2484-13

ICTP-IAEA Joint Workshop on Nuclear Data for Science and Technology: Medical Applications

30 September - 4 October, 2013

Molecular Imaging Part I: SPECT

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Molecular Imaging Part I:

SPECT

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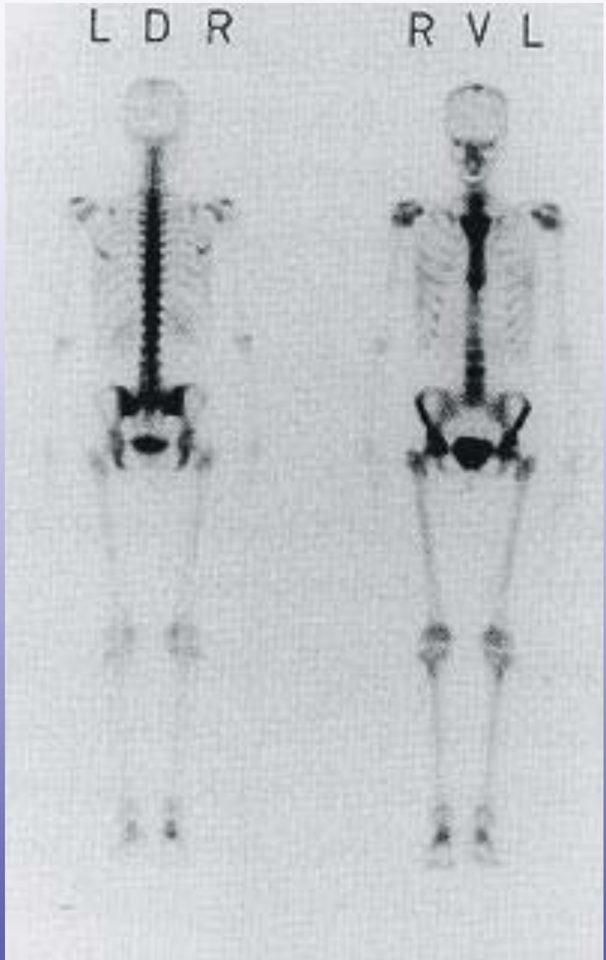
Forschungszentrum Jülich

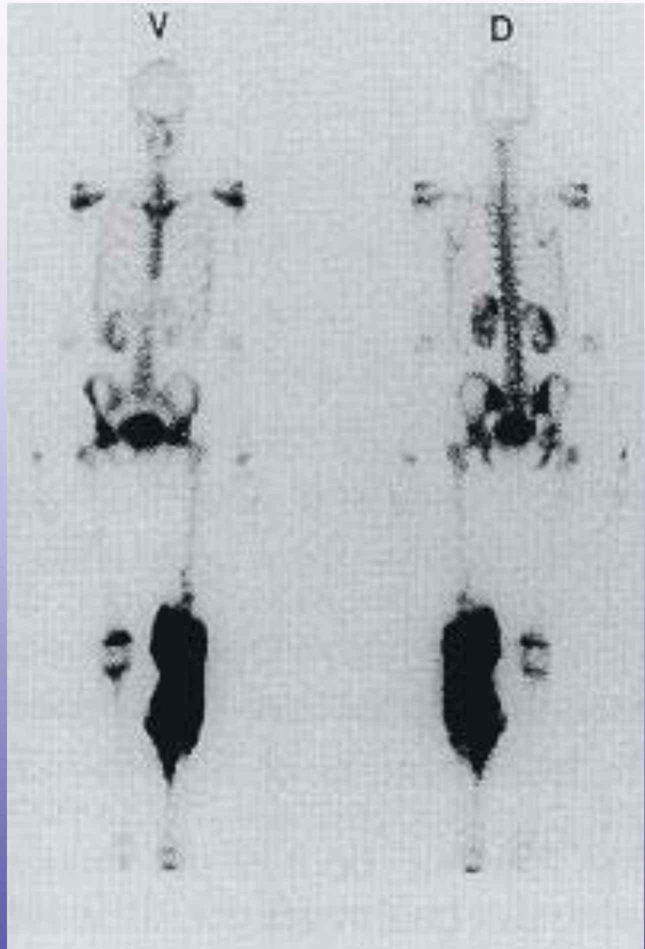
Nuclear Medicine

- Planar Scintigraphy:
  Imaging of Metabolism
- SPECT(omography):
  same + spatial localisation
- PET(omography)
  same + quantitative

Bone Scans with ^{99m}Tc-MDP



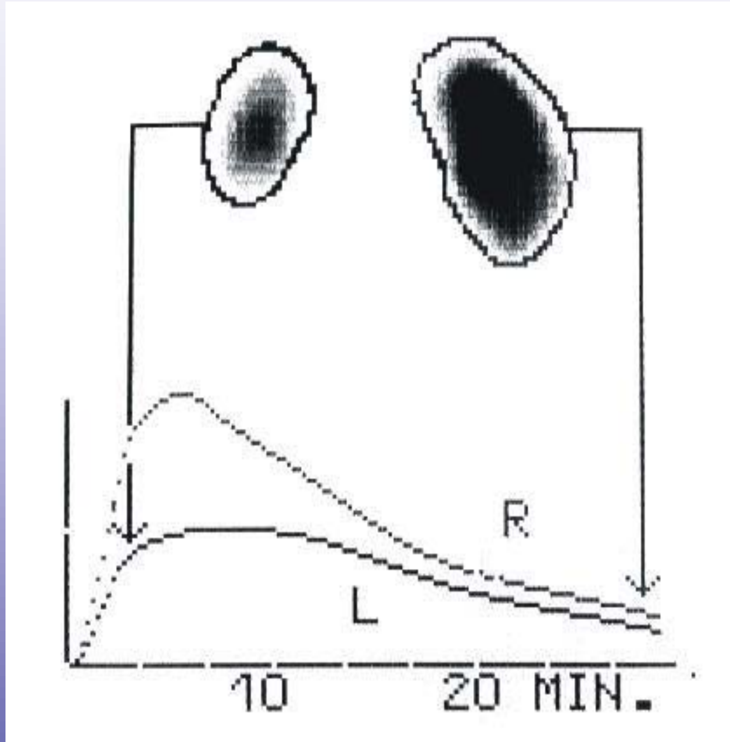
Normal

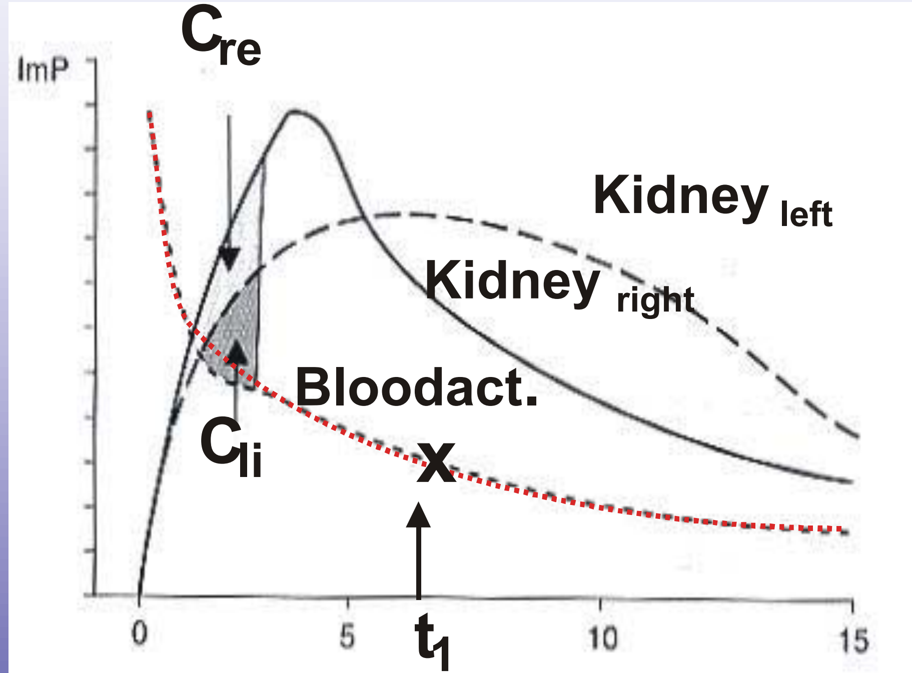


Chondrosarcoma

Rheumatic Arthritis

Using the Dynamics: Kidney Function

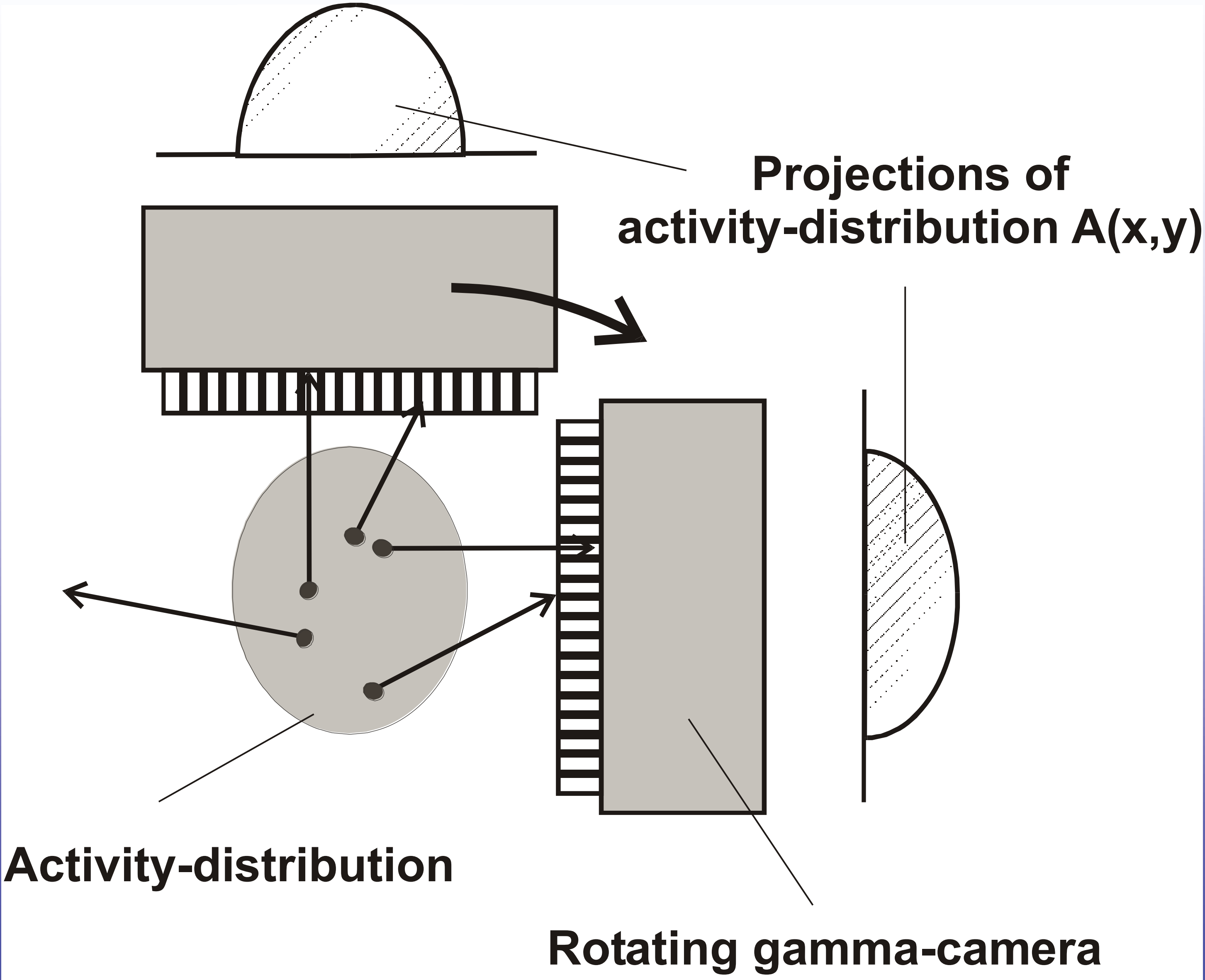




$$\text{Clear}_{tot} = k * (dWB/dt) / \text{Blood}(t)$$

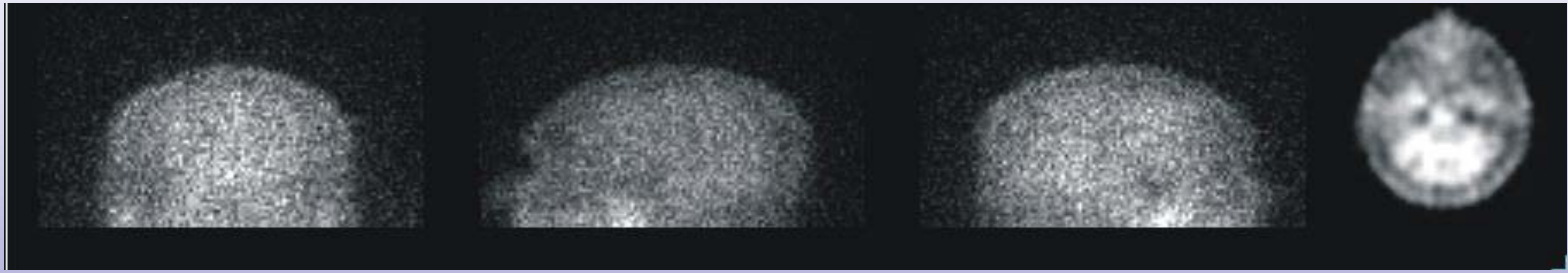
$$\text{Clear}_{re} = \frac{C_{ri}}{C_{ri} + C_{le}} \text{Clear}_{tot}$$

The Tomographic Approach



The Tomographic Approach

Three SPECT projections angled by 120°



Reconstructed SPECT image

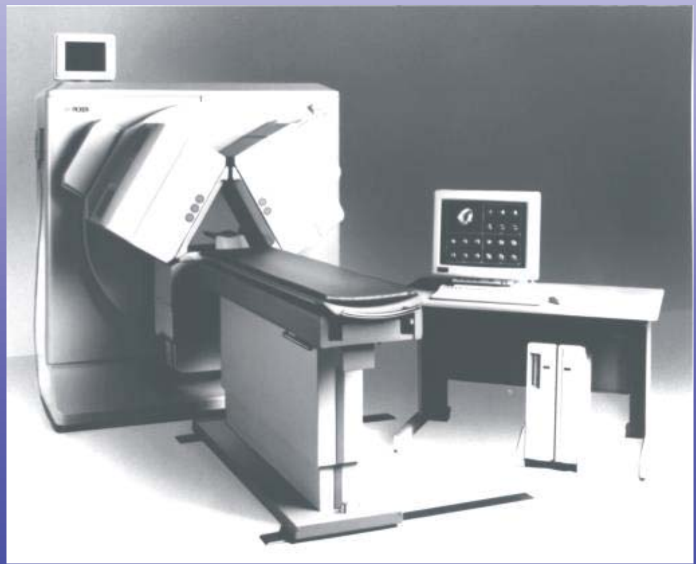
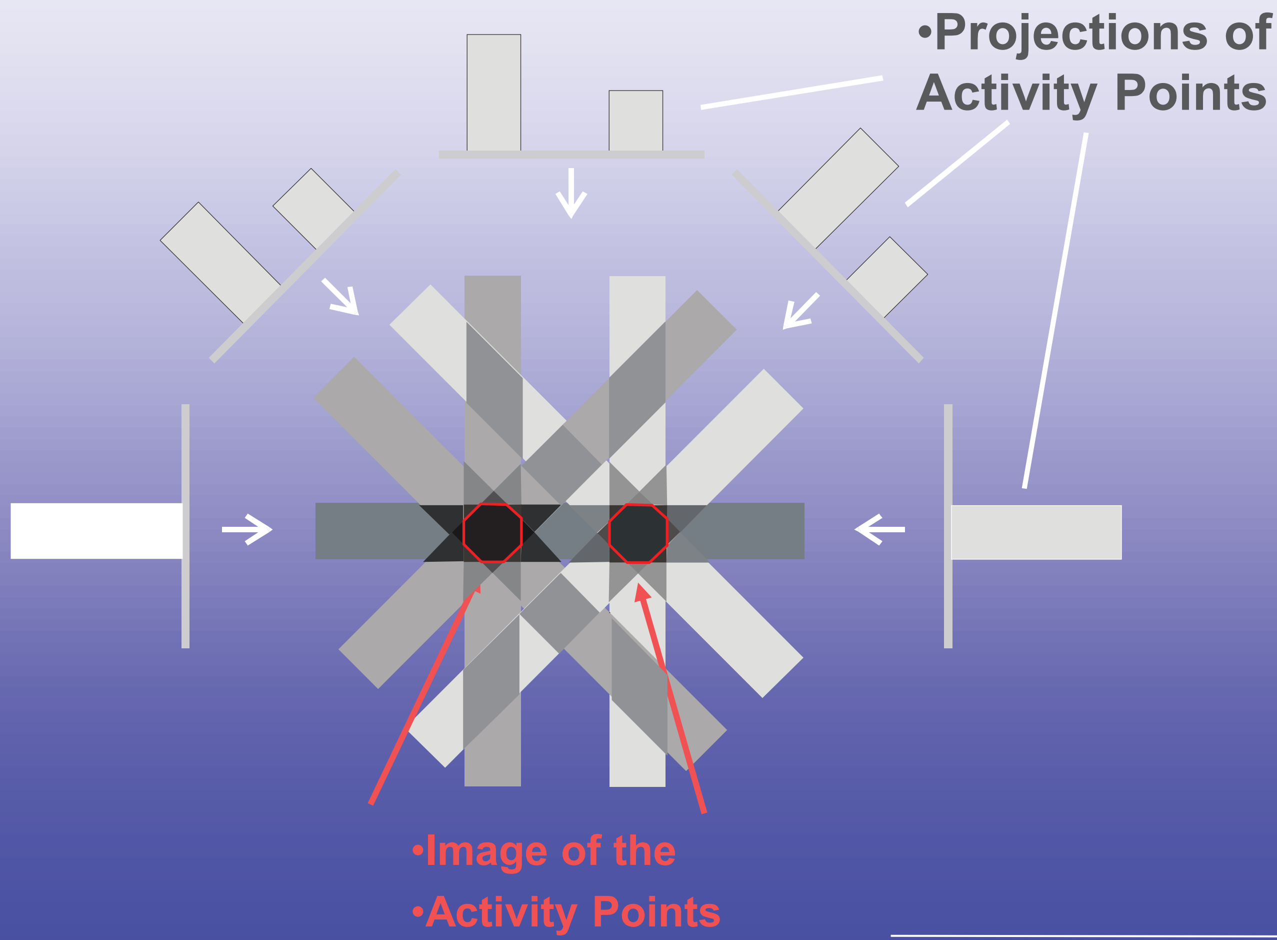
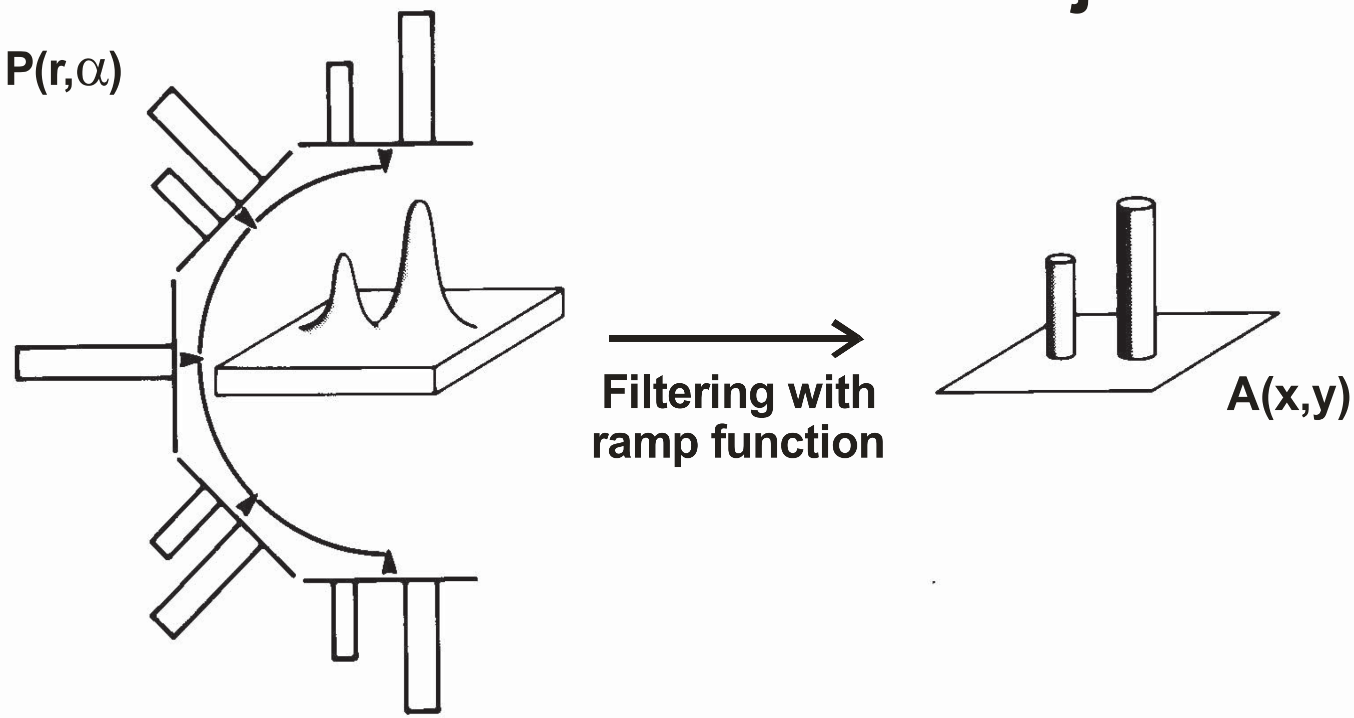


Image Reconstruction:
Backprojection of the Measured Projections and Superposition

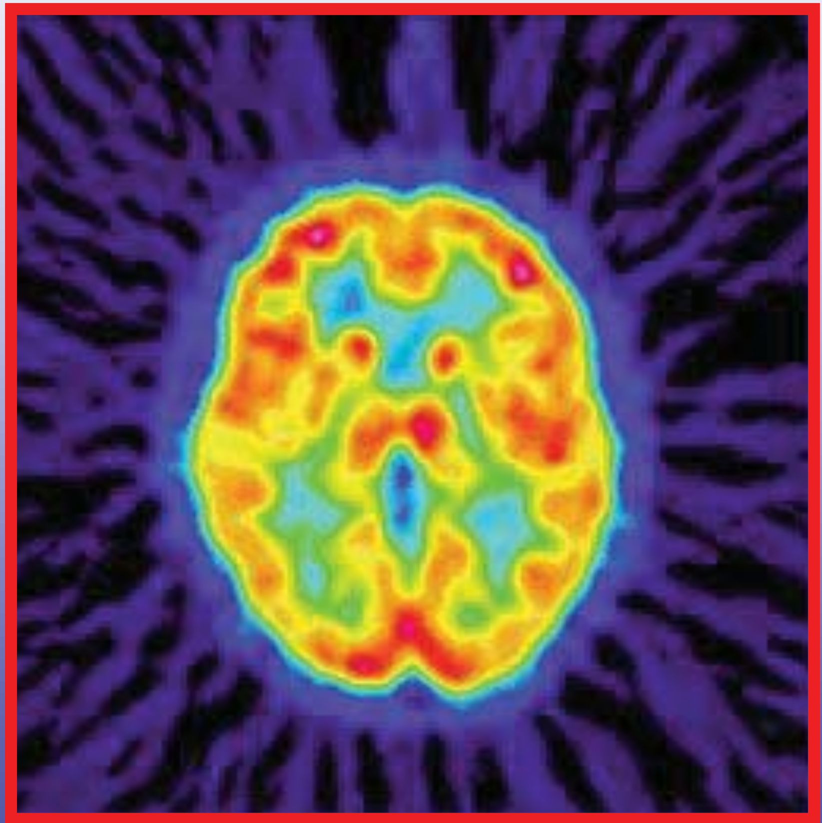


<u>Filtered</u> Backprojetion

Backprojection **Reconstructed object**



Analytic Reconstruction by Reprojection and Superposition

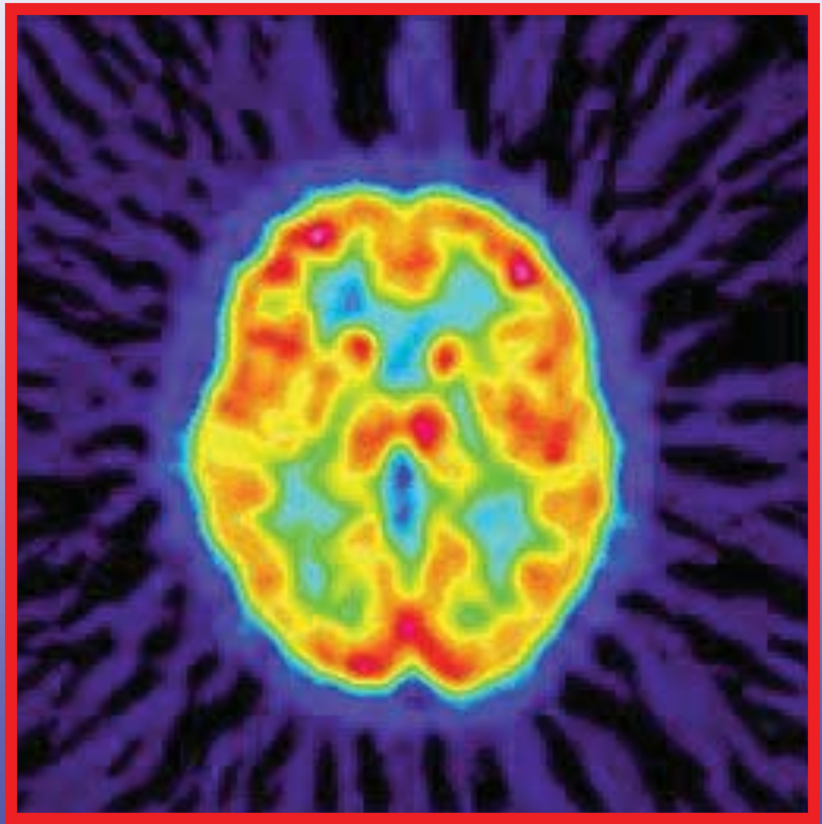


Algebraic Reconstruction by Iterative Solution of a Matrix Equation

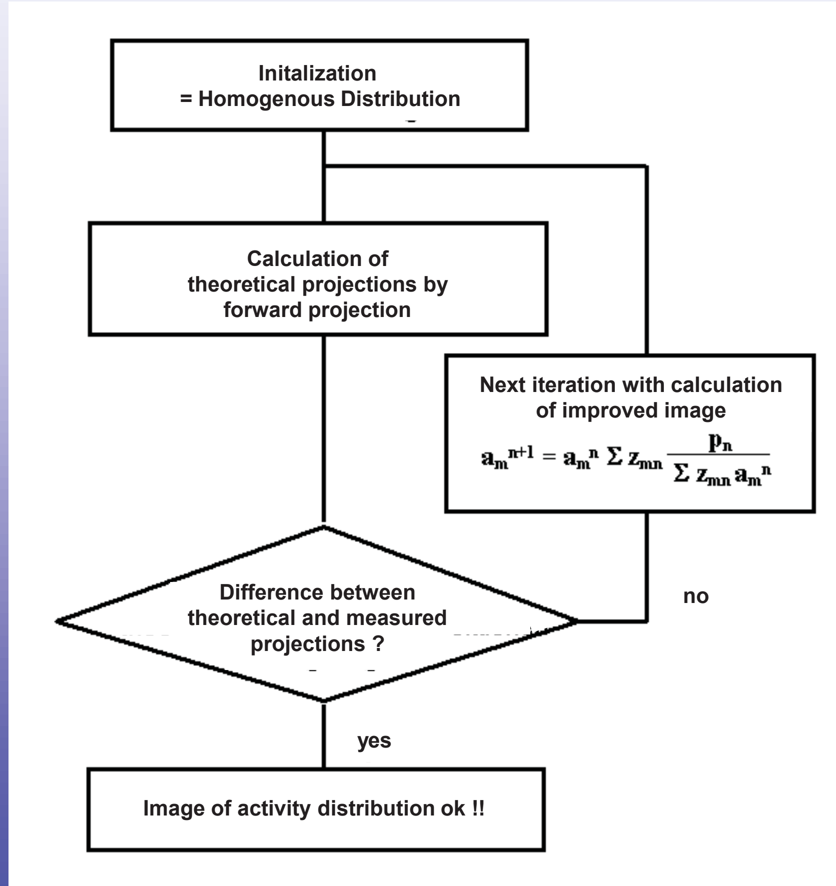
$$P_i = S_{ij}\, A_j$$

i = 1 , ... , 288 x 144
j = 1 , ... , 128 x 128
I x J = 679.477.248

Analytic Reconstruction by Reprojection and Superposition



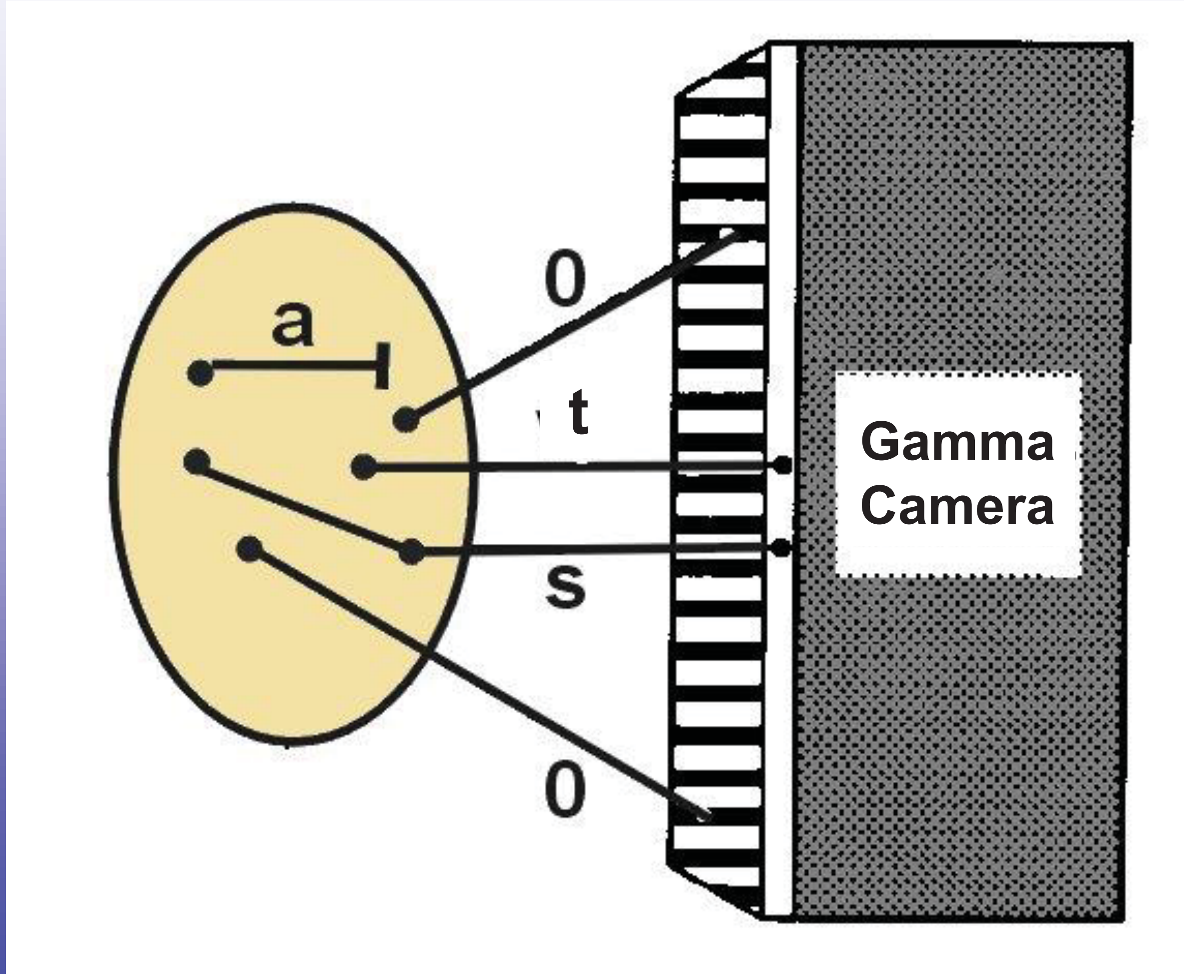
Algebraic Reconstruction by Iterative Solution of a Matrix Equation



Requirements to Images

- Optimal Resolution
- Minimal Artifacts
- Linearity
- (Quantification)

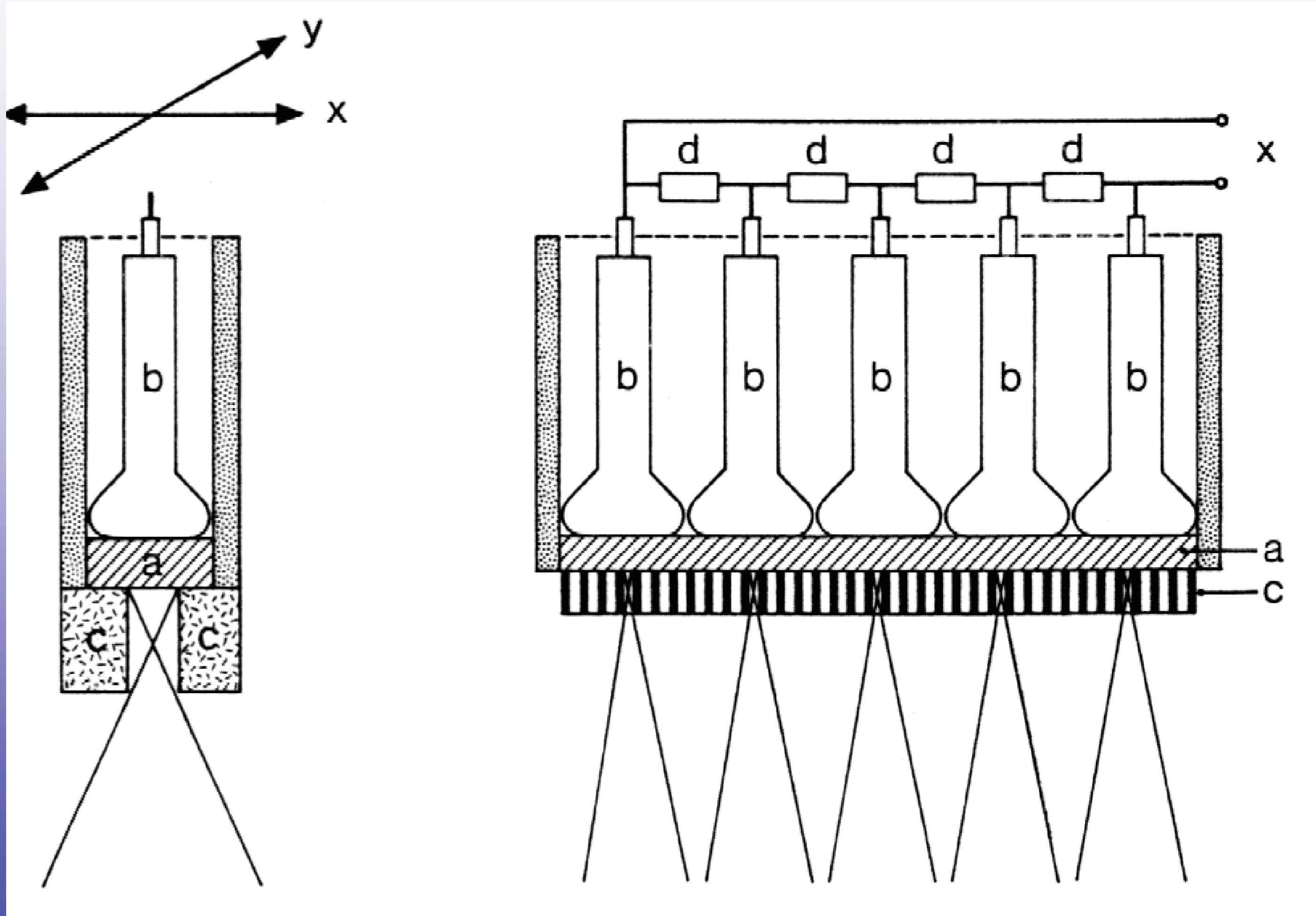
Viewing Single Photons with a Gamma Camera



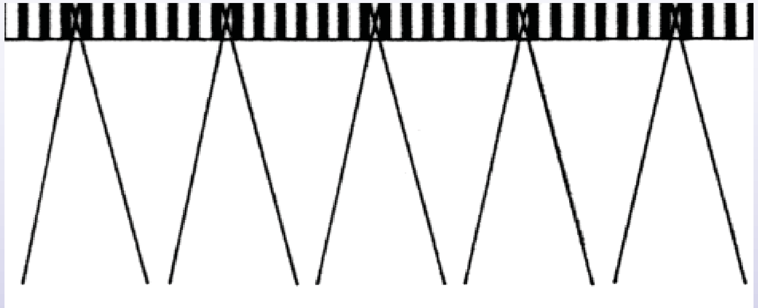
Scintillation Detector and Gamma Camera

Probe Detector

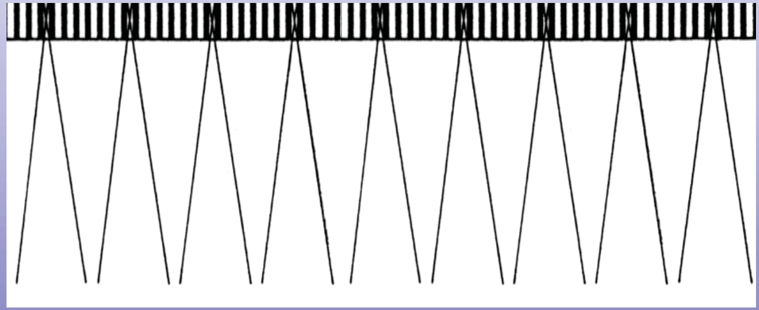
Gamma Camera



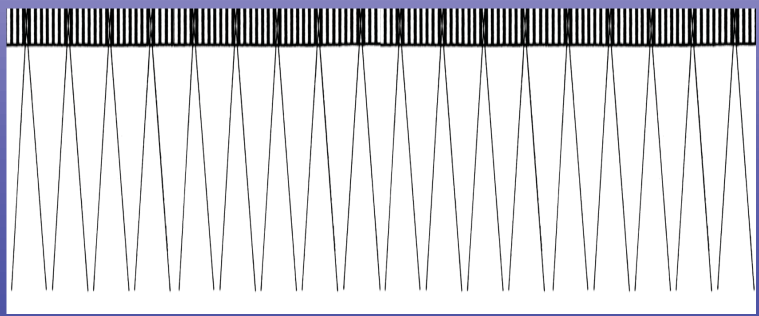
Collimation



from
high sensitivity

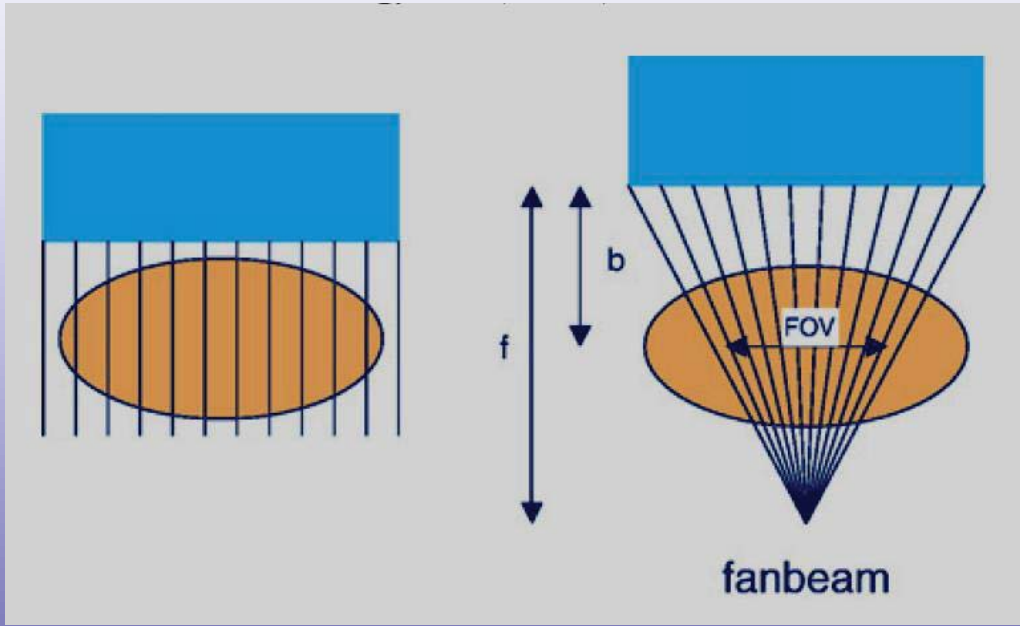


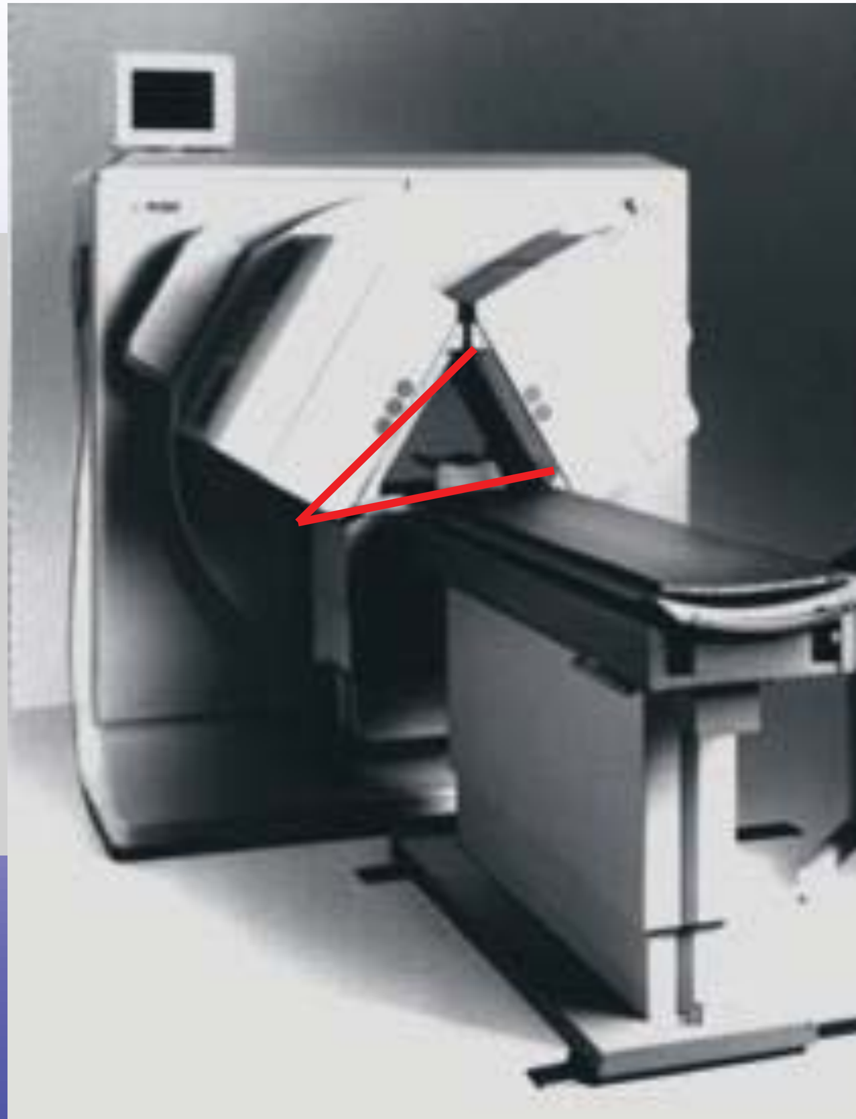
to



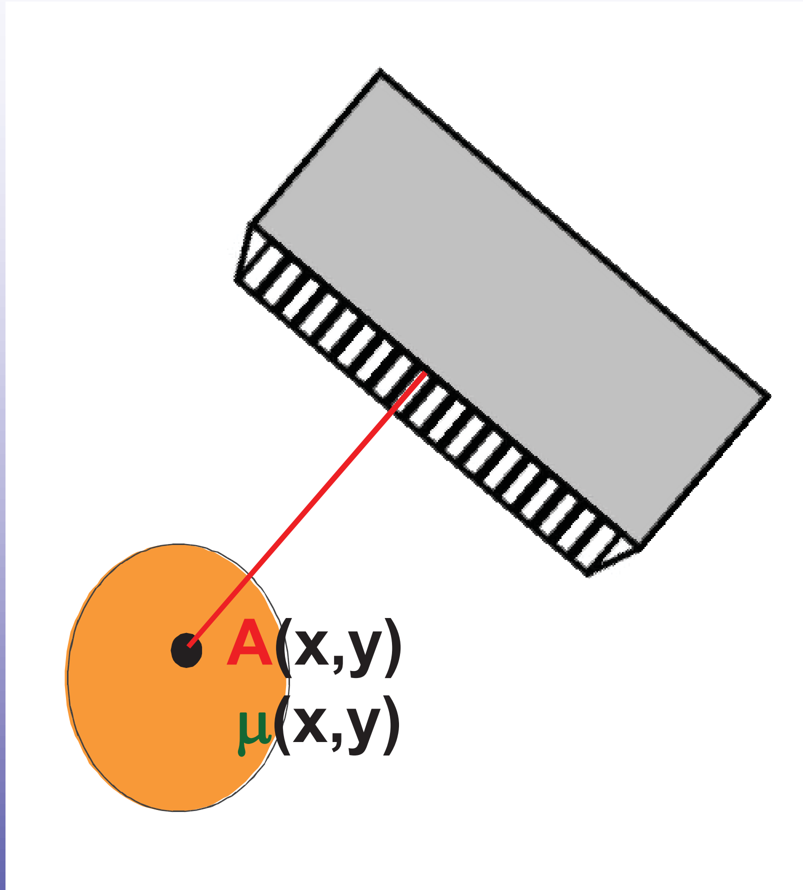
high resolution

Collimation and Multiple Head Camera





Projection Equation for SPECT

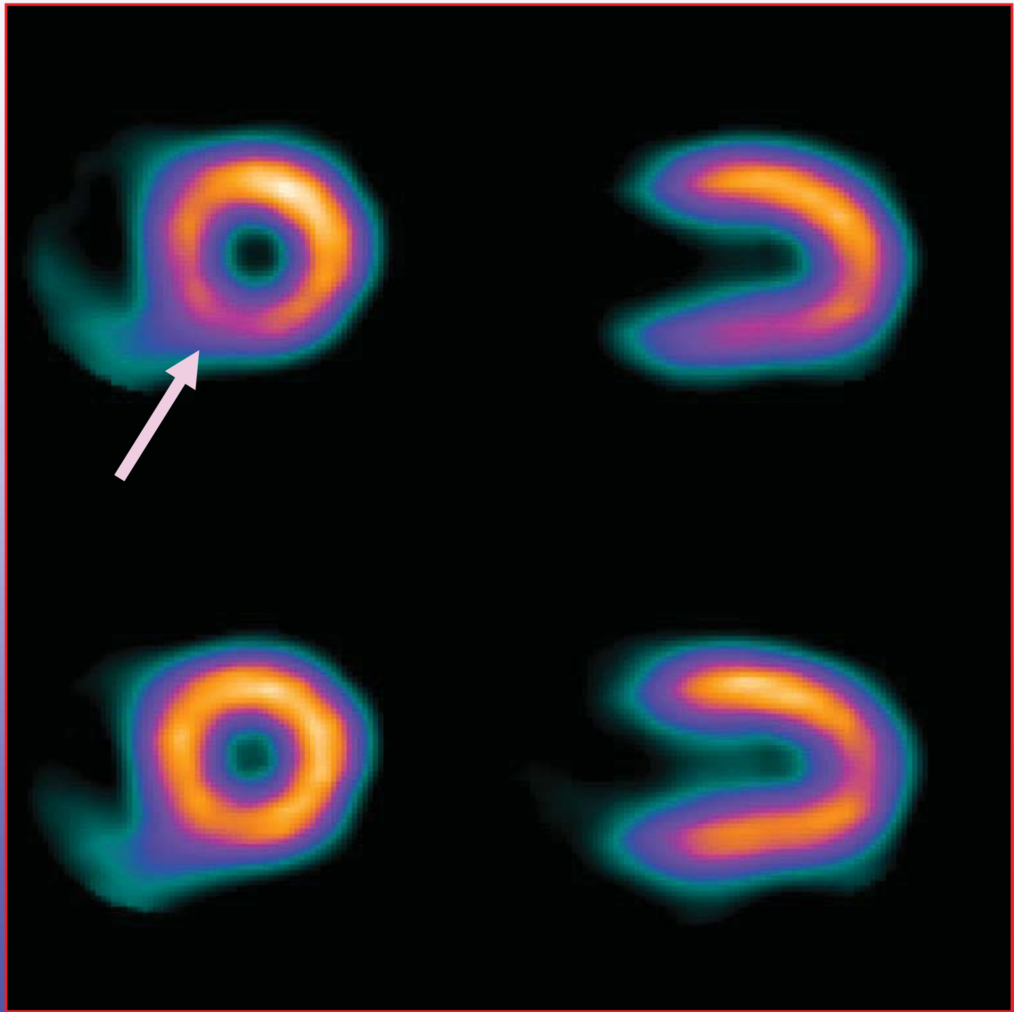


$$P_E = \int A(x,y) * \underbrace{\exp\left(-\int \mu\,(x,y)\,dl'\right)}\,dl$$

Term of attenuation not extractable:

No analytic solution of projection equation

Absorption Artifact in Heart-SPECT



without

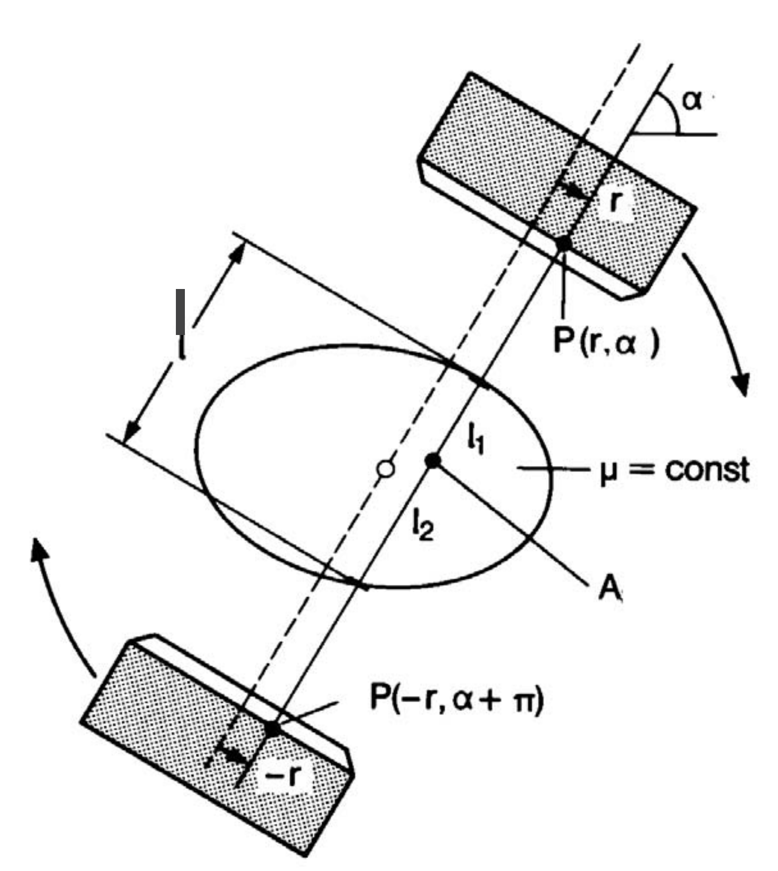
Attenuation correction

with

Attenuation Correction before Reconstruction

(pre-processing)

(Sörensen, 1971; Larsson,1980)



Prerequisites:

- Conjugate measurement:
  Geometric mean
  of opposite projections
- Homogenous attenuation
- Homogenous radioactivity

$c_1 = k\,A\,e^{-\mu l_1}$ $\qquad$ $c_2 = k\,A\,e^{-\mu l_2}$

$$AF = (1 - e^{-\mu l}) / \mu l$$

$$(c_1\,c_2)^{1/2} = k\,A\,e^{-\mu (l_1 + l_2)/2}$$

$$P^{corr}(r,\alpha) \quad = P^{geo}(r,\alpha) / AF = \int A(x,y)\, dl(r,\alpha)$$

Attenuation Correction after Reconstruction
(post-processing)
(Chang, 1978)

- Reconstruction of projection data recorded over 360°

- Calculation of correction matrix:

$$K(x,y) = \left[\frac{1}{M} \sum_{i=1}^{M} e^{-\mu L_i(x,y,\theta)} \right]^{-1}$$

- Multiplication of reconstructed image with $K(x,y)$

Inclusion of Attenuation Correction into the Iterative Reconstruction

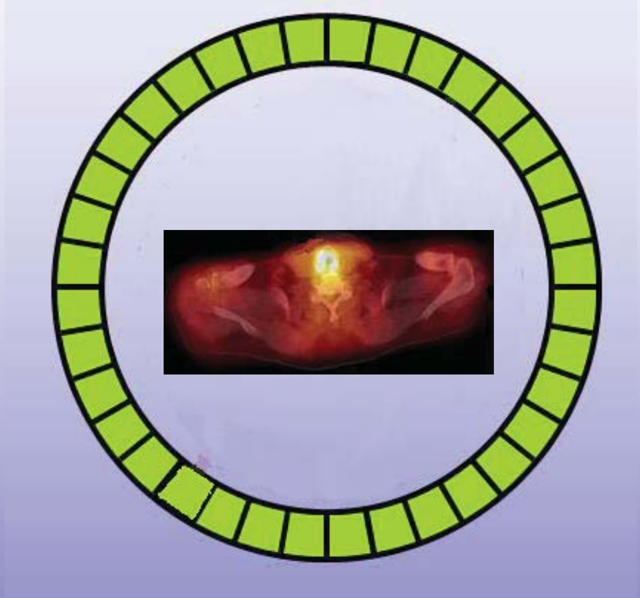
$$x^{i+1} = x^i \sum w \frac{p^{meas}}{p^{calc}}$$

$$x^{i+1} = x^i \quad \sum w \frac{p^{meas}}{\sum w \, x^i \exp\left(-\int \mu(x,y)\, dl'\right)}$$

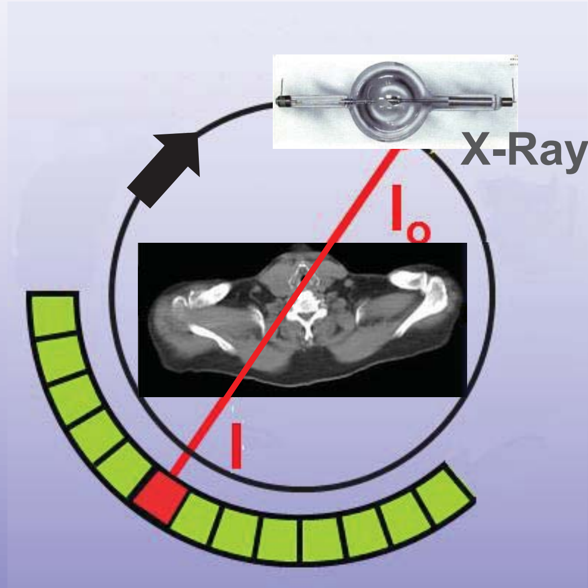
e.g. from reconstructed transmission measurement

Calculation of Attenuation Map Using a Transmission Scan by CT

Emission Scan



CT Scan



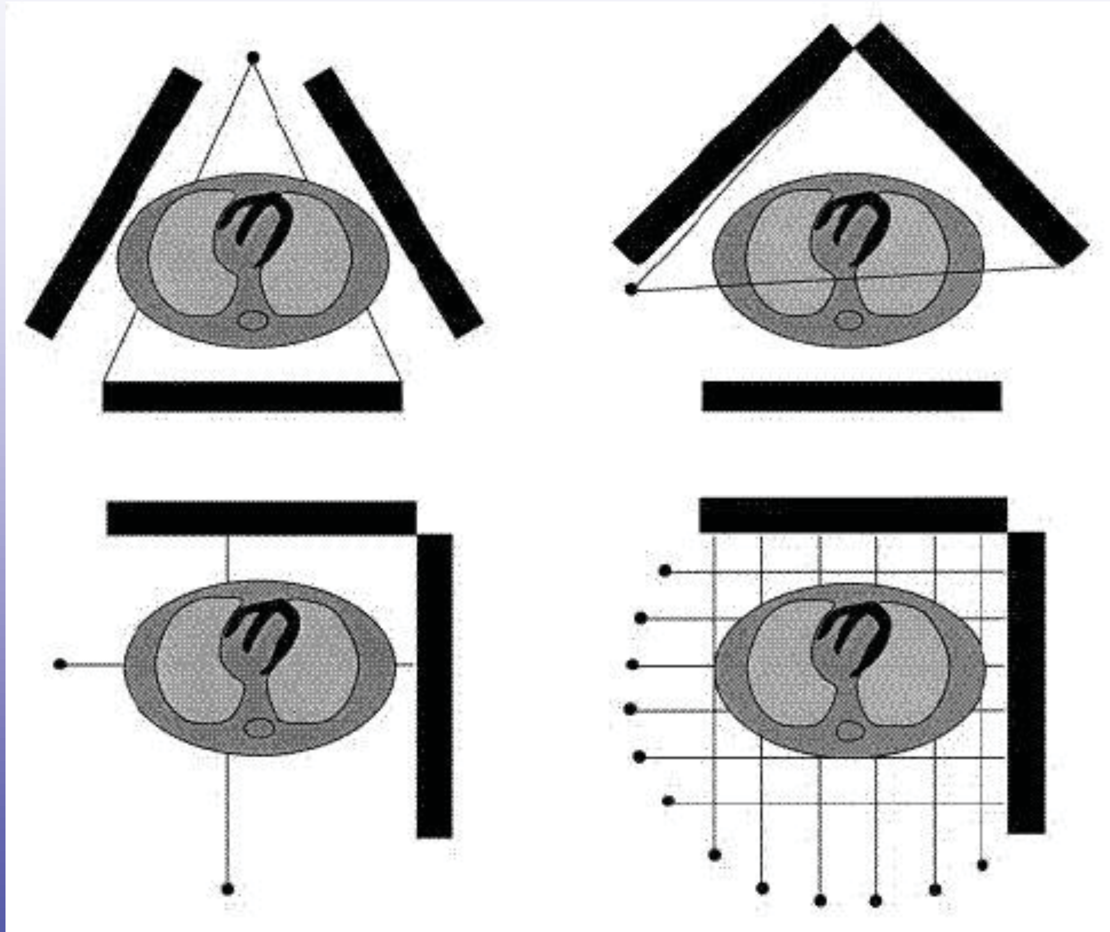
$$\ln \frac{I_0}{I} = \int \mu(x,y)\, dl, \quad \Rightarrow \quad \text{CT: Image of Hounsfield Units (HU)}$$

HU = μ (X-Ray) ⇒ μ (140 keV)

Institut für Medizin
Forschungszentrum Jülich

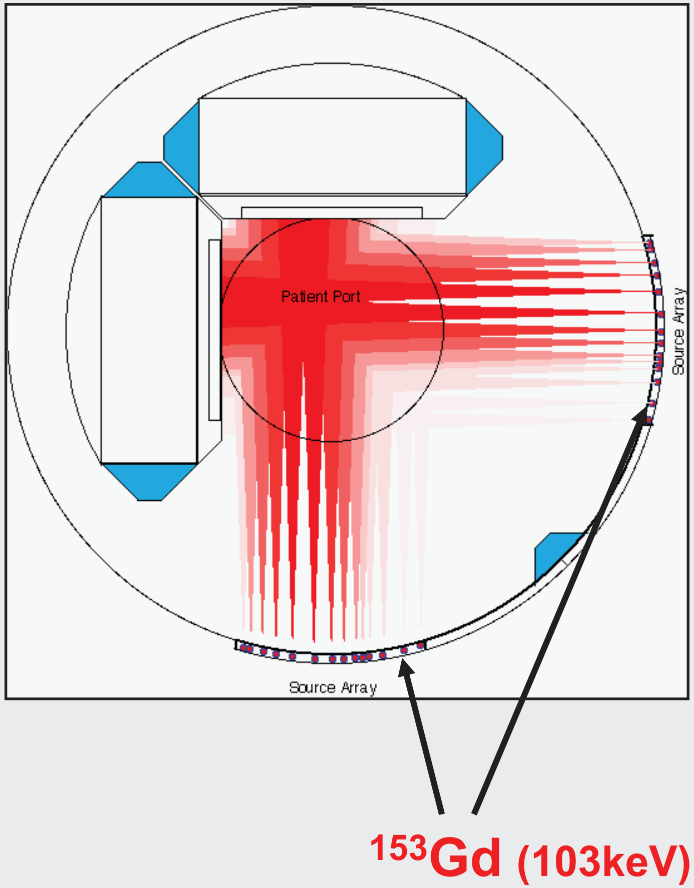
Measured Attenuation at 140 keV:

Using Transmission Sources



Hendel et al., (3) 2002, JNM

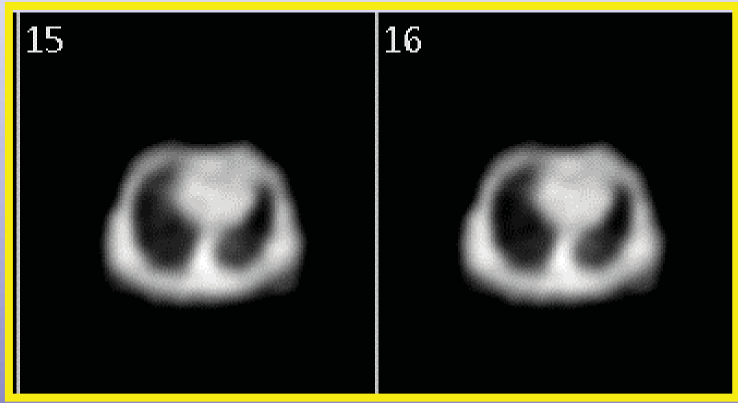
Determination of Attenuation



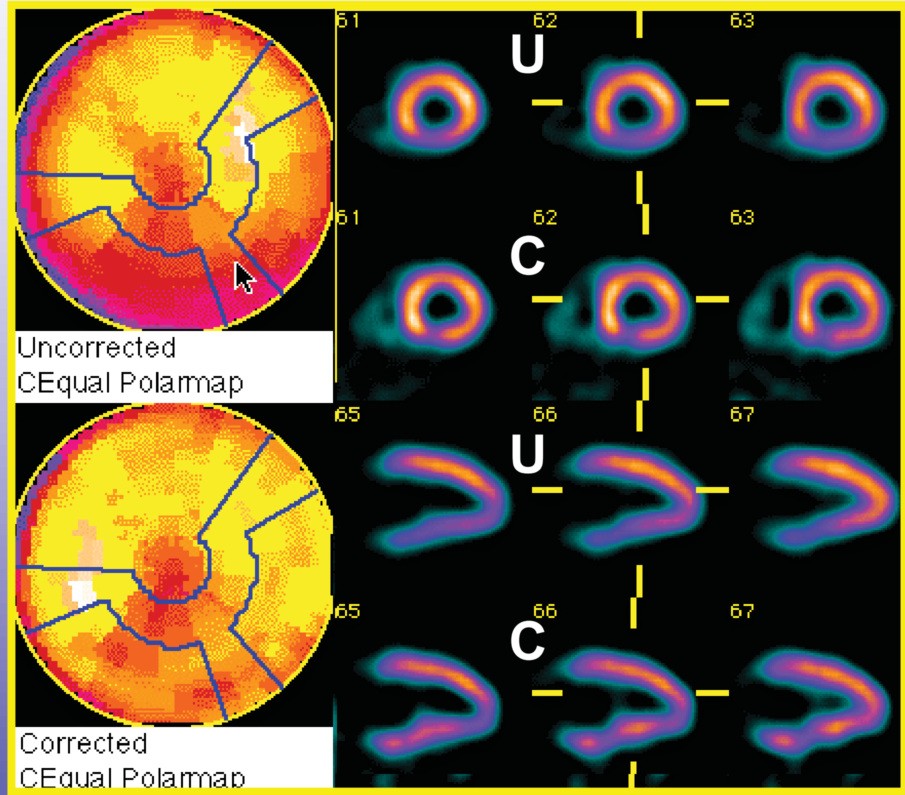
- **External Radiation Source**
  - true measure of patient-specific attenuation
  - CT approach to measure density distribution within patient
- **Unique Iterative Pre-Correction**
  - convergence achieved faster than conventional approaches
  - improved accuracy over conventional filtered backprojection

SIEMENS

„Profile“ Attenuation Correction by SIEMENS



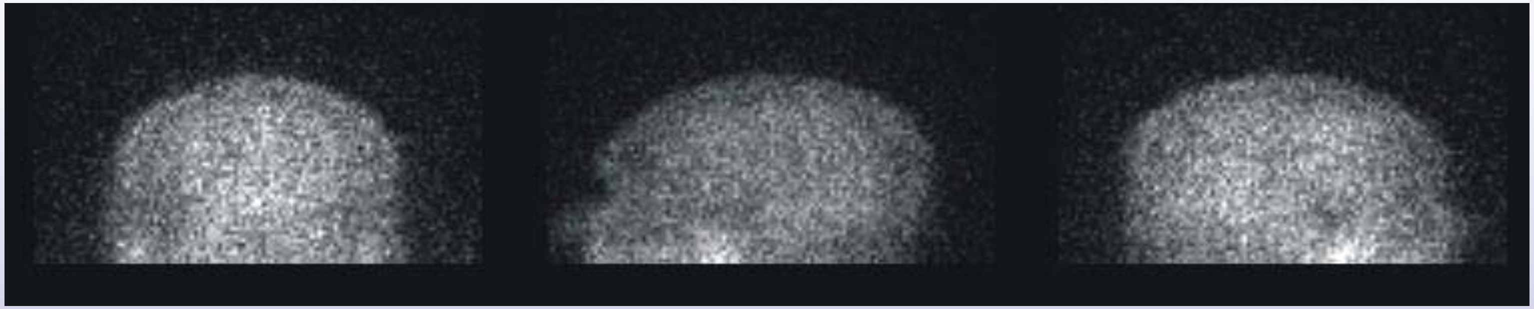
Attenuation Images



Single Photon Emitters Used for SPECT

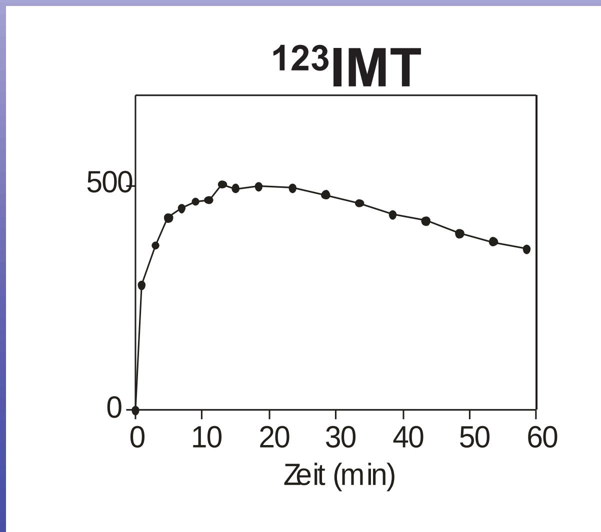
Radionuclide	Gamma Energy (keV)	Half-life (h)
^{99m}Tc	140	6.1
^{123}I	159	13.2
^{201}Tl	70/169	72
^{111}In	171/245	67
^{67}Ga	93/185/300	79

Three SPECT projections angled by 120°



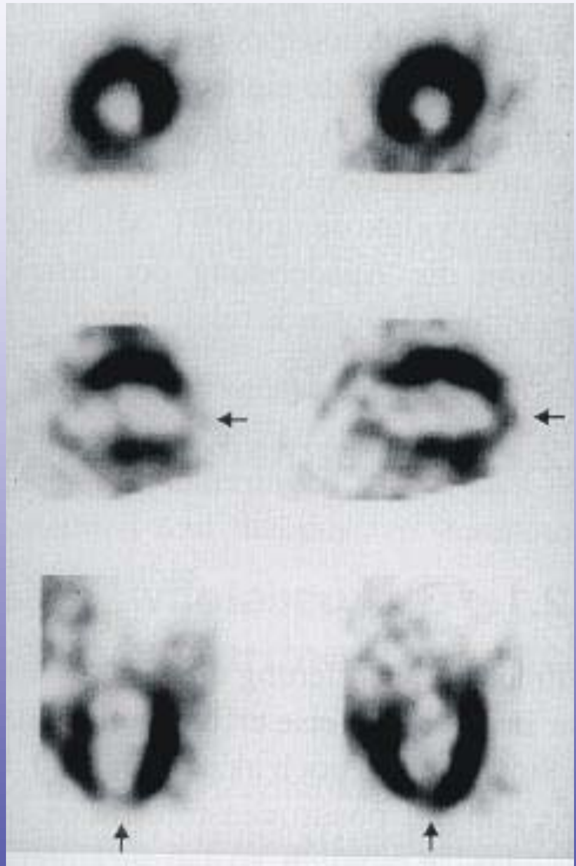
The rotation of a SPECT camera may last for many minutes.

During the rotation the distribution of the SPECT tracer must not change.



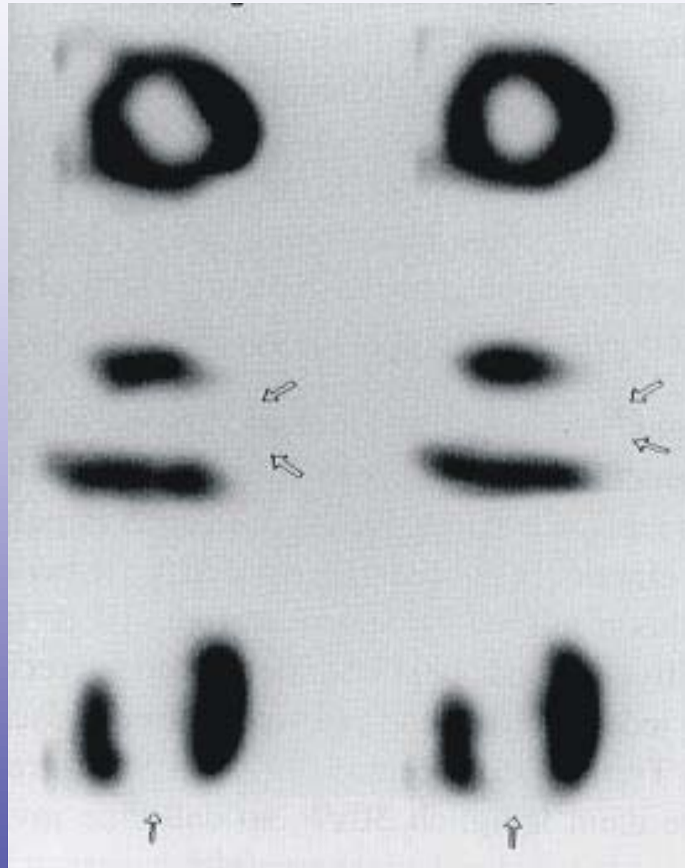
SPECT: Myocardial Perfusion with ^{201}Tl-Chloride

Exercise Rest



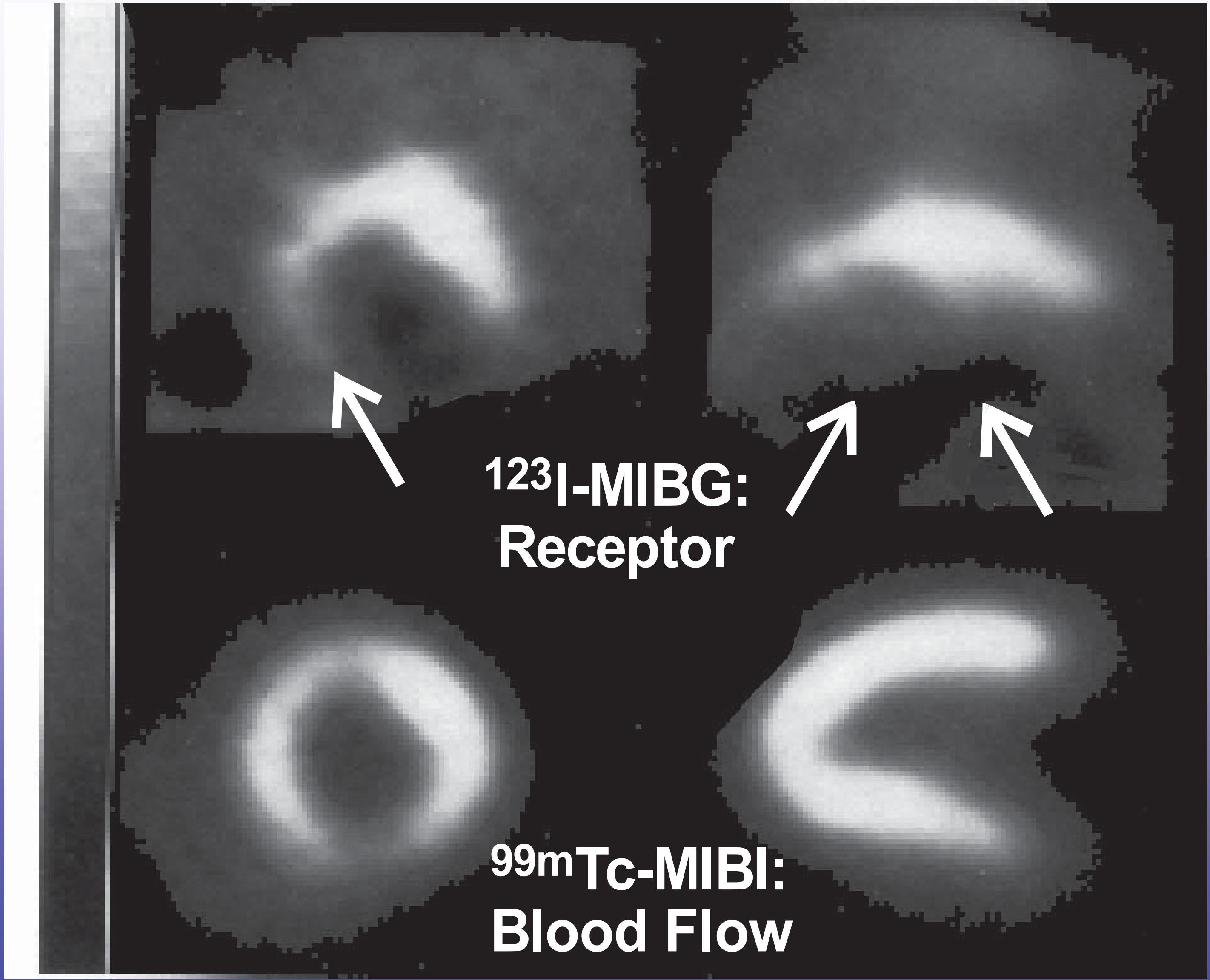
Ischemia

Exercise Rest

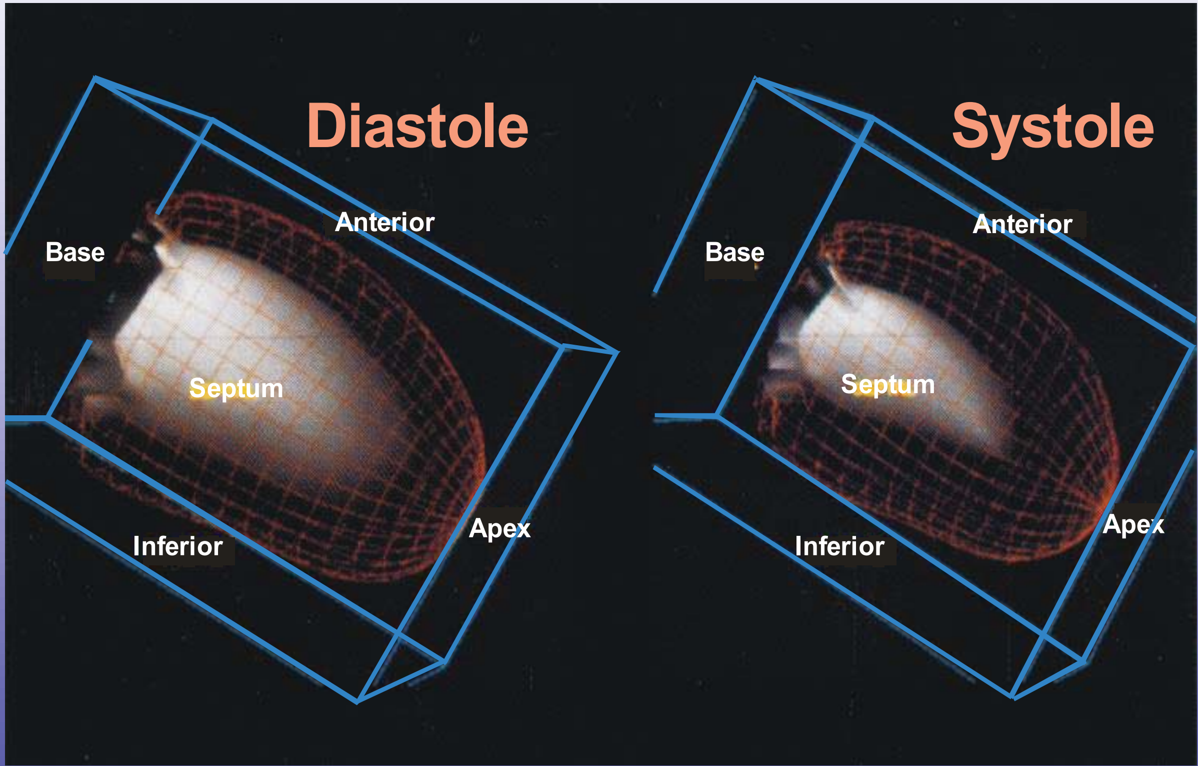


Infarction

Diabetes: Disturbed Cardial Autonomic Innervation



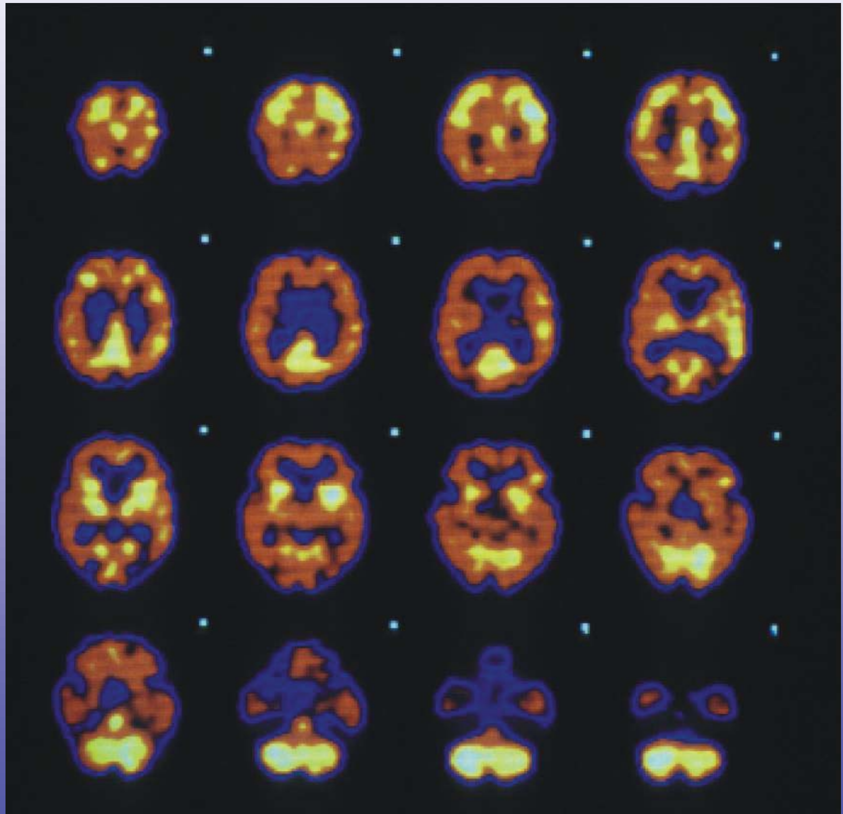
Automatic Determination of the Heart Ejection Fraction with ^{99m}Tc-Sestamibi-Perfusion-SPECT



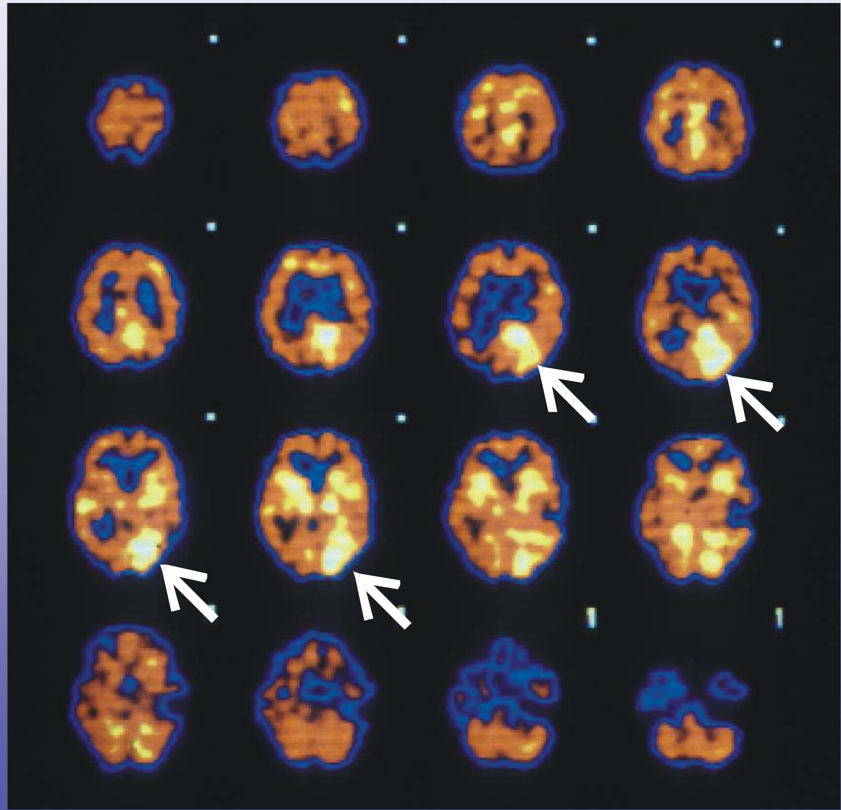
Germano et al., JNM 2138ff (1995)

Cerebral Perfusion with ^{99m}Tc-HMPAO

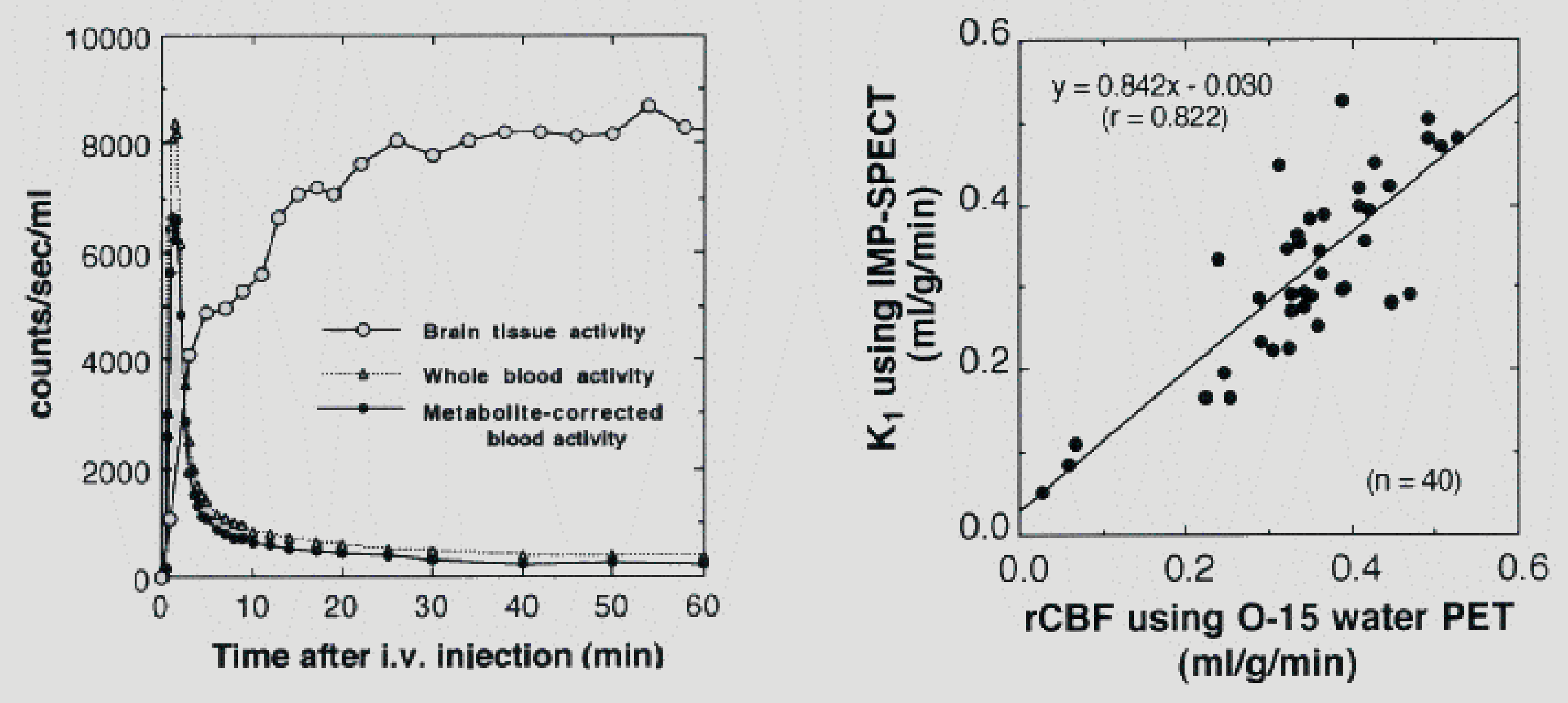
Normal



Malignant Tumor

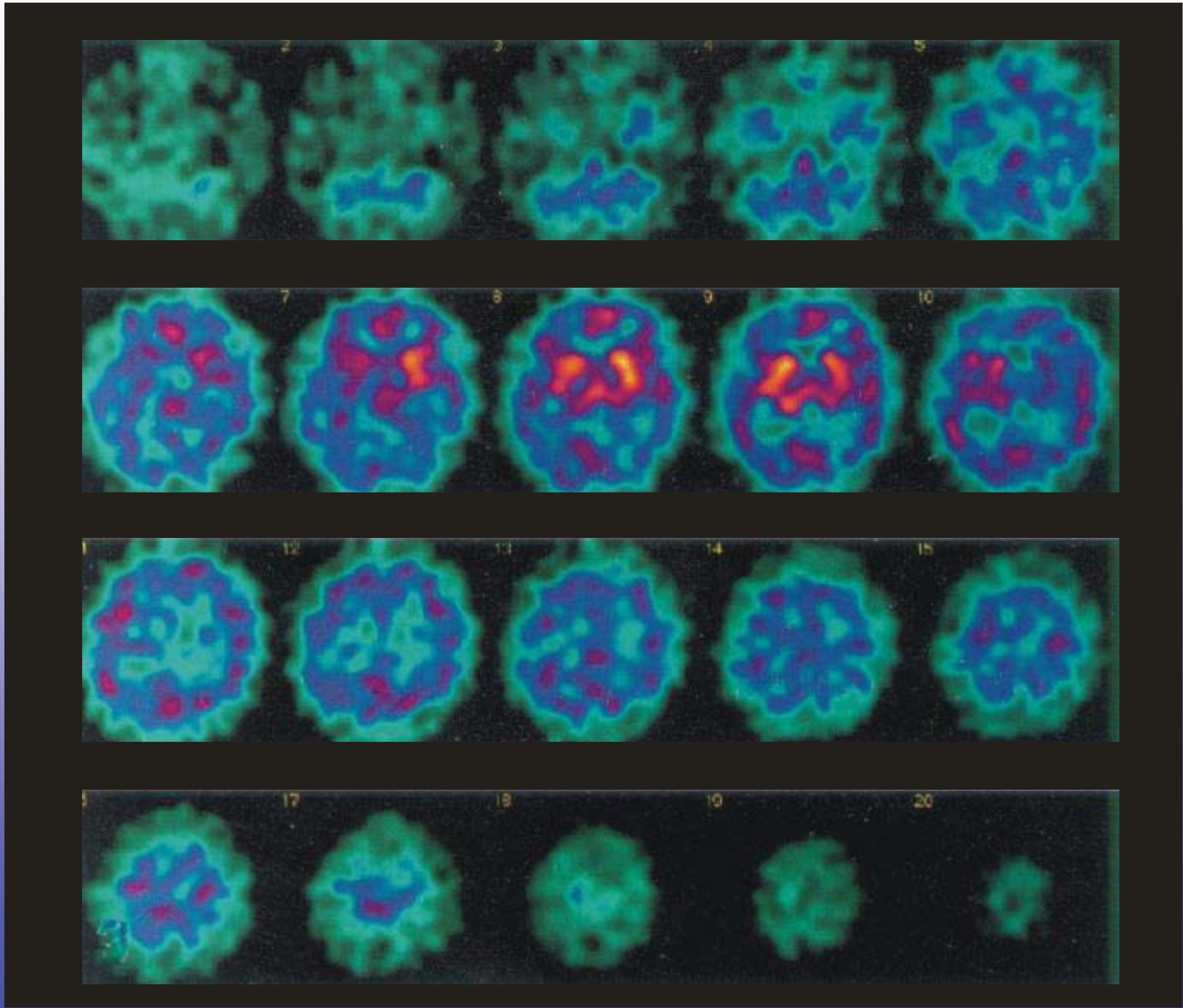


Cerebral Perfusion with ^{123}I-IMP



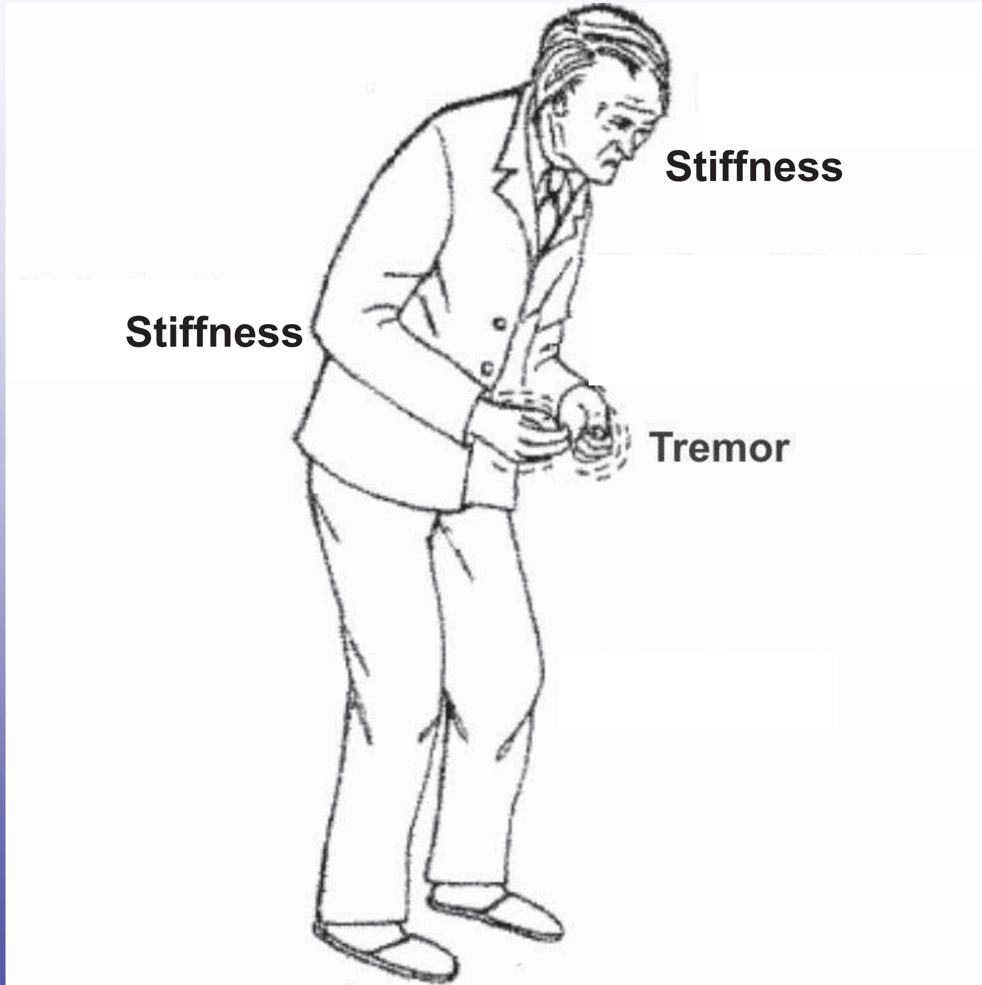
Yokoi et al., JNM 1993

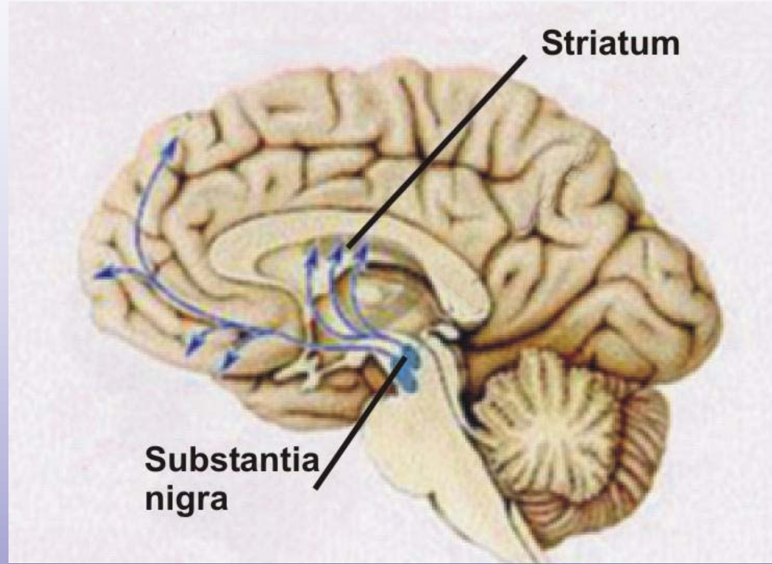
Dopamine Transporter: ^{123}I-ß-CIT

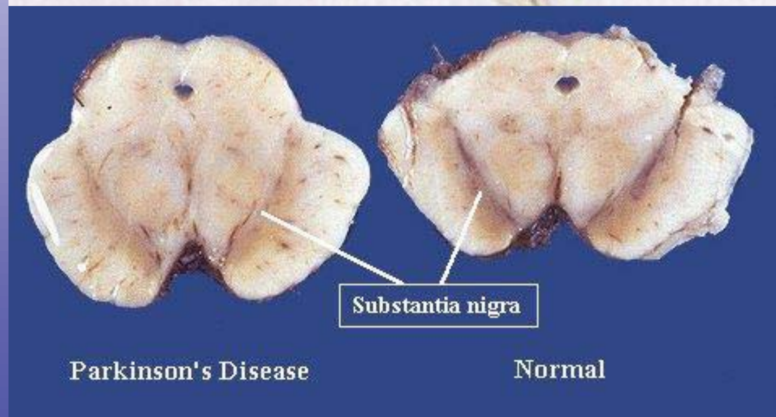


Kuikka et al., EJNM 783ff (1993)

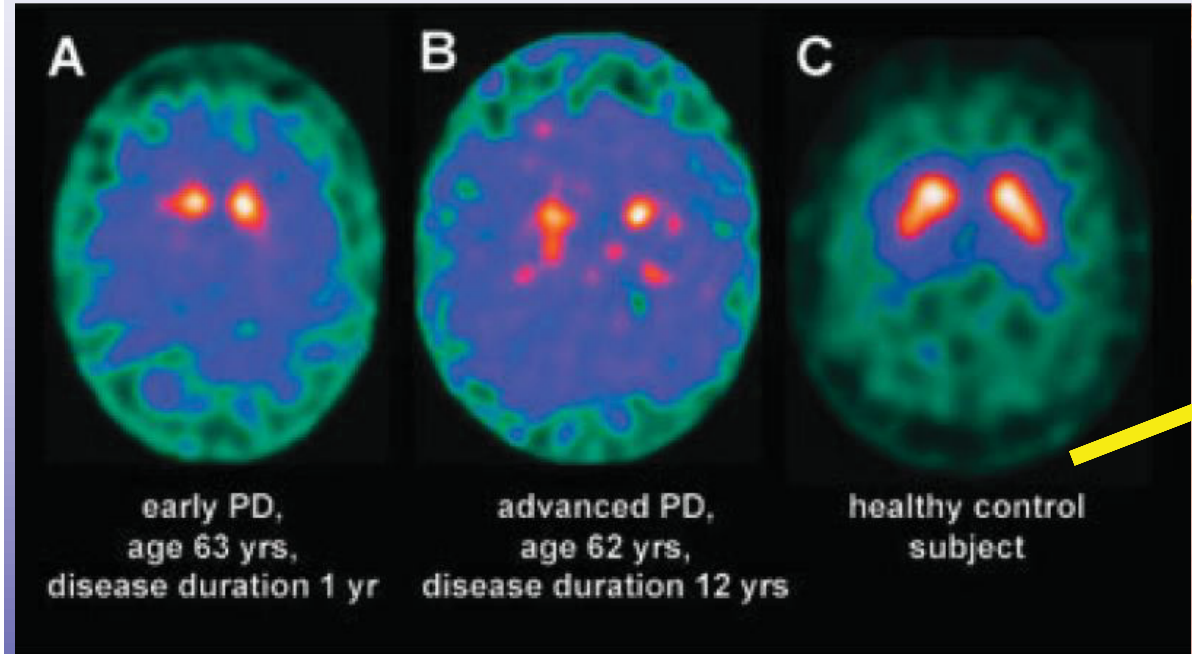
Morbus Parkinson



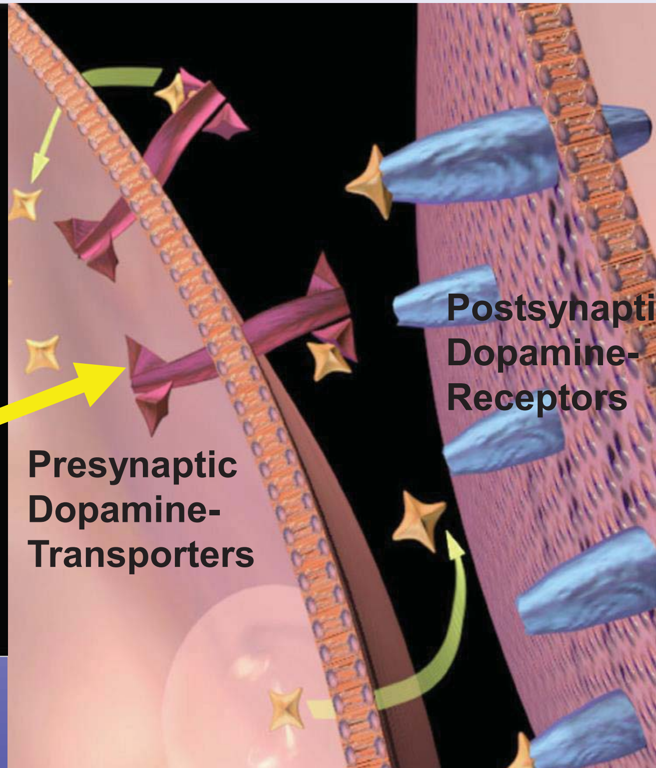




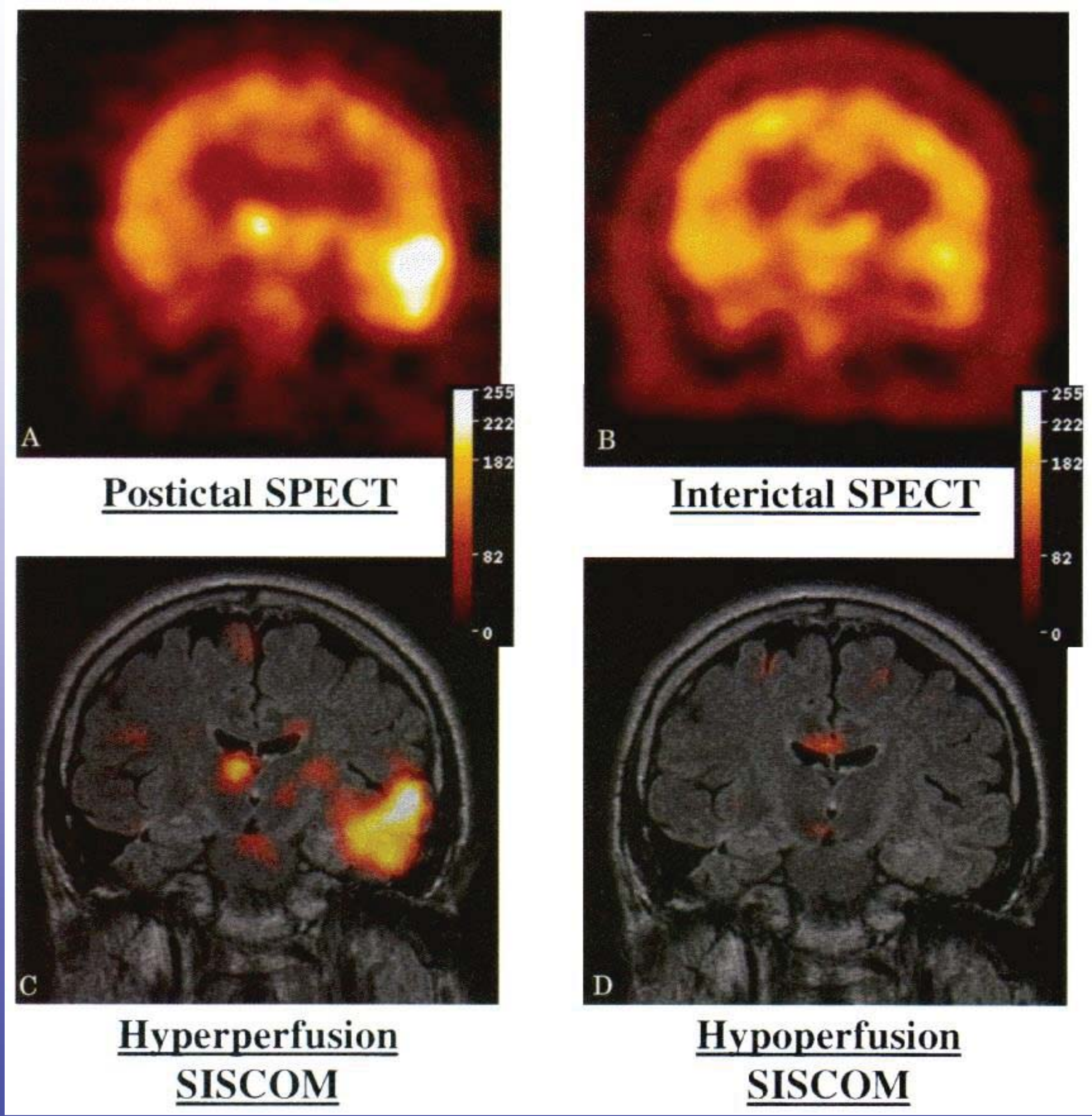
SPECT Imaging in Parkinson`s Disease



Scherfler et al., Movement Disorders, 2007



Focus of Seizure



Perfusion SPECT

with

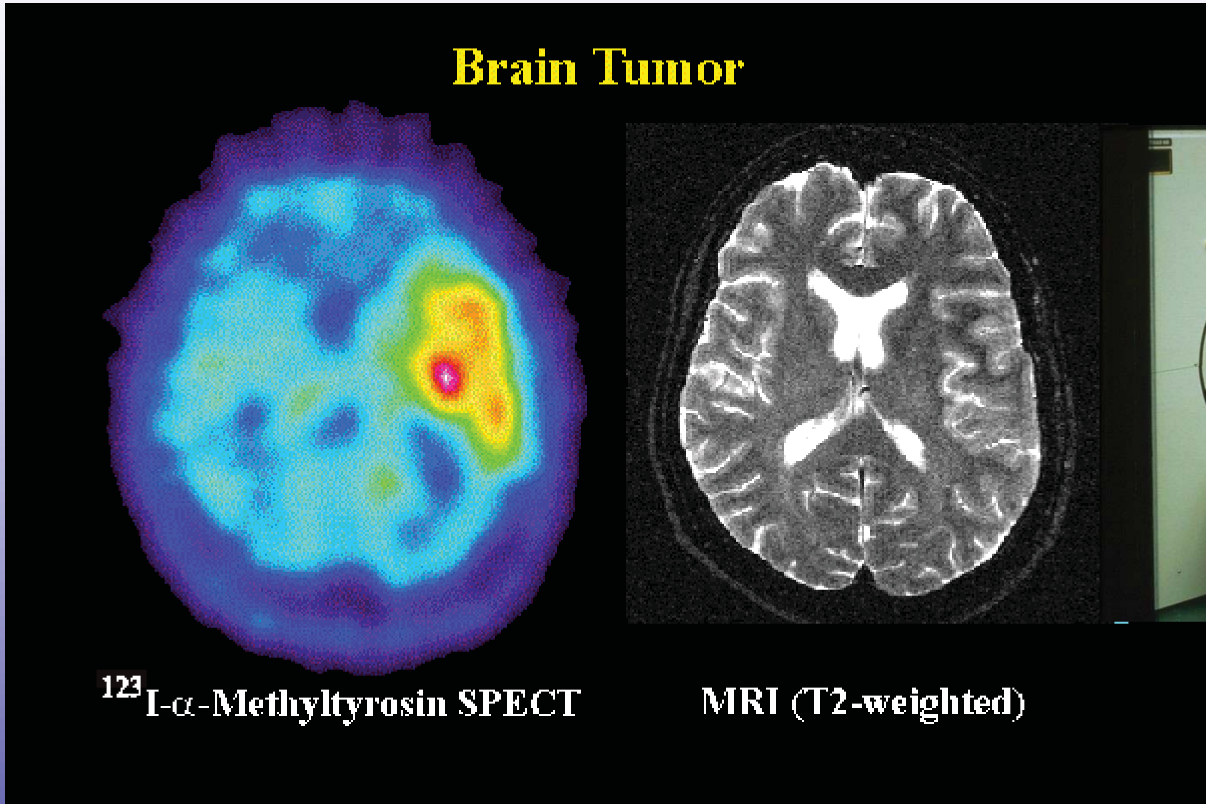
^{99m}Tc-ECD

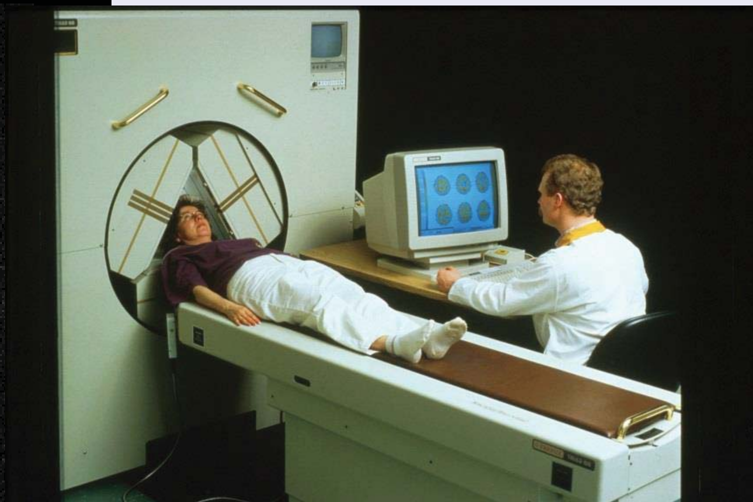
or

^{123}I-HMPAO

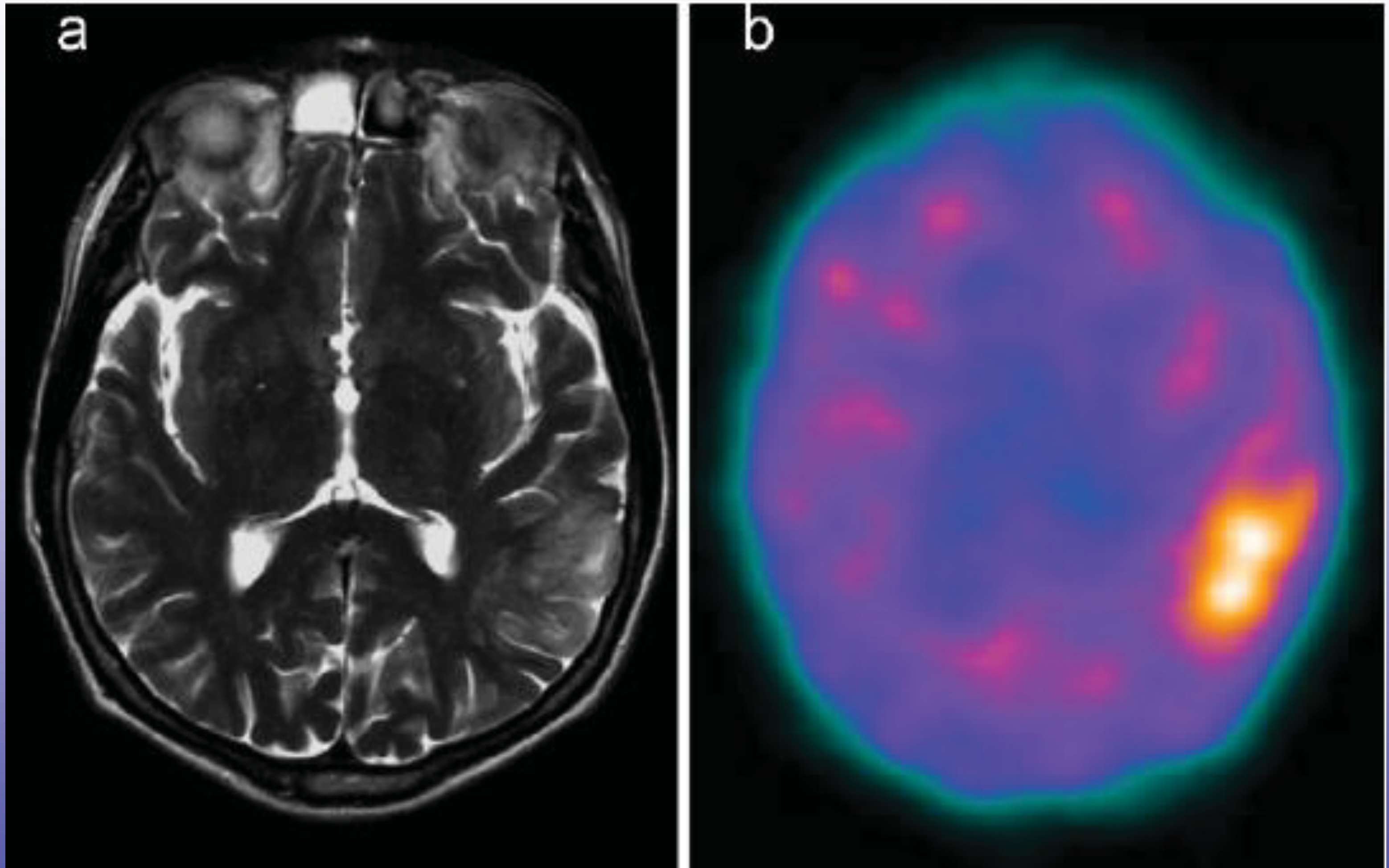
O'Brien, Neurology, 1999, 137pp

Imaging of Brain Tumours with ^{123}I-α-methyl-tyrosine (^{123}I-IMT)



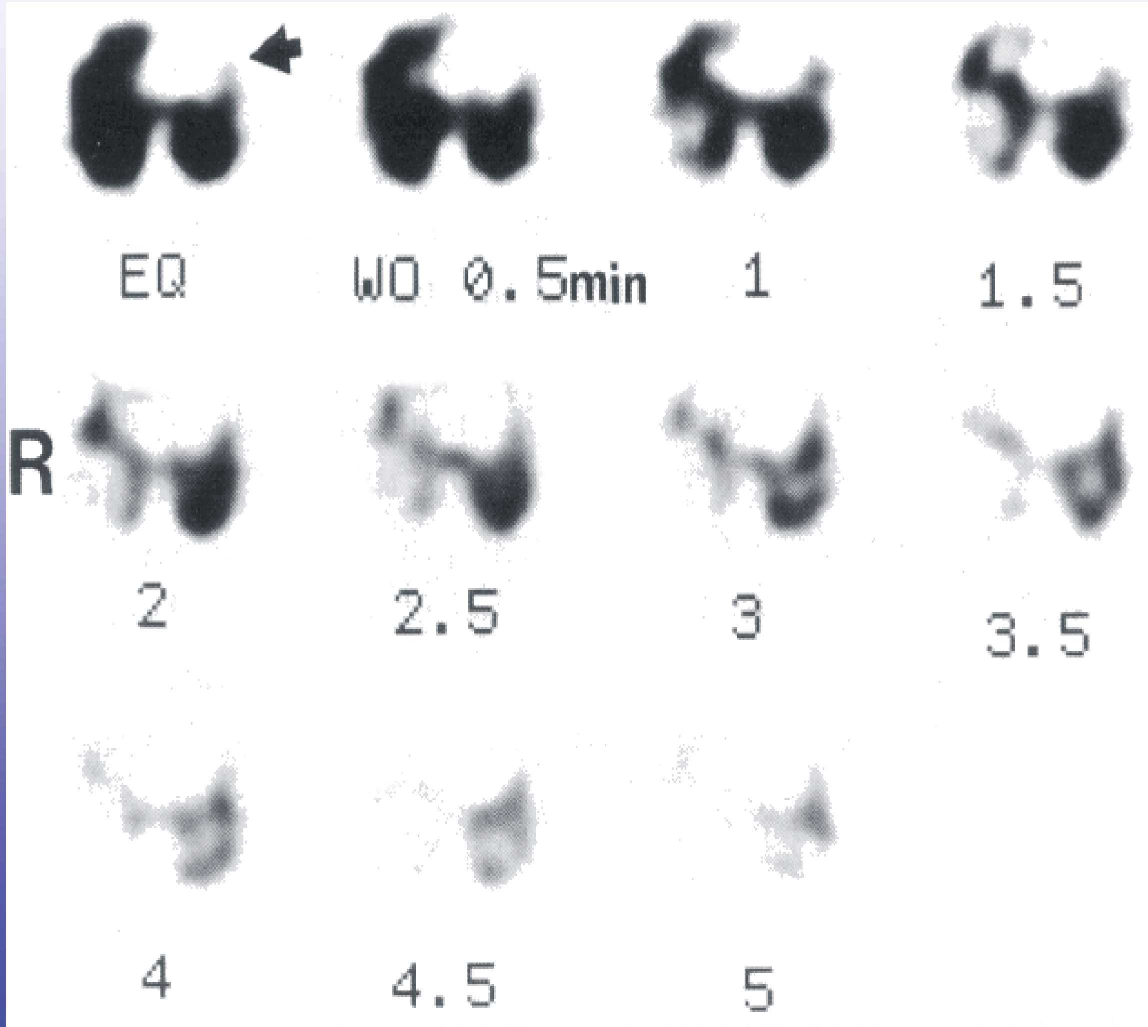


Imaging of Brain Tumours with ^{123}I-2-iodo-tyrosine (^{123}I-2IT)



Keyrarts, EJNMMI, 2007, 994pp

Regional Ventilation of Lunge: dynamic SPECT with ^{133}Xe



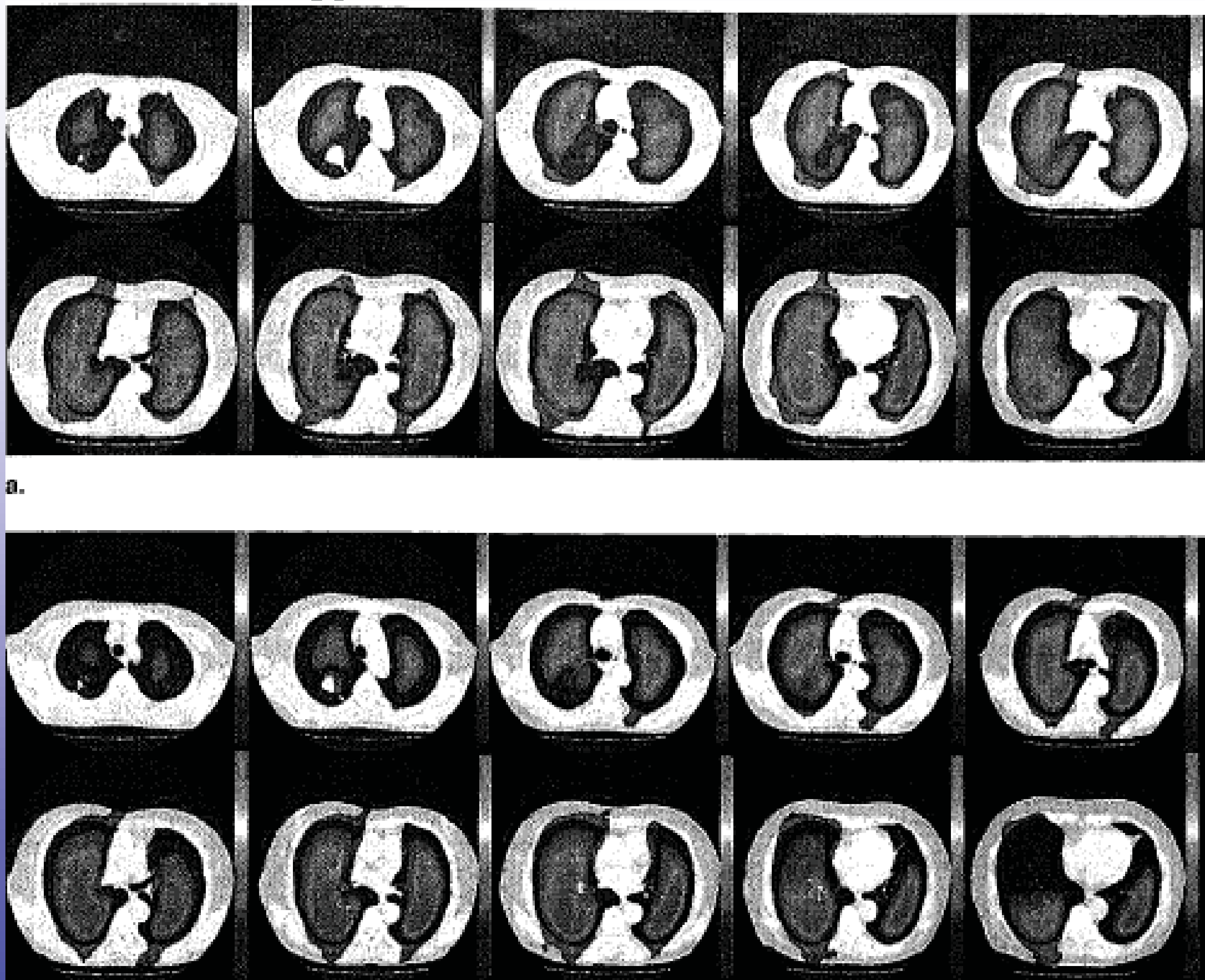
Asthma Bronchiale

59 yrs, female

CT w.F.

Suga et al., EJNM 220ff (1995)

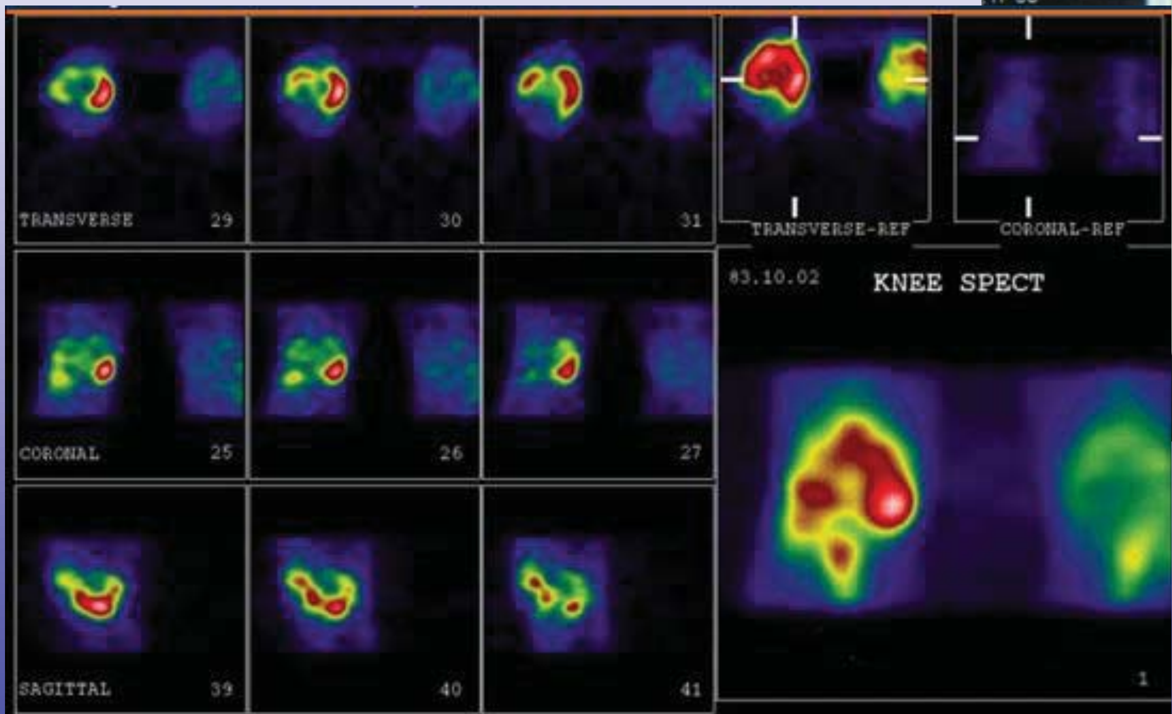
Combined Ventilation/Perfusion SPECT of Lung with ^{81m}Kr and ^{99m}Tc-MAA



Superimposed with CT by software

Ohno et al., Acad Radiol, 2007

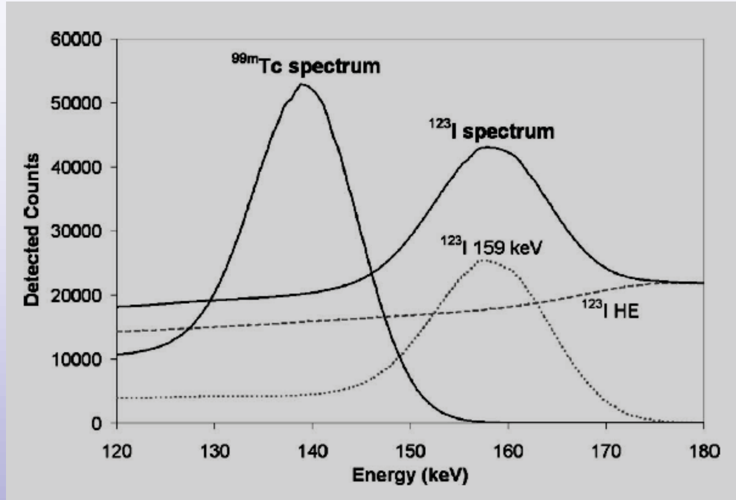
Bone SPECT with ^{99m}Tc-MDP

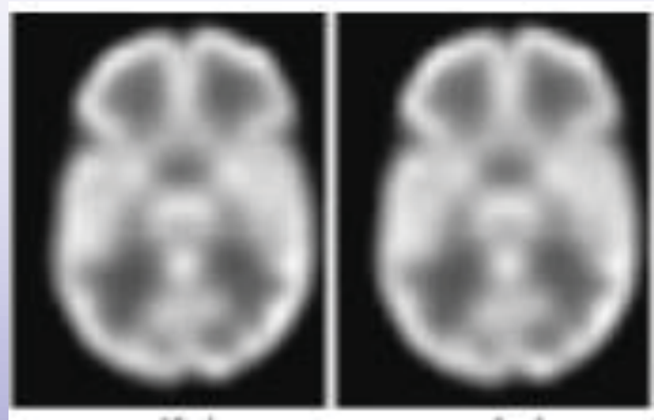


MRI

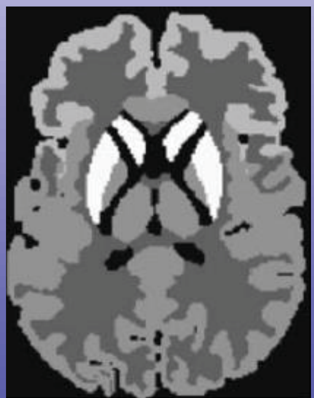
Tahmasebi et al., BMC Nuclear Medicine, 2007

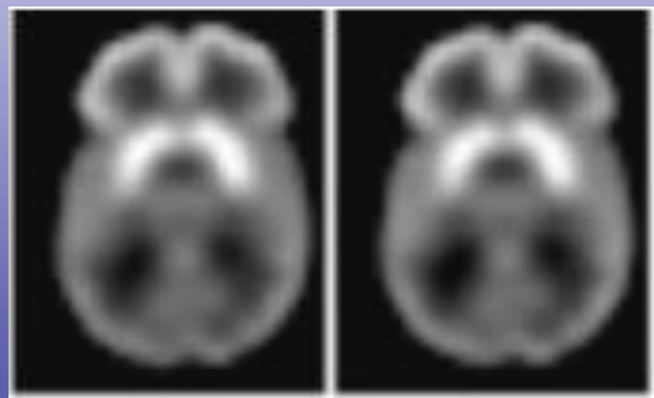
Dual Isotope SPECT
with Model-Based Crosstalk Compensation





^{99m}Tc-MAA



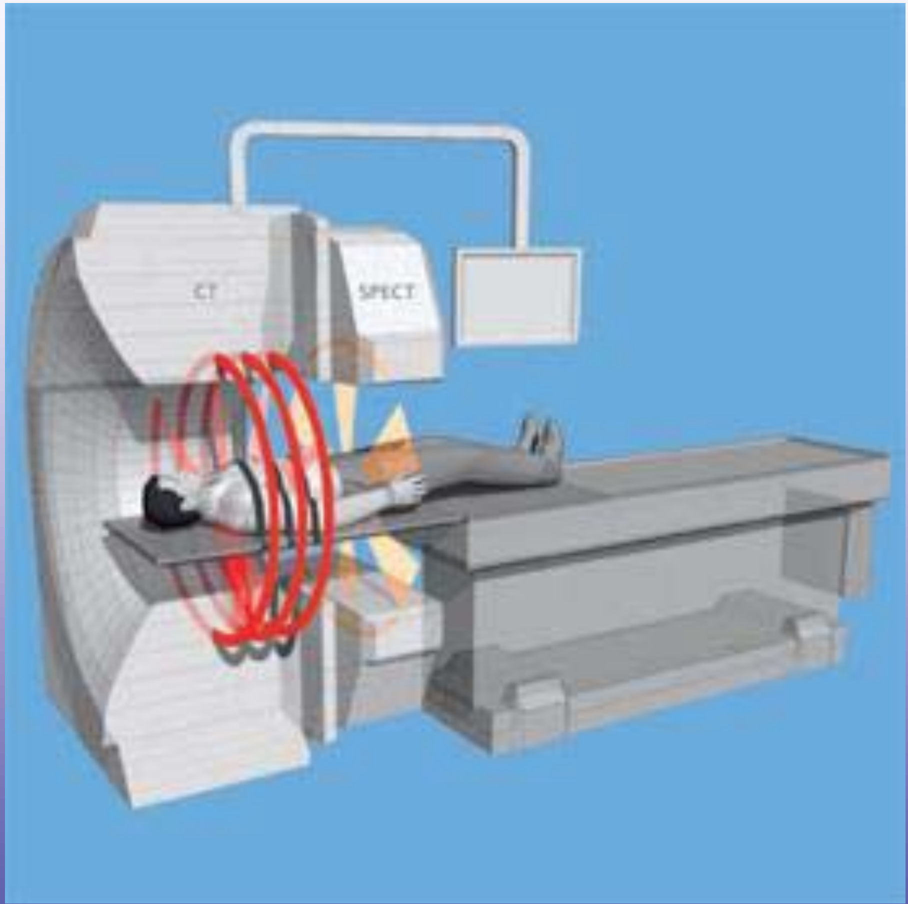


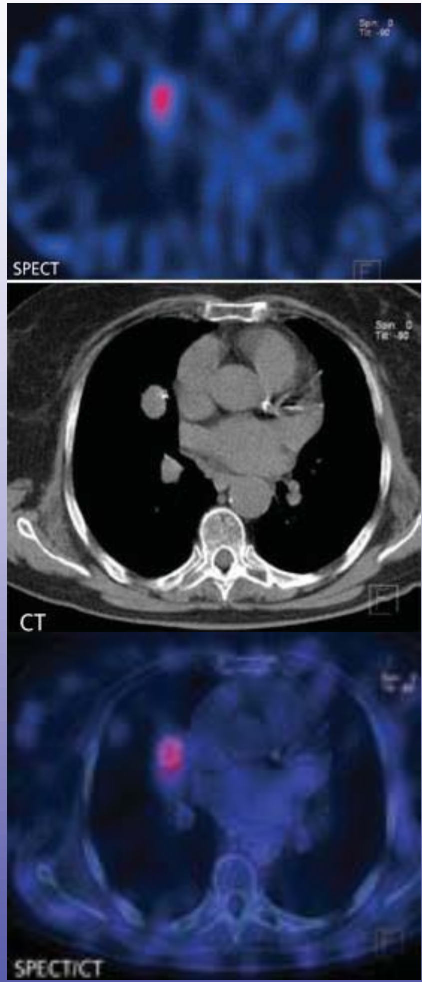
^{123}I

combined single

Du, Tsui, amd Frey, Med Phys. 2007

SPECT/CT





http://www.medical.siemens.com

Highlight Lecture SNM-Meeting 2012:

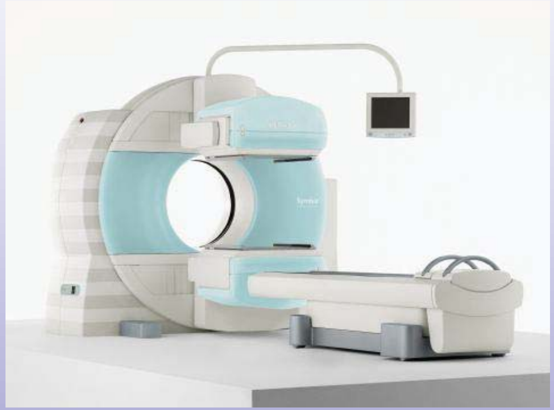
SPECT/CT is increasingly becoming the standard of care over simple planar imaging for many clinical nuclear medicine imaging applications.

All the major camera manufacturers are now involved in production and marketing.

SPECT/CT

Philips: BrightView XCT

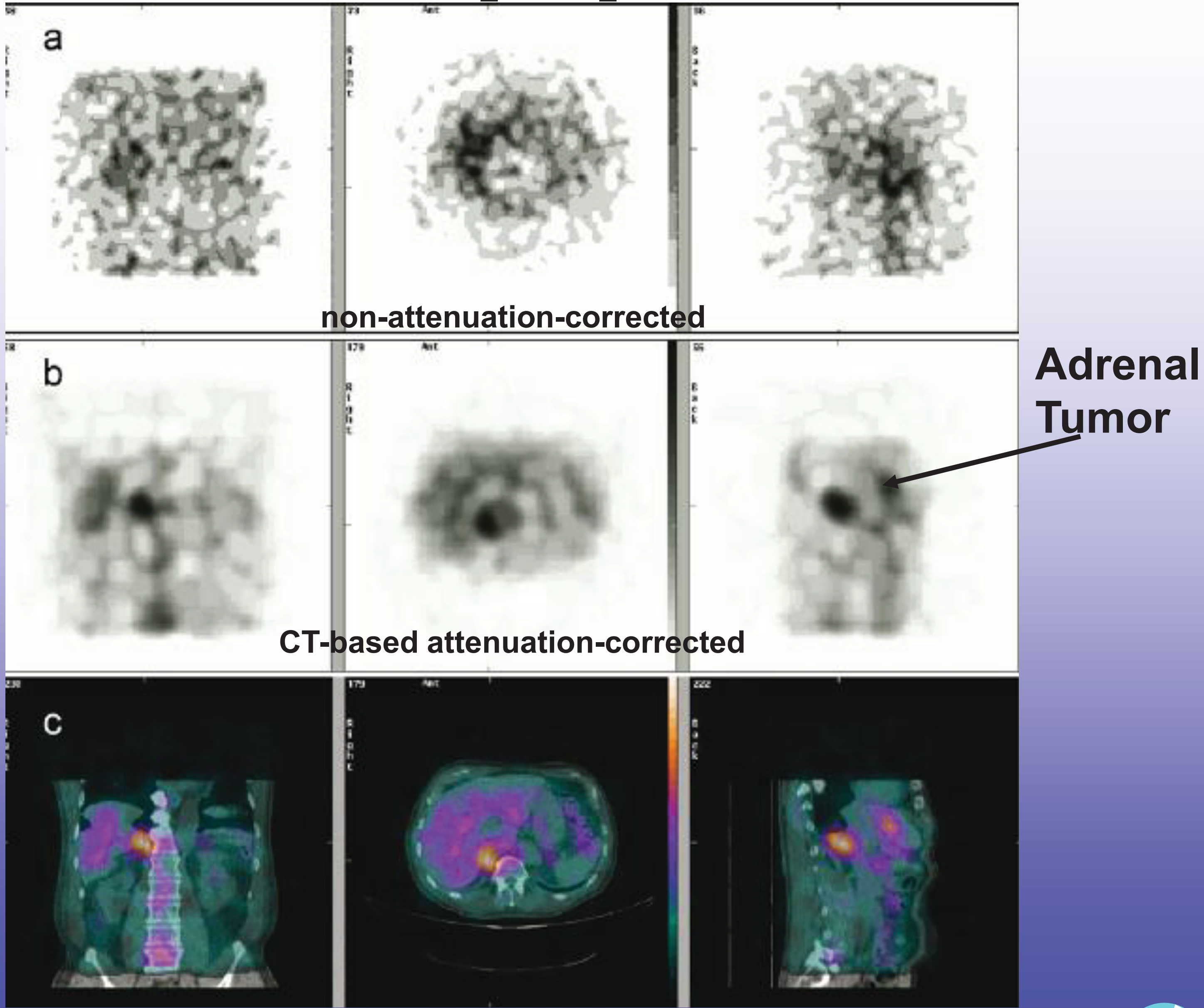
Siemens: Symbia



Mediso: AnyScan SC

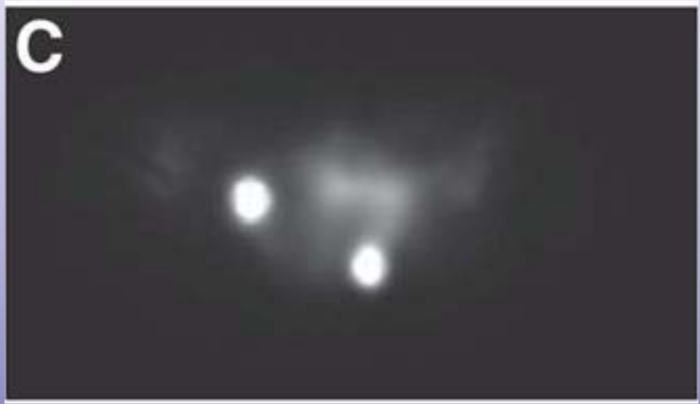
GE: Discovery NM/CT 670

SPECT/CT with [^{131}I]norcholesterol



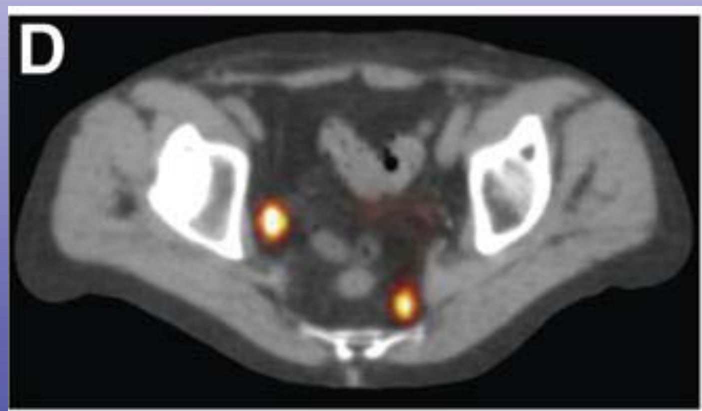
D. Bailey, EJMMI, 2007, 1415pp

SPECT/CT with [^{99m}Tc]nanocolloid for Sentinal Node Imaging in Prostate Cancer



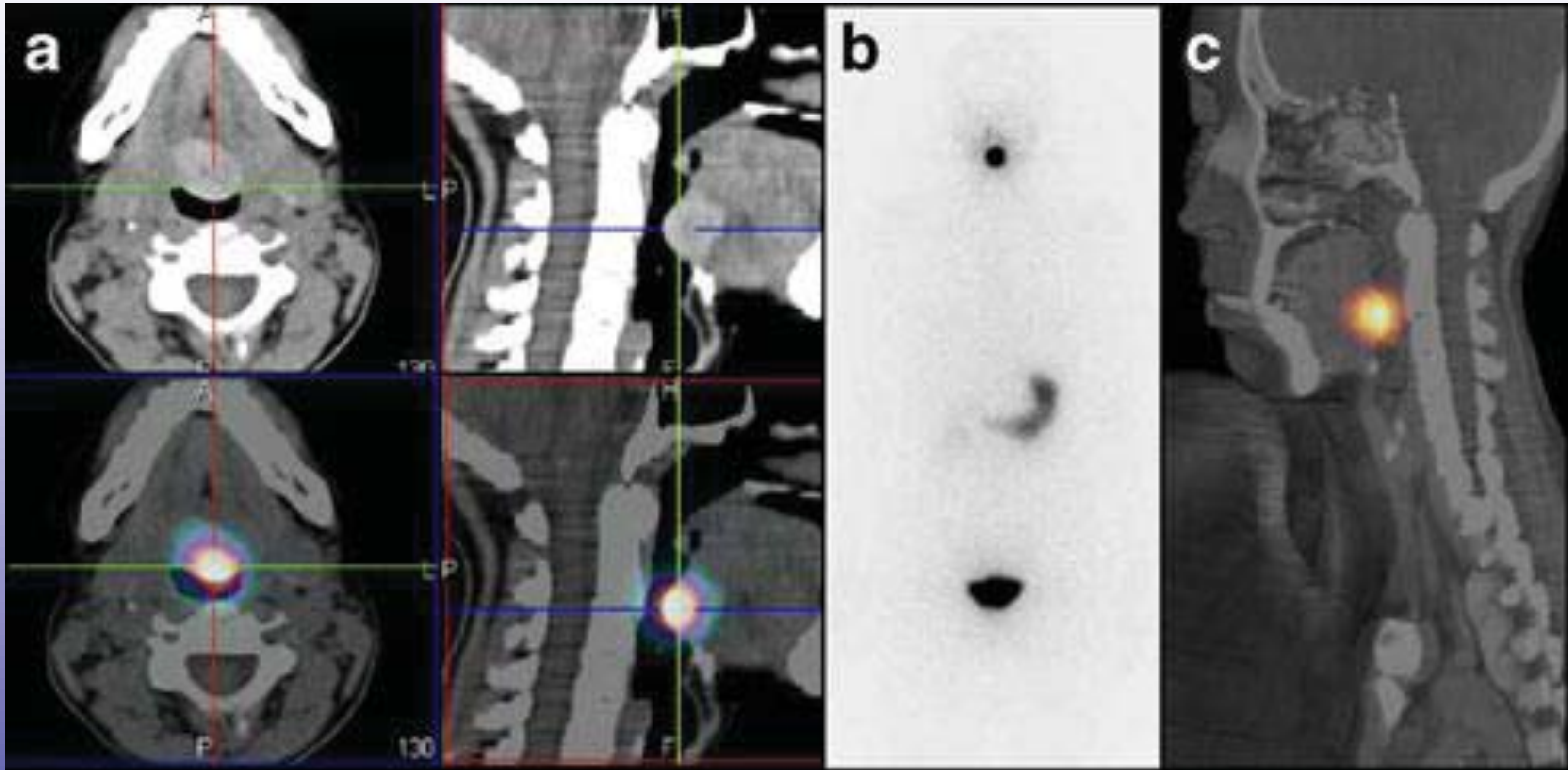
SPECT

SPECT/CT



Vermeeren L et al. , J Nucl Med 2009

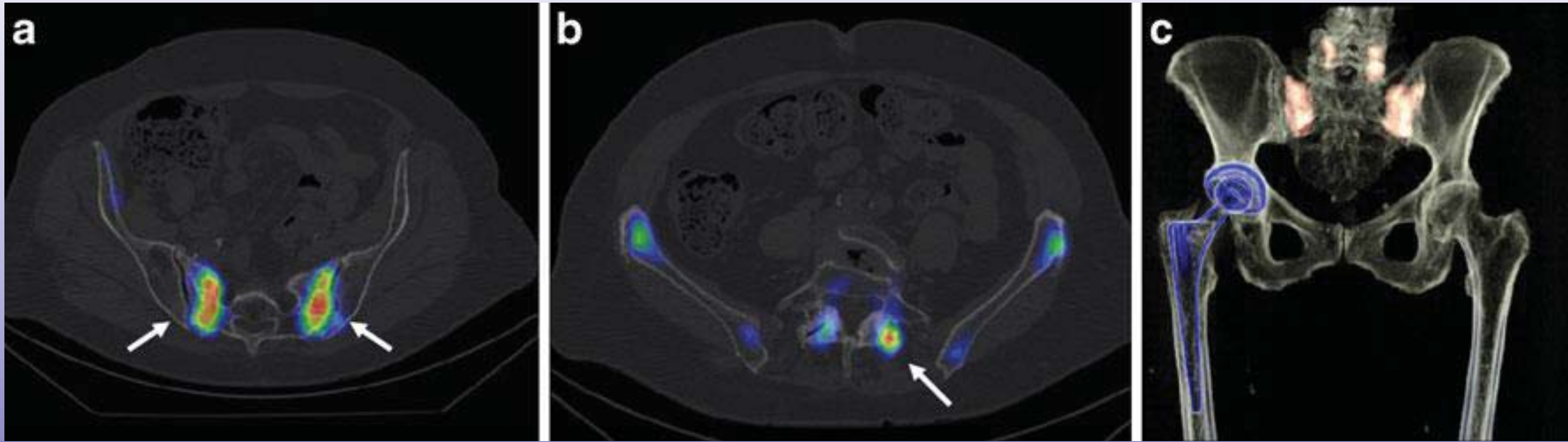
SPECT/CT with [^{123}I]



Lingual ectopic thyroid tissue

Vercellino L et al. , EJNMMI 2011

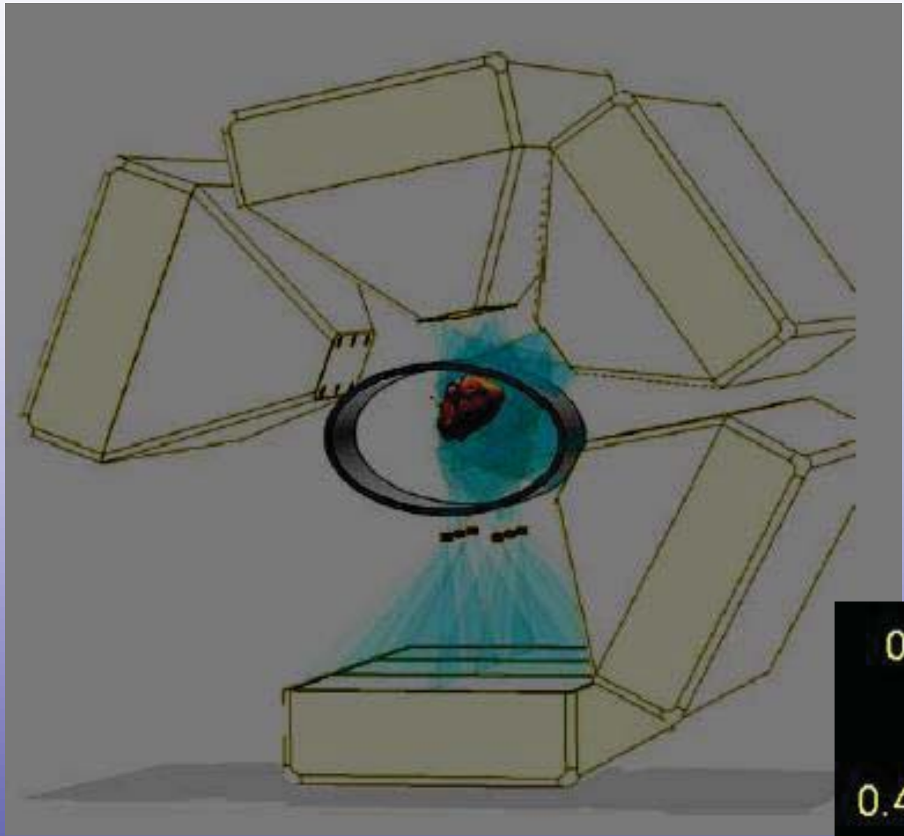
SPECT/CT with ^{99m}Tc-MDP

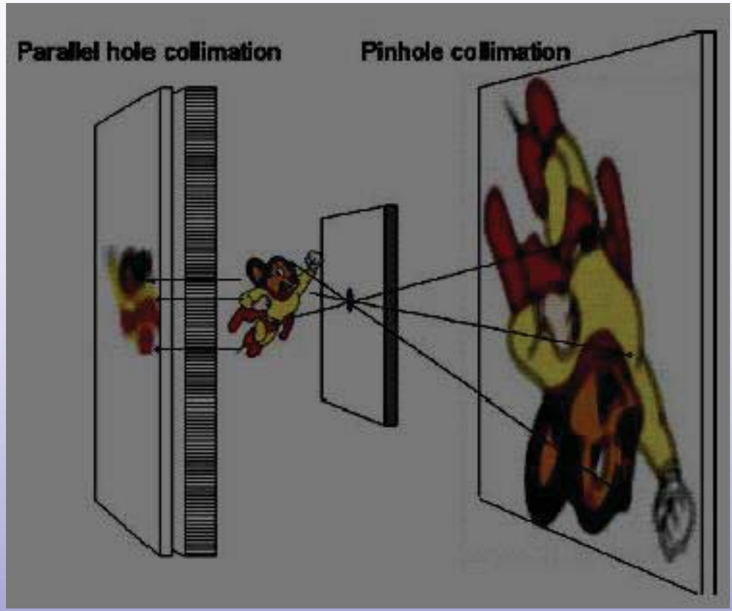


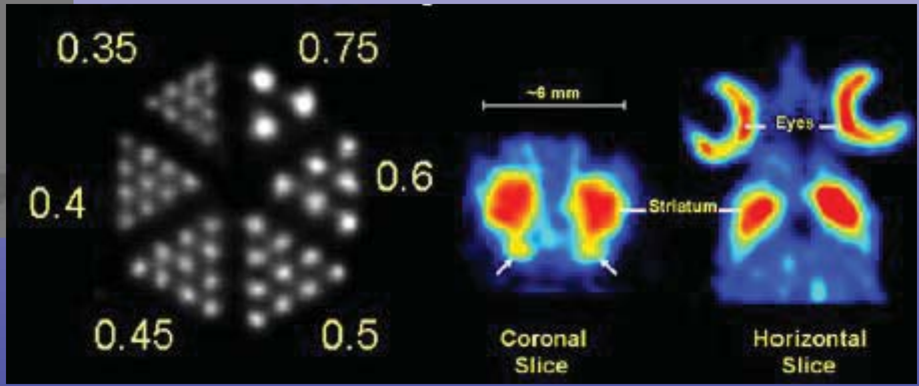
Suspicion of iliosacral joint arthritis

Scheyerer MJ et ak., EJNMMI 2013 (in press)

Animal Multipinhole SPECT







Beekman, EJMMI, 2007, 151pp

Thank you

Appendix

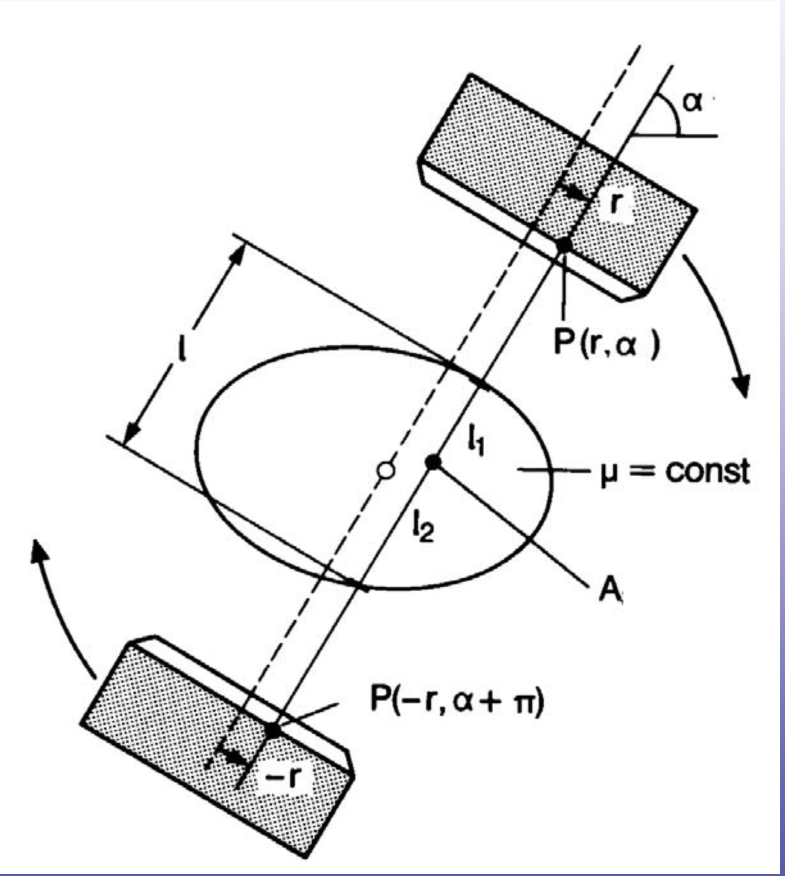
What about

Quantitation

Using SPECT ??

To quantify radioactivity using SPECT you must do scatter correction in addition to attenuation correction

Very Simple Scatter Correction

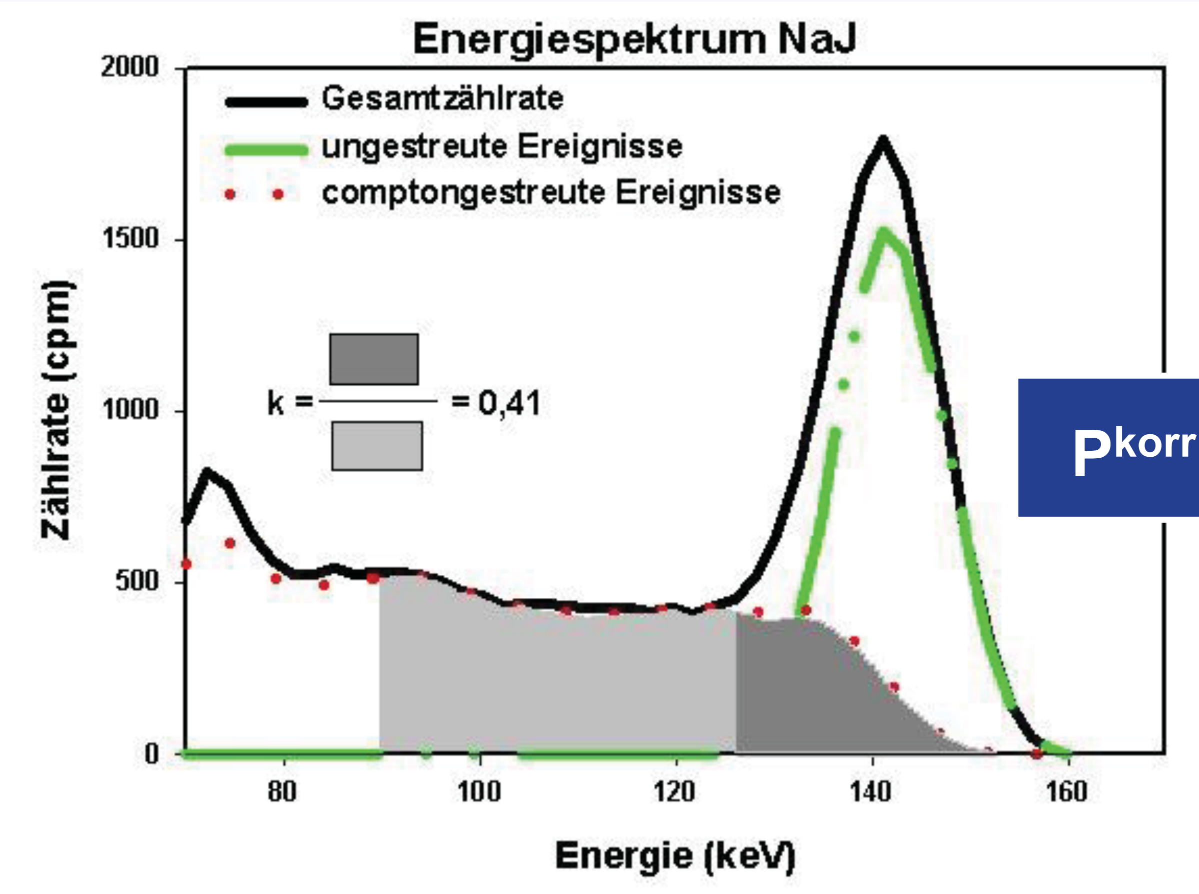


$$SF = (1 – \exp(-\mu l)) / \mu l$$

Use $\mu = 0.12\ cm^{-1}$
instead of $0.154\ cm^{-1}$,

so that
the attenuation correction
becomes less

Scatter Correction Using a Double Window Method

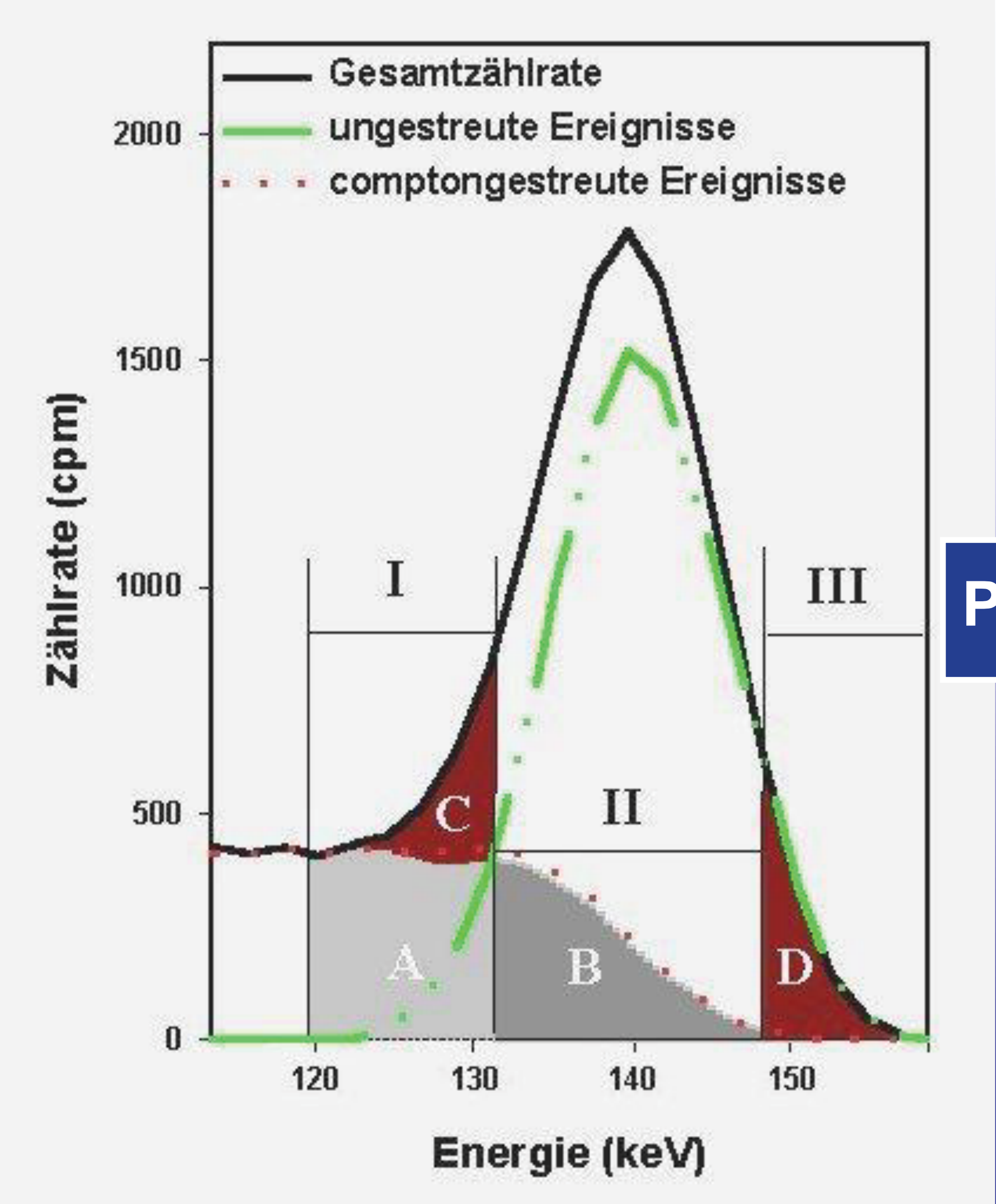


$$P^{korr} = P^{pp} - k * P^{Compton}$$

Jaszczak et al., 1984

Problem:
Shape dependency

Scatter Correction Using a Triple Window Method



Sonnenberg et al., 1995

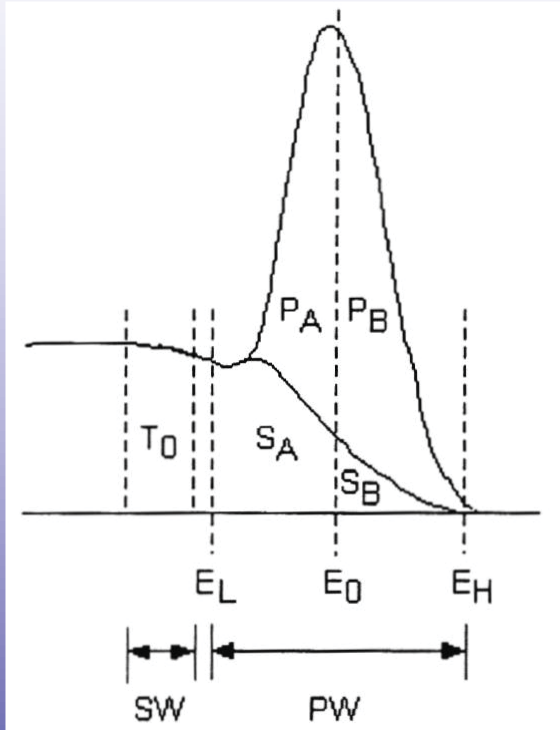
$$P^{korr} = P^{II} - (P^{I} - k\,P^{III}) + P^{III}$$

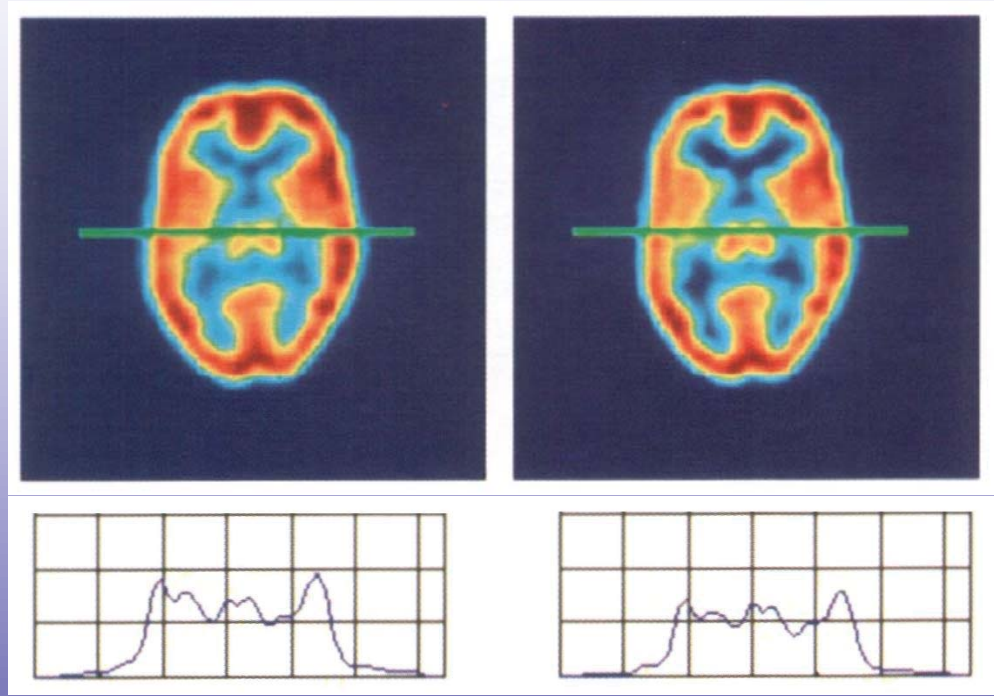
$k = C/D$

➔ Less shape dependency

Locally Variable Scatter-Correction Using the Klein-Nishina-Formula

(Jonsson, 2001)





$$P^{scatt} = S_A + S_B = \int [\, t_A(E) - t_B^*(E) + 2Fm\, KN(E) \,]\, dE$$

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