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Från positron till bild

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Abstract …

"Ämnen som berörs är hur en cyklotron fungerar, produktion av radiofarmaka, hur detekteras och mäts radioaktiviteten i kroppen, registrering av dynamiska och statiska PET-undersökningar. En vanlig fråga – Vad är egentligen det semikvantitativa måttet som kallas SUV (standardized uptake value), hur räknar man ut SUV och vad speglar SUV_{max} och SUV_{mean}?"

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Översikt

- Från positron till bild: hur fungerar PET?
- Tracermetod: kvantifiering
- FDG och SUV

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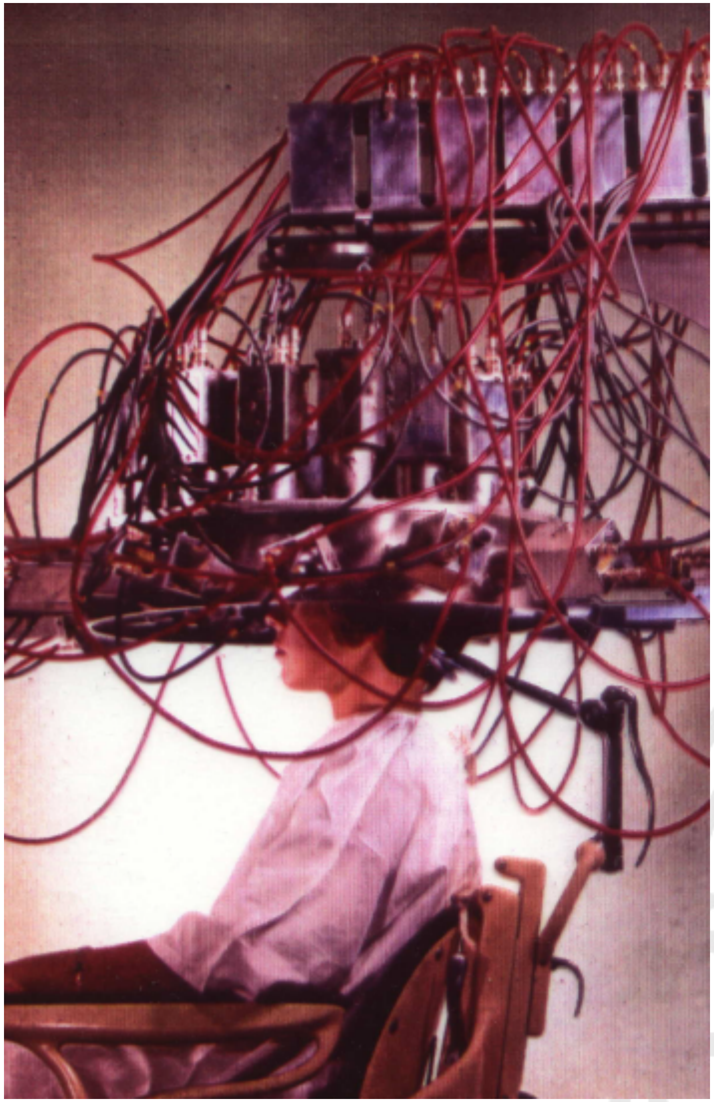

Brookhaven National Laboratory, around 1975

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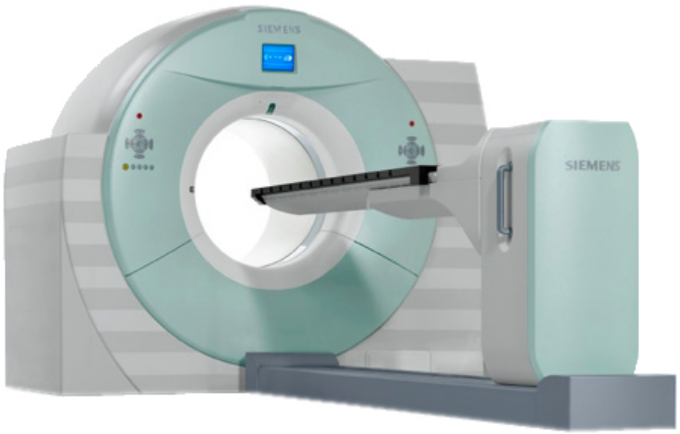

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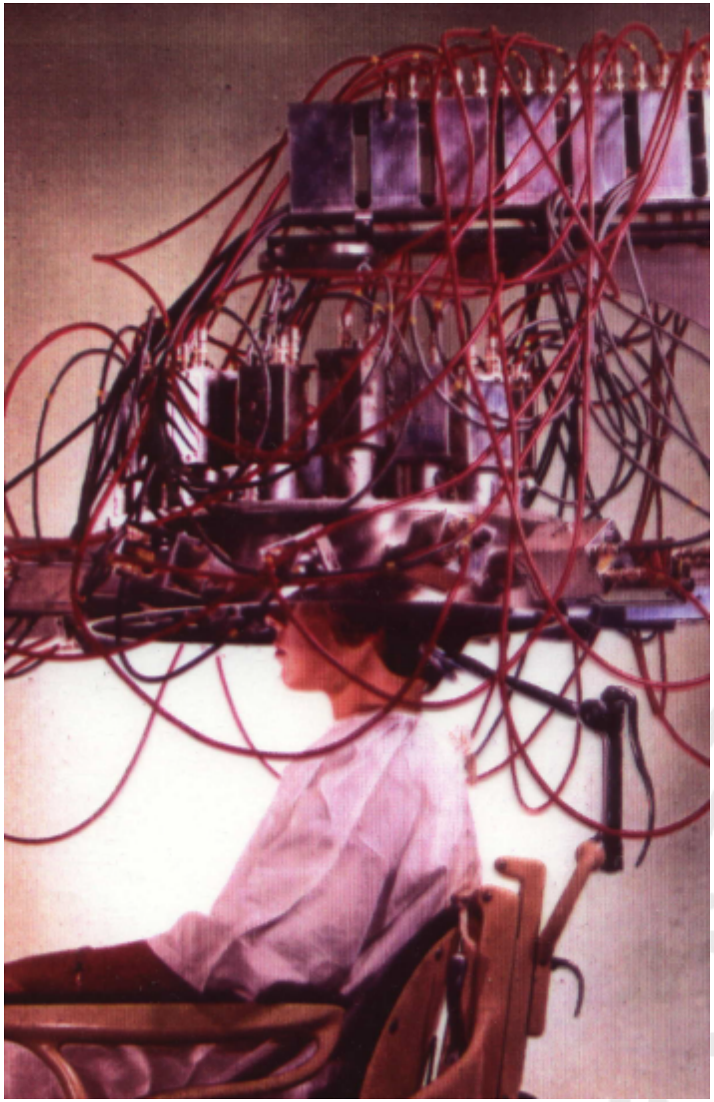

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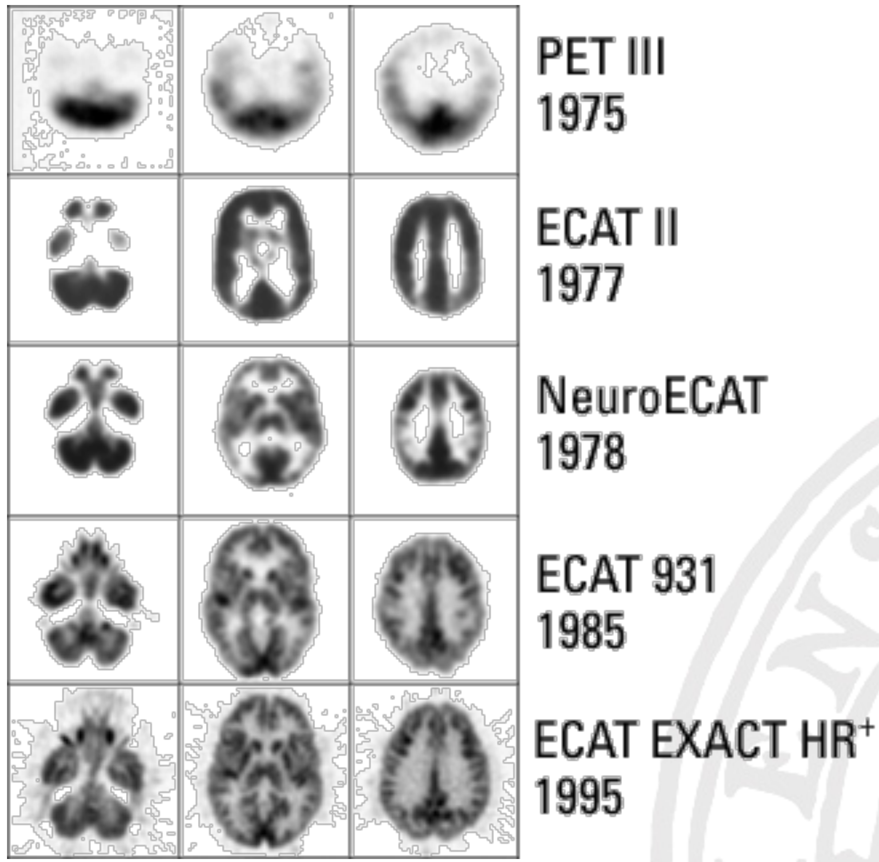
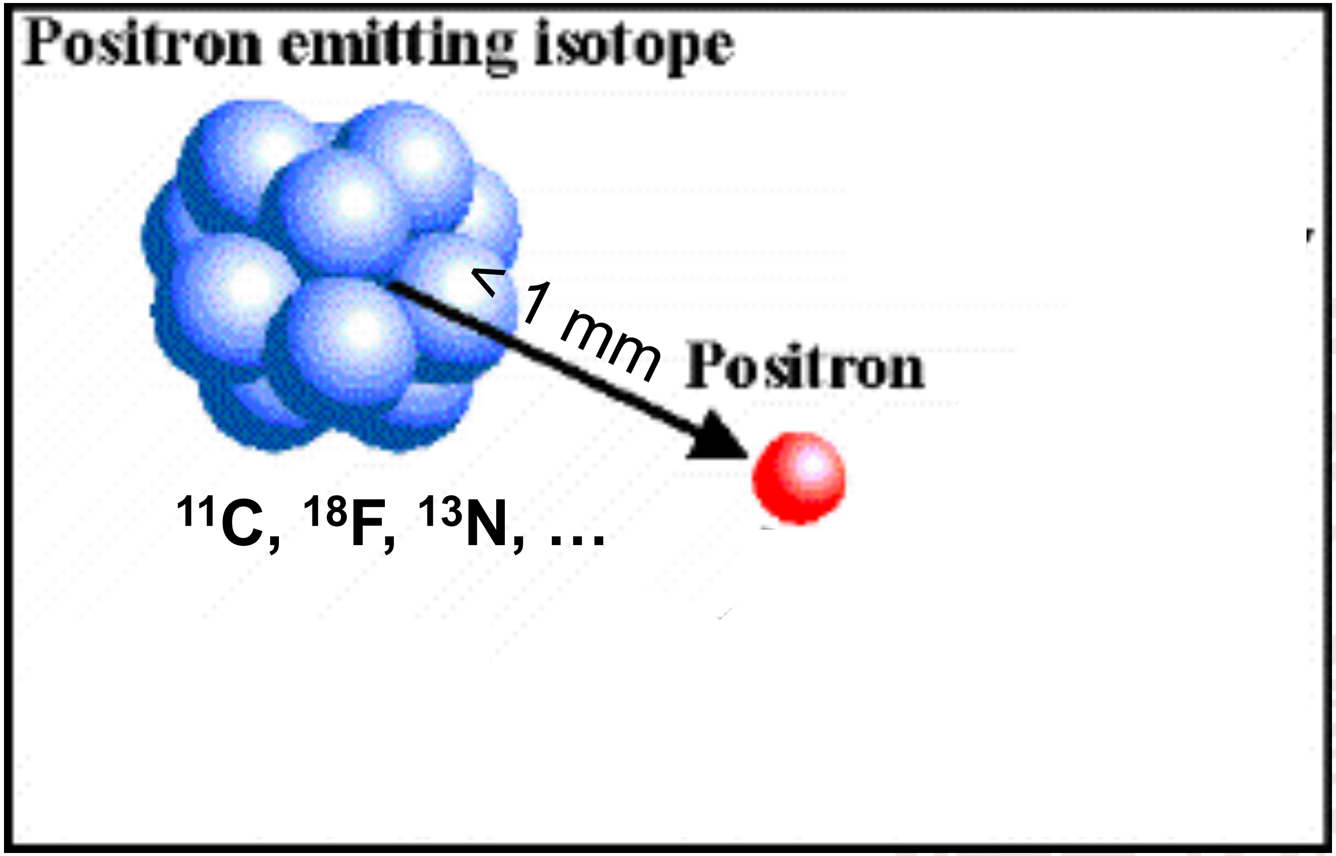


Radioaktivt sönderfall



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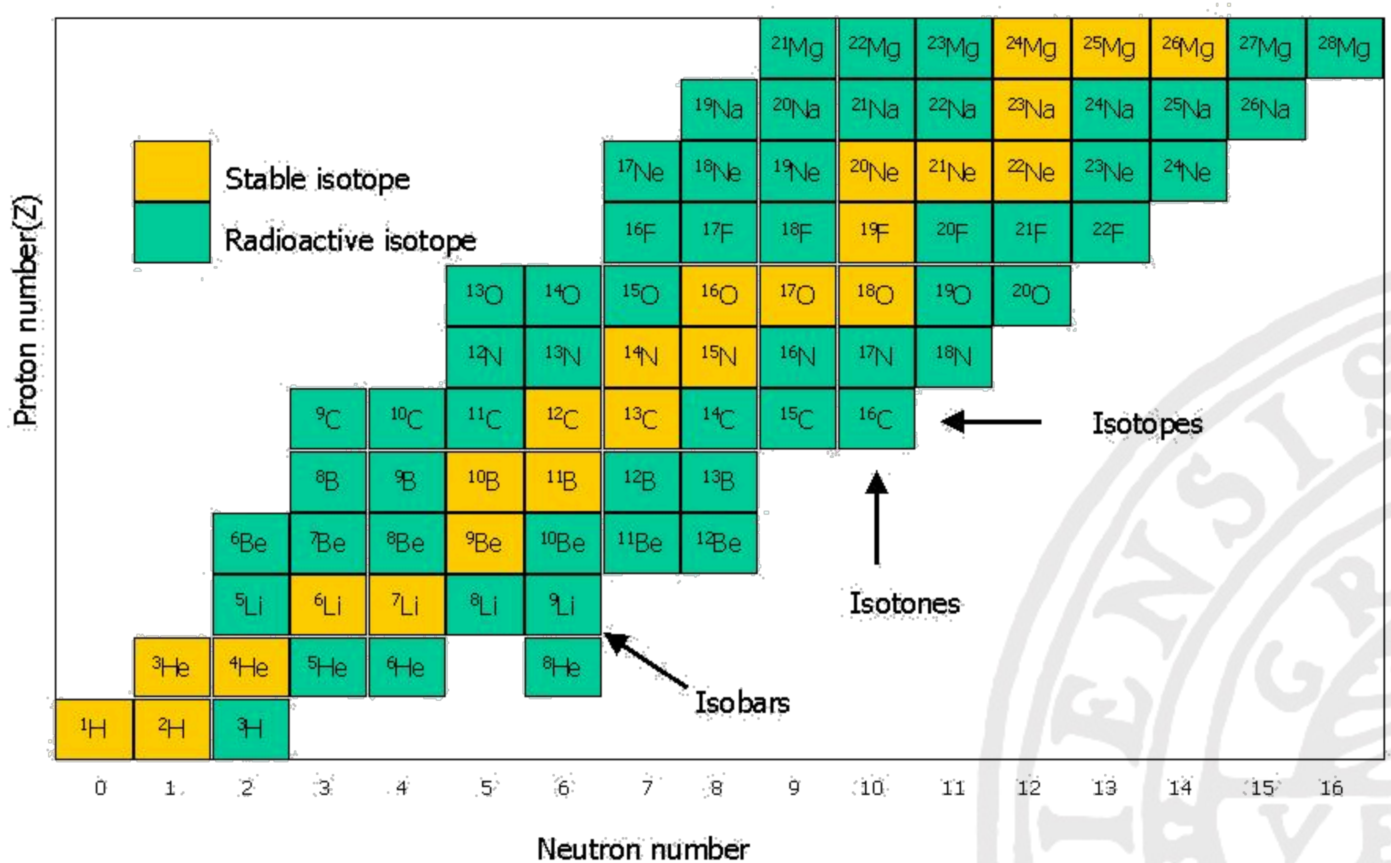
Radioaktivt sönderfall



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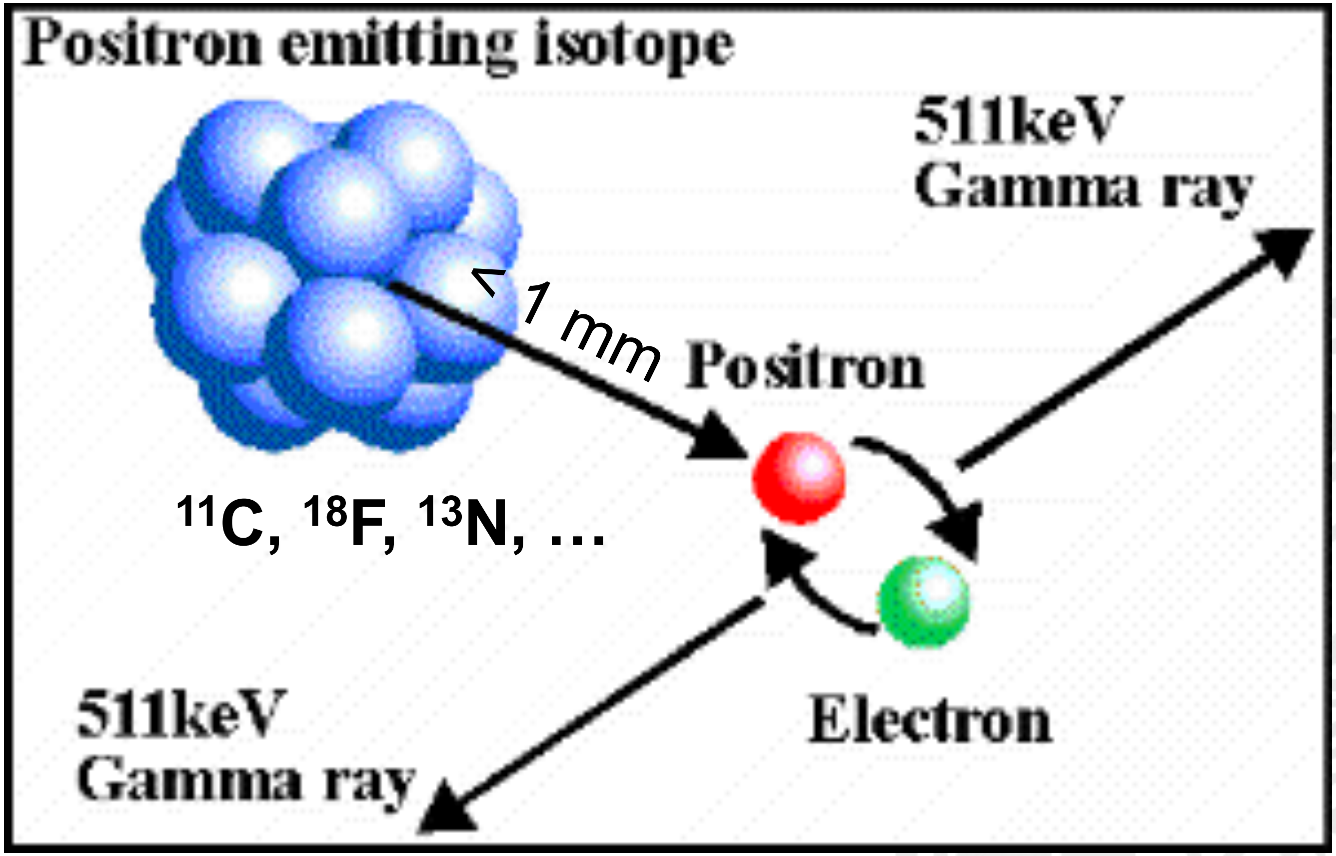
PET



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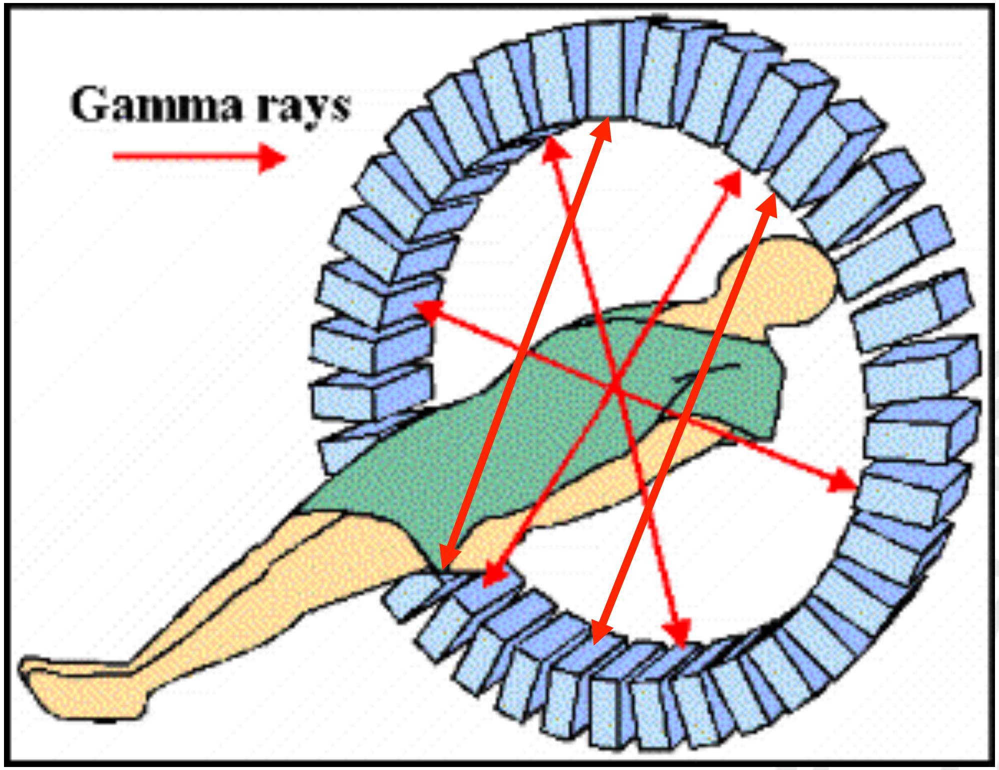
PET



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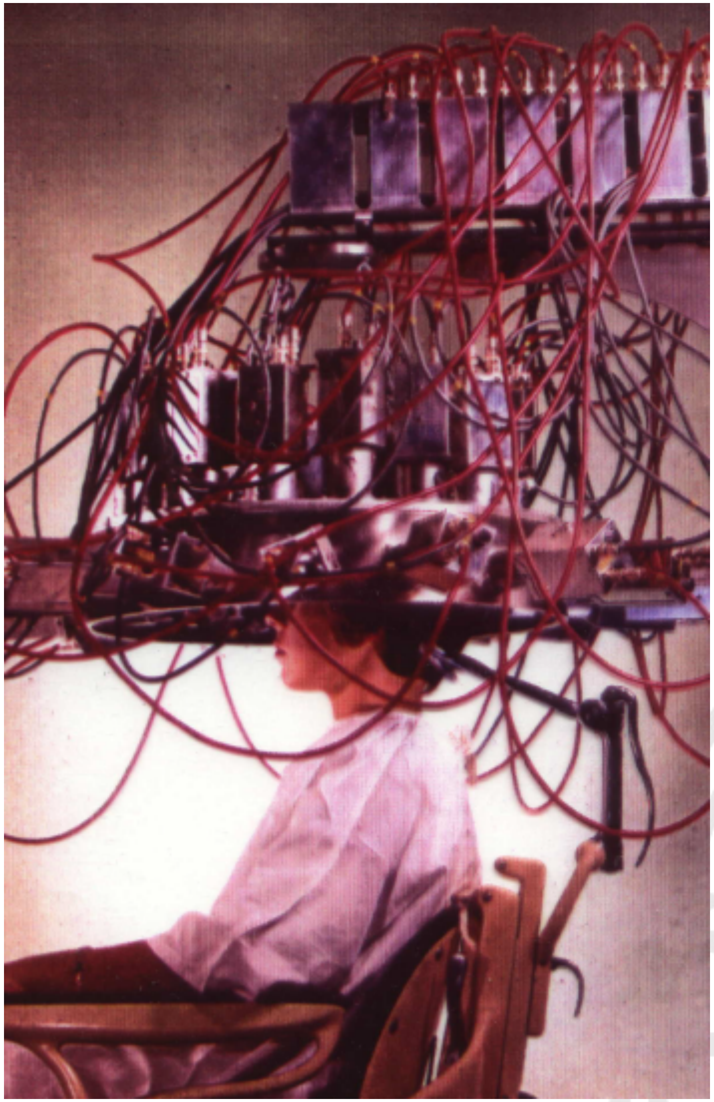
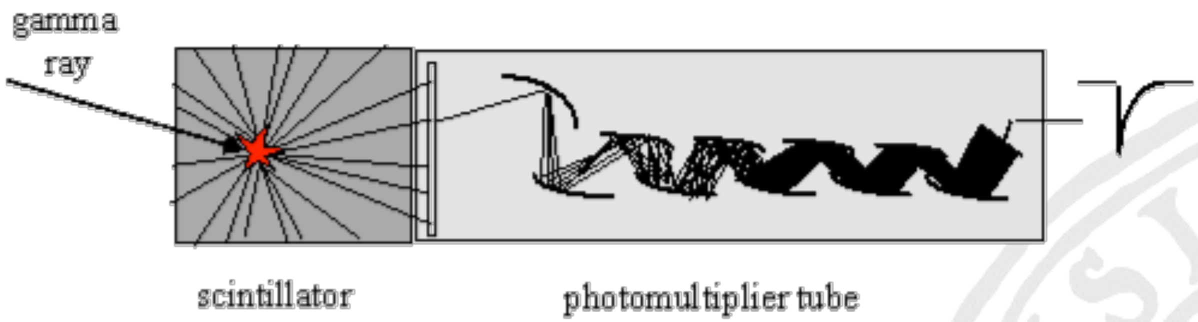


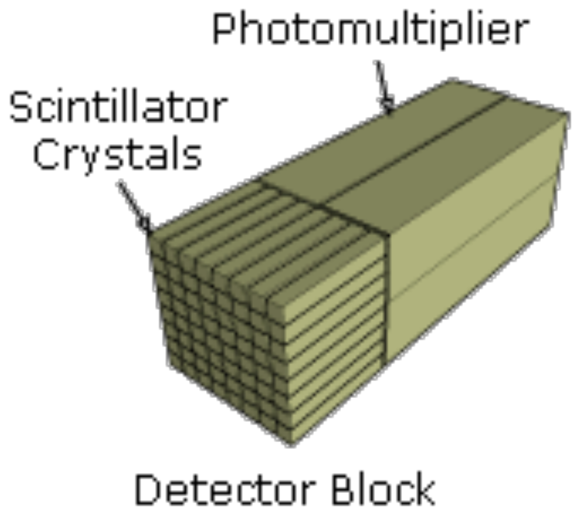
Brookhaven National Laboratory, around 1975

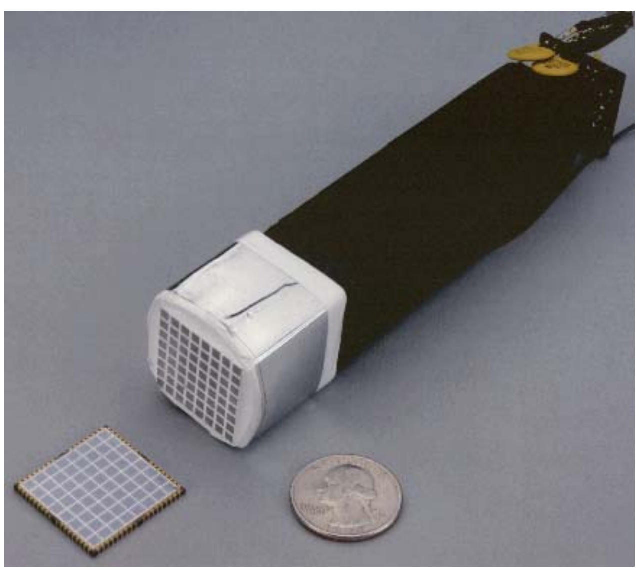
Detektor



Tellurium-doped sodium iodide (NaI(TI))
Bismuth germanate (BGO)
Lutetium oxyorthosilicate (LSO)
Yttrium-doped LSO (LYSO)
Etc.

Block detektor; flera ringar





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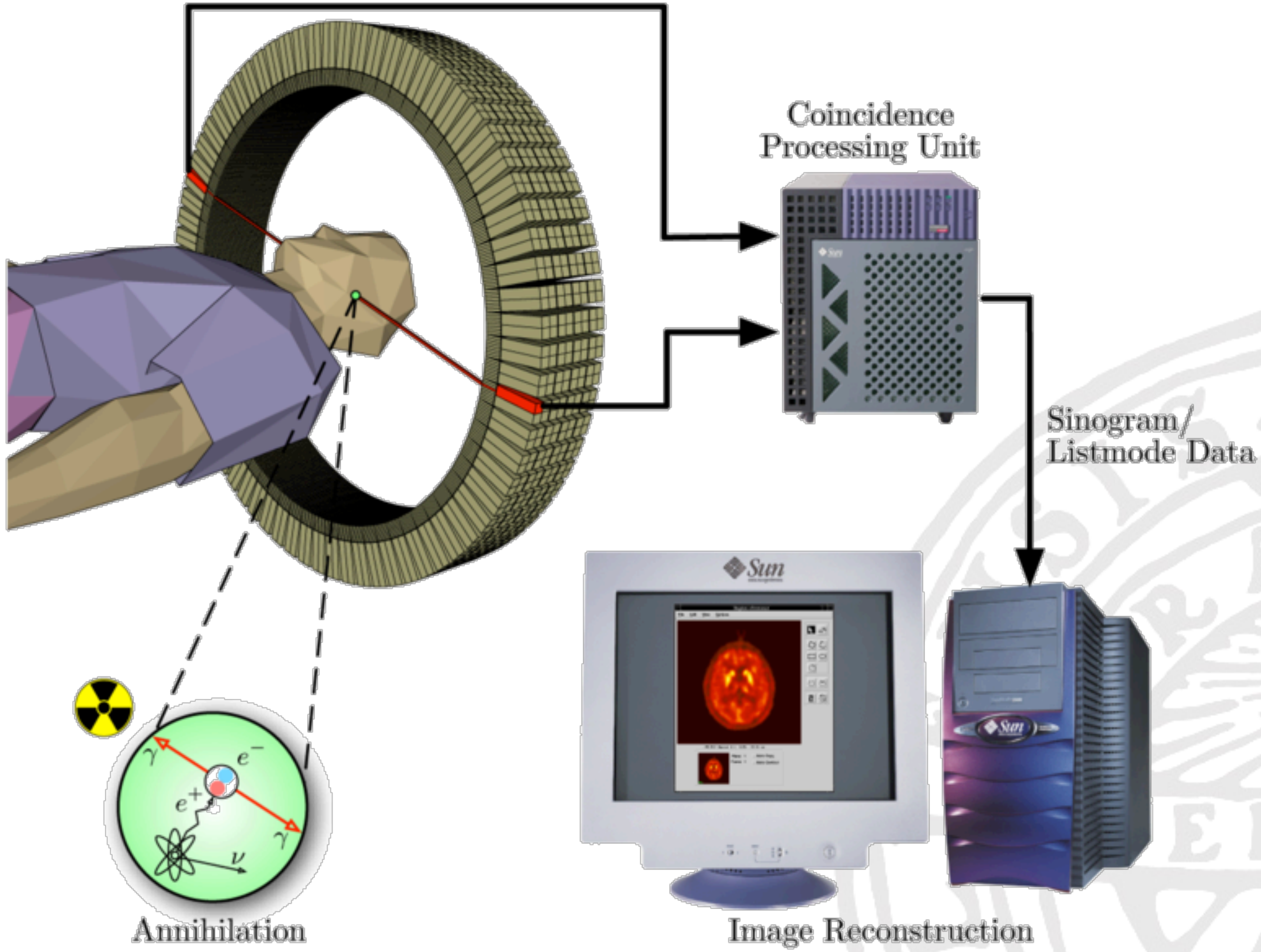

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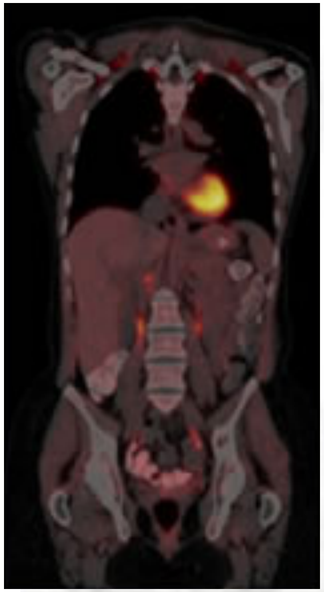
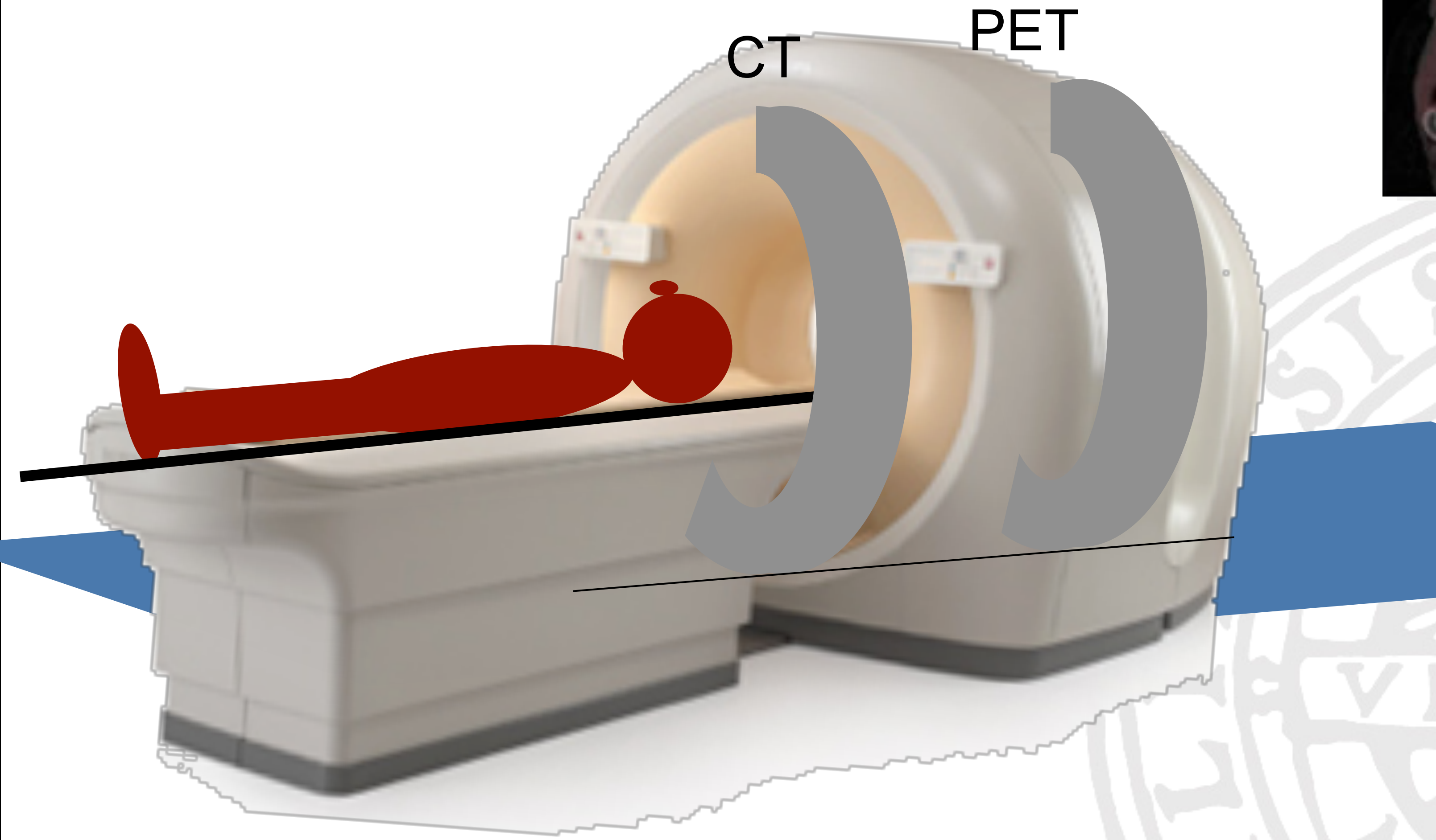
PET/CT bildtagning





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PET characteristics

- Field of view
  - Axial: 15-25 cm
  - Transaxial: 55-70 cm
- Number of detectors: 20-30000
- Number of lines of response: 10^8

- Spatial resolution: 3-8 mm
- Sensitivity ≈ 1%

- Image reconstruction: iterative

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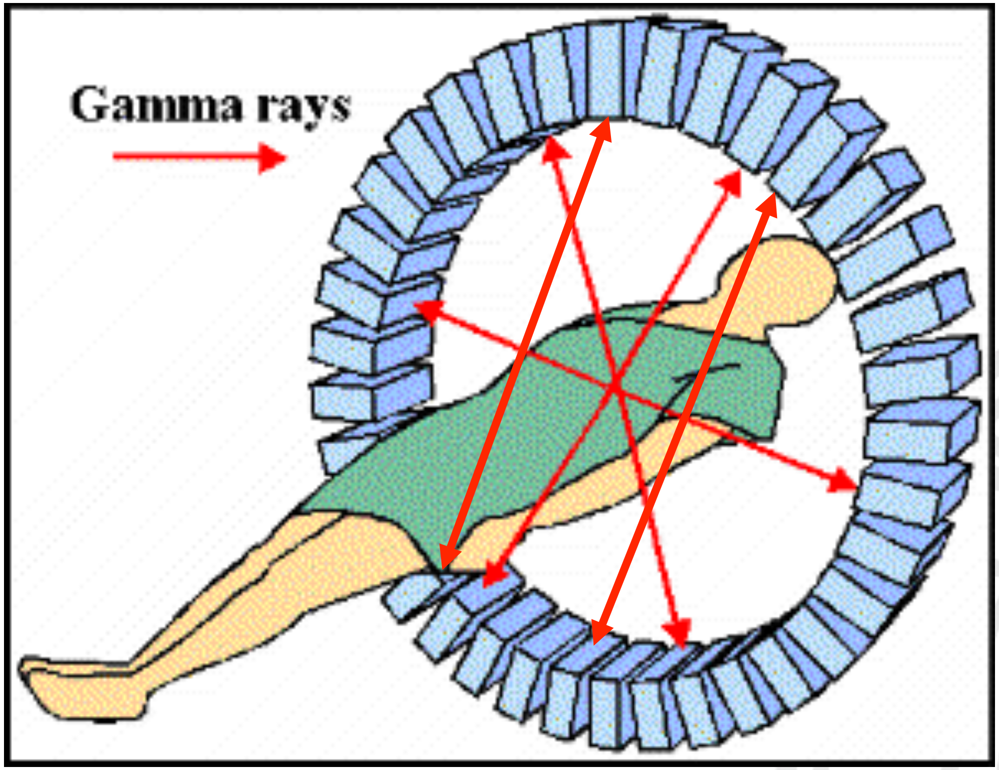
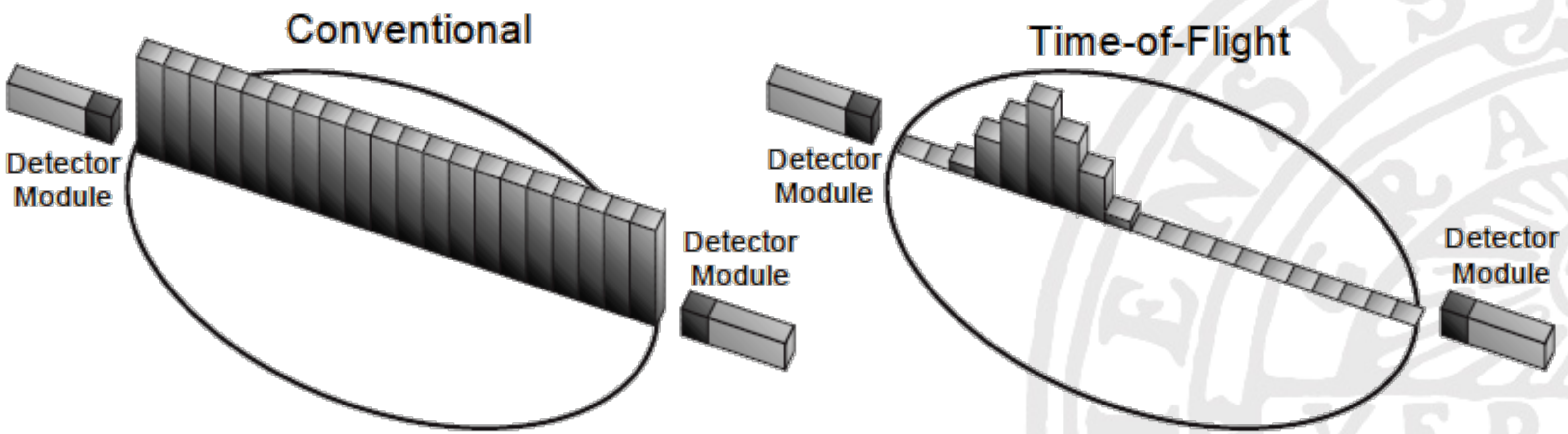
PET



Tidsupplösning (beroende på kristal): > 1 ns

Time of flight (TOF)-PET

- Bättre signal-to-noise-ratio
- Ingen bättre spatiell upplösning!



W. W. Moses, IEEE Trans Nucl Sci, 3 (2002) 1670-1675

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PET: tracer method

- George de Hevesy, Nobel prize 1943, "*for his work on the use of isotopes as tracers in the study of chemical processes*"
- Allan M Cormack and Godfrey Newbold Hounsfield, Nobel prize 1979, "*for the development of computer assisted tomography*".
- A tracer method is a method that can measure a process *without disturbing it*

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Tracer method

PET

MRI

Isotoper

^{18}F	$^{18}O(p,n)^{18}F$	110 min halveringstid
^{11}C	$^{11}B(p,n)^{11}C$	20 min
	$^{14}N(p,\alpha)\ ^{11}C$	
^{15}O	$^{15}N(p,n)^{15}O$	2 min
	$^{14}N(d,n)^{15}O$	
^{82}Rb	^{82}Kr generator	1 min
^{68}Ga	^{68}Ge generator	68 min
^{124}I	$^{124}Te(p,n)^{124}I$	4.2 d
^{89}Zr	$^{89}Y(p,n)^{89}Zr$	3.2 d

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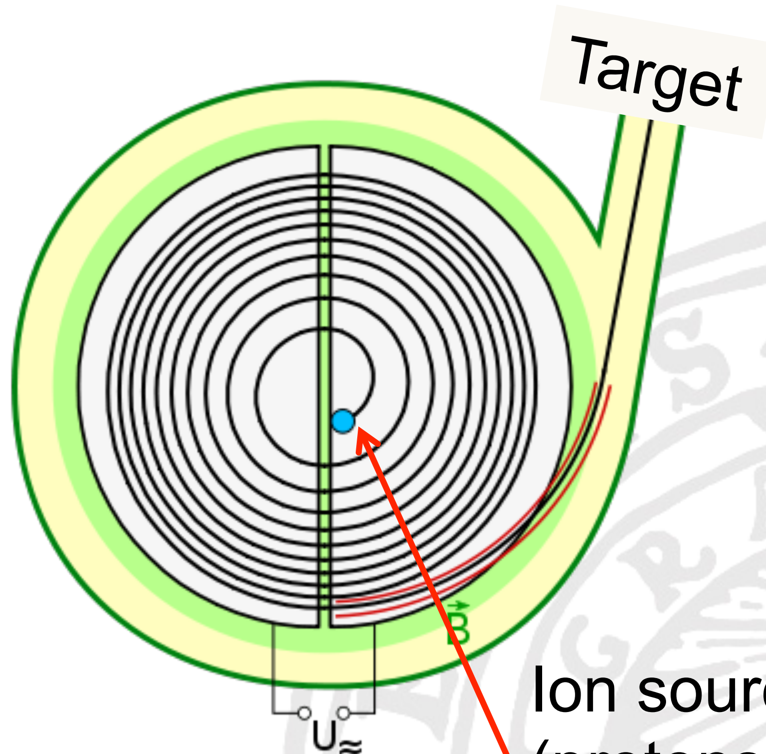
Cyclotron



•Magnetic field forces ions to fly in circles

•Acceleration due to a switching electric field

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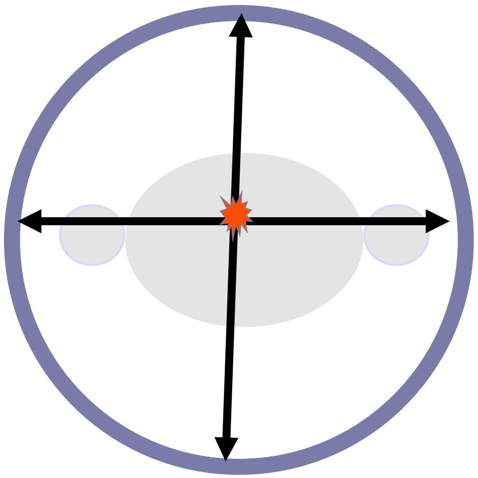
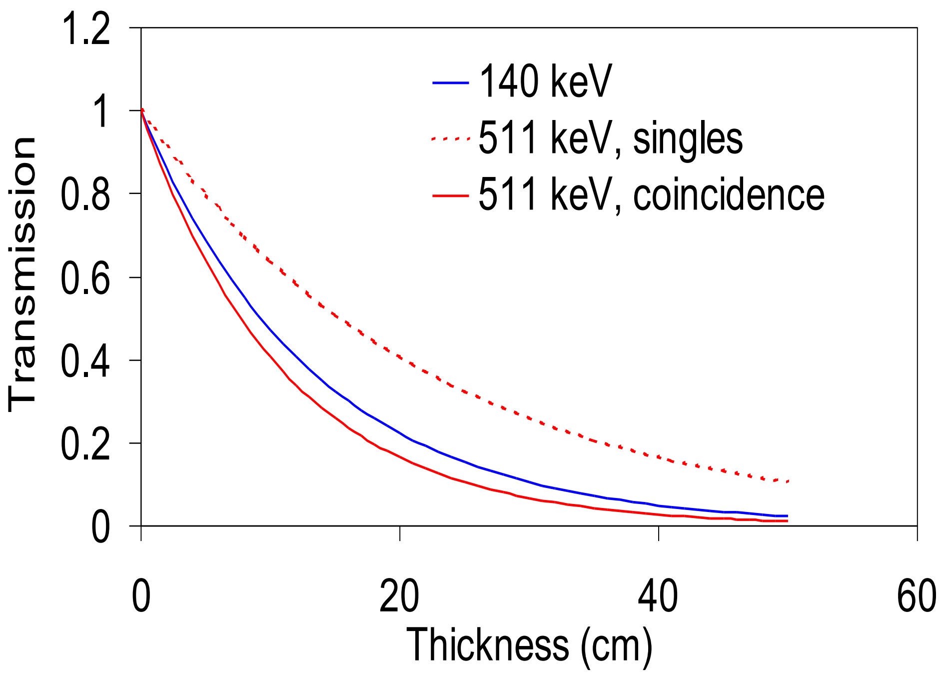
Radiokemi-laboratorium

PET

- PET mäter funktion, ingen anatomi!
- PET är kvantitativ, inte bara bilder!
- PET ger nogranna mätningar av radioaktivitetskoncentration
  - inom en voxel eller ROI/VOI, över tiden

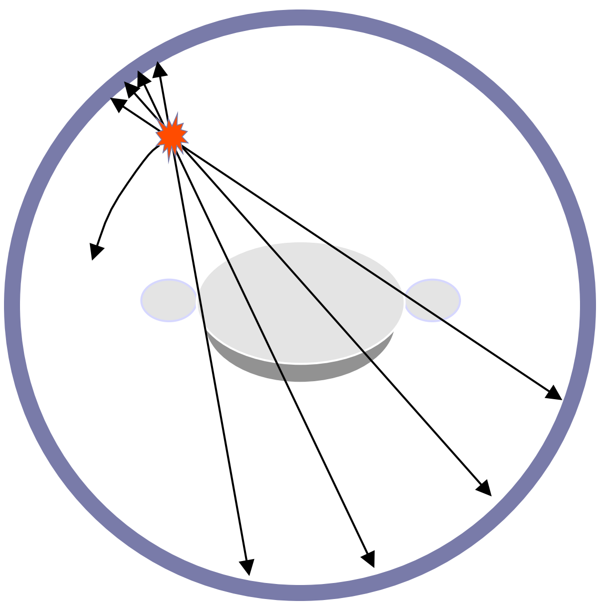
Attenuation

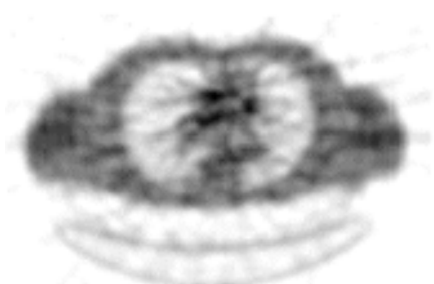




VU university medical center

Coincidence transmission scan





Rotating ^{68}Ge rod source(s)

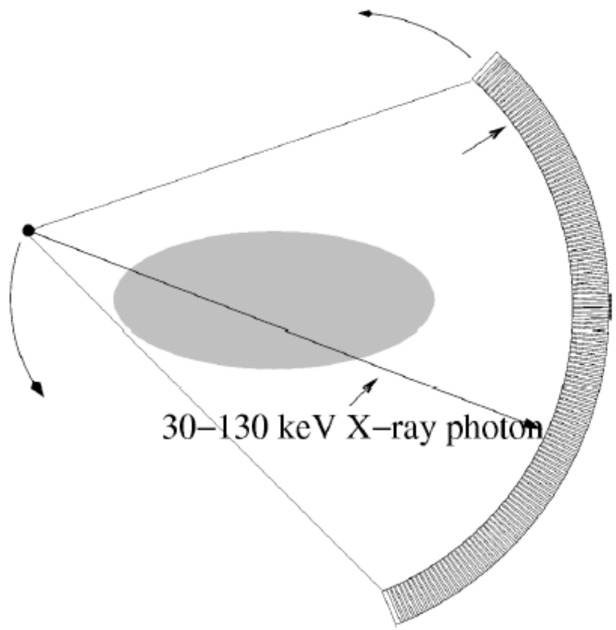
- Non-windowed: like emission scan
  - measures all coincidences
    includes scatter!

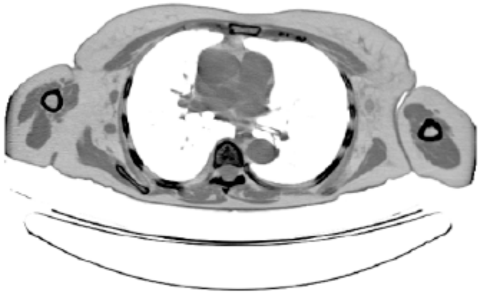
- Windowed (or 'gated'): measures only detectors close to source
  - most scatter eliminated

Requires blank scan: transmission scan with empty FOV

VU university medical center

X-ray transmission





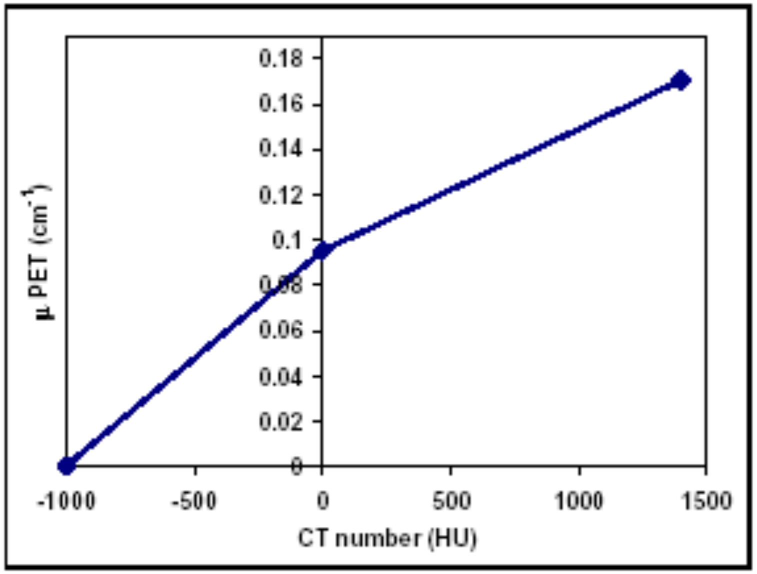
CT attenuation correction

+ No transmission sources needed allows for larger FOV
+ Low-noise attenuation correction
+ No emission contamination
+ Fast

- …

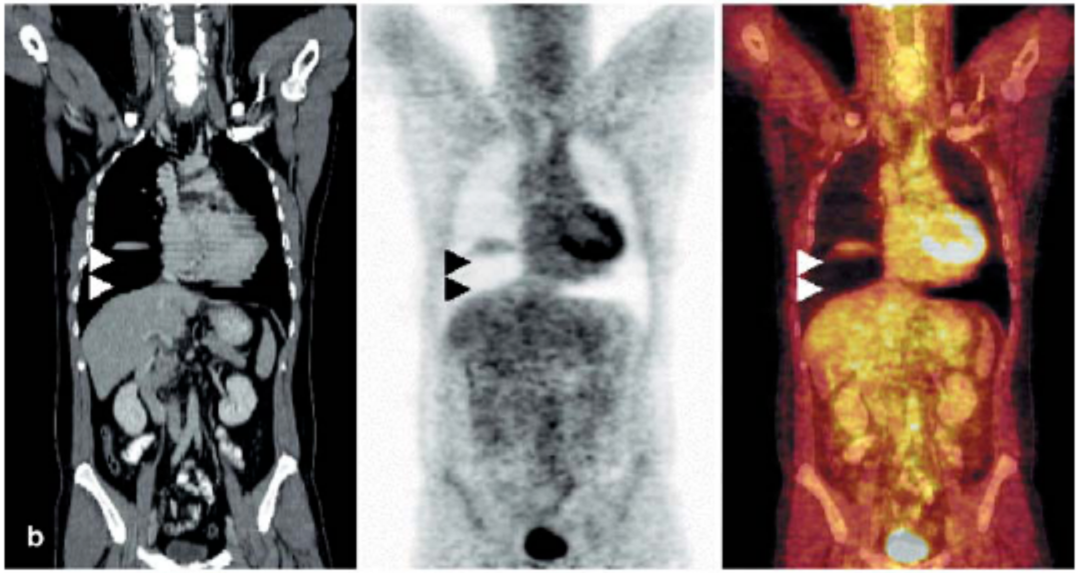
X-ray → 511 keV

Figure 6: Mapping CT number to PET attenuation coefficient



Burger et al, Eur J Nucl Med 2002

Respiratory motion



Beyer et al, Eur J Nucl Med 2003

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PET provides

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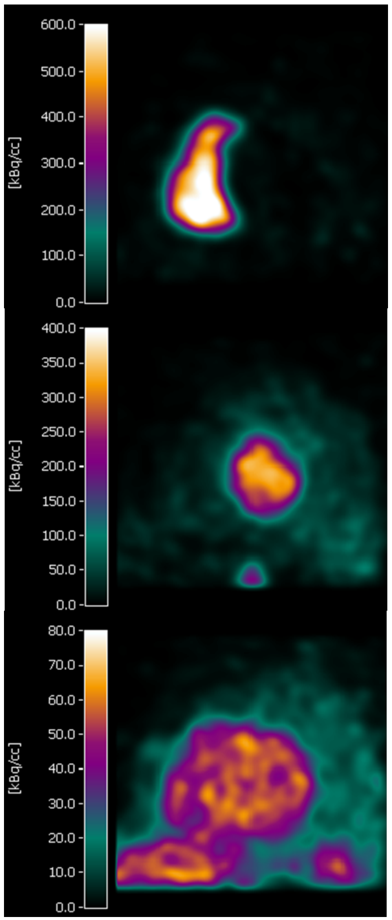
Hjärtperfusion: ^{15}O-vatten ($H_2{}^{15}O$)

Uptake (kBq/ml)

15 s p.i.

25 s p.i.

2 min p.i.



PET

- PET *<u>mäter</u>* funktion, ingen anatomi!
- PET är kvantitativ, inte bara bilder!

- PET ger noggranna mätningar av radioaktivitetskoncentration
  - inom en voxel eller ROI/VOI, över tiden

- *Tracer-kinetic (farmakokinetiska) modeller*: kvantitativa mått på funktionen i vävnaden

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PET ger

- Perfusion: ml blod / (min * g vävnad)
- Glukoskonsumption: µmol glukos / (min * g vävnad)
- Receptor-ligand bindning; koncentration och affinitet av receptor (B_{max} , K_D)
- Syrgaskonsumption: ml O_2 / (min * g vävnad)
- Proliferation, proteinsyntes, etc, etc, …

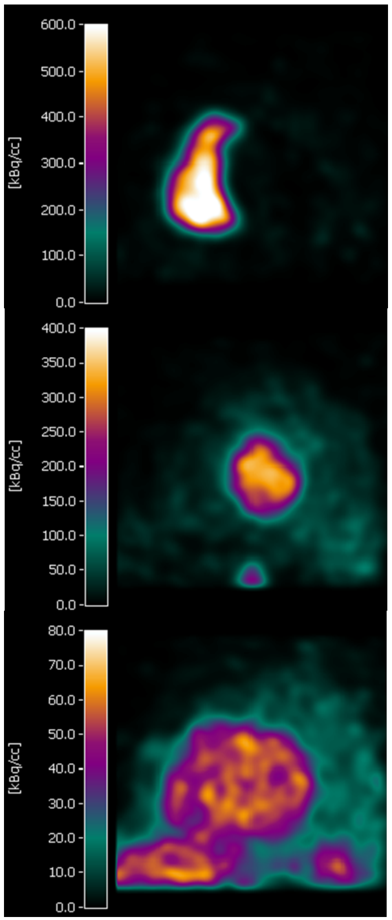
Hjärtperfusion: ^{15}O-vatten

Uptake (kBq/ml)

15 s p.i.

25 s p.i.

2 min p.i.



→ *Tracer kinetic model*

Blodflöde (ml/g/min)

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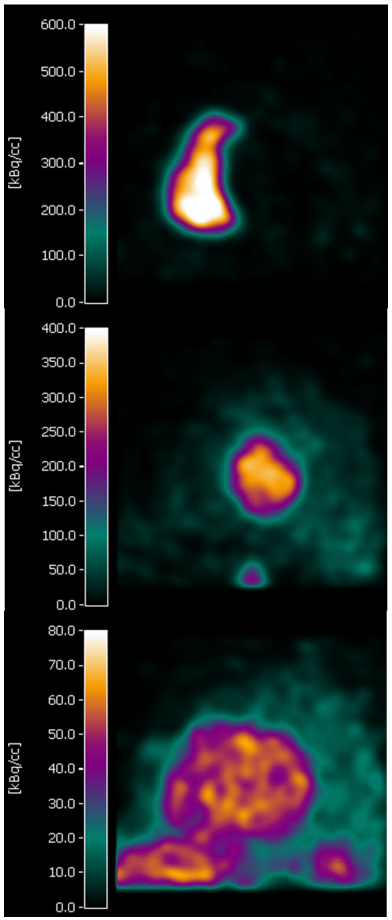
Hjärtperfusion: ^{15}O-vatten

Uptake (kBq/ml)

15 s p.i.

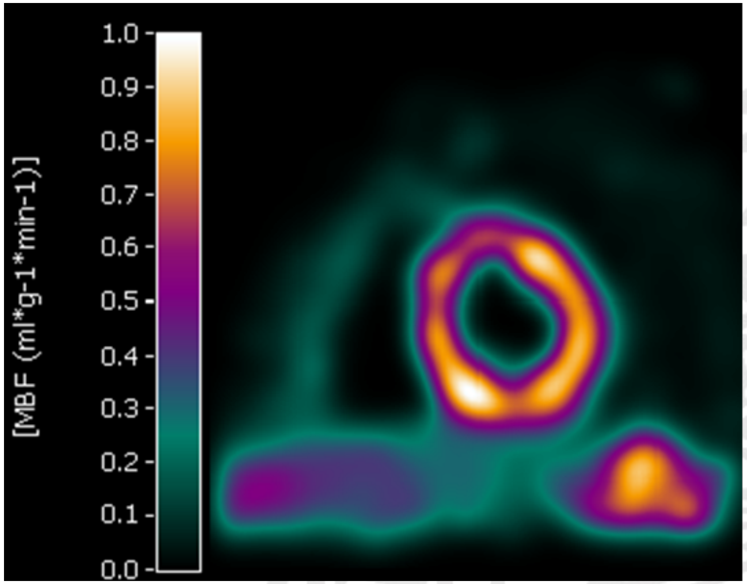
25 s p.i.

2 min p.i.



Tracer kinetic model

Blodflöde (ml/g/min)



Harms H … Lubberink M, Eur J Nucl Med Mol Imaging 2011

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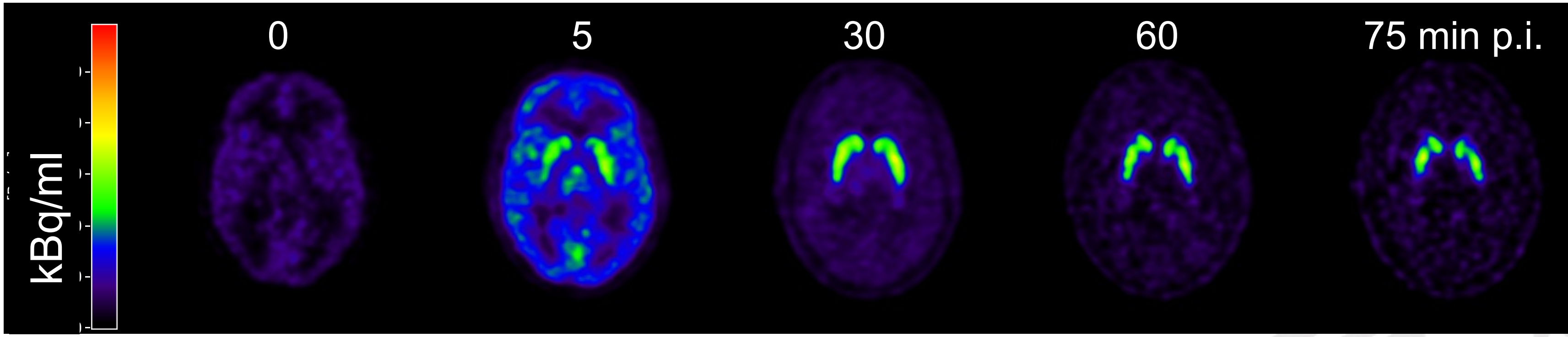
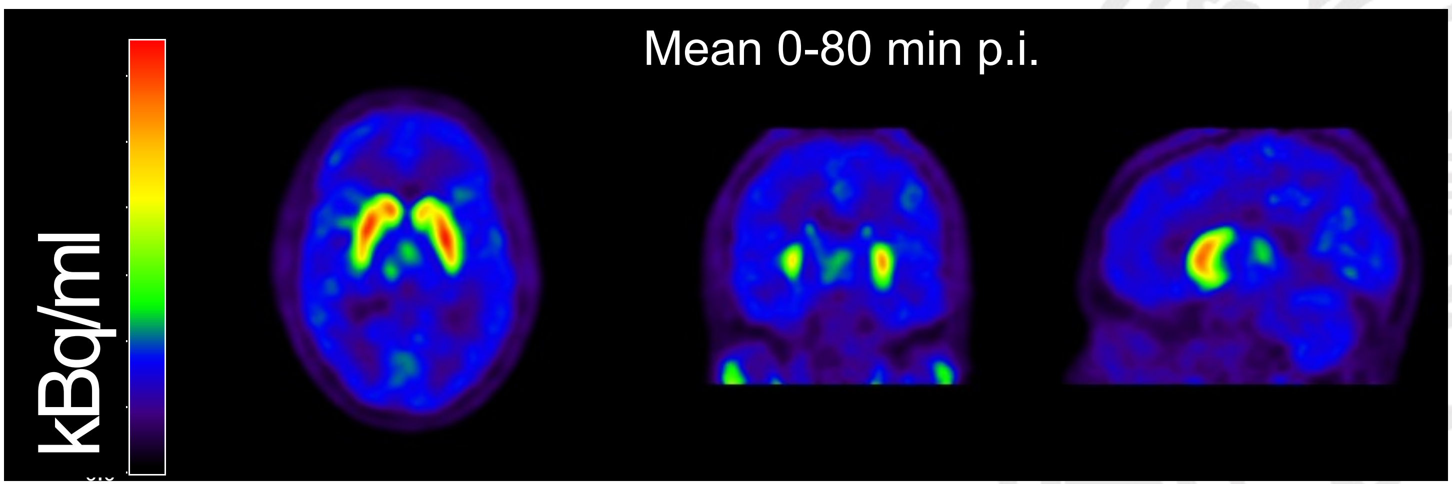
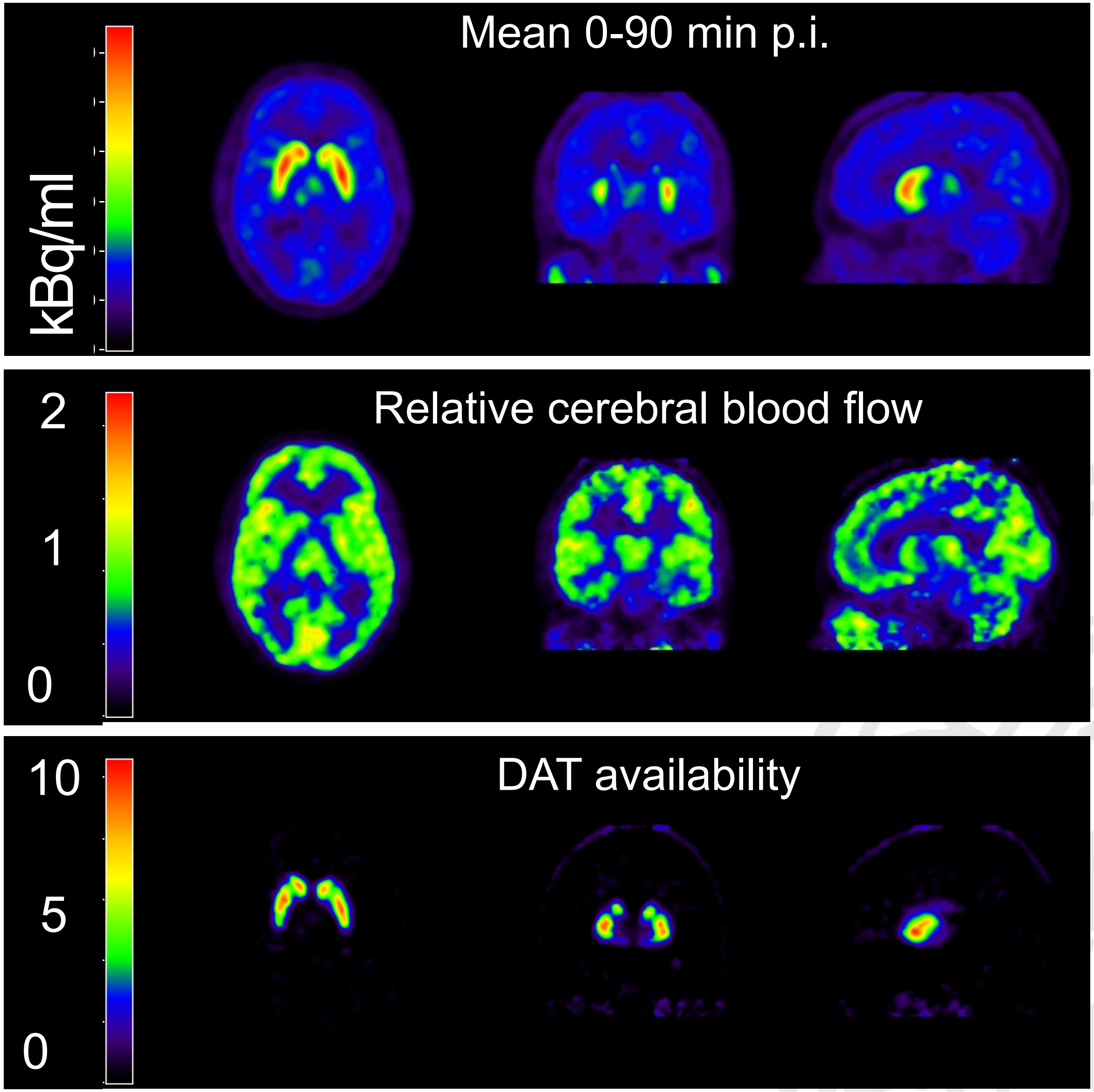
DAT (dopamintransportör): [^{11}C]PE2I







SRTM: Receptor parametric mapping (Gunn *et al*, 1997)

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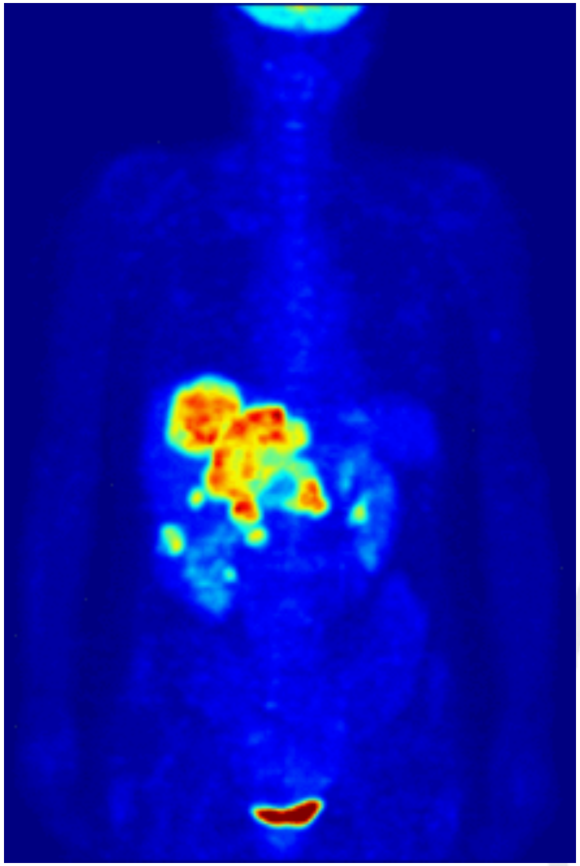
Tracers

• $[^{18}F]$fluorodeoxyglucose (FDG)	glucose consumption	~3-10 mSv
• $[^{18}F]$fluorothymidine	proliferation	
• $[^{18}F]$flutametamol	β–amyloid	
• $[^{18}F]$choline	prostate cancer	
• $[^{18}F]$fluciclovine (FACBC)	prostate cancer	
• $[^{11}C]$acetate	oxygen consumption	~1-3 mSv
• $[^{11}C]$methionine	protein synthesis	
• $[^{11}C]$PIB	β–amyloid	
• $[^{11}C]$choline	prostate cancer	
• $[^{11}C]$PE2I, $[^{11}C]$FPβ-CIT	dopamine transporter	
• $[^{15}O]$water	blood flow	< 1 mSv
• ^{82}Rb, $[^{13}N]$ammonia	myocardial blood flow	

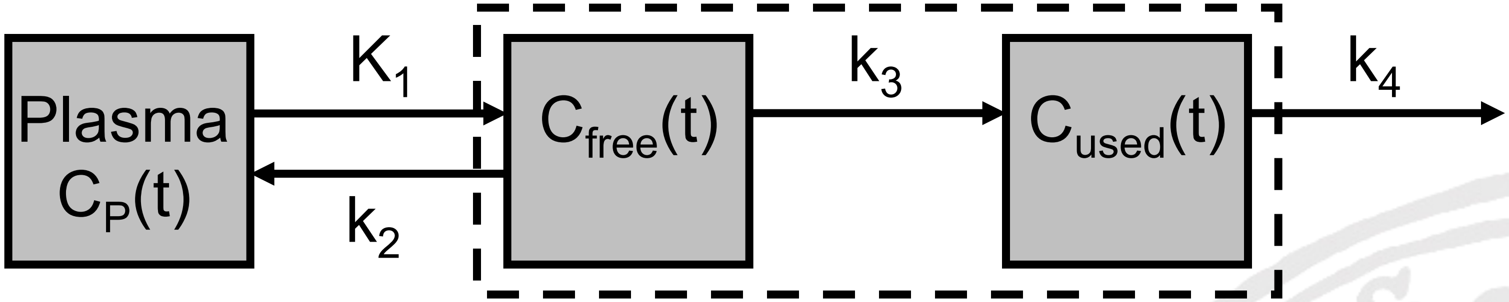
- Etc, etc.

Whole-body cancer imaging with [^{18}F]fluorodeoxy-glucose



Uptake (kBq/ml)

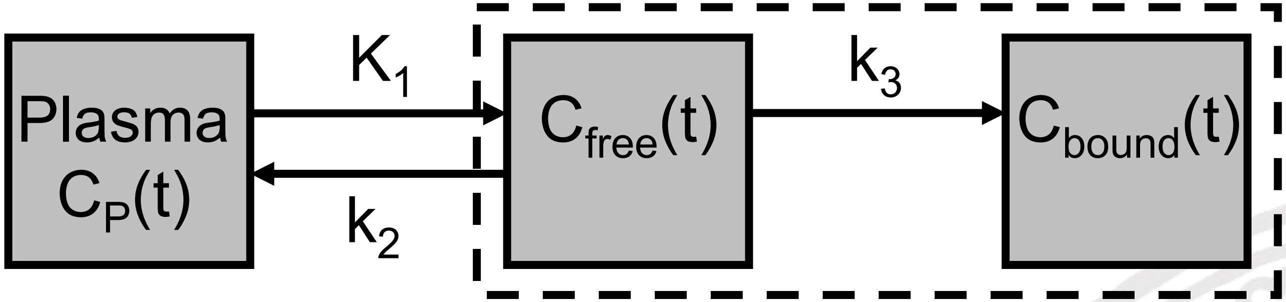
Glukosmetabolism



$$\frac{dC_{free}(t)}{dt} = K_1 C_P(t) - (k_2 + k_3) C_{free}(t)$$

$$\frac{dC_{bound}(t)}{dt} = k_3 C_{free}(t) - k_4 C_{used}(t)$$

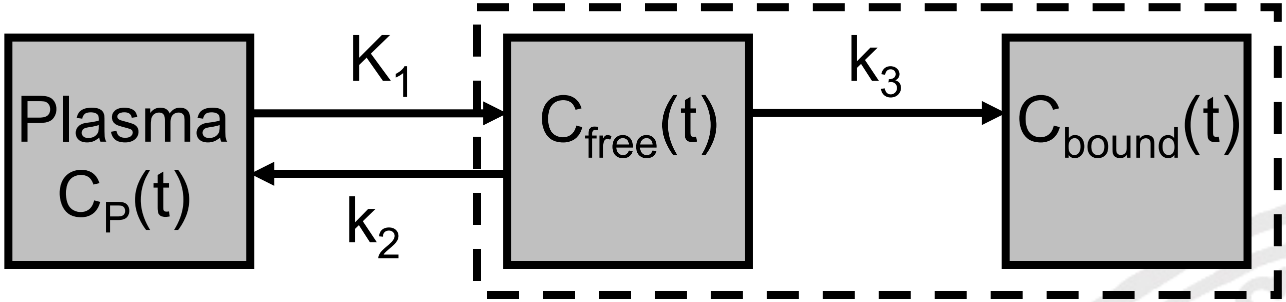
2-Deoxyglucose metabolism (FDG; Sokolov)



$$\frac{dC_{free}(t)}{dt} = K_1 C_P(t) - (k_2 + k_3) C_{free}(t)$$

$$\frac{dC_{bound}(t)}{dt} = k_3 C_{free}(t)$$

2-deoxyglukos (FDG; Sokolov)

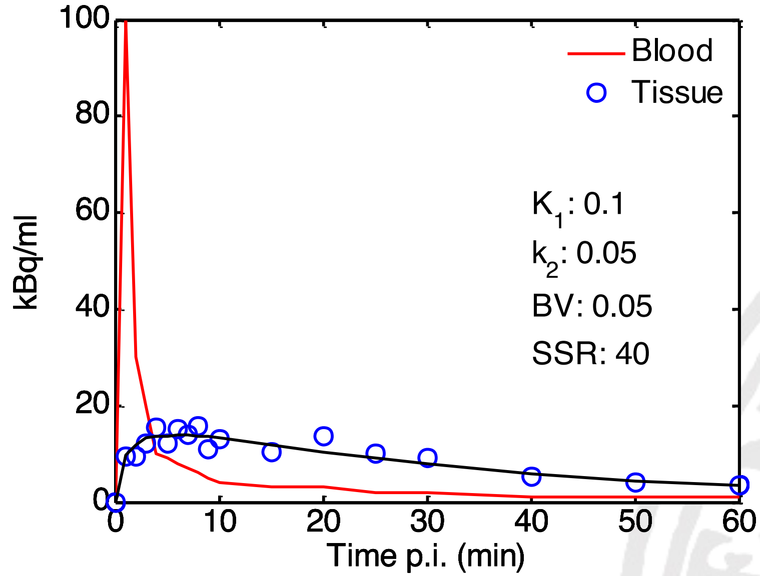


$$\frac{dC_{free}(t)}{dt} = K_1 C_P(t) - (k_2 + k_3) C_{free}(t) \qquad \frac{dC_{bound}(t)}{dt} = k_3 C_{free}(t)$$

- K_i: net uptake rate, ml cm^{-3} min^{-1} $\quad K_i = \frac{K_1 k_3}{k_2 + k_3}$

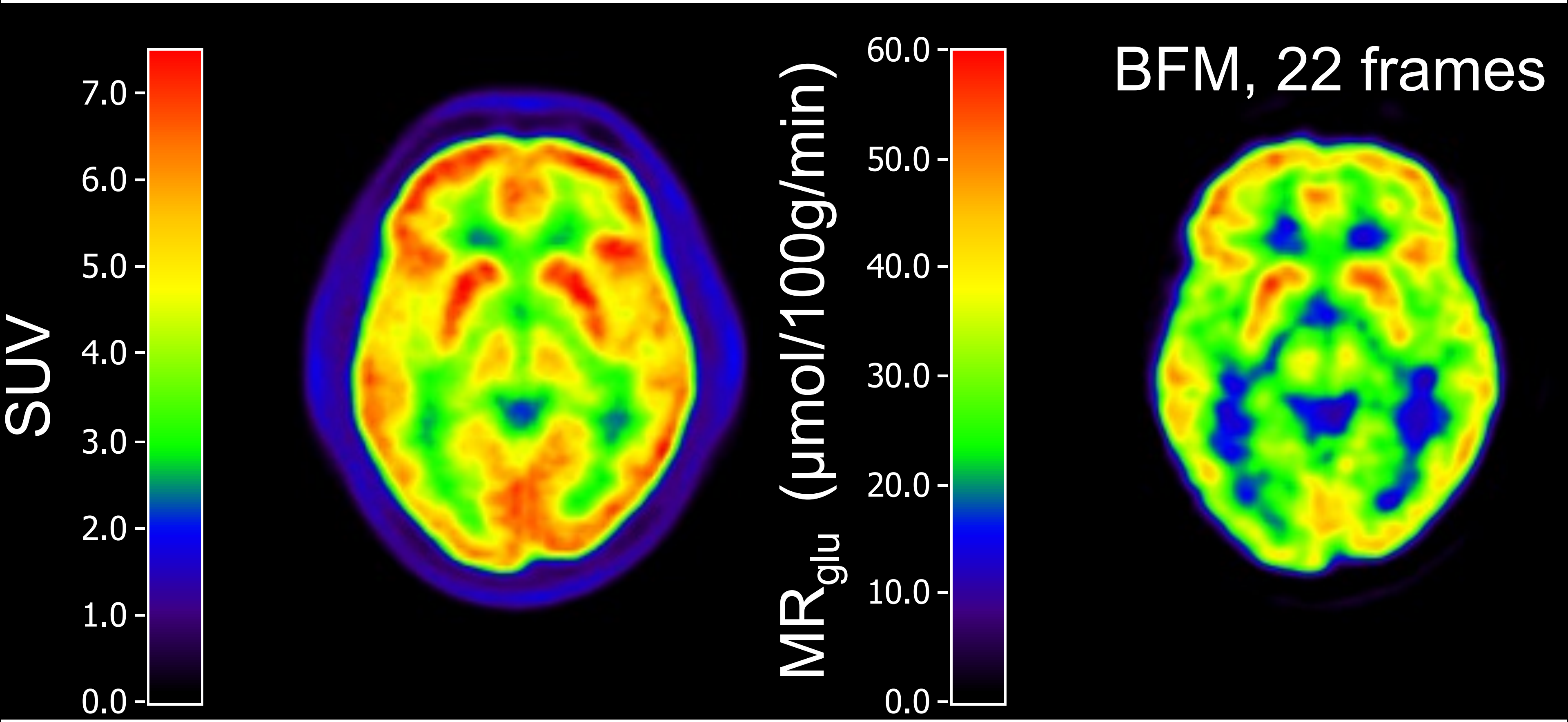
- MR_{glu}: glucose consumption, mol cm^{-3} min^{-1} $\quad MR_{glu} = \frac{C_{pl}^{glu} \cdot K_i}{LC}$

Compartment model fit



$$C_{PET}(t) = (1 - V_B) \cdot K_1 C_P(t) \otimes e^{-k_2 t} + V_B C_B(t)$$

Cerebral glucose metabolism



SUV

- För mätning av FDG kinetik och beräkning av MR_{glu} krävs
  - >45 min dynamisk mätning
  - Mätning av radioaktivitet i blodprover
- Bara för en (1) bäddposition

- SUV: Standardized Uptake Value

$$SUV = \frac{kBq / ml}{MBq\ injected\ per\ kg\ body\ weight} \quad [g / ml]$$

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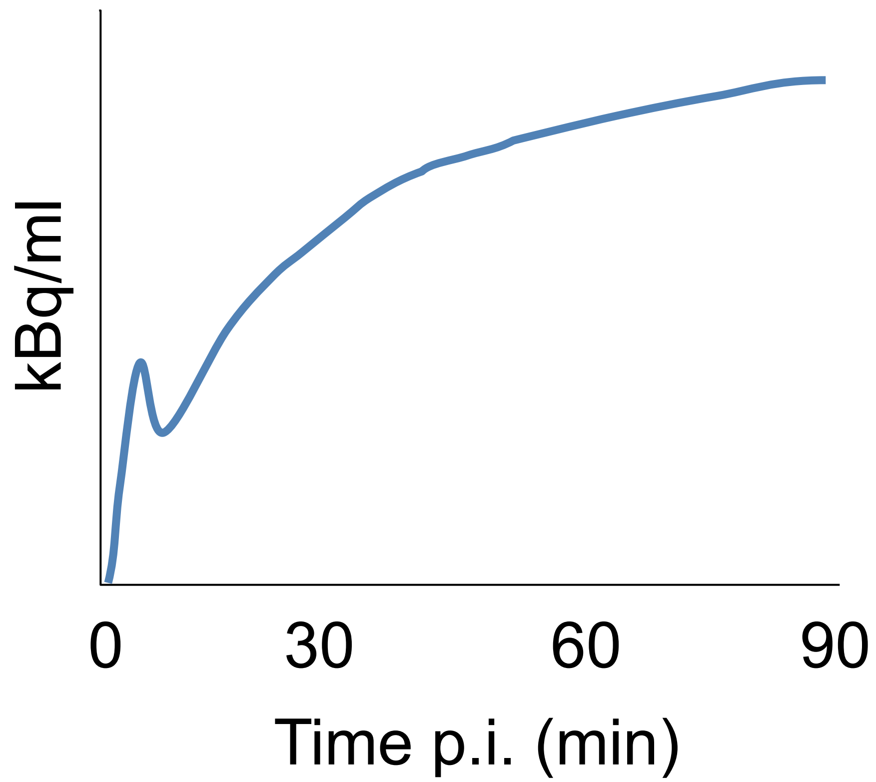
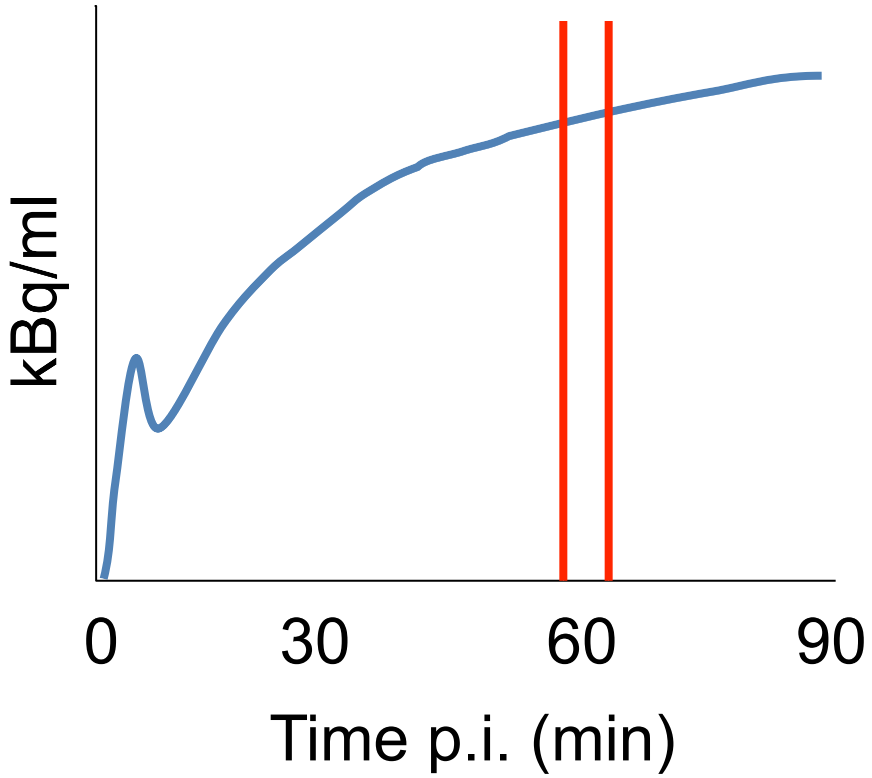
FDG - SUV



FDG - SUV



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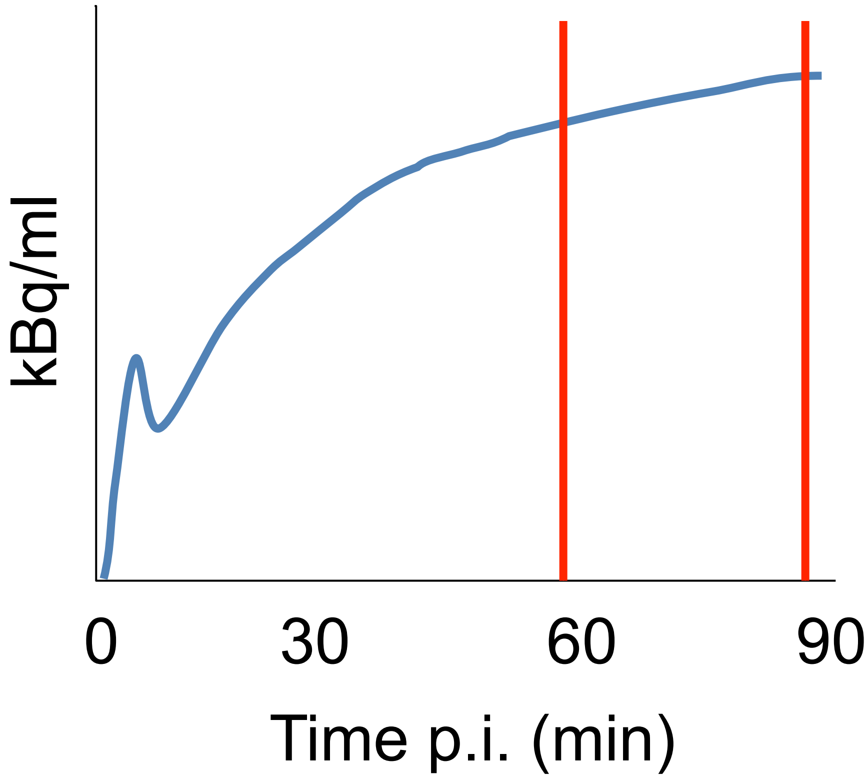
FDG - SUV



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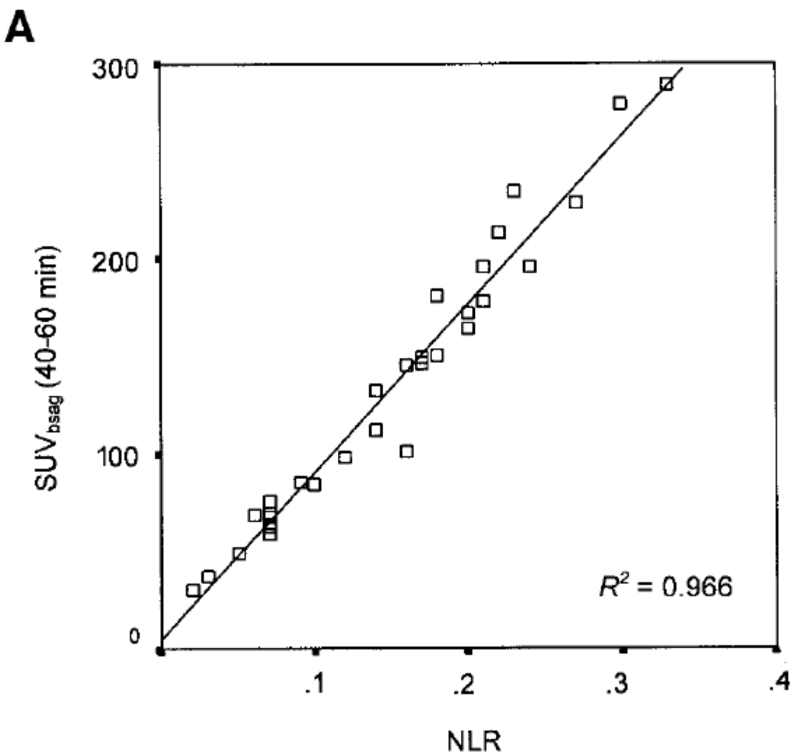
SUV vs glukoskonsumption

FDG



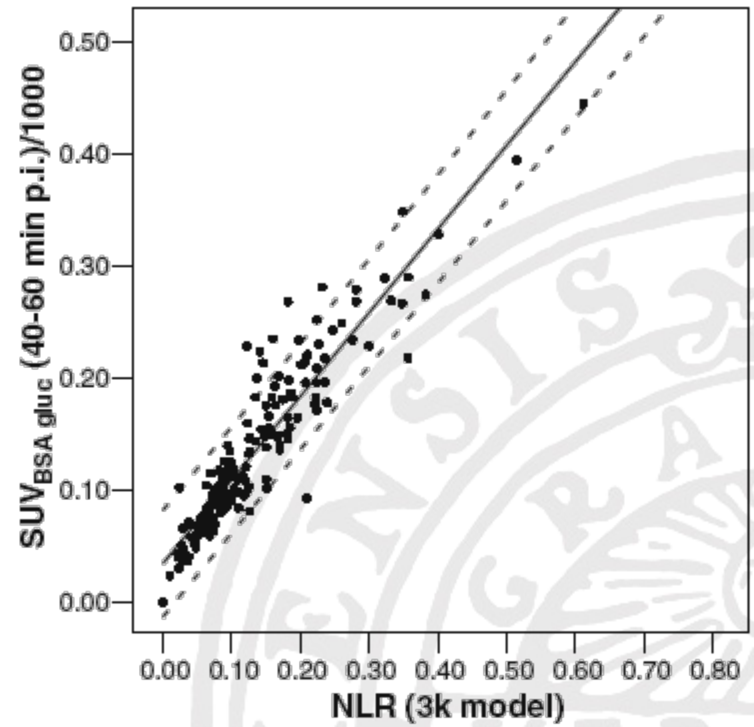


Fig. 1. Regression of $SUV_{BSA,glu}$ (corrected for plasma glucose) versus NLR for a database of 170 scans

Hoekstra et al, J Nucl Med 2002; Lammertsma et al, Eur J Nucl Med 2006

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SUV

- Praktiskt: en enda mätning
- Går att använda med helkroppsscans
- Fungerar bara bra med
  - standardiserade protokoll
  - noggrann kalibrering av kameran
  - noggrann bestämning av patientens vikt
- Inte säkert att SUV fungerar för andra tracers!

Mer om SUV i morgon, 10:45, sal B

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