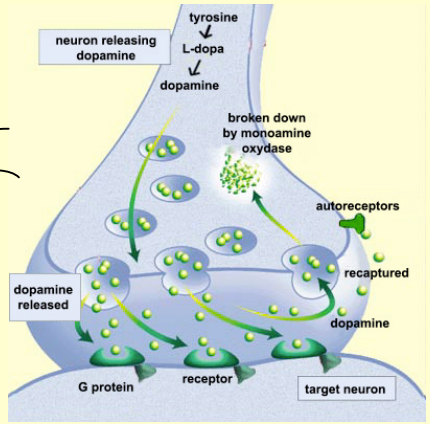
What is quantification in emission tomography?

Extracting *physiologically meaningful values* from PET or SPECT images



SPECT image





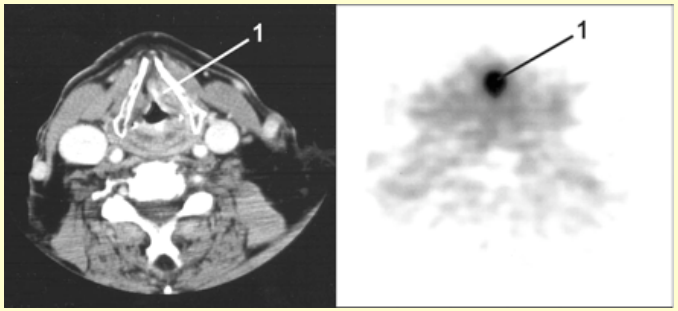
Density of dopaminergic transporters

Why do we need quantification?

Physiological parameters are richer than visual assessment

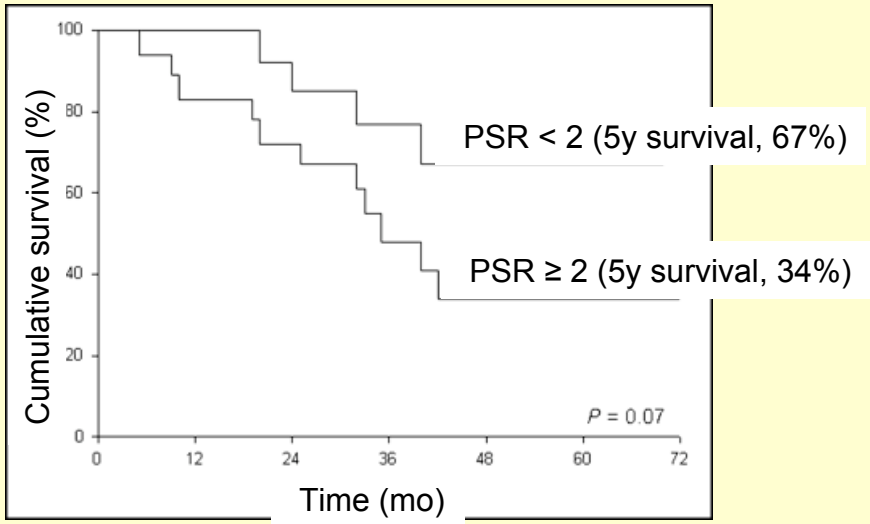
- Differential diagnosis
- Prognosis
- Therapeutic management
- Treatment monitoring
- Radiotherapy

CT C11-TYR PET



Supraglottic squamous cell carcinoma

Cumulative survival of patients with T1–T4 laryngeal carcinomas (*n* = 34)

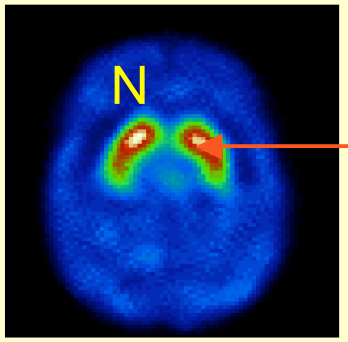


PSR: protein synthesis rate from C11-TYR PET

de Boer et al, J Nucl Med 2004

Is quantification easy?

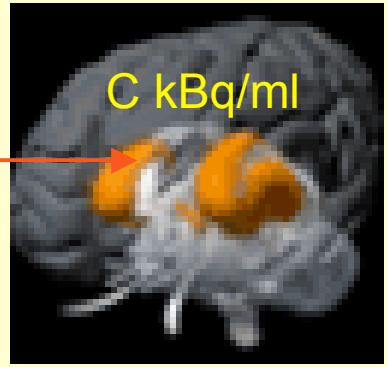
No



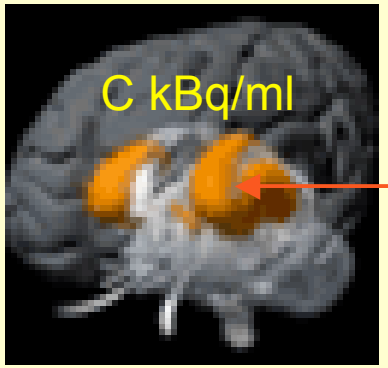
ET image

$N \neq k\,C$

Find $C=f(N)$



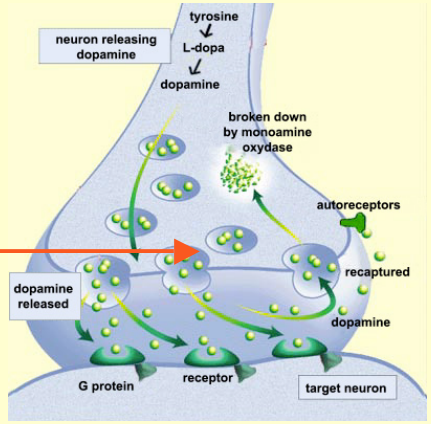
Radiotracer concentration



Radiotracer concentration

$C \neq k'\,\phi$

Find $\phi = g(C_i, P_n)$

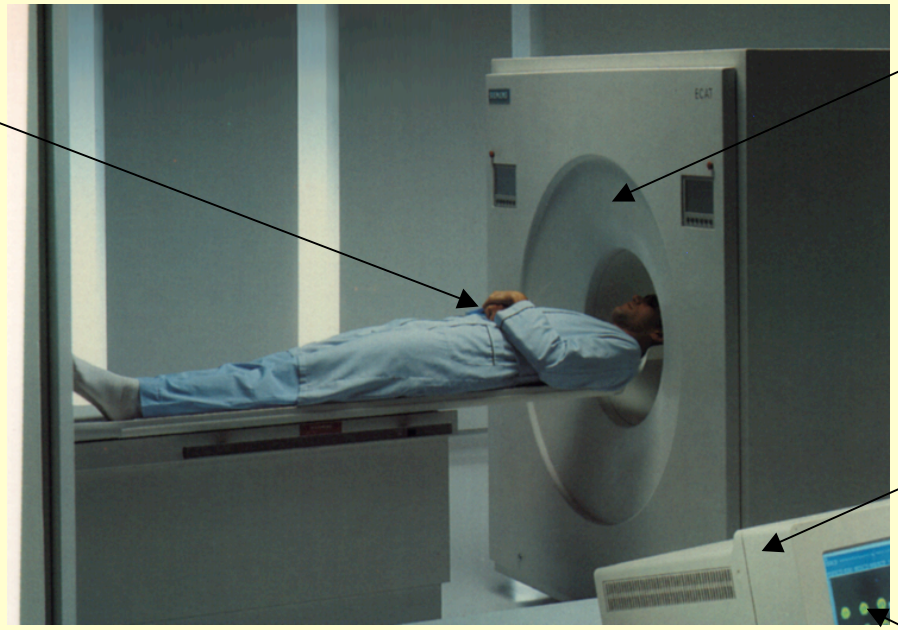


Density of dopaminergic transporters

Deriving radiotracer concentration from ET images

What should be accounted for

- patient motion
- photon attenuation
- photon scatter



- limited spatial resolution
- [randoms (PET)]
- [deadtime]

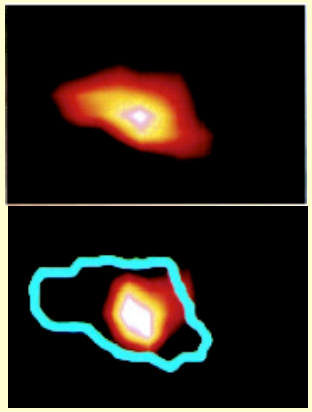
- tomographic reconstruction

- measurement procedure

Patient and organ motions

Spurious or physiological (cardiac, respiratory)

Lung FDG PET



with respiratory motion

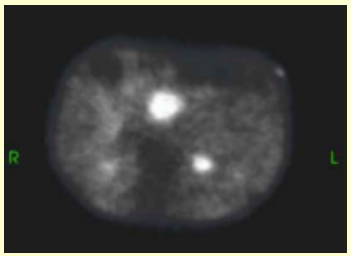
without

➡ Increase of lesion size from 10% to 30%

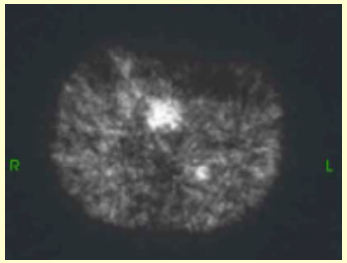
➡ Decrease of SUV_{max} from 5% to > 100%

Nehmeh et al, J Nucl Med 2002:876-881

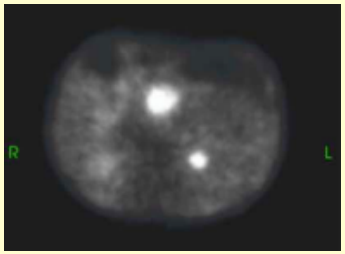
- Reduce scan duration
- Gating (cardiac, respiratory, or both) and further processing



no gating



keeping one gate



gating + combining gates

Li et al, Med Phys 2006:1288-1298

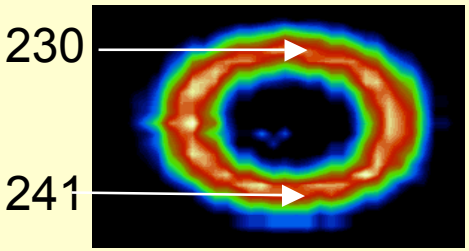
Hot topic !

Photon attenuation

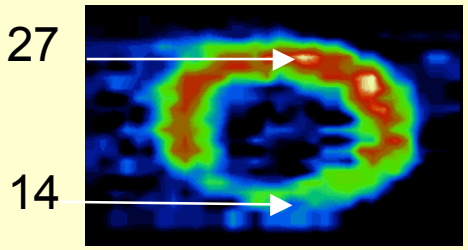
Attenuation introduces activity underestimation > 70% in SPECT and PET!

Tc99m cardiac SPECT

no attenuation



attenuated



1. Measure tissue density (e.g., using a CT)

2. Pre or post correction, or model attenuation in reconstruction

$$\mathbf{p} = R_{\mu}\,\mathbf{f}$$

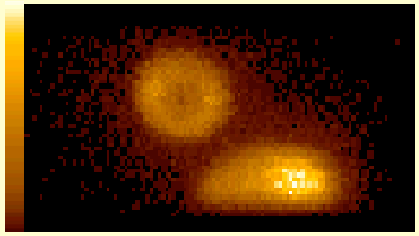
Very efficient
Fine tuning stage (motion, contrast medium, aso)

Photon scatter

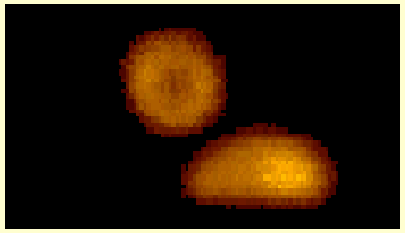
20 to 50% of detected photons can be scattered (hence mislocated) in ET

Decrease contrast

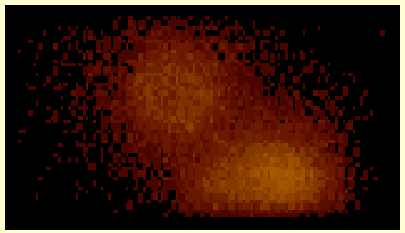
Tc99m cardiac SPECT



20% projection



unscattered



scattered (37%)

- Subtraction of scattered photons after modelling scatter distribution
- Better : towards relocation of scattered events

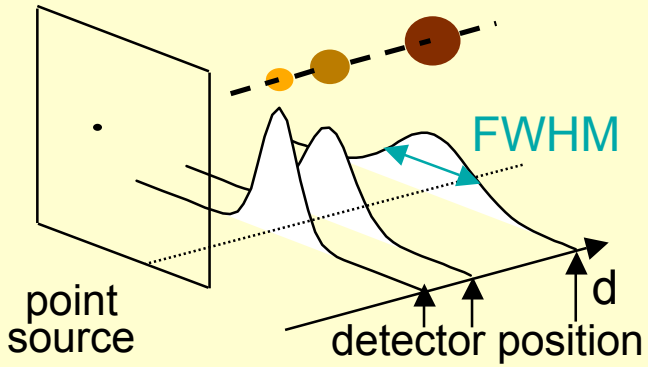
$$\mathbf{p} = R_s \mathbf{f}$$

Relocation under investigation (much less non zero elements in R_s, out of the FOV activity)

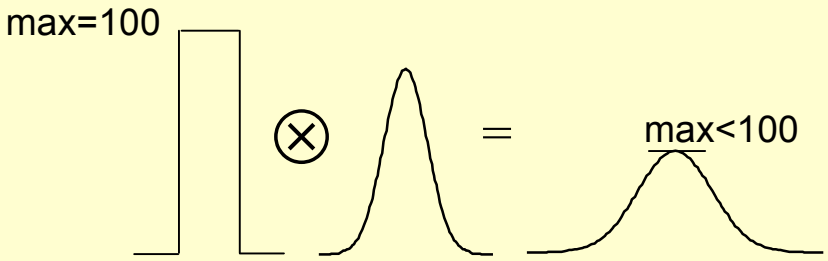
Limited and non stationary spatial resolution

Introduces non stationary partial volume effect

In SPECT

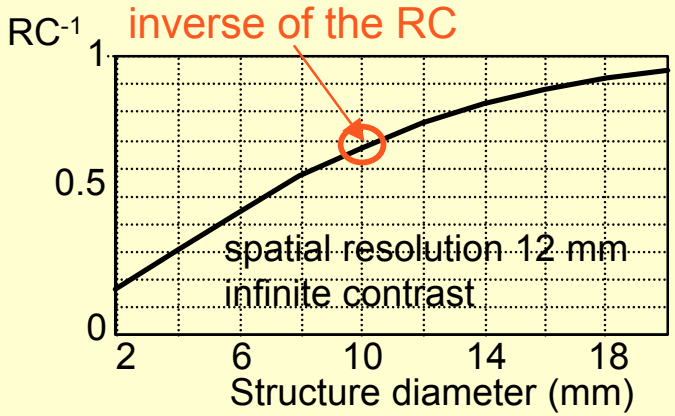


Partial volume effect in ET

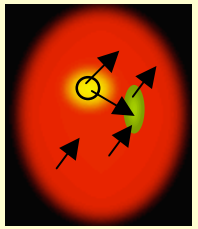


severely affects structures < 3 FWHM in size

- Multiply measured values by a recovery coefficient



- Invert a cross-contamination matrix

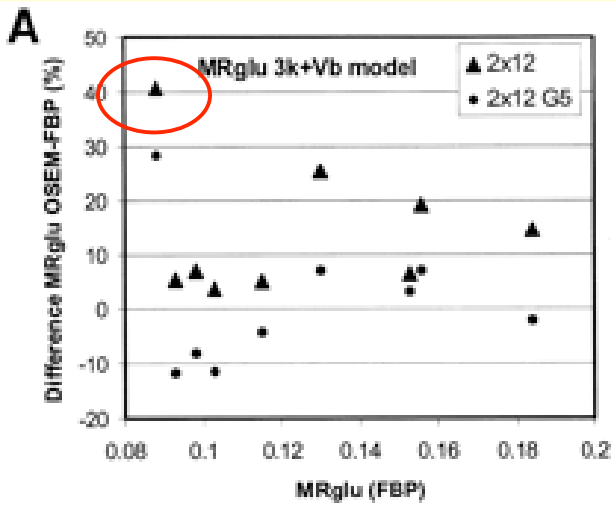


Definitely useful
But all methods assume that functional contours same as anatomical contours

Tomographic reconstruction

Indirectly affects quantitation

FBP, MLEM, OSEM, conjugate gradient ? Does that change quantitative accuracy?



Boellaard et al, J Nucl Med 2001:808-817

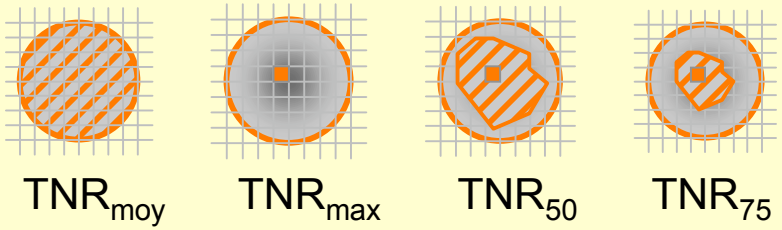
- Control spatial resolution, so that partial volume effect can be predicted
- Control noise level, which affects measurement variability

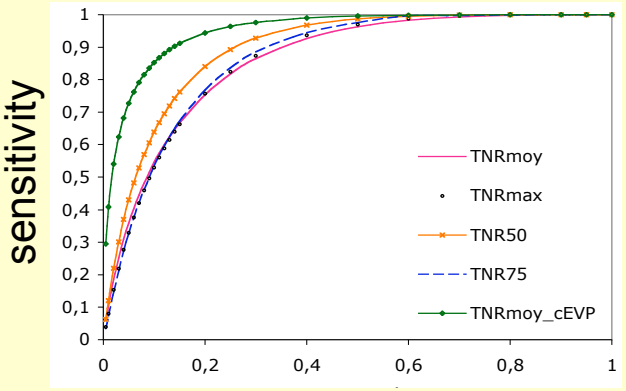
Need for more systematic report on the spatial resolution / noise trade-off achieved by the reconstruction to determine quantitative accuracy

Measurement procedure

Significant impact of VOI drawing

In PET, therapeutic follow-up based on TNR





Feuardent et al, SNM 2005

- Empirical work so far
- Home-made approaches

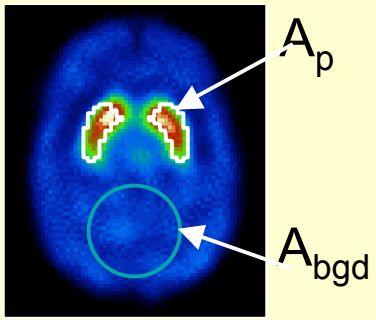
Large room for improvement

Need for optimization and standardization

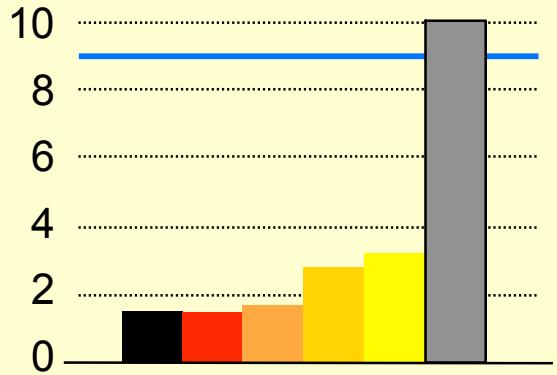
Hot topic : Definition of functional regions

How accurate can one be in SPECT?

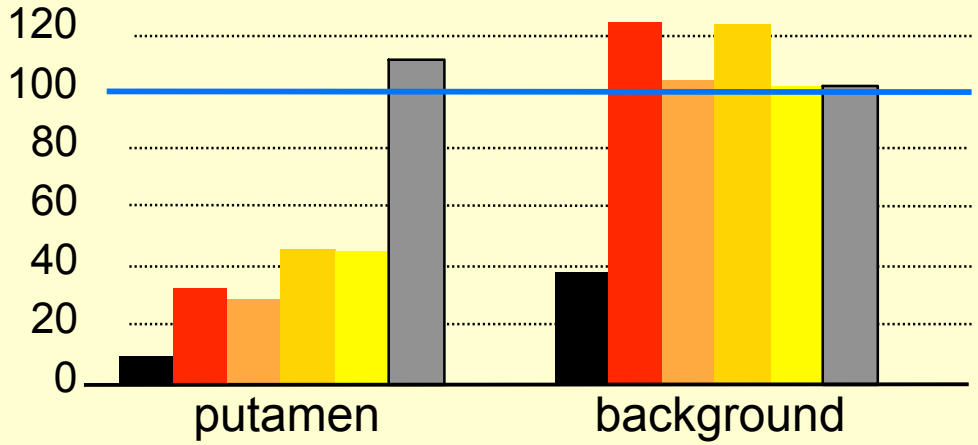
Brain SPECT of dopaminergic system (no motion)



binding potential = $(A_p - A_{bgd})/A_p$



restored activity (%)

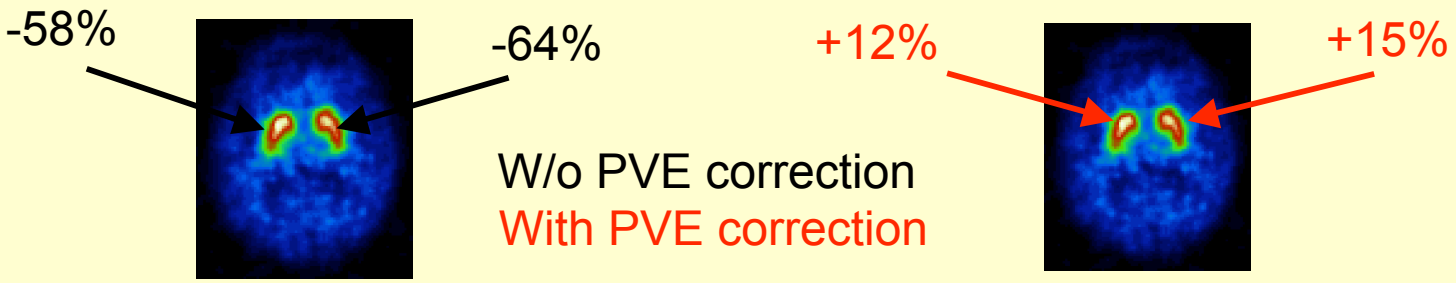


Soret et al, J Nucl Med 2003:1184-1193

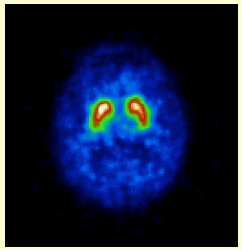
Need for accurate quantification in SPECT

Brain SPECT of dopaminergic system

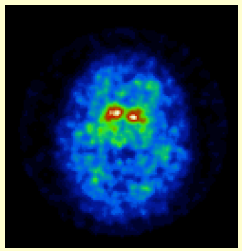
Binding potentia (BP) estimate



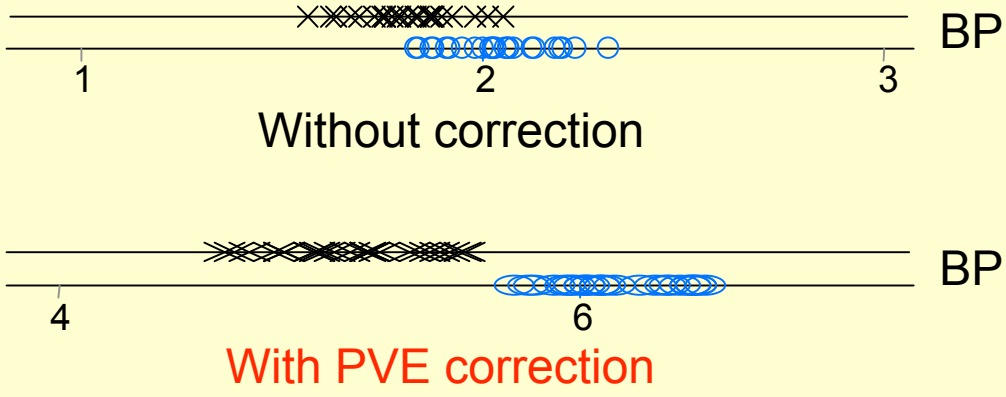
Differential diagnosis in presymptomatic patients



Alzheimer

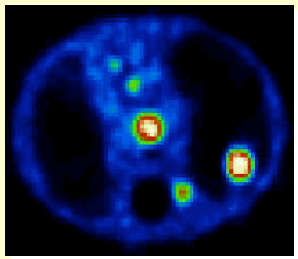


Lewy body dementia



Soret et al, Eur J Nucl Med Mol Imaging 2006

Example: quantification in FDG-PET



True tumor/bgd ratio = 8

Clinical conditions (CPET!)

- 6 min acquisition
- Cs137 transmission scan for attenuation correction
- No PVE correction
- mean count value in the tumor region

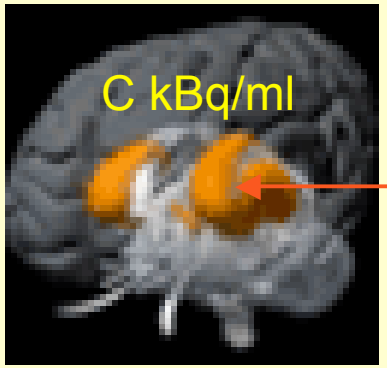
	Lung spheres diameter (in mm)			
	10.5	16	22	33
Tumor/bgd ratio	0.5	1.4	2.4	3.5

Different conditions

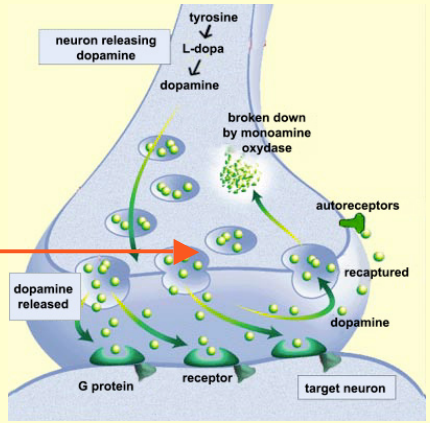
	Lung spheres diameter (in mm)			
	10.5	16	22	33
18 min acquisition	0.4	1.5	2.4	3.7
CT att correction	0.7	2	2.8	3.7
PVE correction	5.2	5.4	5.4	5.5
Max in tumor region	0.6	2.3	4.1	6.3

Feuardent et al, IEEE Trans Nucl Sci 2006

2nd step: deriving physiological parameters

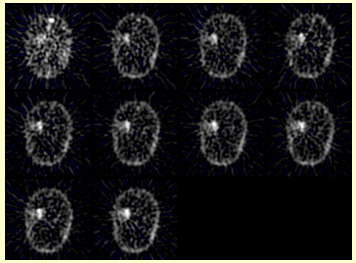


Radiotracer concentration

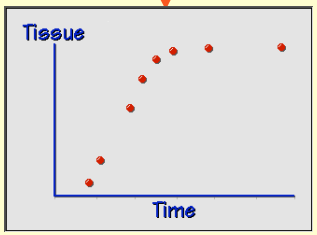


Density of dopaminergic transporters

General and appropriate approach

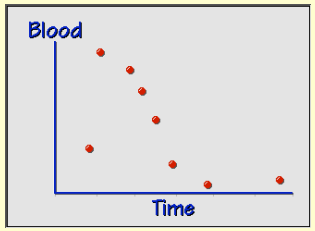


Dynamic image sequence

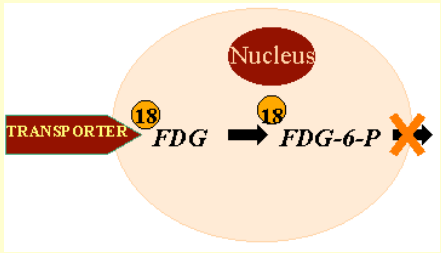


Tracer kinetic in regions of interest

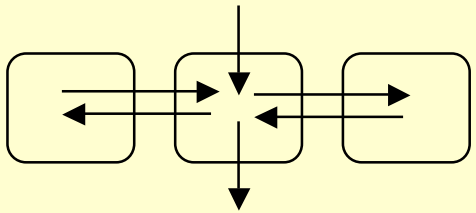
Blood sampling



Arterial input function

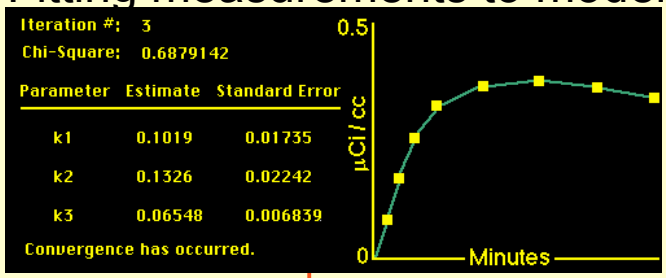


Biochemical knowledge



Model

Fitting measurements to model



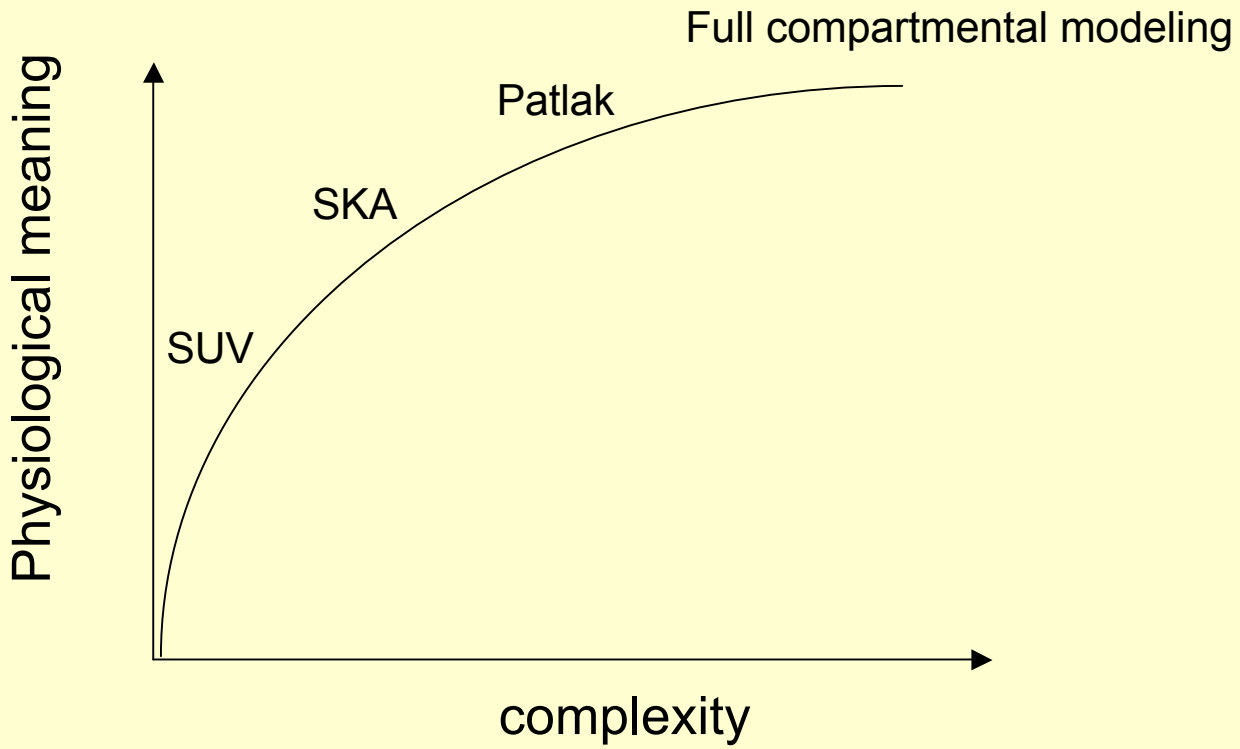
Region-dependent physiological parameters
e.g., glucose metabolic rate, blood flow, blood volume, mean transit time

Practical trade-off

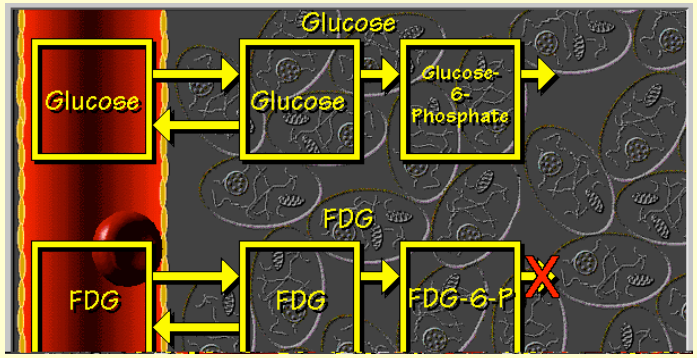
- Simplifying the whole procedure to achieve some reasonable trade-off between feasibility and index usefulness

Example of FDG-PET

Glucose metabolic rate



Example of F18-FDG PET



$$\text{Tumor FDG (t)} = K_i \int_0^t AIF(\theta)d\theta + \text{unmetabolized FDG (t)}$$

Glucose metabolic rate

FDG made available to tumor

$$SUV = \frac{\text{Tumor (t)} - \text{unmetabolized FDG}}{\int_0^t AIF(\theta)d\theta}$$

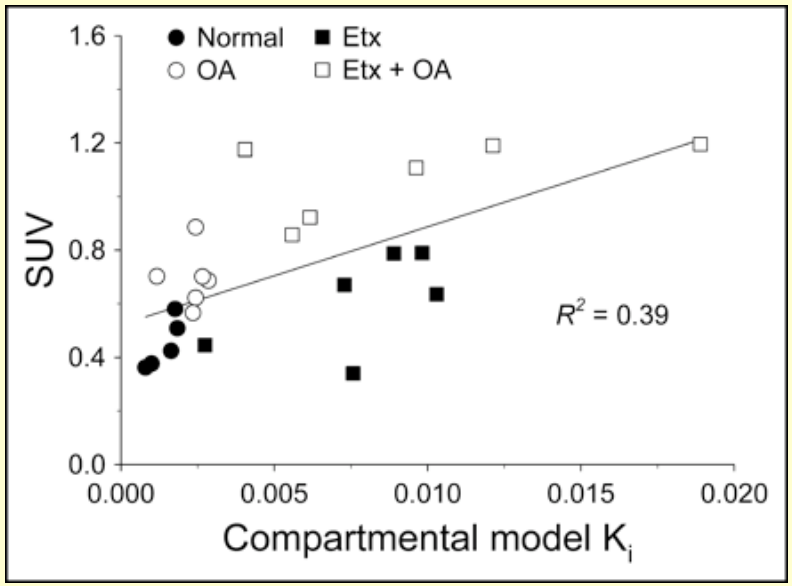
~ injected dose / dilution volume

~ injected dose / patient weight

Accuracy depends on complexity

- SUV versus K_i

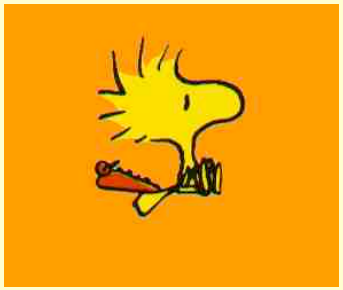
FDG-PET in accute lung injury



Chen et al, J Nucl Med 2004:1583-1590

Quantitative accuracy depends on the relevance of the model used for physiological parameter estimates

Conclusions



- Quantification is feasible in PET and SPECT

- Quantification is a complicated process, requiring tissue density map, perfectly controlled acquisition and processing protocols, high resolution anatomical information, accurate kinetic modeling

- Accurate quantification is easier in PET than in SPECT, just because attenuation correction is more accessible, and mostly because spatial resolution is better

- SPECT/CT and PET/CT scan could make quantification a clinical reality

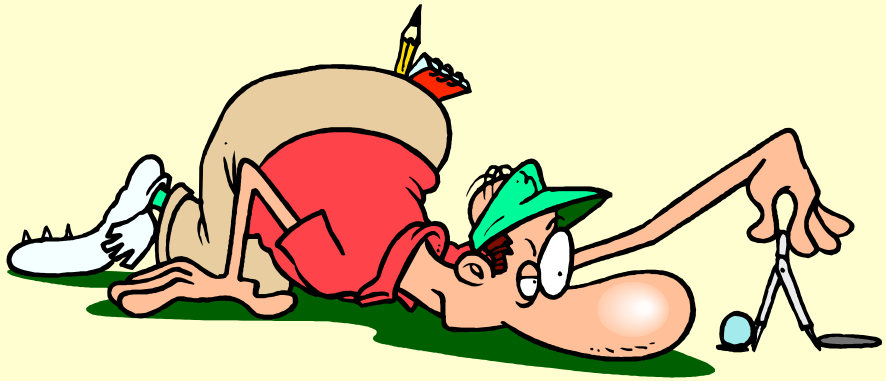
- Partial volume effect and motion are currently the toughest effects to deal with

Conclusions

- Quantification accuracy highly depends on the acquisition and processing protocols, and should be characterized

- Meta-analyses are often impossible - or meaningless - given the variety and lack of information regarding acquisition and processing

- Comparing quantitative values (e.g. for therapeutic follow-up, malignancy indices) requires highly controlled protocols to ensure constant acquisition and processing conditions



Thank you for your attention

Slides available on
http://www.guillemet.org/irene