

# IMAGING IN NUCLEAR MEDICINE

## BASIC PRINCIPLES OF NUCLEAR MEDICINE

### RADIOPHARMACEUTICALS

### INSTRUMENTS (SPECT, PET, HYBRID EQUIPMENTS)

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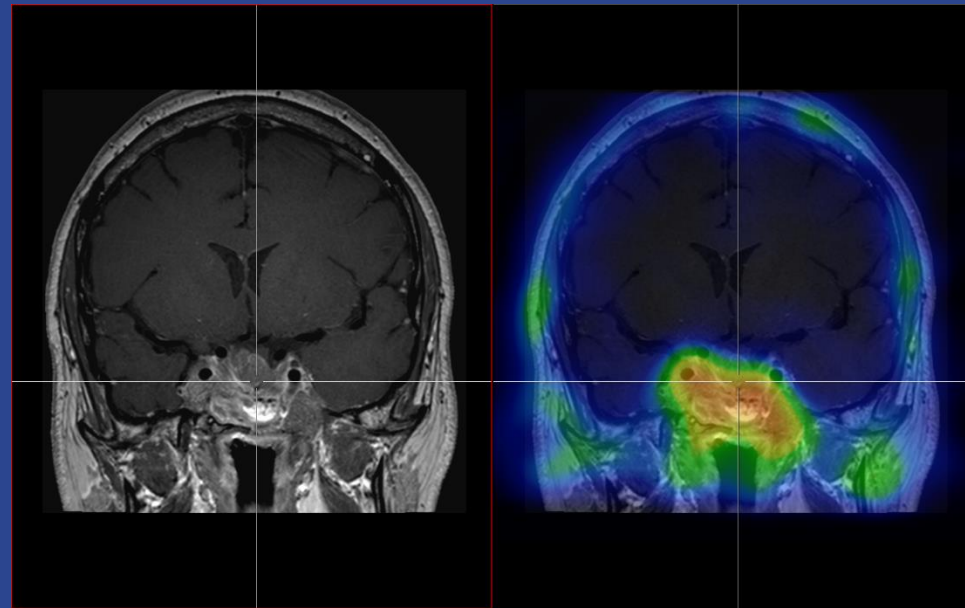
Department of Nuclear Medicine, Head: Györke Tamás, MD, PhD

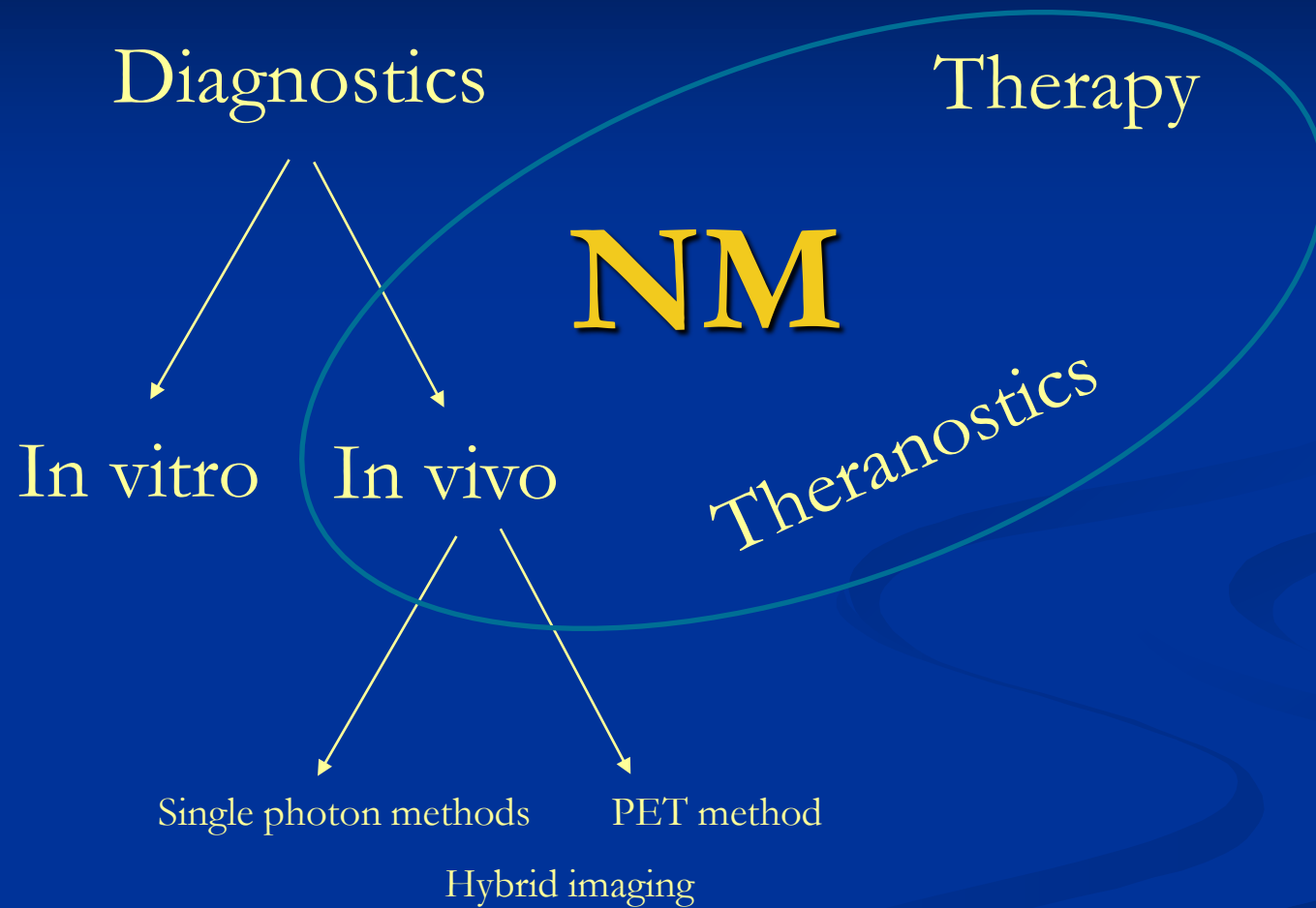
<http://semmelweis.hu/nuklearis-medicina/>

email: [titkarsag.nmt@med.semmelweis-univ.hu](mailto:titkarsag.nmt@med.semmelweis-univ.hu)

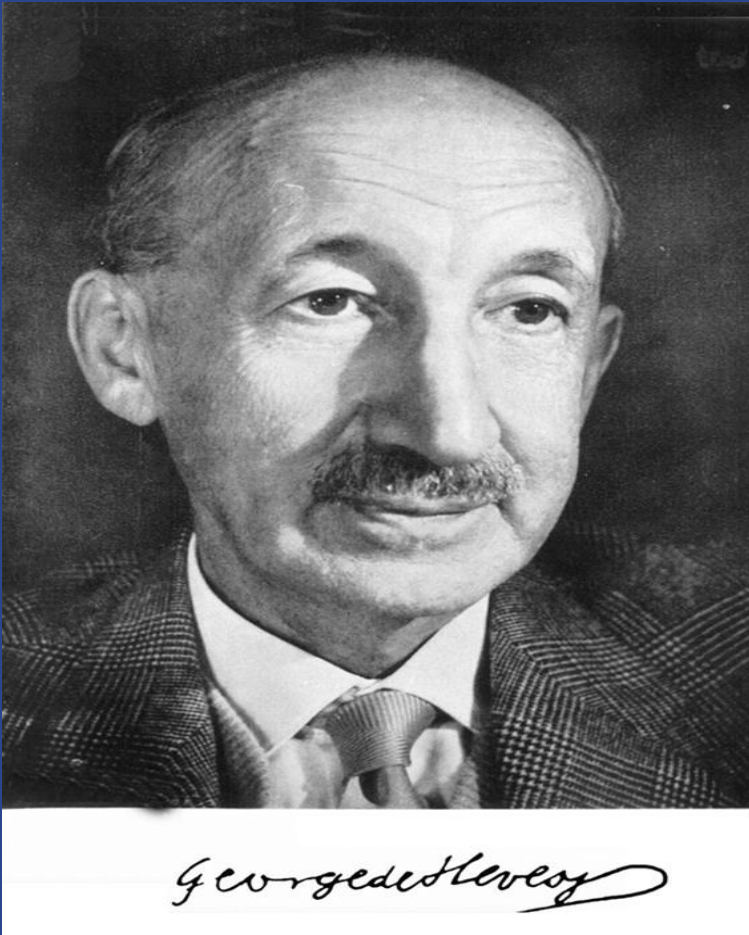
# NUCLEAR MEDICINE

- Medical activities using unsealed radioactive isotopes in the
  - diagnosis,
  - treatment, and
  - research of diseases
- Where is the functioning tissue?





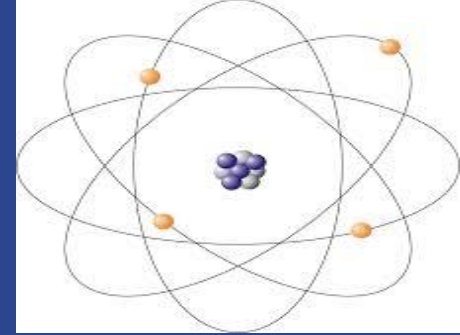
# George de Hevesy (1885-1966)



- The father of nuclear medicine
- Chemist, born in Hungary
- He used radioactive isotopes for examining biological processes
- Nobel prize in 1943 in chemistry
- The tracer theory was elaborated by Hevesy



# Basic principles



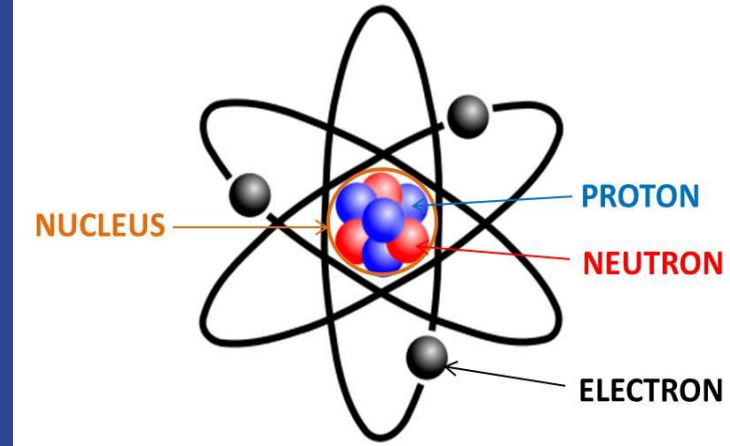
- Tracer theory
  - Radioactive compounds participate in an organism's physiological processes in the same way as nonradioactive materials
- Radiolabelling
  - The substance is "labeled" by including radionuclides in its chemical composition
  - When these decay, their presence can be determined by detecting the radiation emitted by them

# Radiopharmaceuticals



- **Organ-, tissue-, cell-, or molecule-specific compounds** labelled with radioisotopes
- Can be target-specific
- Can be traced from outside
- Functional imaging
- Intact and abnormal tissue function can be identified and characterized
- Capable for quantifying biochemical processes

# Radioactive isotopes



- Isotopes
  - Same atomic number (protons), different mass number (nucleons=protons+neutrons)
  - Stable vs. unstable
    - At a given mass number the nucleus is stable if the number of neutrons is the same as the number of protons (for small nuclei), or the number of neutrons is greater than the number of protons (for large nuclei)
    - Stable nuclei:  $p=n$  or  $p<n$
- **Radioactive isotopes**
  - Unstable nuclei  $\rightarrow$  radioactive decay

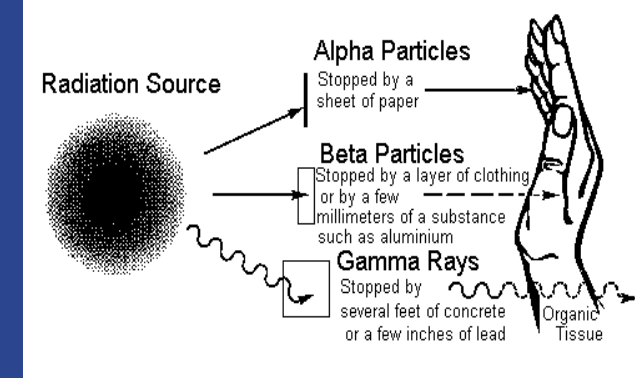
# Radioactive decay

- Types

- Proton deficiency → Beta decay ( $\beta$ -particle +  $\gamma$ -radiation)
- Excess protons → Positron emission (annihilation + 2  $\gamma$  photons)  
→ Electron capture (characteristic X-ray emission)
- Large nuclei → Alpha radiation ( $\alpha$ -particle)

- Ionizing radioation

- Particle radiation ( $\alpha$ ,  $\beta$ , positron)
  - Depending on the type of the decay
- Electromagnetic radiation ( $\gamma$ , X-ray)
  - All types of radioactive decay are typically accompanied by  $\gamma$ -rays

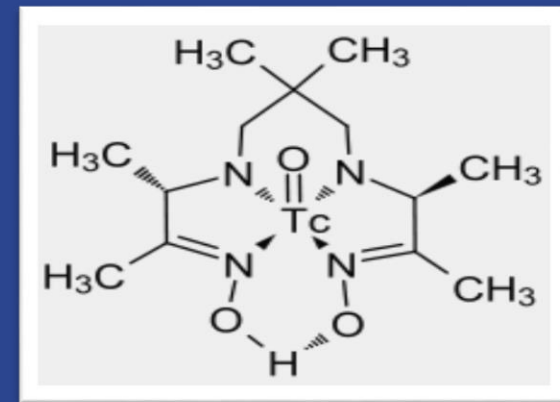


# Most important radioisotopes

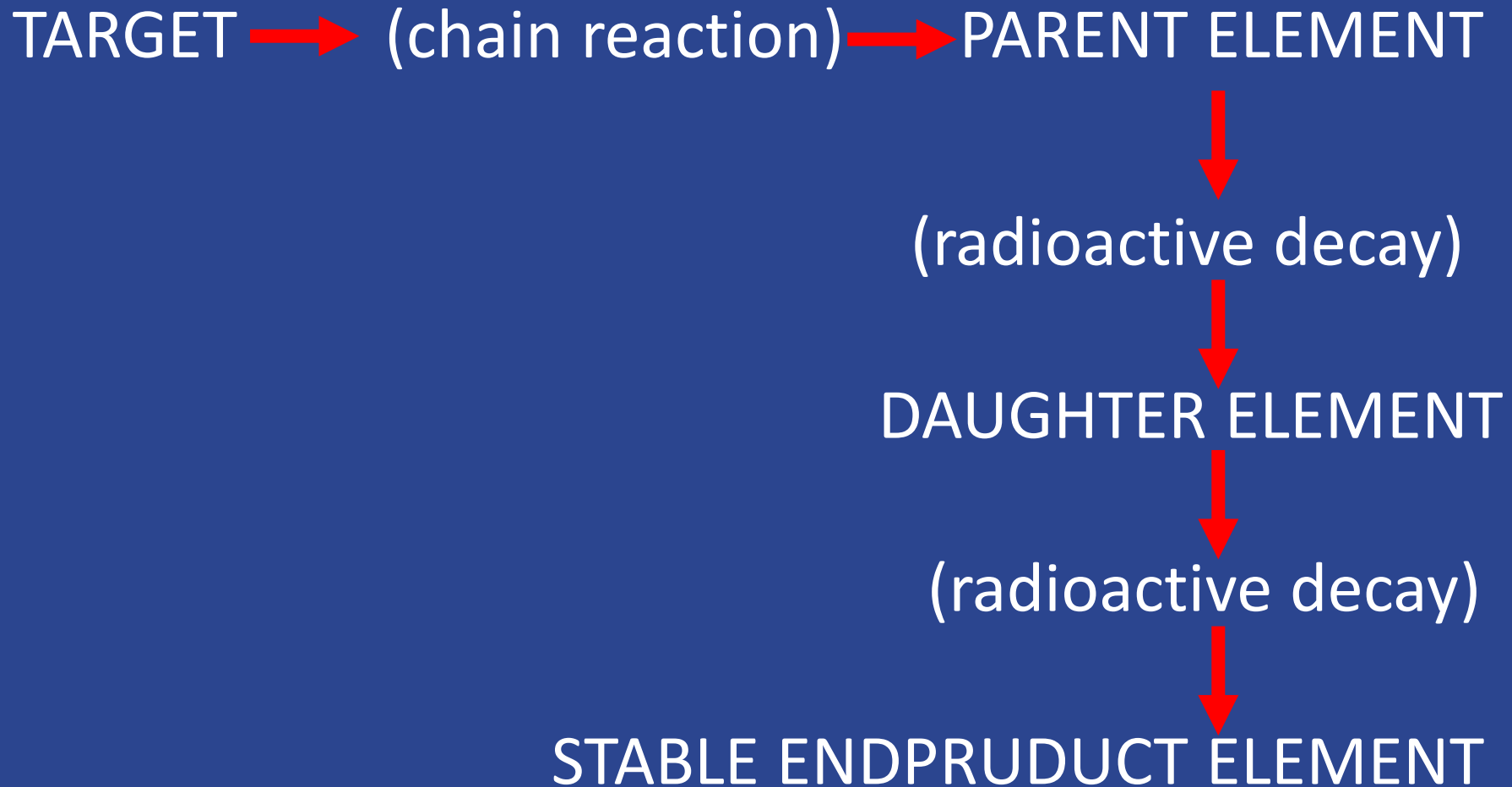
Nuclid	Gamma-energy (keV)	Half life ( $T_{1/2}$ )
<b>Gamma emitting radioisotopes</b>		
$^{99m}\text{Tc}$	140	6 h
$^{131}\text{I}$	364	8 day
$^{123}\text{I}$	159	13 h
$^{67}\text{Ga}$	93, 185, 296	78 h
$^{111}\text{In}$	172, 247	2,8 day
$^{201}\text{Tl}$	31, 135, 167	73,5 h
<b>Positron emitting radioisotopes</b>		
$^{18}\text{F}$	511	109,7 m
$^{68}\text{Ga}$	511	1,2 h
$^{124}\text{I}$	511	4,2 day
$^{11}\text{C}$	511	20,4 m
$^{13}\text{N}$	511	9,96 m
$^{15}\text{O}$	511	2,07 m

# Technetium-99m ( $^{99m}\text{Tc}$ )

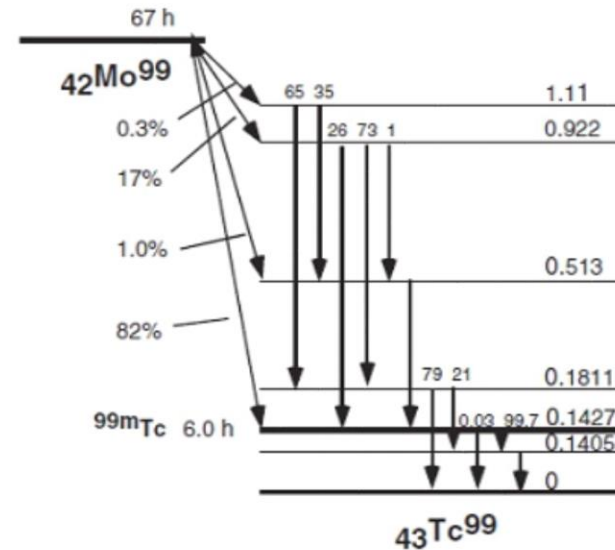
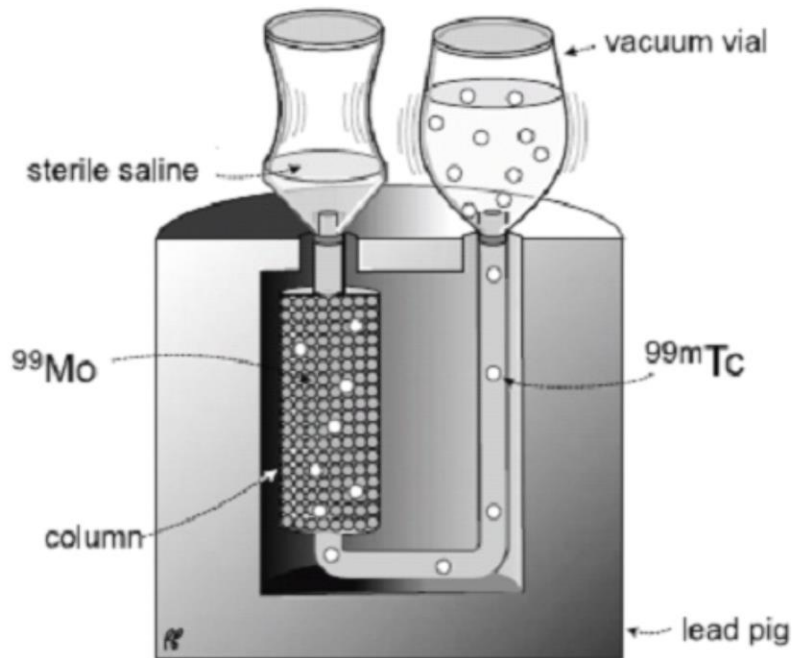
- Physical properties
  - Pure gamma ( $\gamma$ ) radiation
  - Half life ( $T_{1/2}$ ): 6 hours
  - Gamma energy: 140 keV (optimal for detection)
- Chemical properties
  - Huge number of radiopharmaceuticals be labelled with Tc
- Accessibility
  - Generator



# $^{99\text{m}}\text{Tc}$ generator



# $^{99m}\text{Tc}$ generator

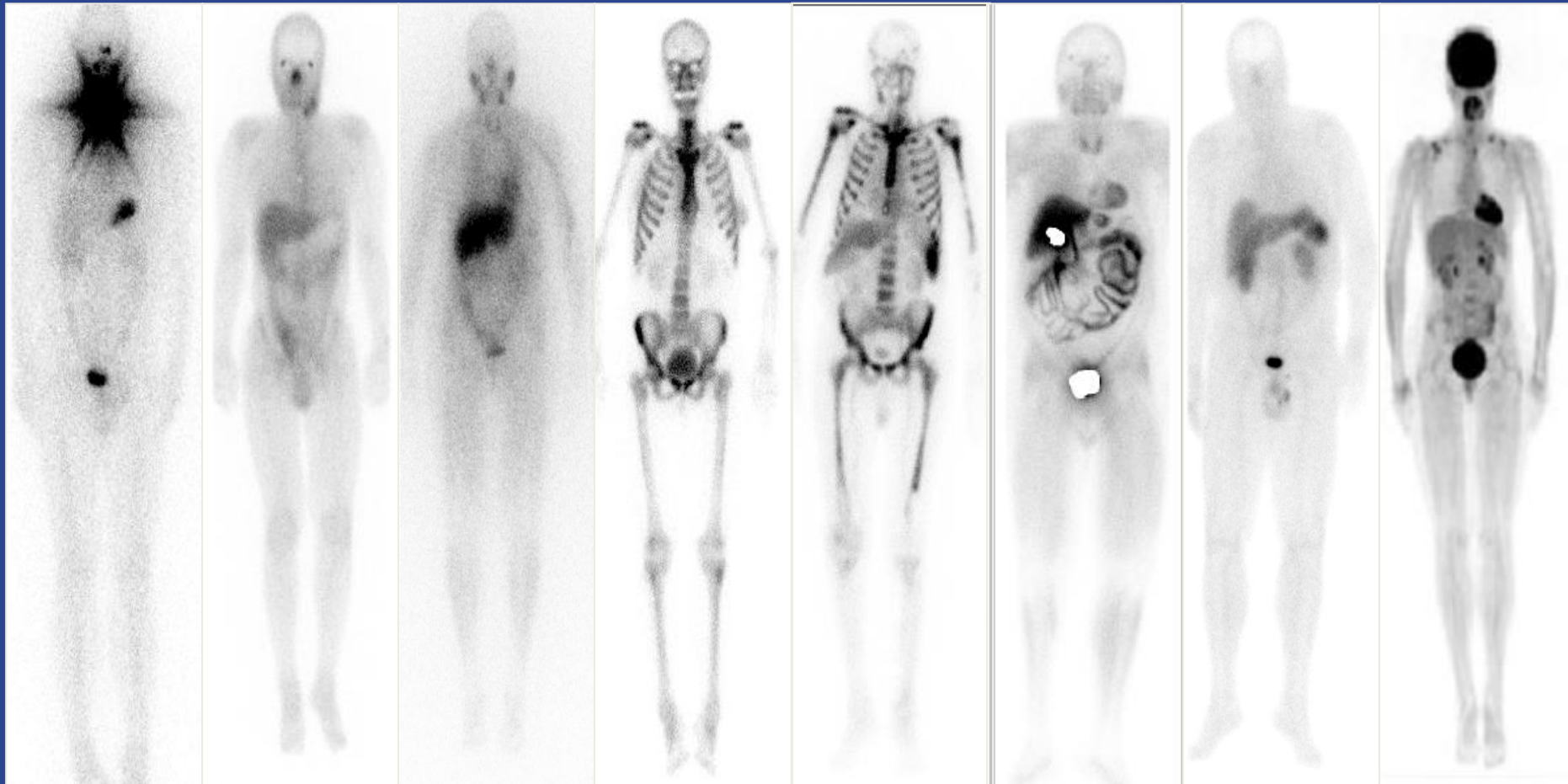




# Specific compounds for NM investigations

Tissue or organ	Function	Specific compound	Mechanism
Bone	Osteoblast activity	Bisphosphonates	Adsorption
Thyroid	Iodine uptake	Sodium-pertechnetate, sodium-iodine	Ion transport
Kidney	Tubular secretion	MAG3, EC	Active transport
Lung	Ventilation	Aerosols	Passive transport with diffusion
	Perfusion	Macroaggregate albumine	Capillary blockade
Liver and spleen	RES function	Colloide	Phagocytosis
Neuroendocrine system	Somatostatine receptor expression	Somatostatine receptor agonist/antagonist	Receptor-ligand binding
<i>Any organ or tissue</i>	Glicolysis	Deoxy-glucose	Metabolism (FDG uptake by glucose transporter, phosphorylation by hexokinase)
<i>Any organ or tissue</i>	Antigen expression	Antibody	Antigen-antibody complex

# Different radiopharmaceuticals – different distributions



I-131

Ga-67

I-123-  
MIBG

Tc-99m-DPD

Tc-99m-  
Antibody

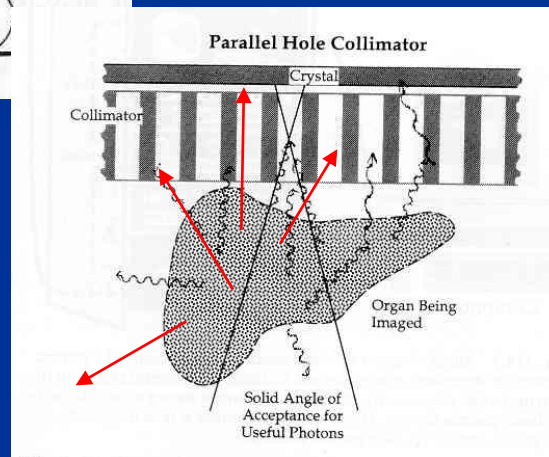
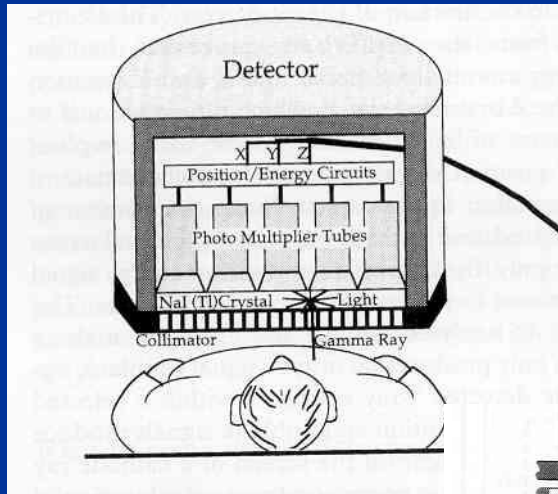
Tc-99m-MIBI

In-11-SMS

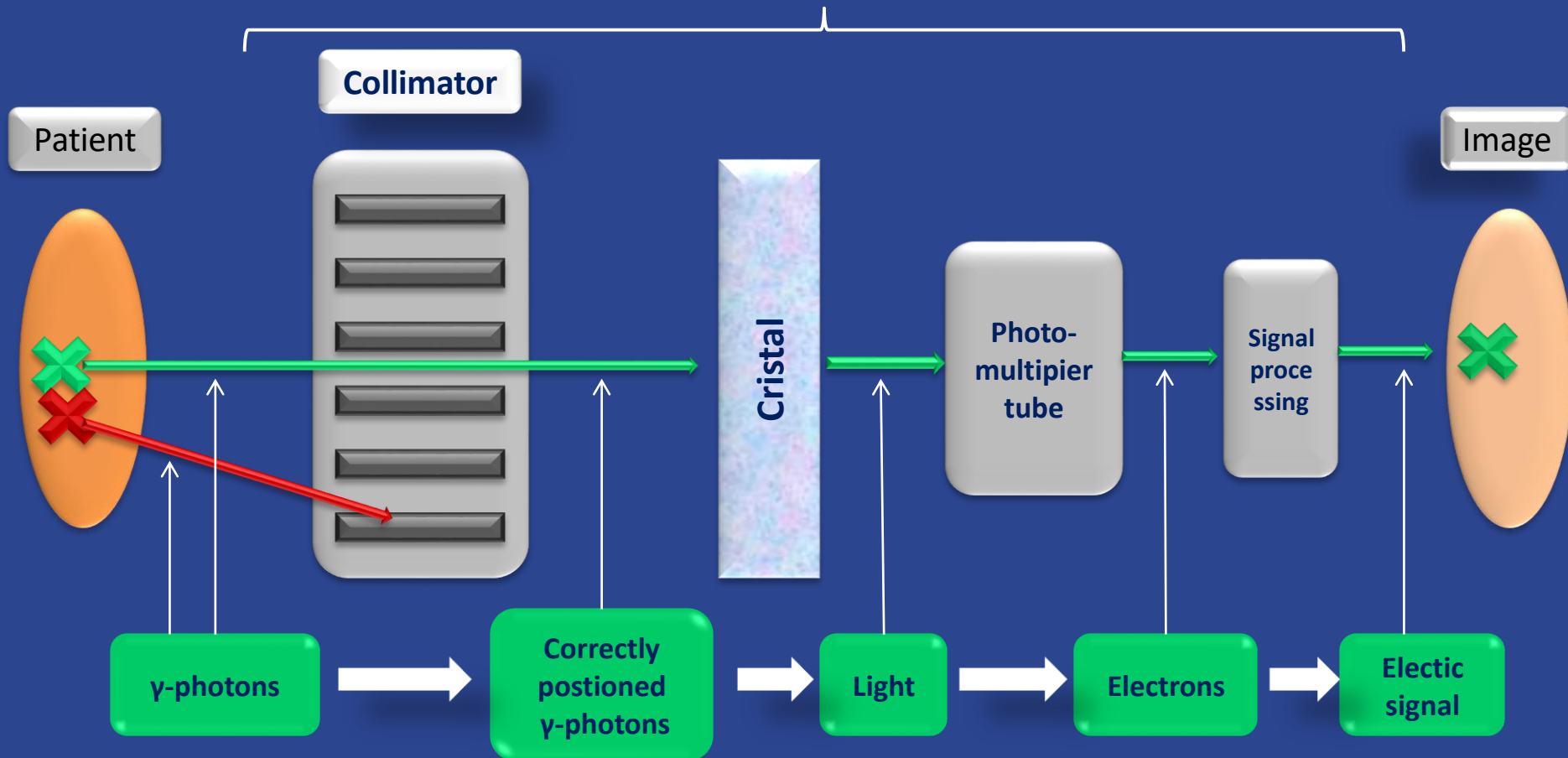
F-18 FDG

# Imaging devices

- Gamma camera (Anger camera, scintillation camera)



# Gamma detector



# Gamma (planar) camera

- Gamma-emitting radioisotopes
- Planar imaging
  - 1 detector head
  - 2D summation image

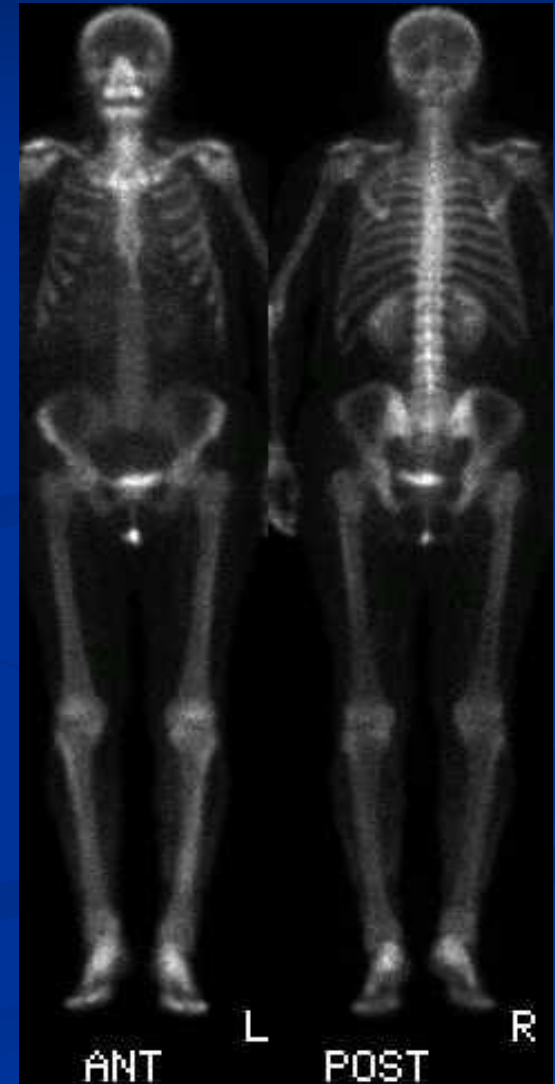
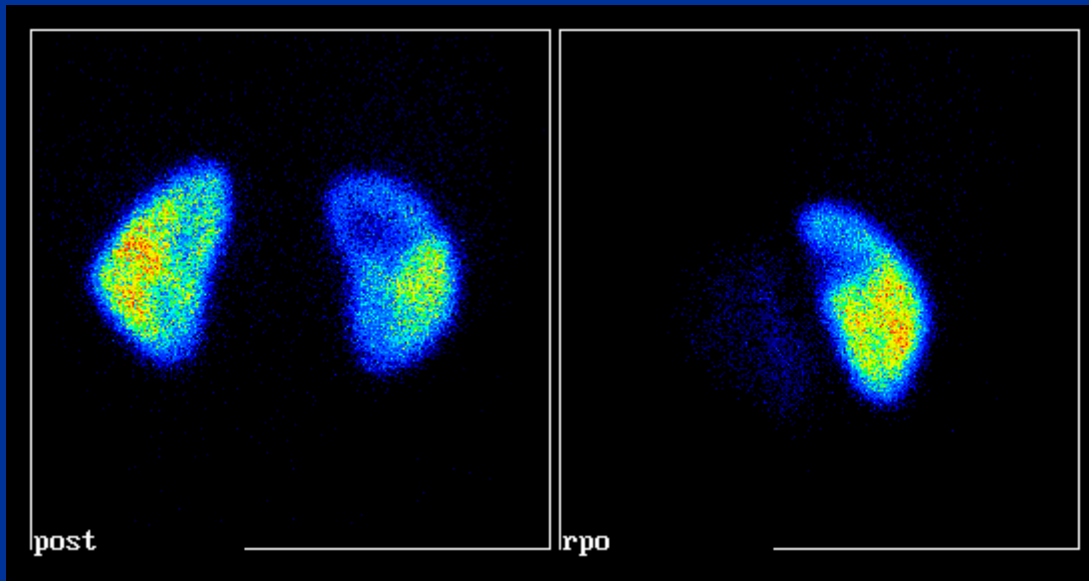


# Types of studies

- Static study
  - After the injection an equilibrium state is reached and the distribution of the radiopharmaceutical is stable and does not change over time (during the acquisition)
- Dynamic study
  - After the injection a series of images (with short acquisition time) are performed to record and visualize the different phases of metabolic, excretion, or other processes

# Planar investigations

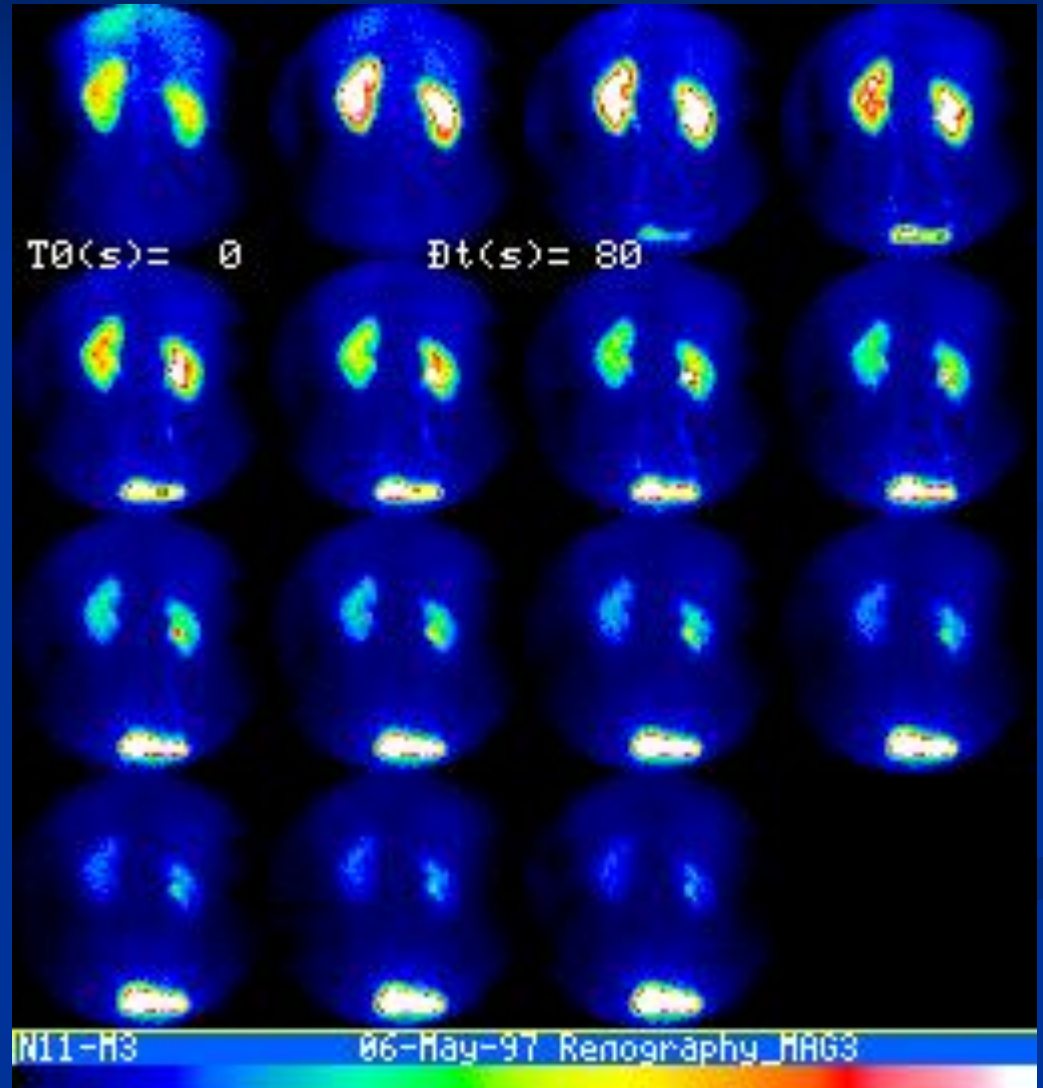
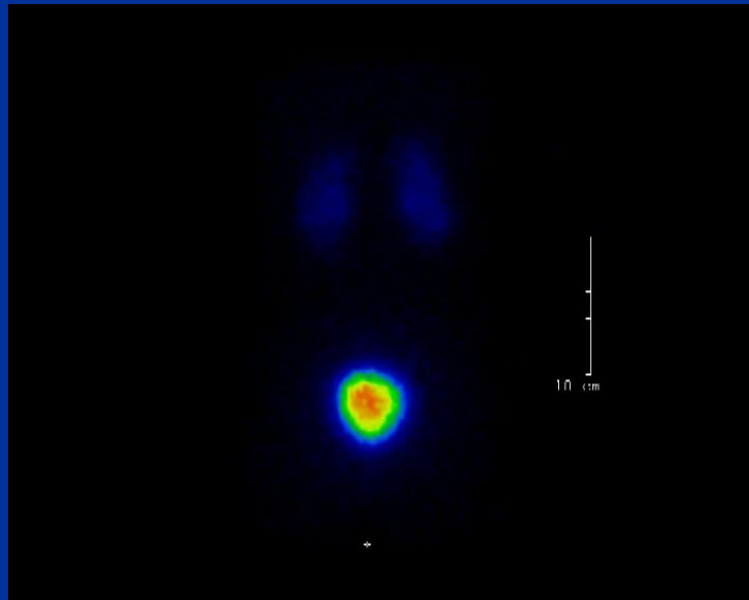
## 1. Static Investigation





# Planar investigations

## 2. Dynamic / functional investigations



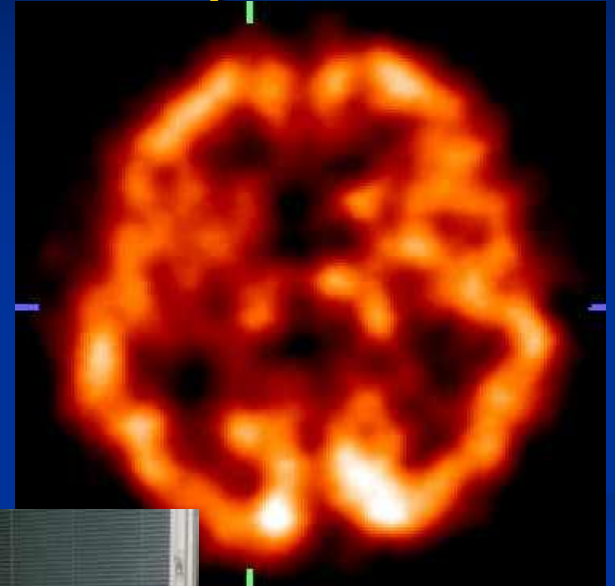


# SPECT

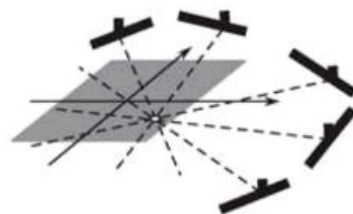
- Single Photon Emission Computed Tomography
- Gamma-emitting radioisotopes
- Cross-sectional (tomographic) imaging
  - 1 or more detector heads
  - **Rotational motion**
  - Multi-directional projection images
  - Computerized reconstruction
    - Cross-sectional images
    - 2D tomographic images in 3 planes
    - 3D



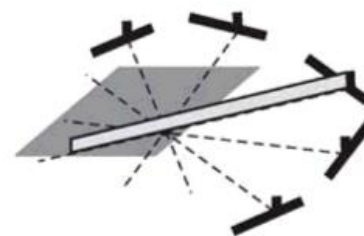
# Single Photon Emission Computed Tomography (SPECT)



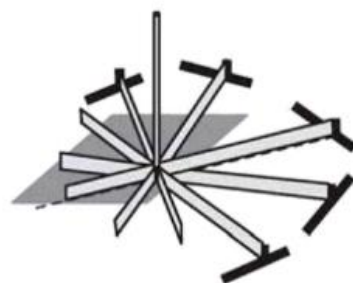
# Simple Backprojection



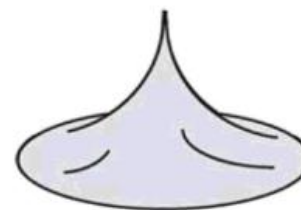
(a) Project a point source



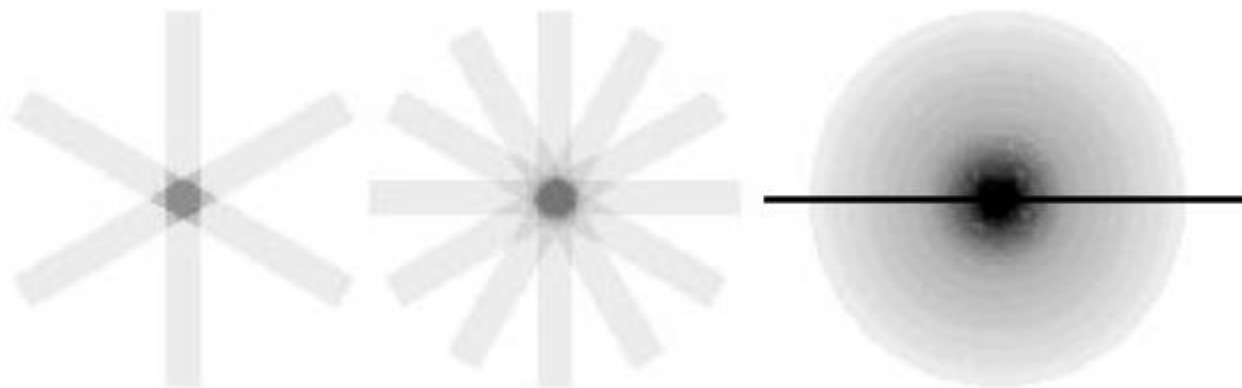
(b) Backproject from one view



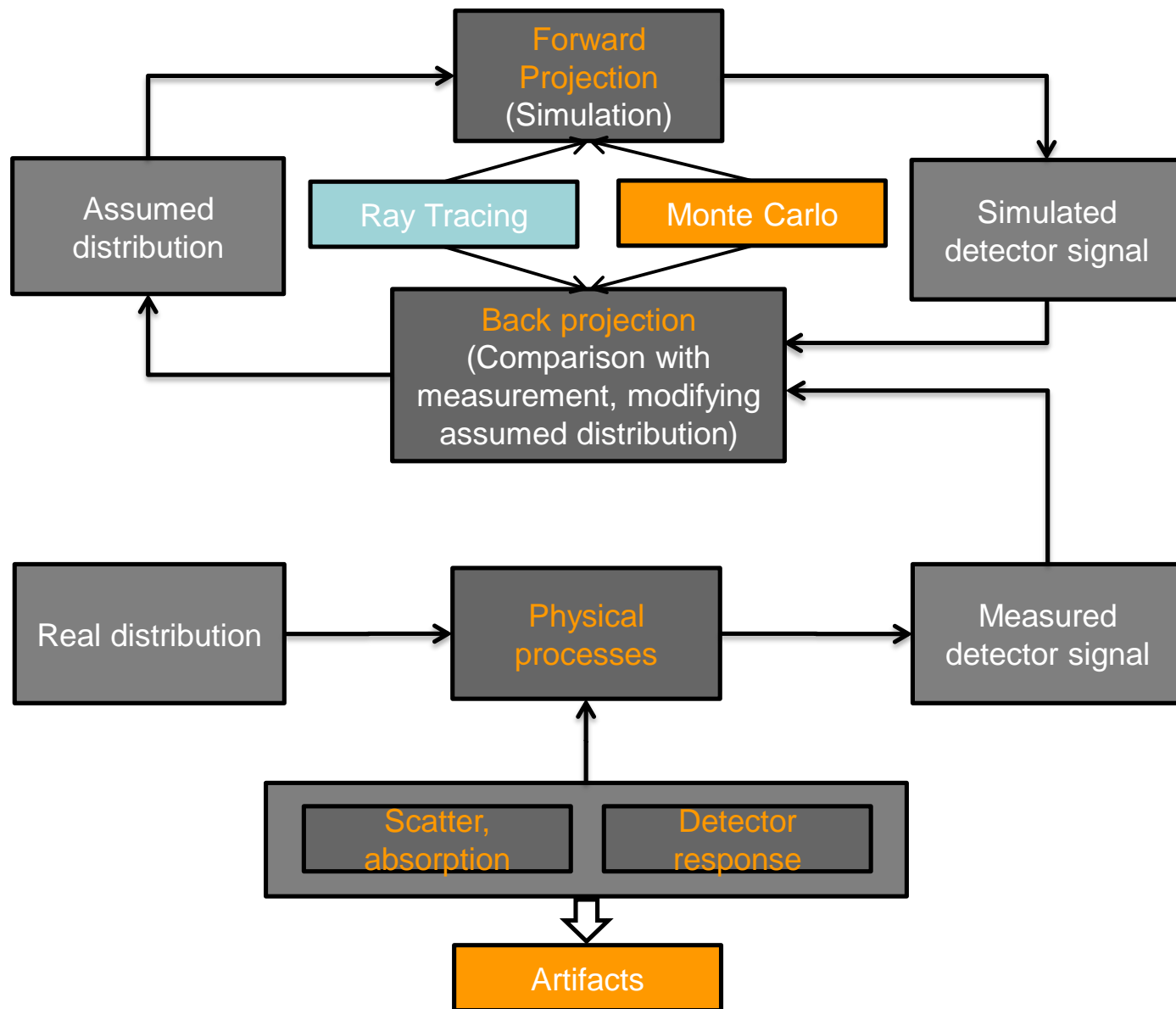
(c) Backproject from a few views



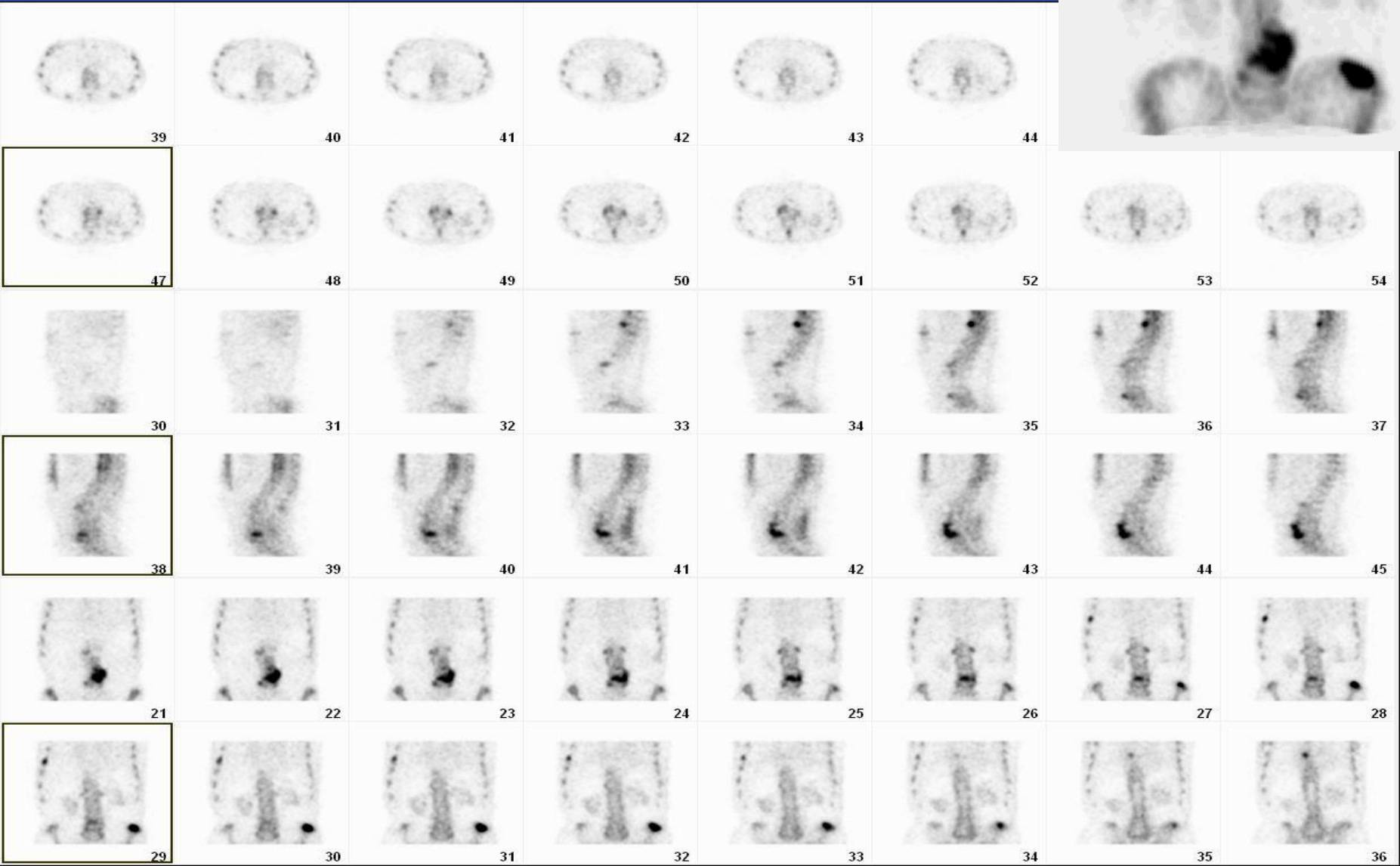
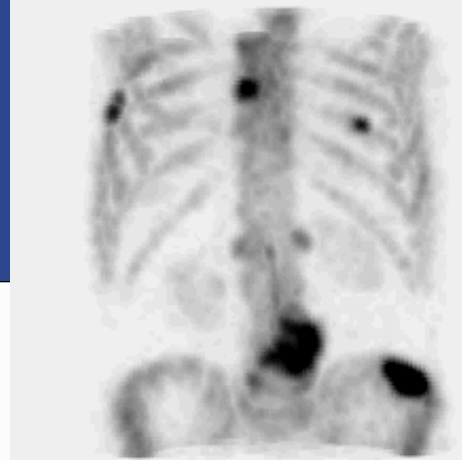
(d) Backproject from all views



# Iterative Reconstruction



# SPECT images



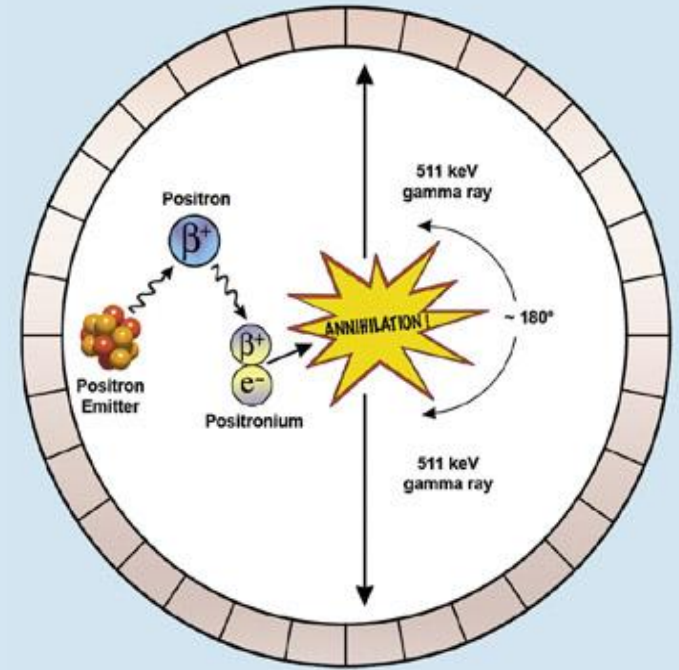
# SPECT vs. planar imaging

- Anatomical localisation
  - Complex anatomical structures
  - Overlap-free display
- Higher contrast resolution
  - More sensitive



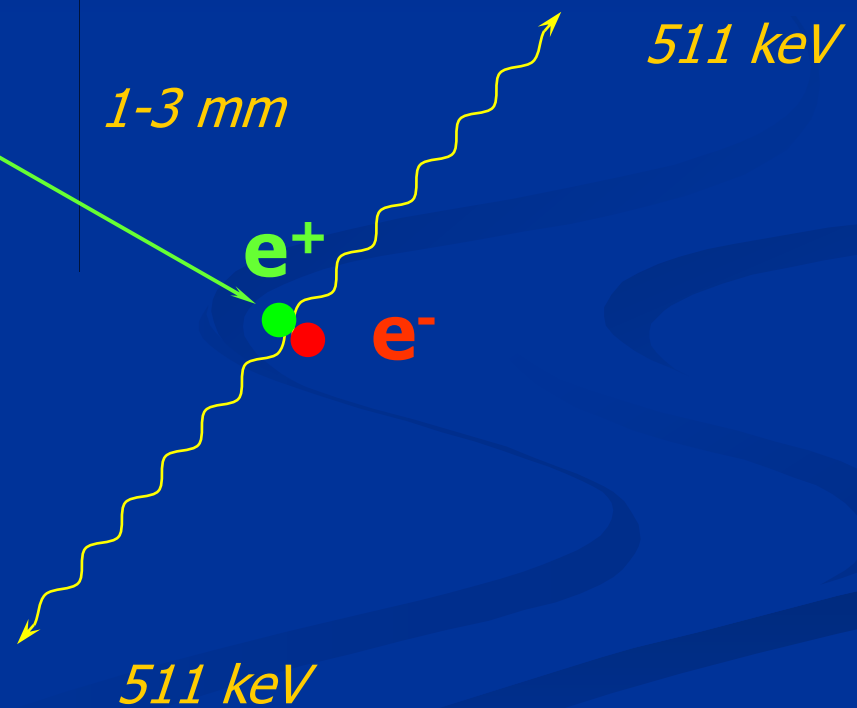
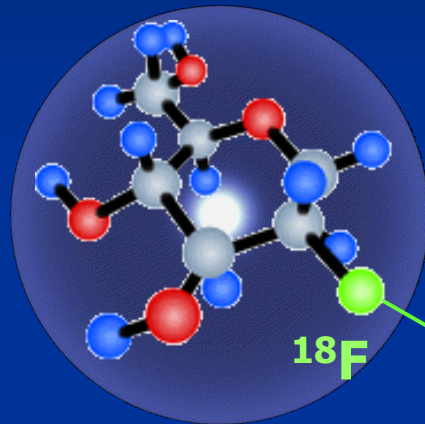
# PET

- Positron Emission Tomography
- Positron emitting radioisotopes
  - Annihilation coincidence detection
- Cross-sectional (tomographic) imaging
  - Detector ring
  - Multi-directional projection images
  - Computerized reconstruction
    - Cross-sectional images
    - 2D tomographic images in 3 planes
    - 3D

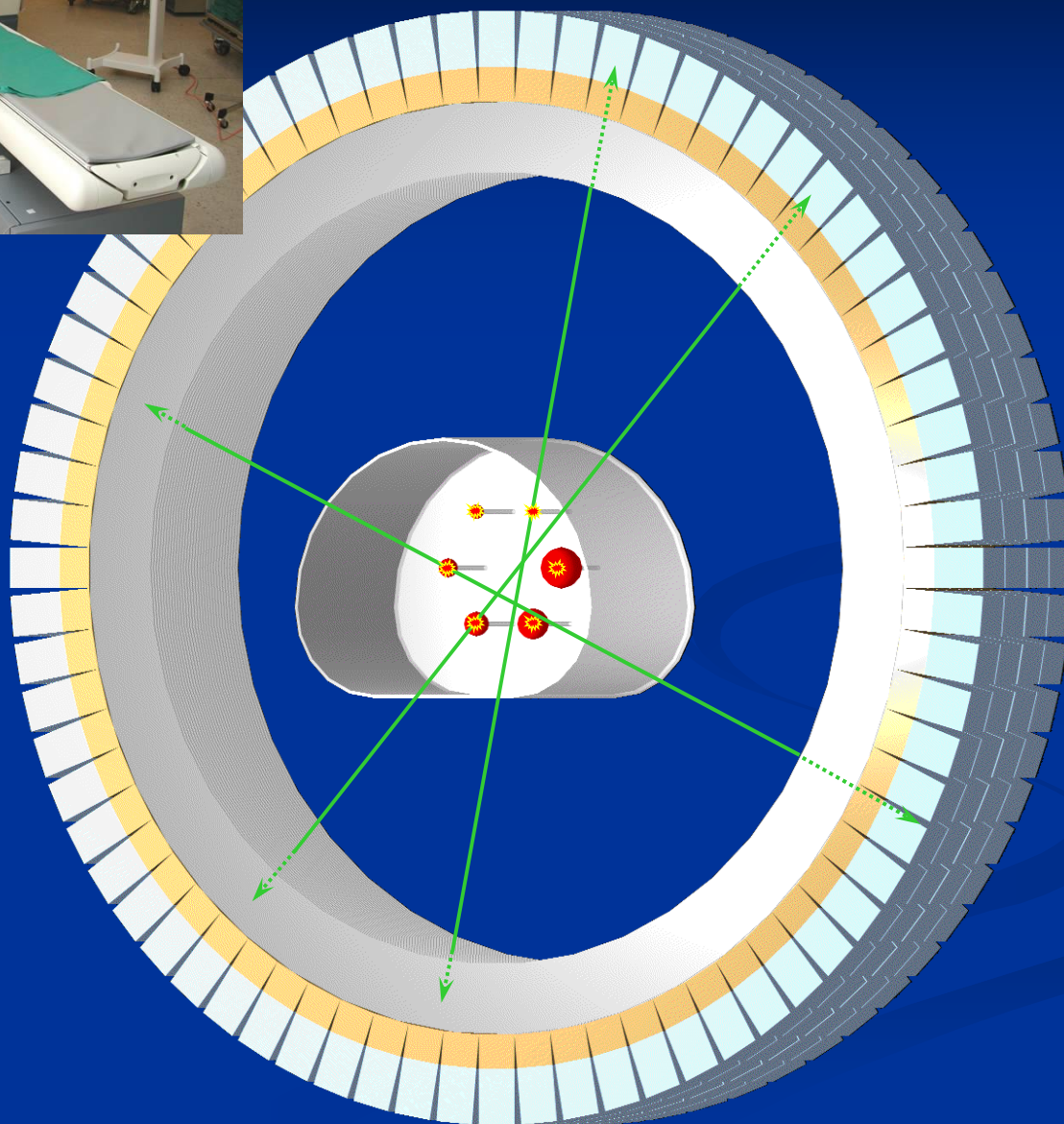


# $\beta^+$ decay

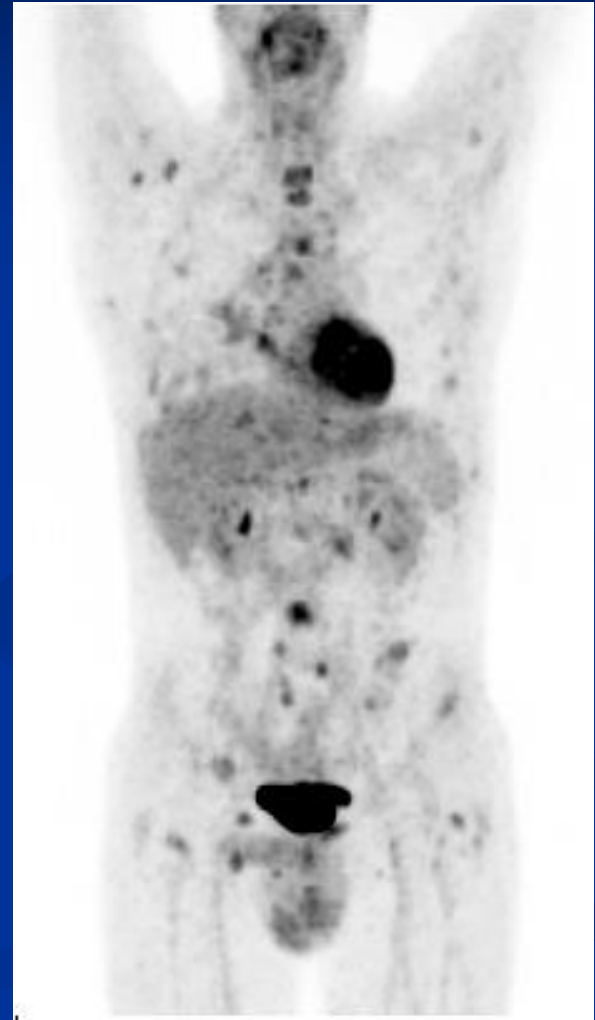
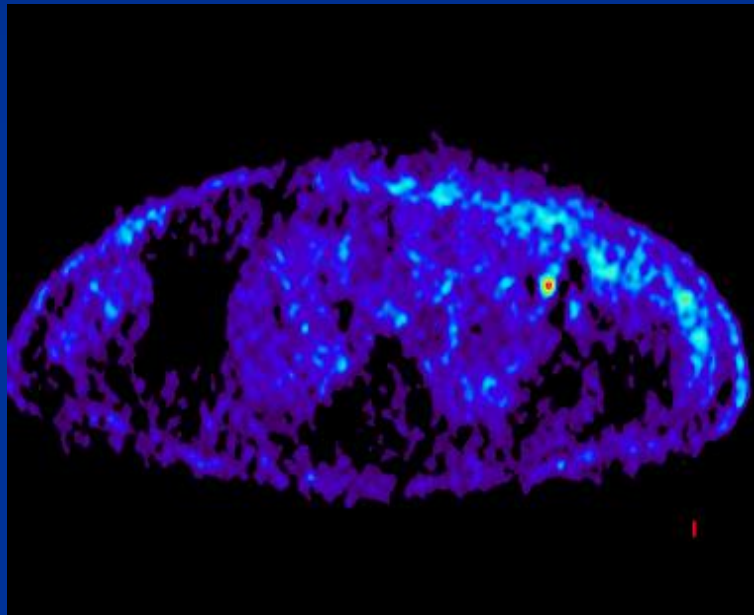
Positron-emitting molecule  
(e.g.:  $^{18}\text{F}$ -FDG)







# Positron-emission tomography (PET)



MIP (maximum intensity projection)

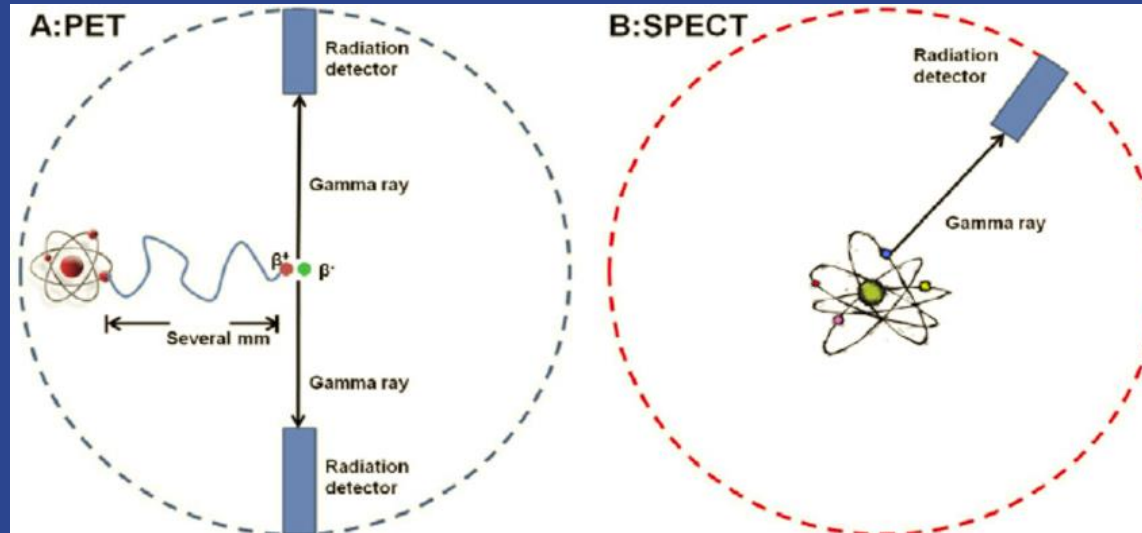
- Axial field of view: ca. 20 cm
- One bed position - acquisition time: 1-3 minutes
- Whole body examination: 4-6 bed positions (120 cm) 4-18 minutes

# Why we need PET?

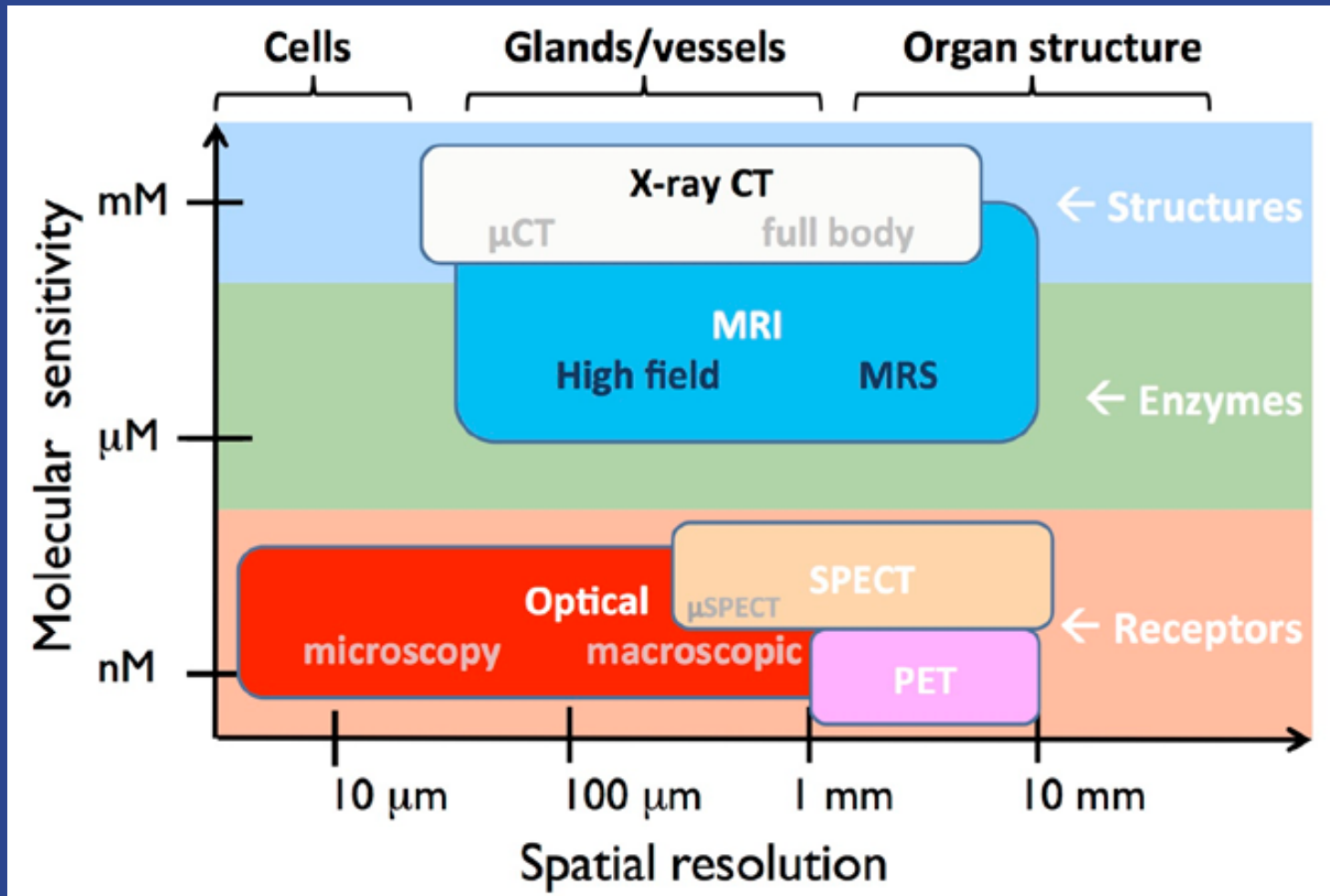
- Most important positron-emitting radionuclides and their half lives:

$^{11}\text{C}$	20,4 min
$^{13}\text{N}$	9,96 min
$^{15}\text{O}$	2,07 min
$^{18}\text{F}$	109,7 min

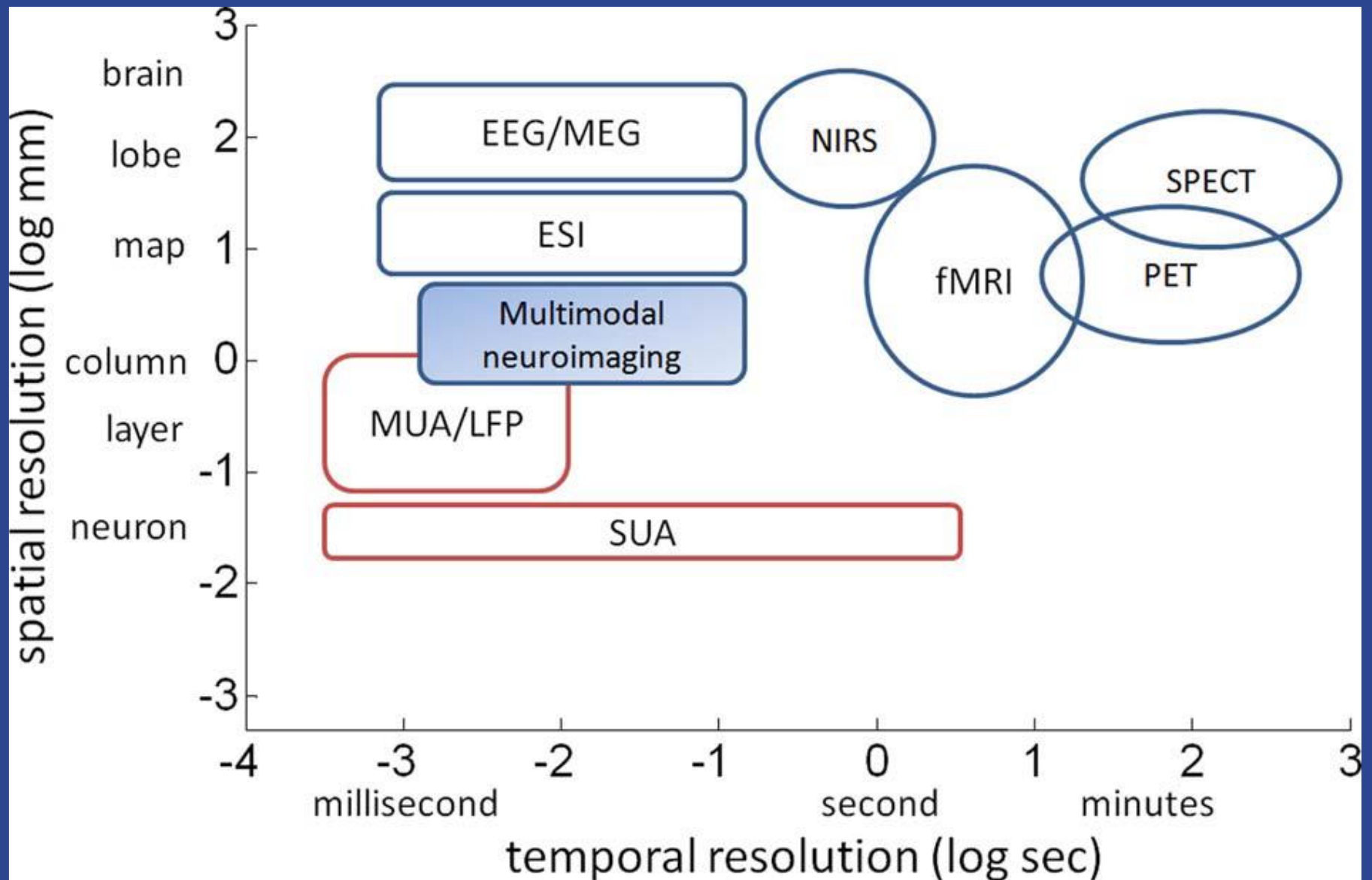
# PET vs. SPECT



	PET	SPECT
<i>Physical properties of tracers</i>	Double-photon	Single-photon
<i>Sensitivity</i>	More sensitive (no collimator)	
<i>Resolution</i>	4 mm	10 mm
<i>Quantification (pl. mL/min/g; mol/min/g)</i>	Yes	Yes



Kenneth MT et al. - Phys. Med. Biol. 60 (2015) R239–R269

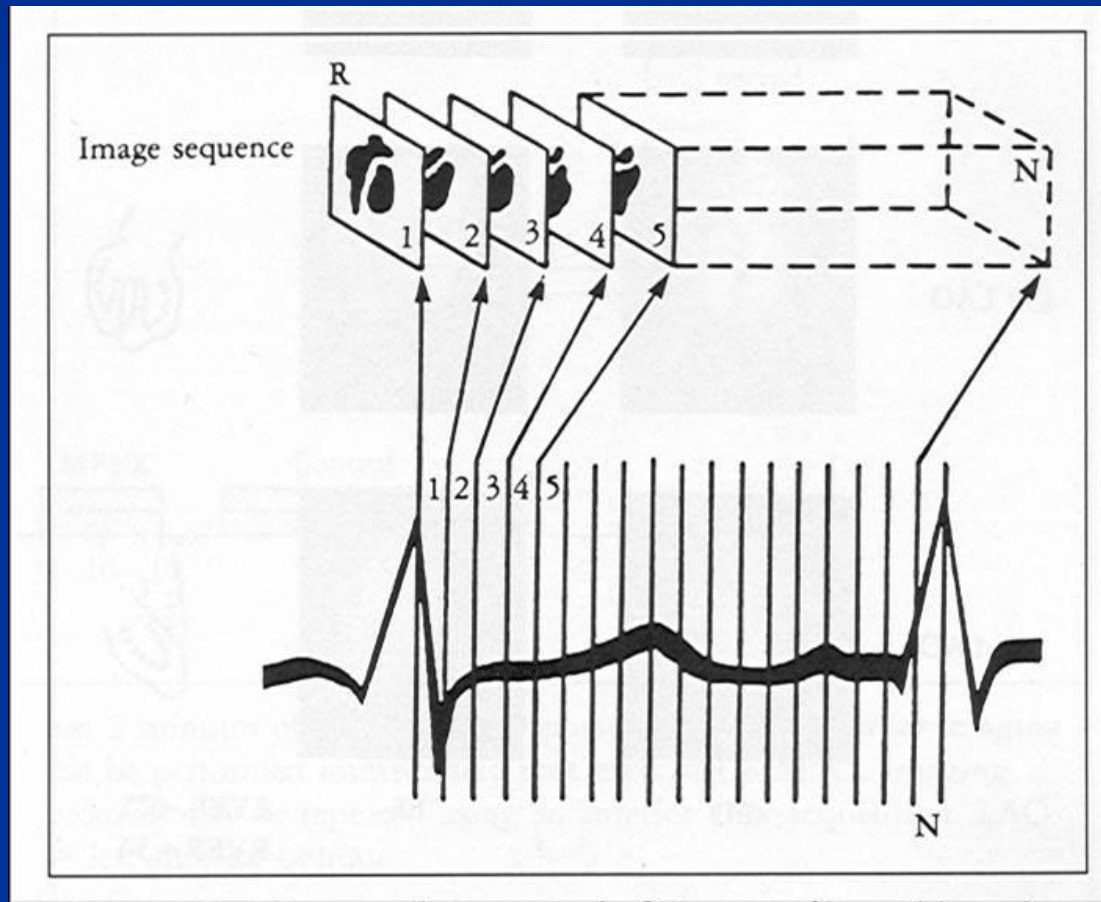


He B et al. IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 58, NO. 7, JULY 2011



# Nuclear Cardiology - Function

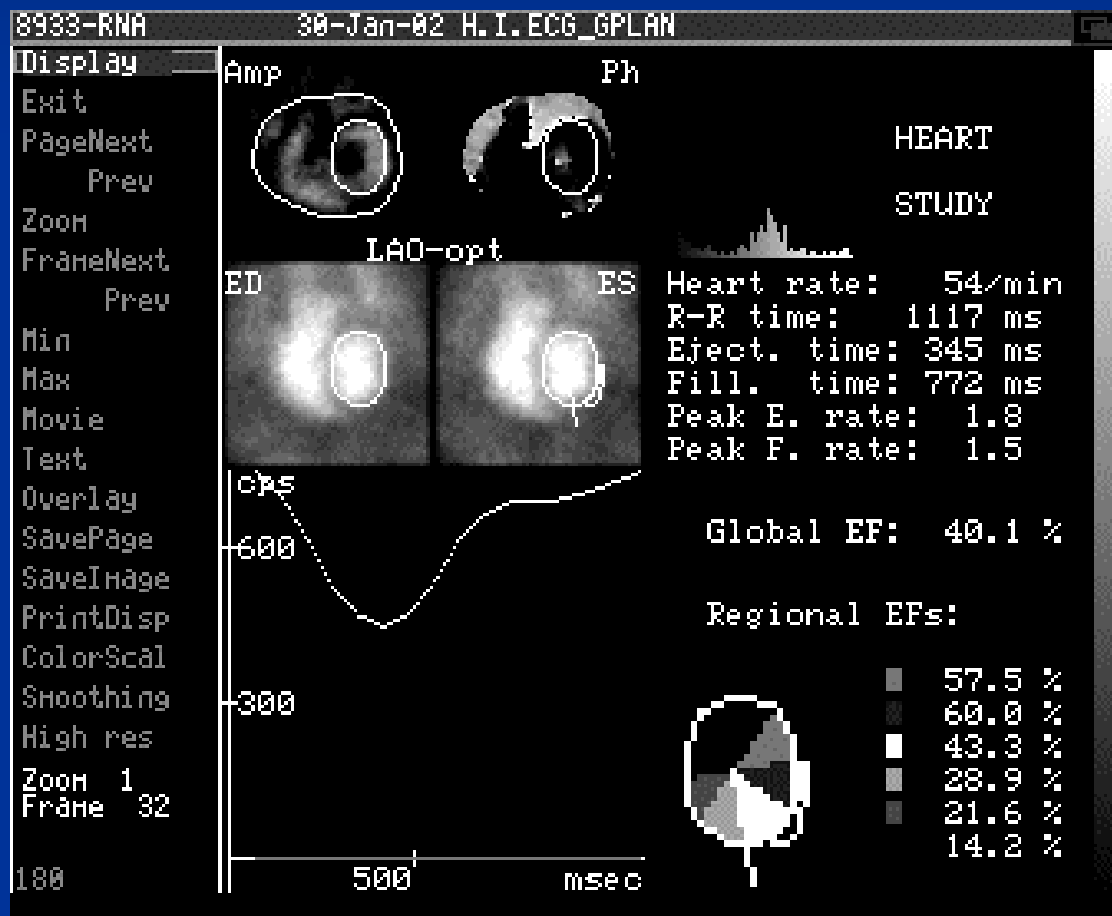
- Equilibrium gated radionuclide ventriculography (MUGA-Multiple Gated Acquisition)



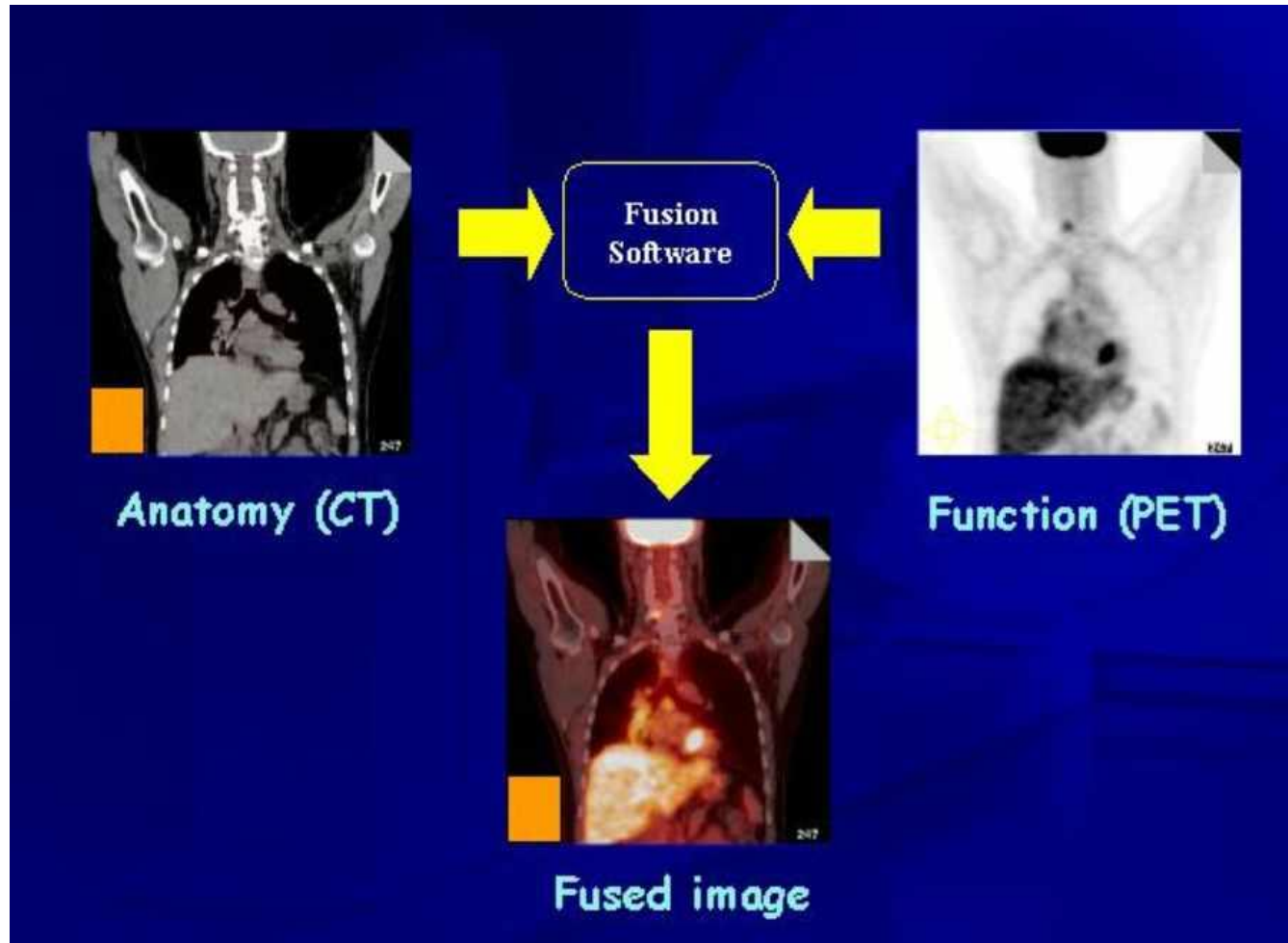


# Nuclear Cardiology - Function

- Equilibrium gated radionuclide ventriculography (MUGA-Multiple Gated Acquisition)



# Image fusion – helps functional imaging



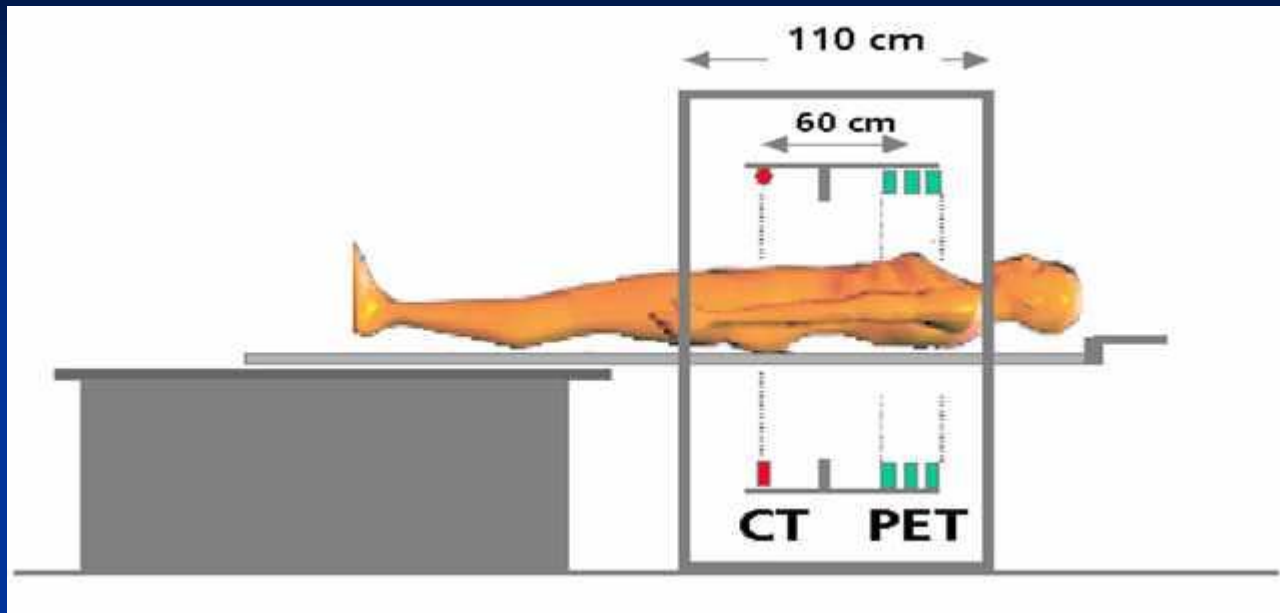
- *Registration, co-registration:*
  - Examinations made at different times and with different modalities in the same (common) 3D coordinate system
- *Image fusion:*
  - Fusion of different, already registered images

# Hybrid imaging

- Combines the advantages of SPECT/PET and CT (or MRI)
- Two modalities in one device (functional + morphological)
  - SPECT-CT, PET-CT, PET-MR, SPECT-PET-CT
  - Imaging at the same time (one after another), in the same position
  - Software based image fusion
- Role of CT
  - Localization
  - Attenuation correction
  - Increases the specificity of PET/SPECT



# Hybrid imaging, PET-CT, SPECT-CT, PET-MR







CT



PET, SPECT



PET-CT, SPECT-CT

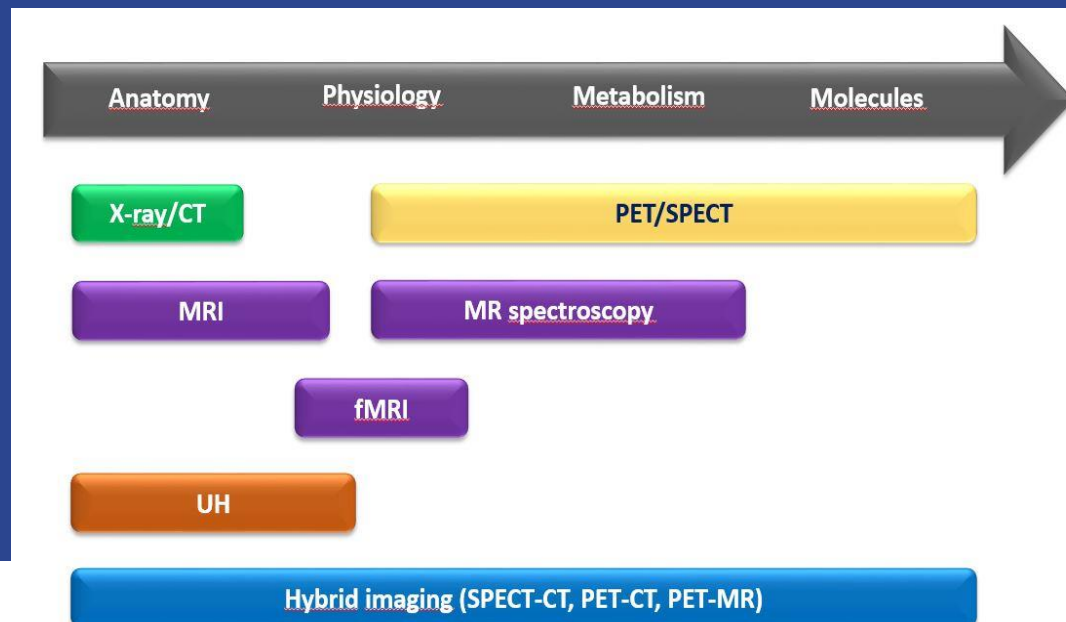
# Why PET/SPECT is necessary?

## Nuclear medicine (PET/SPECT)

- Sensitive
  - Highest functional sensitivity imaging technique
  - Functional abnormalities can be detected earlier than morphological abnormalities
  - High biological contrast between the normal and abnormal tissues
- Specific
  - Radiopharmaceuticals accumulate specifically in pathologic tissues
- Metabolic information
  - Differentiation between non-viable (necrotic) and viable tumor tissue
- Disadvantages
  - Lower resolution
  - Lack of precise localization
  - Longer acquisition time

## Radiology (CT)

- Lower specificity
- High resolution
- Morphological information
- Localization and extent of the disease
- Short acquisition time



# NM – What is functioning?

NM

A

Semmelweis University

R

L

P



# CT – Where is it?

CT+NM

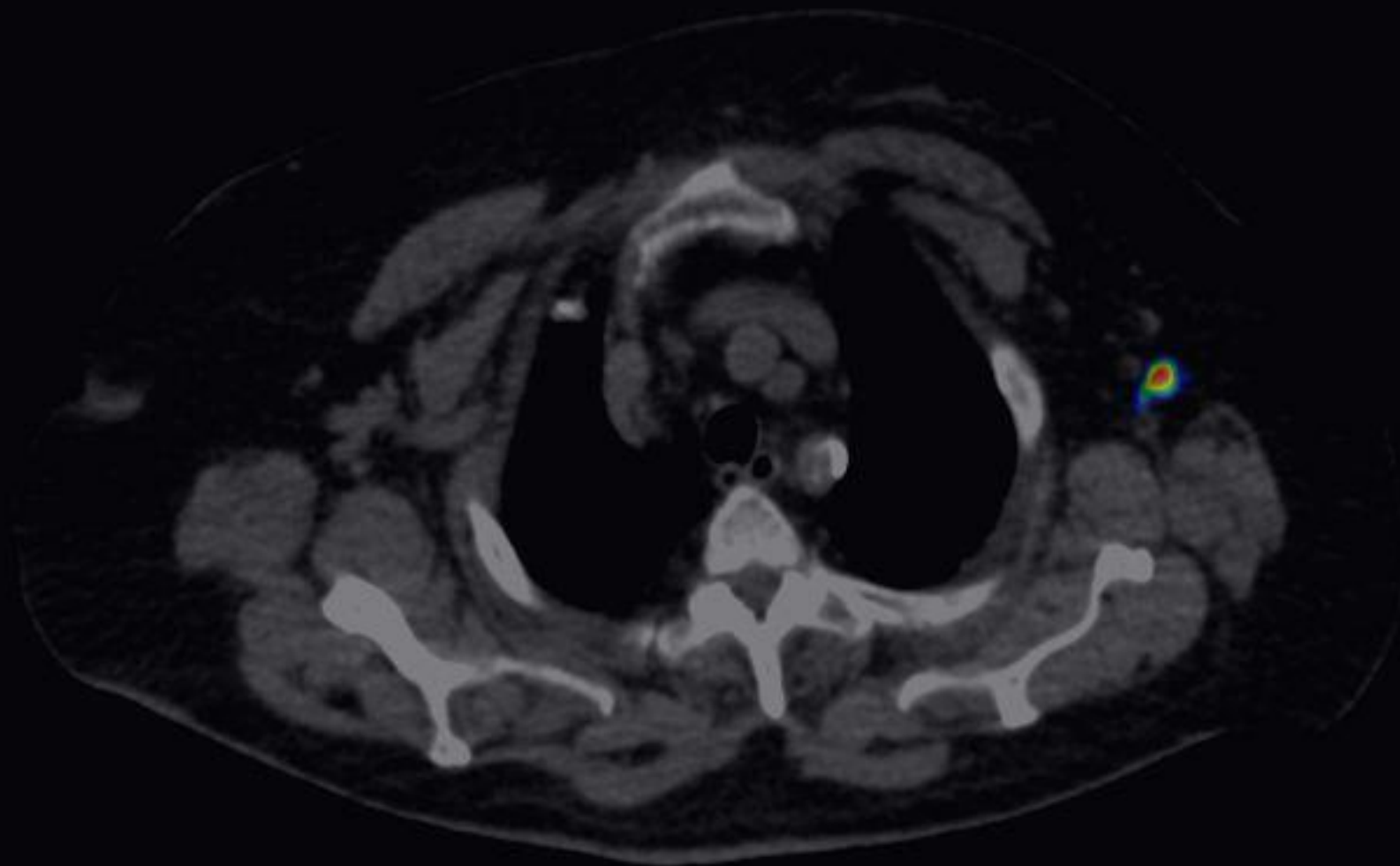
A

Semmelweis University

R

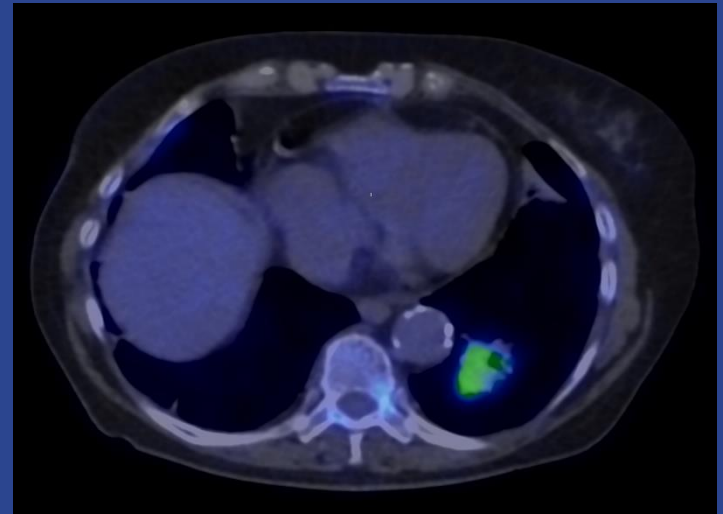
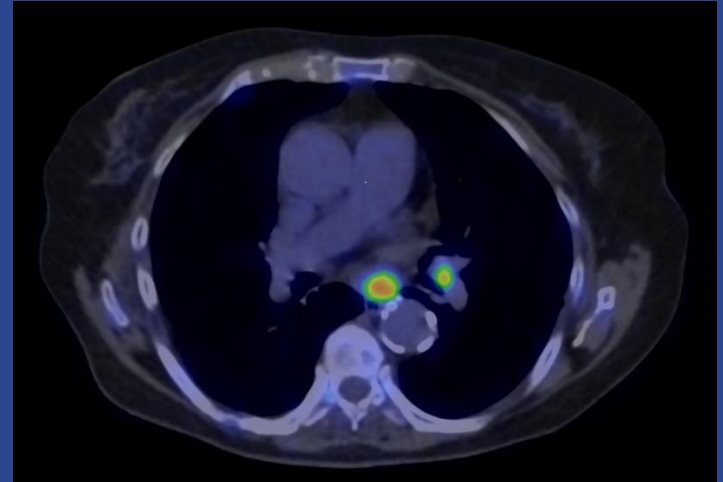
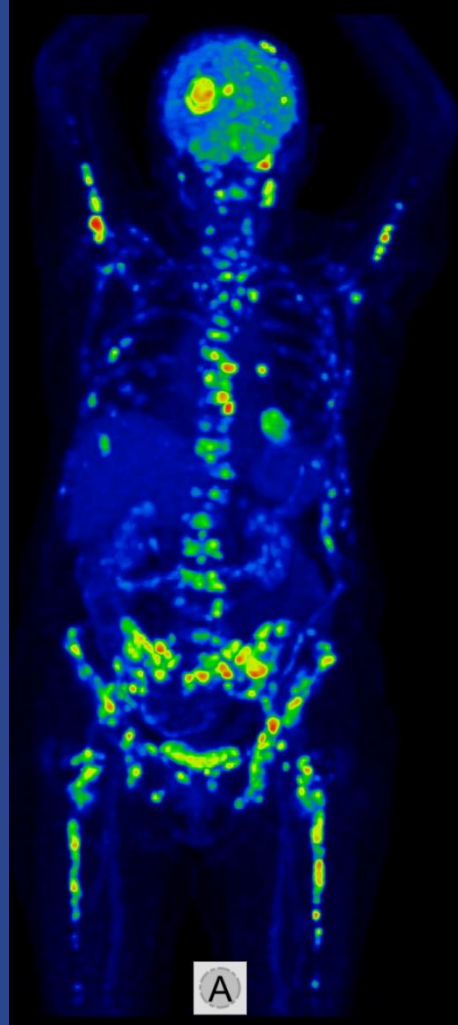
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P





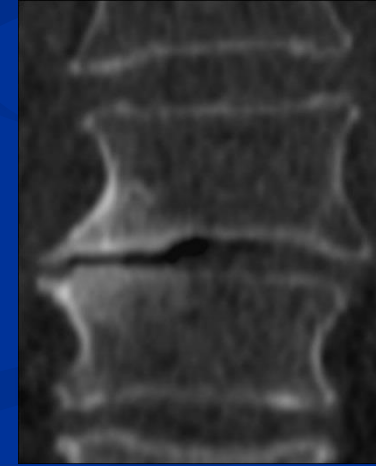
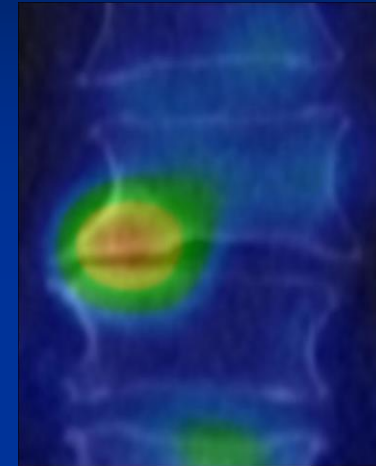
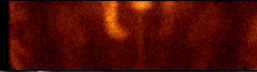
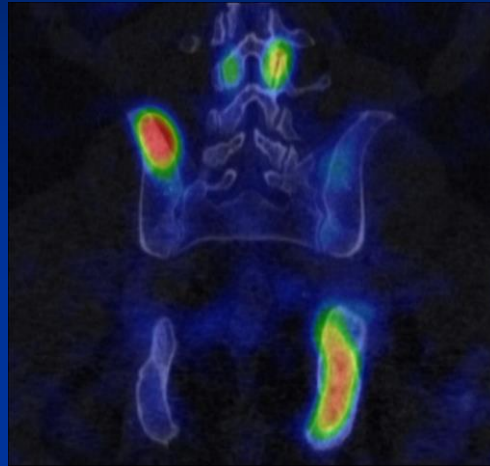
# Hybrid imaging in practice



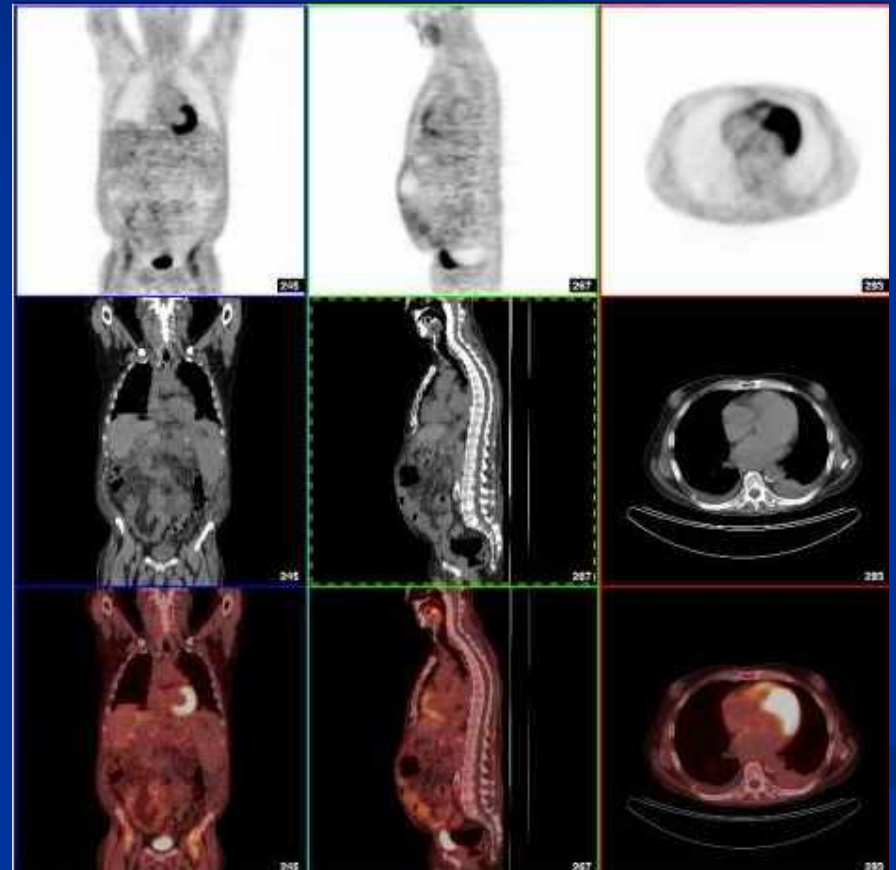
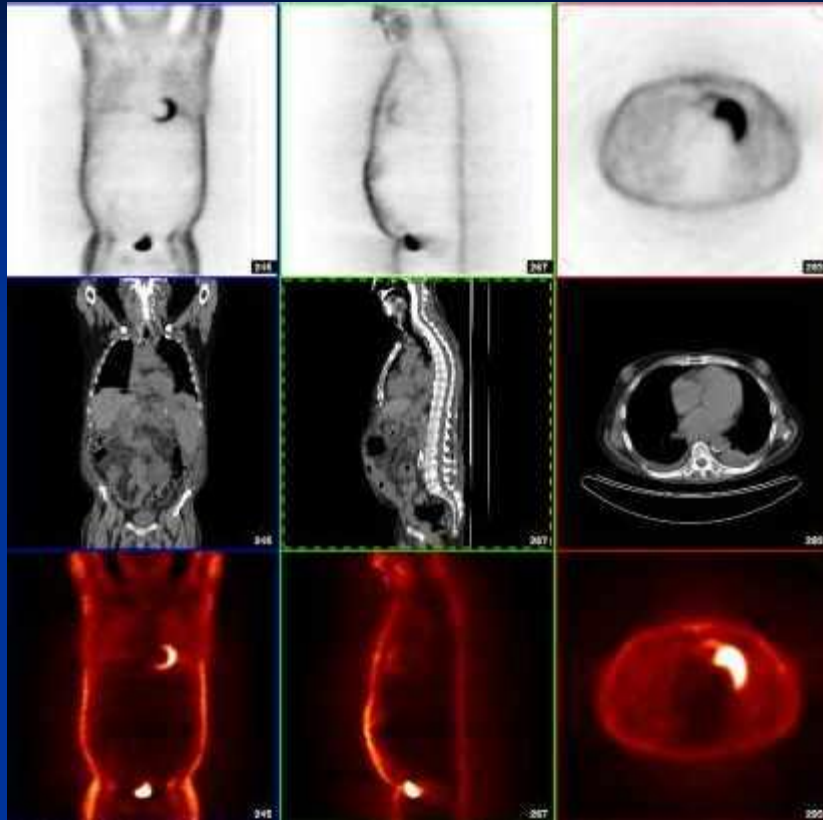
# Hybrid imaging - the role of CT

- Anatomic localisation
- Attenuation correction
  - Low dose native CT is enough
- Characterisation
- Increasing diagnostic safety
- Patient comfort
- Cooperation of radiology and NM

# Characterisation



# CT-based attenuation correction



# Hybrid imaging is popular...



# NM in general

- Functional information - functional imaging

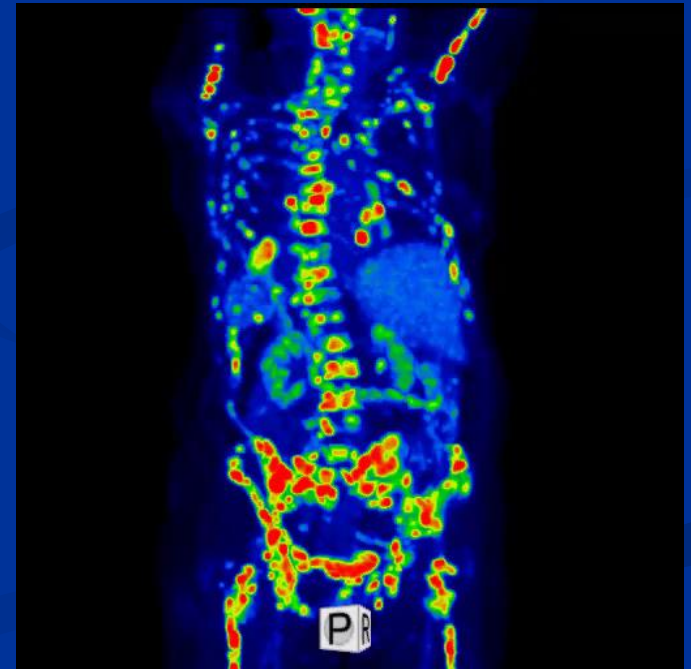
# NM in general

- Functional information
- Sensitivity



# High sensitivity

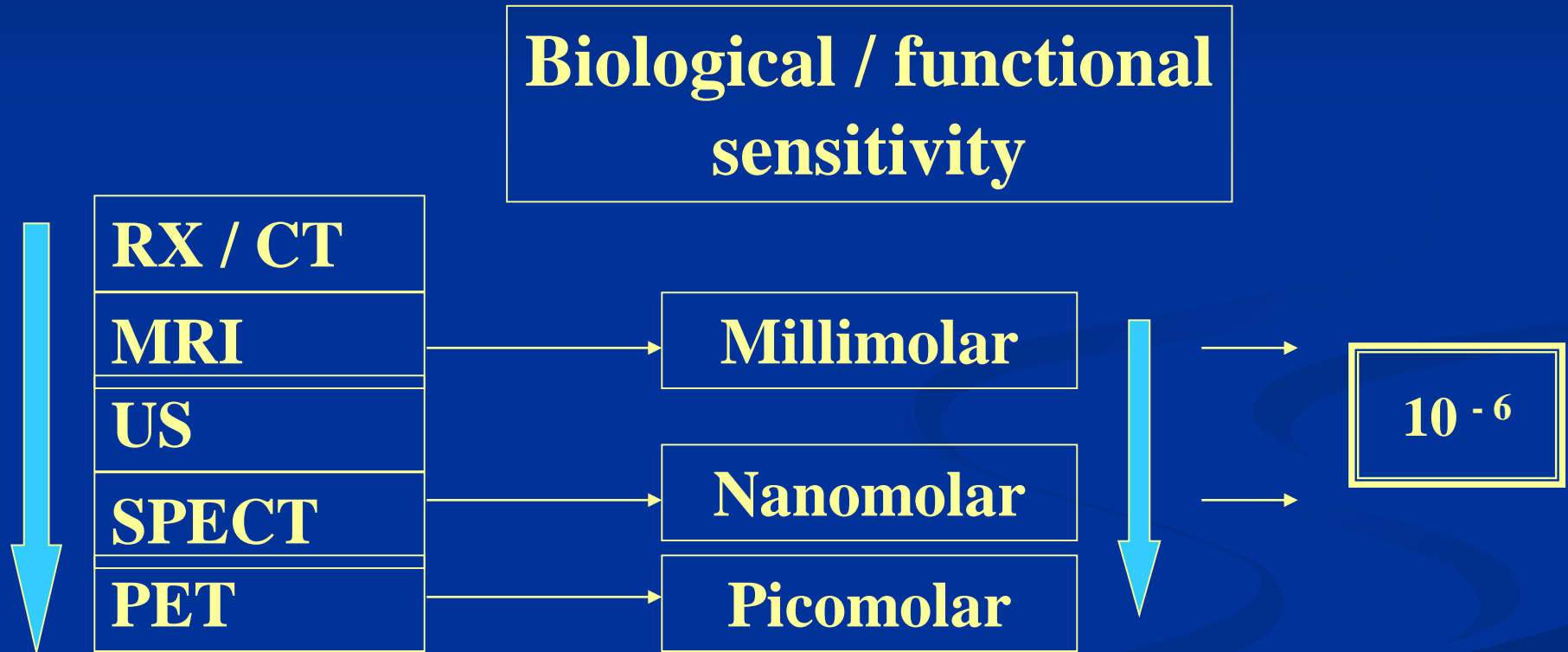
- Tracer-principle
- Functional lesions appear before morphological lesions
- High biological contrast between normal and abnormal processes



MIP (maximum intensity projection)



# Sensitivity of imaging modalities



# NM in general

- Functional information
- Sensitivity
- Specificity

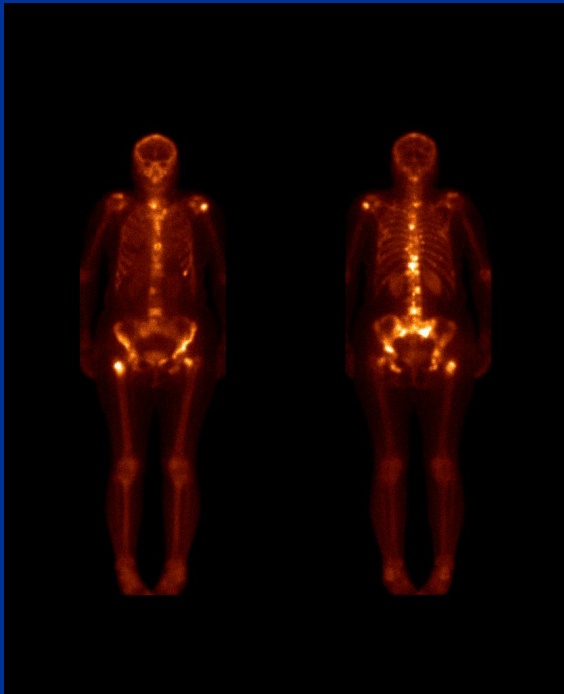
# Bone scintigraphy



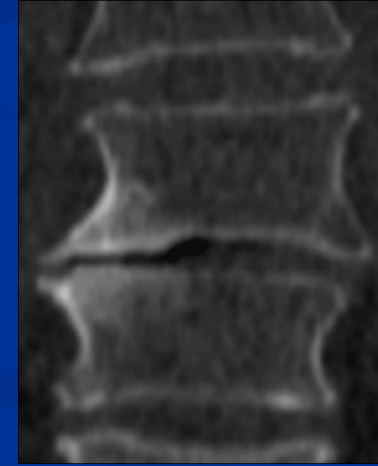
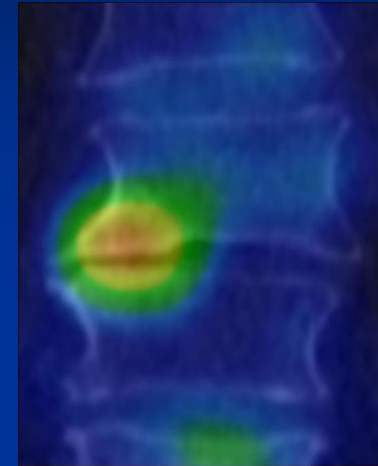
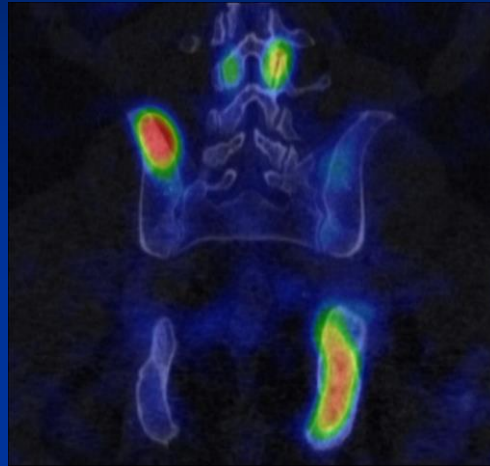
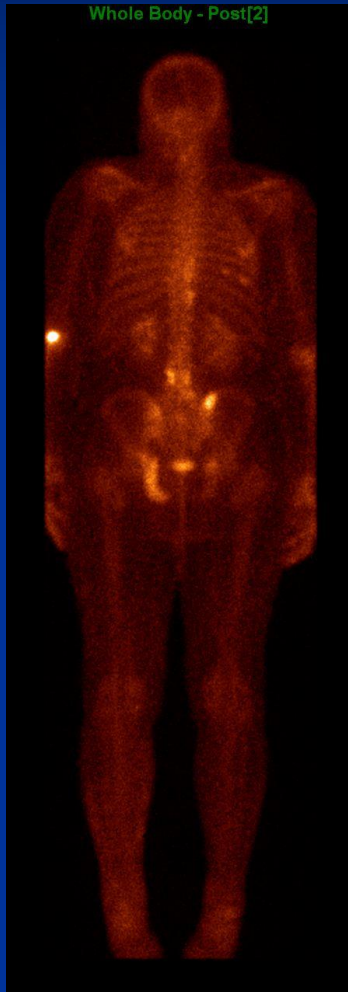
- Tc-99m-diphosphonate
  - Adsorbs to bones in proportion to ***osteoblastic activity***
- Almost every bone disease causes increased osteoblastic activity, therefore increased radiopharmaceutical uptake
- ***Very sensitive***
  - Can detect bone lesions before X-ray
  - Positive bone scan + negative X-ray indicates bone metastasis
- ***Not specific***
  - Fractures, inflammation, primary bone tumours, metastases

# Bone scintigraphy – aspecific

- Tc-99m-diphosphonate
- Osteoblast-function



# Characterisation



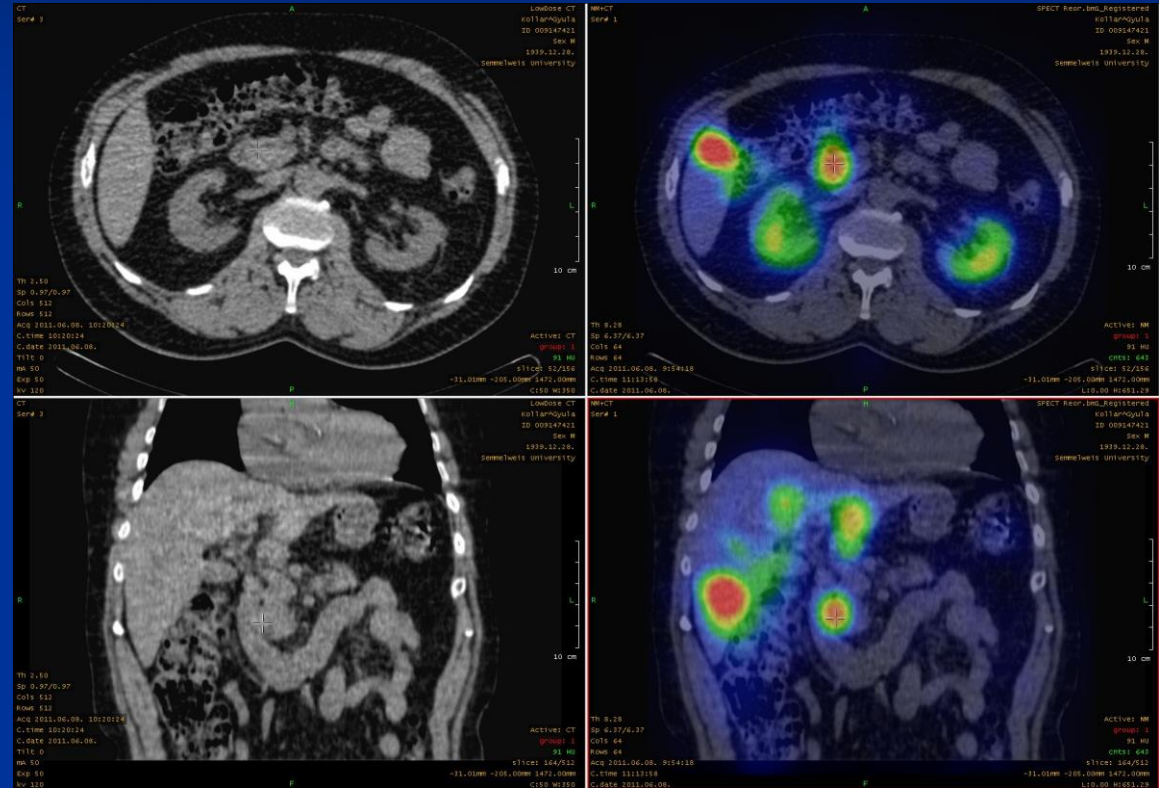
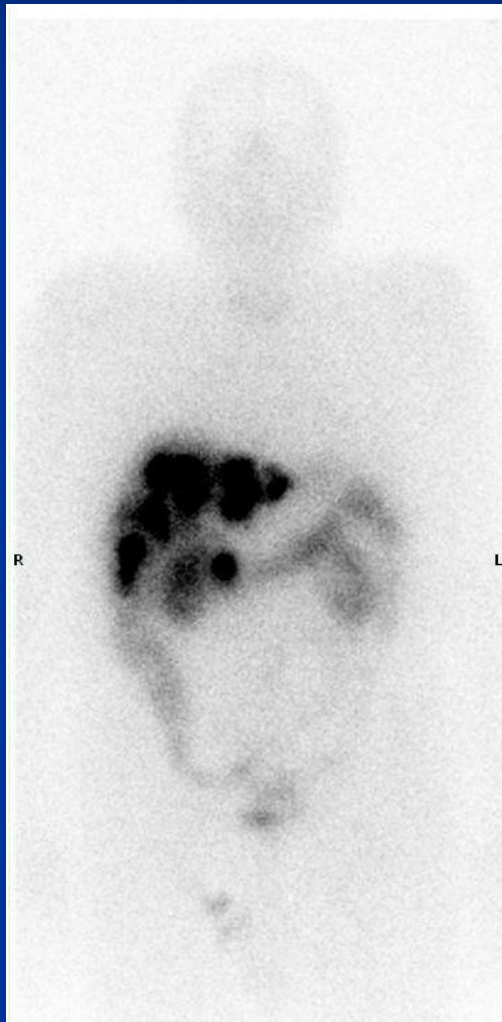
# Molecular imaging

- Visualization of subcellular molecular-biochemical processes in the living organism

Molecular targets	Molecules
Enzymes, transporters	Substrates
Receptors	Ligands
Antigens	Antibodies

# Somatostatin receptor-scintigraphy – specific

- $^{111}\text{In}$ -pentetreotide (Octreoscan)



Radionuclide therapy!

# NM in general

- Functional information
- Sensitivity
- Specificity
- „Bad” spatial resolution



# Spatial resolution...

Planar gamma camera:

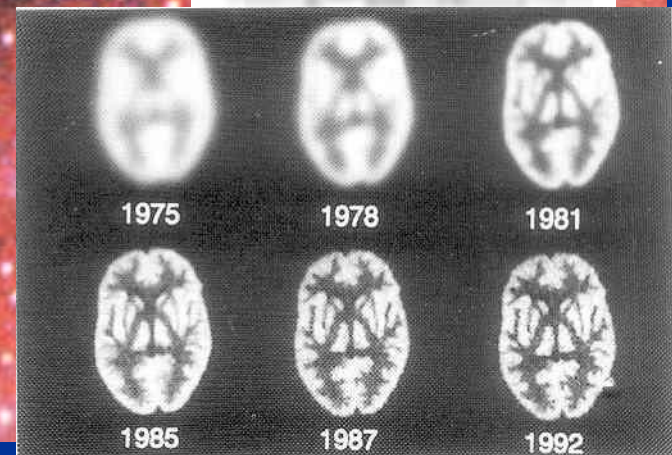
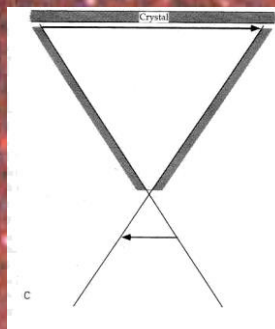
1-3 cm

SPECT:

8-15 mm

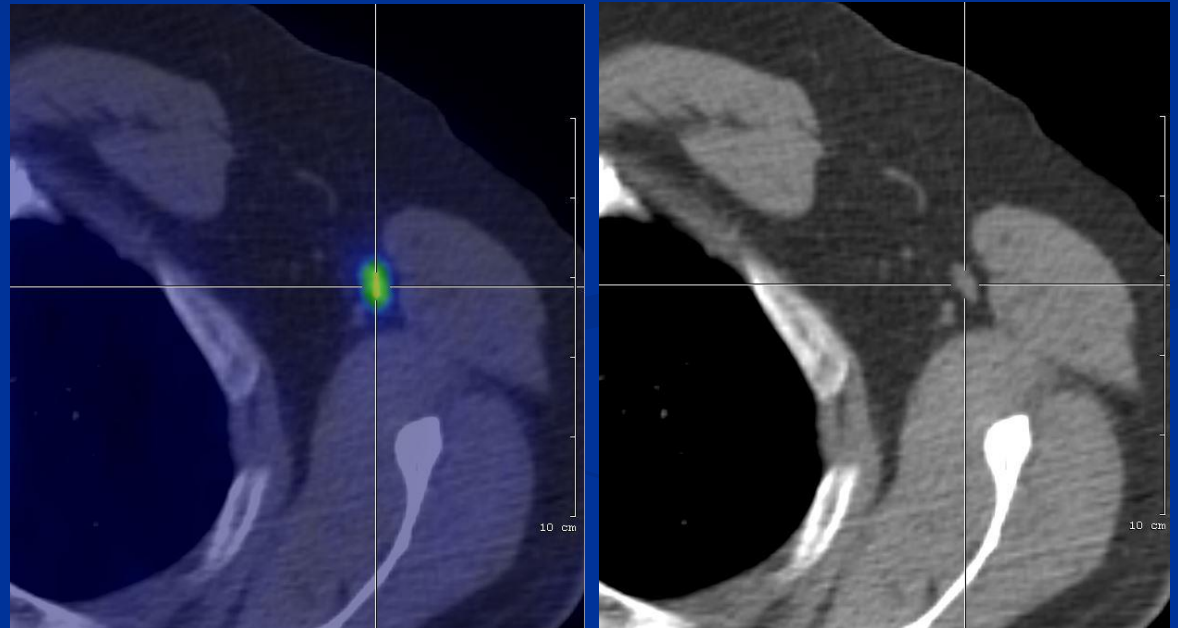
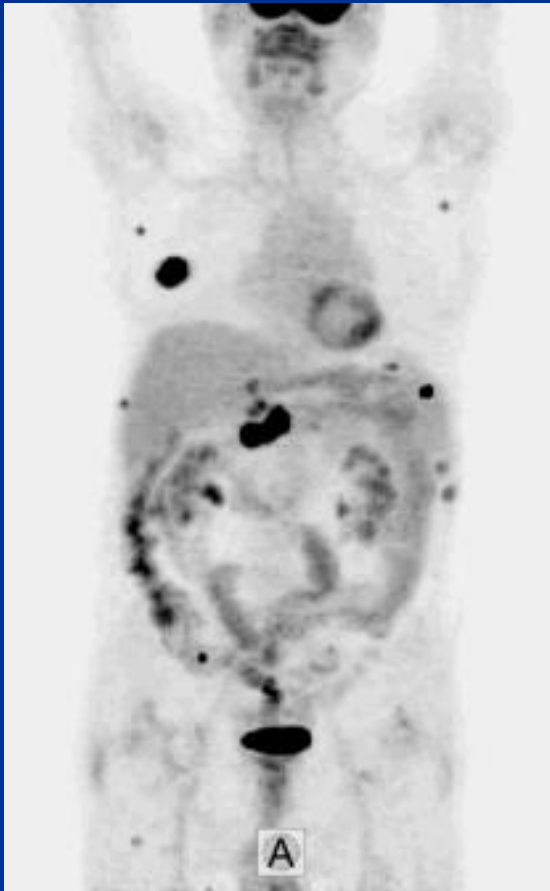
PET:

3-5 mm



# Spatial resolution - Nodal staging

- PET is more sensitive if the lymph nodes are smaller than 1 cm



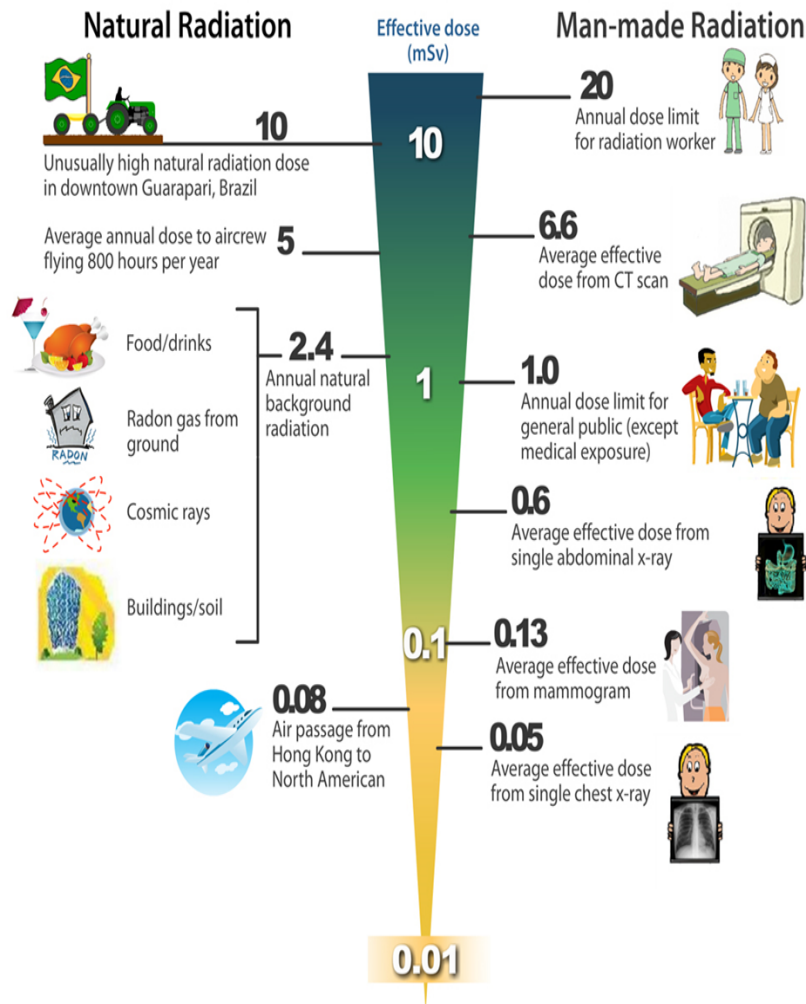
Diffuse large B-cell lymphoma,  
relapse after autologous stem cell  
transplantation

# General considerations

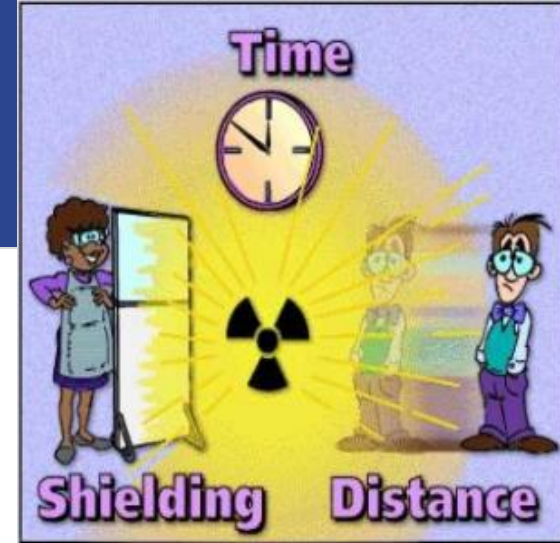
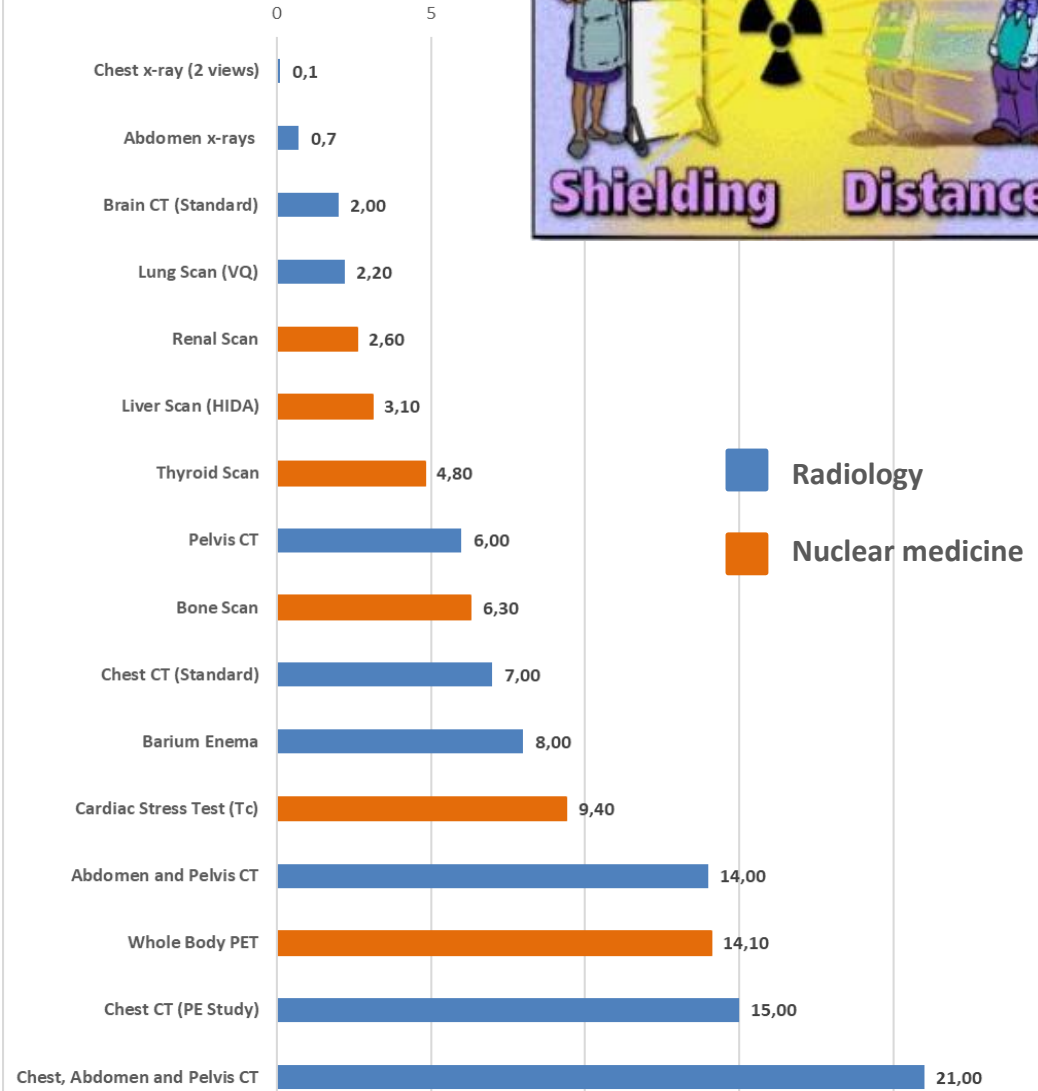
- Functional information
- Sensitivity
- Specificity
- „Poor” spatial resolution
- Radiation exposure

# Radiation protection

## Radiation in Daily Life



Average adult effective doses (mSv)





# General considerations

- Functional information
- Sensitivity
- Specificity
- „Poor” spatial resolution
- Radiation exposure
- Quantification

# Quantification

Quantitative: Glucose Metabolic Rate ( $\text{Mr}_{\text{glu}}$ )

$$\mathbf{Mr}_{\text{glu}} = (C_P / LC) \times \{K_1 \times k_3 / (k_2 + k_3)\} = (C_P / LC) \times K_i$$

( $\mu\text{moles/min/ml}$ )

Semiquantitative: Standardized Uptake Value (SUV)

$$\mathbf{SUV} = \frac{\mathbf{\text{tracer concentration (Bq/ml)}}}{\mathbf{\text{injected dose (Bq) / body volume (ml)}}$$

# Specific applications

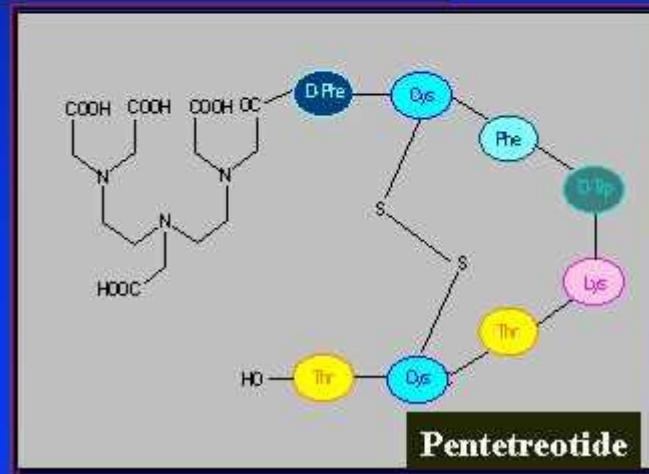
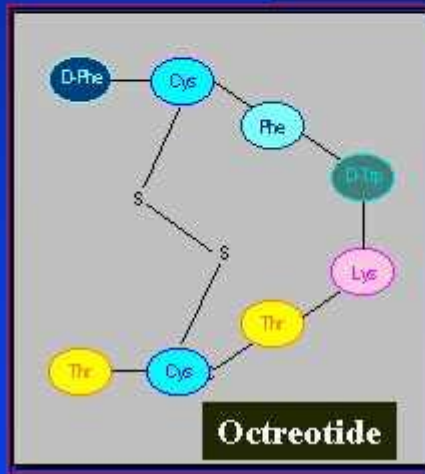
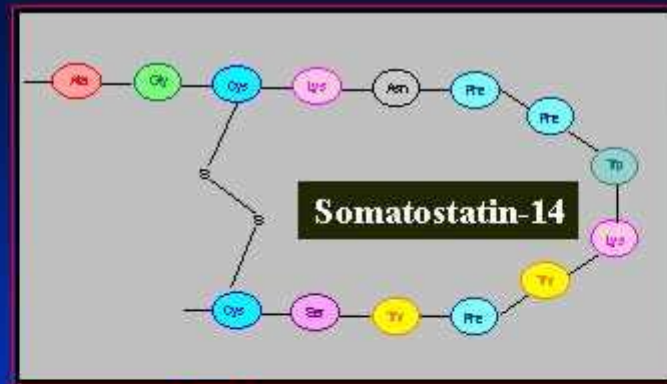
# Receptors, peptides

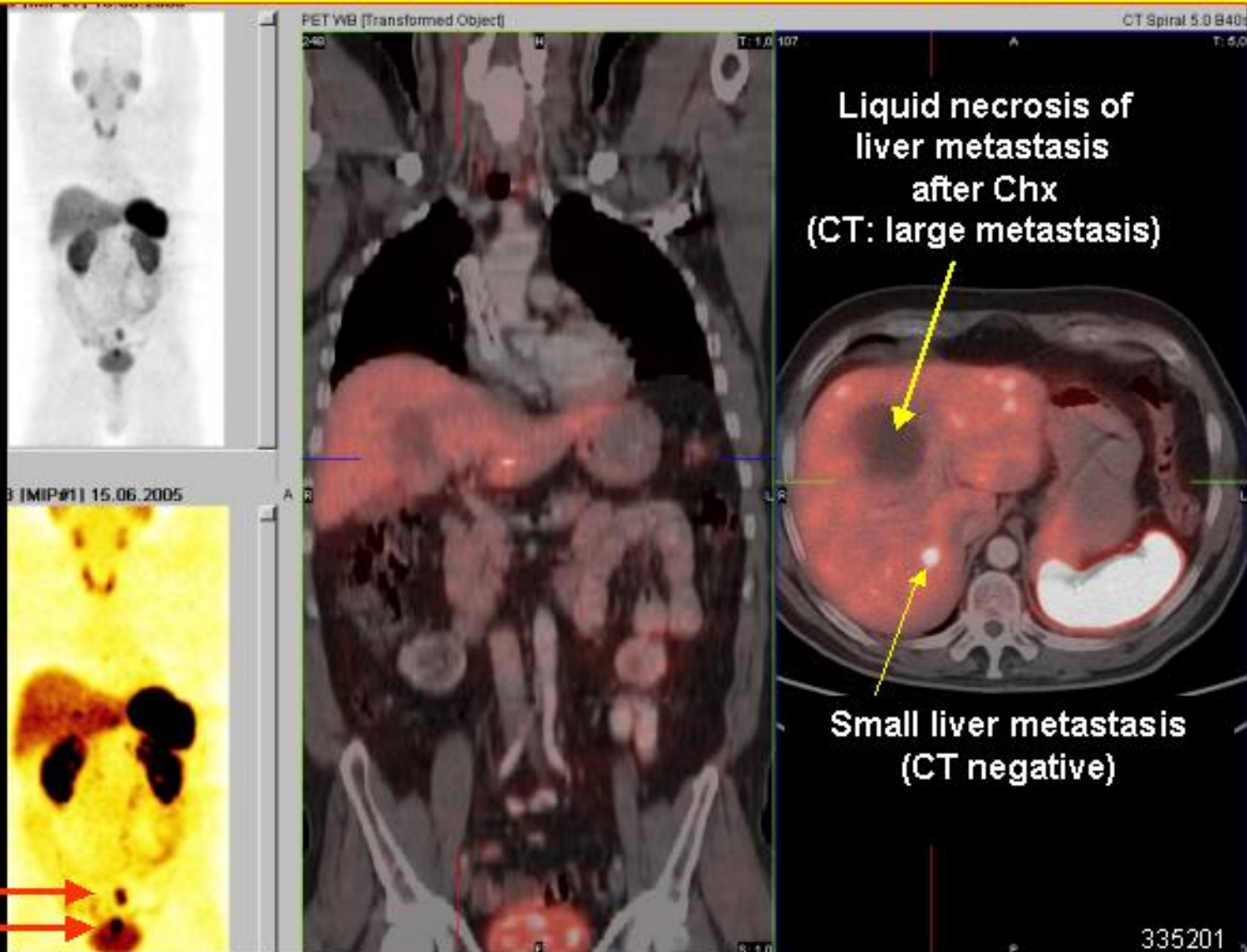
## Imaging of somatostatine receptors (SST-R)

- Incidence of SST-R in neuroendocrine tumors
  - Gastrinoma, glucagonoma 100%
  - Insulinoma 72%
  - Paraganglioma 92%
  - Medullary thyroid cc. 38%
  - Carcinoid 88%
  - Small cell lung cancer 57%
  - Pheochromocytoma 73%

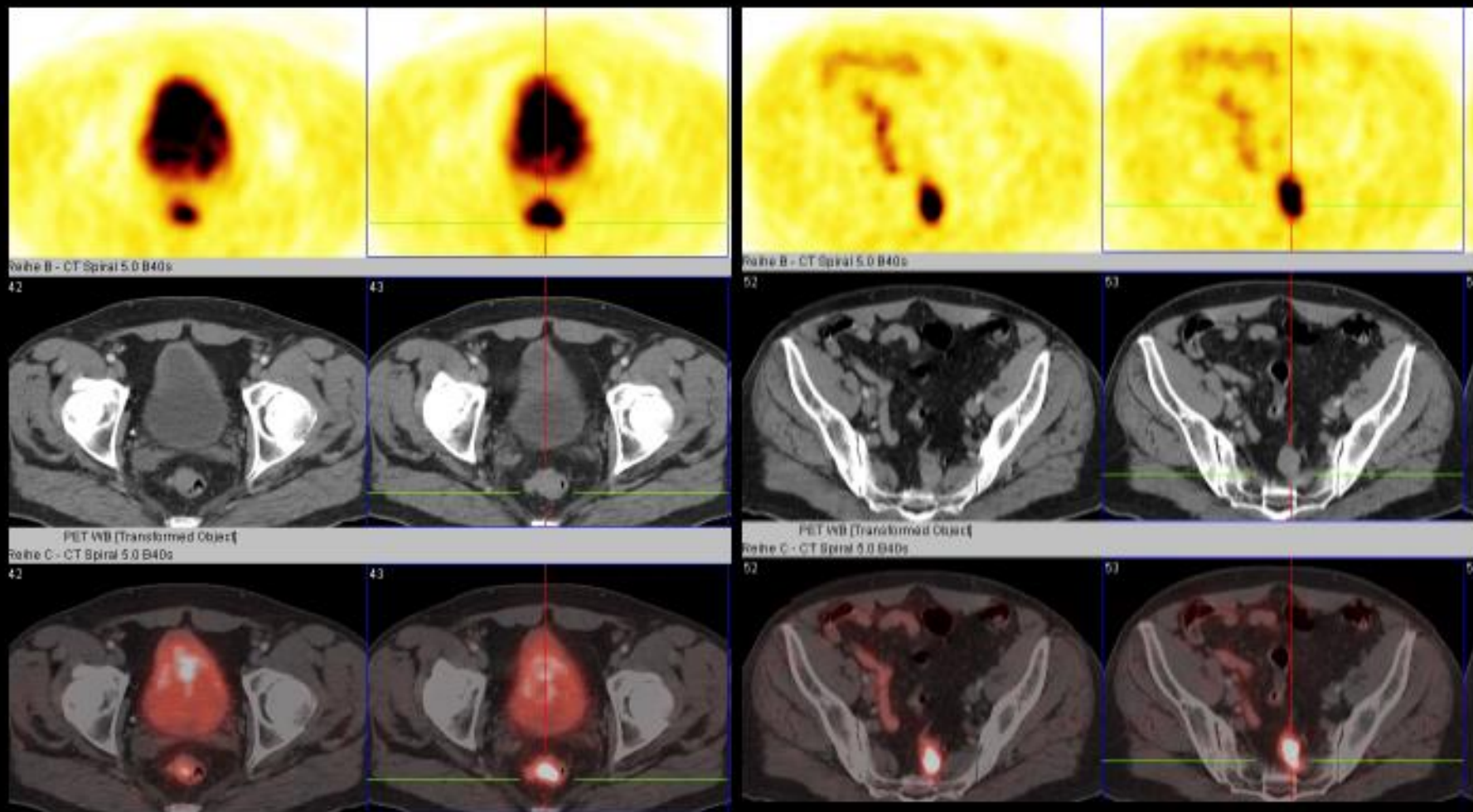


# Basic principles of SST-R scintigraphy





## Patient with CUP (neuroendocrine tumor) referred for PRRT



**Primary rectal carcinoid**

**Presacral lymph node metastasis**



**Patient referred to surgery**

# Theranostics

- Compounds suitable for both diagnosis and treatment, that specifically bind to target molecules
  - For diagnosis → labelled with  $\gamma$ - or positron-emitting radioisotopes
  - For treatment → labelled with  $\alpha$ - or  $\beta$ -emitting radioisotopes
- Target specific molecules
  - Only the diseased cells are visualized → specific diagnosis
  - Only the diseased cells are treated → surrounding normal cells remain intact (low toxicity)

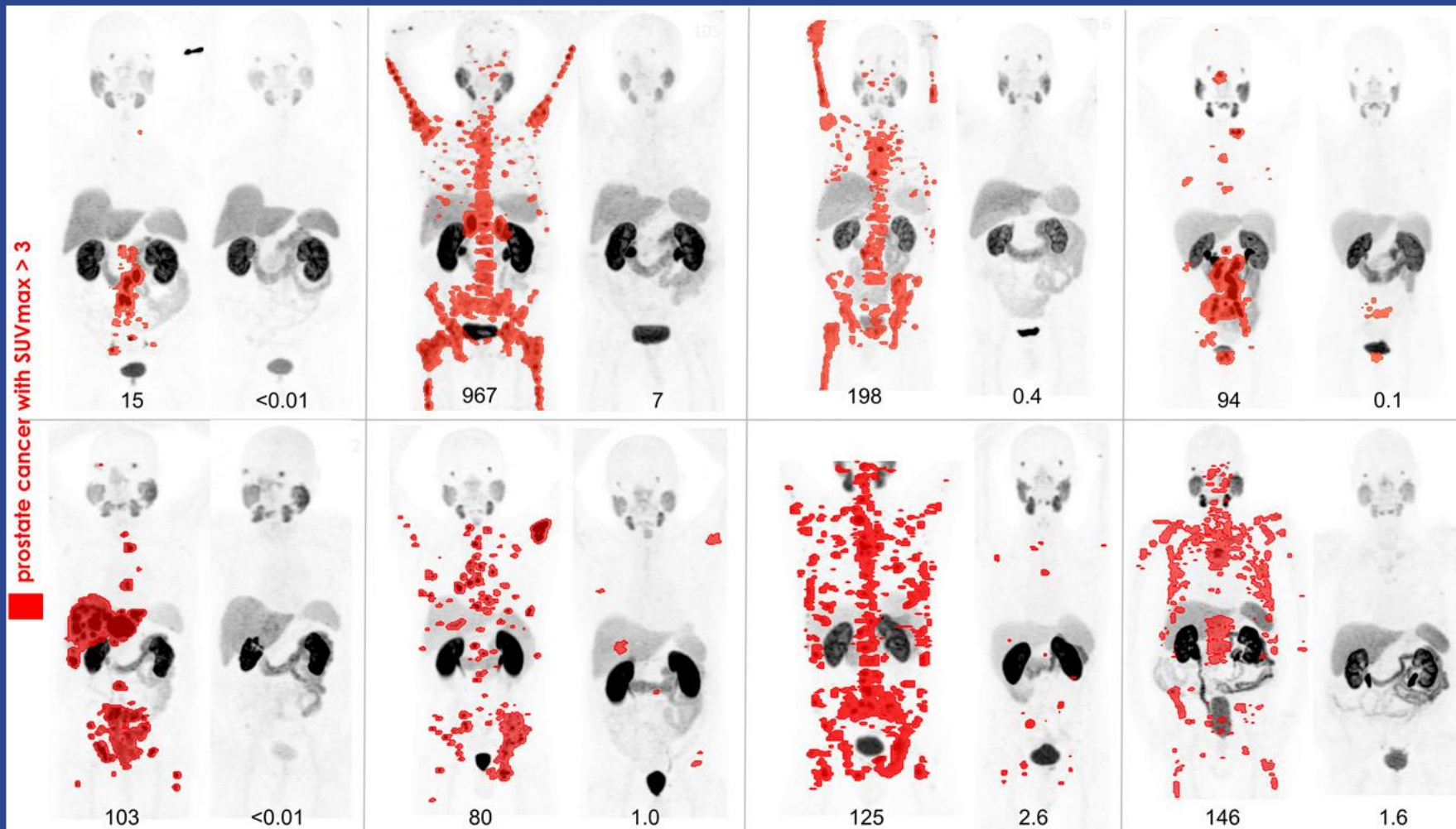


# Prostate Specific Membrane Antigen (PSMA) radiopharmaceuticals

- Membrane glycoprotein
- Small ligand (not antibody) binding to extracellular part of the antigen
- Positron emitting isotopes (diagnostics):
  - $^{18}\text{F}$ ,  $^{68}\text{Ga}$
  - (gamma:  $^{99\text{m}}\text{Tc}$ ,  $^{111}\text{In}$ )
- Radiotherapy:
  - $^{177}\text{Lu}$ ,  $^{131}\text{I}$  (beta neg.)
  - $^{225}\text{Ac}$  (alpha)
- Teranostics: PSMA I&T (Imaging & Therapy)



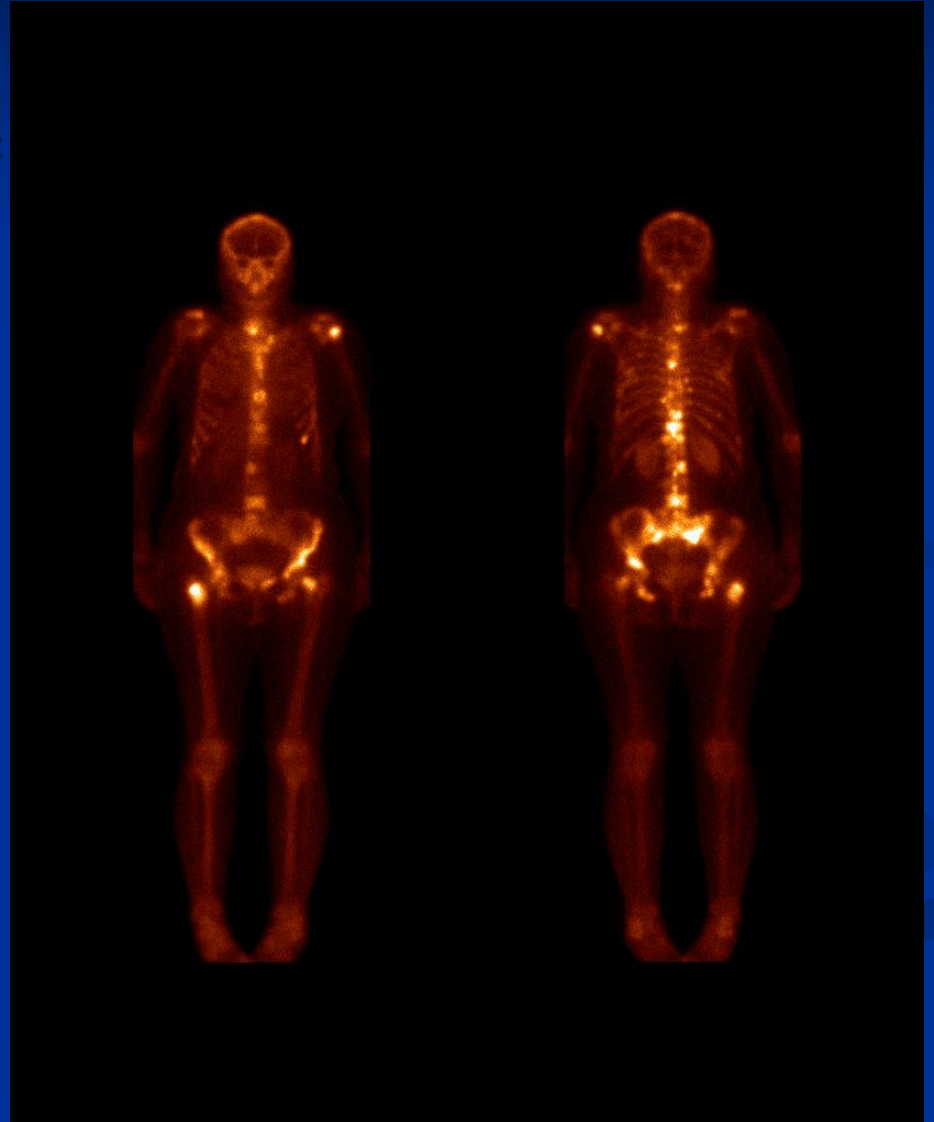
Demirci et al. Nucl Med Commun. 2016



**2018 SNMMI Image of the Year:** PET imaging before and after  $^{177}\text{Lu}$ -PSMA617 therapy for metastatic prostate cancer.  $^{68}\text{Ga}$ -PSMA11 PET maximum-intensity projection images at baseline and 3 months after  $^{177}\text{Lu}$ -PSMA617 treatment in 8 patients who experienced prostate-specific antigen declines of  $\geq 98\%$  in a prospective phase II study. Red = disease with SUV > 3. Used with permission from Hofman et al. from the Peter MacCallum Cancer Centre (Melbourne, Australia).

# Bone scintigraphy

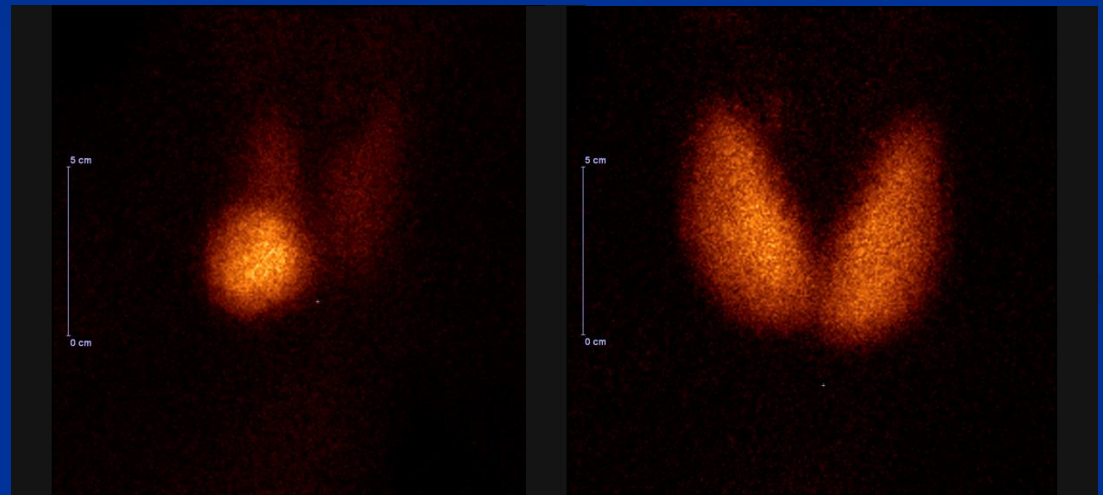
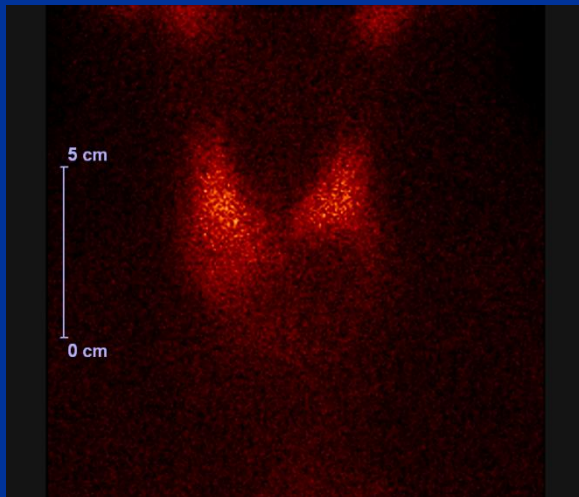
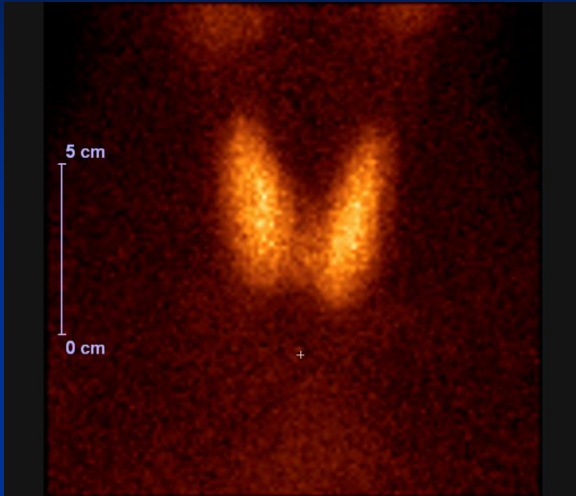
- Tc-99m diphosphonate
- Osteoblast-activity
- Osseous metastasis





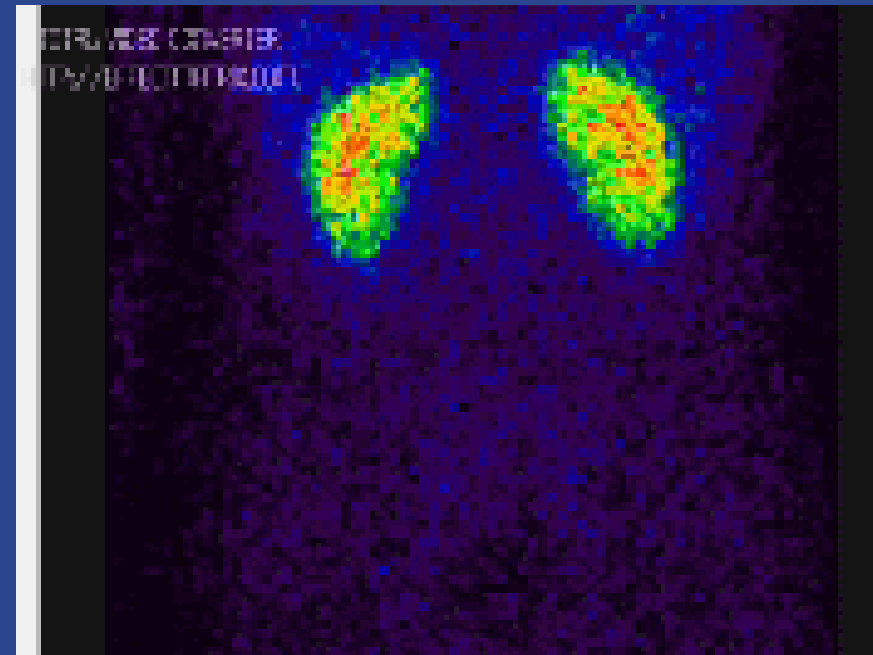
# Thyroid gland

Radiopharmaceutical:  
 $^{99m}\text{Tc}$ -pertechnetate



# Dynamic renal scintigraphy

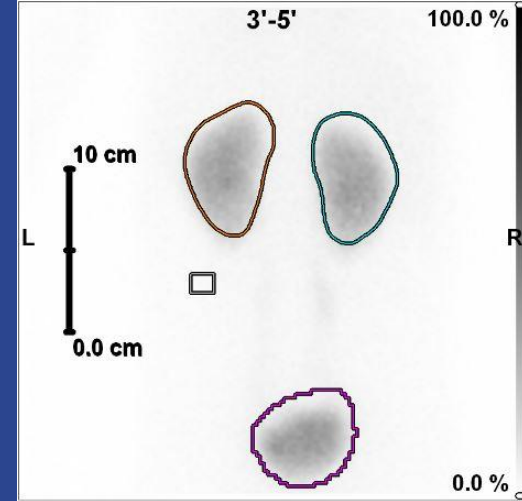
- Radiopharmaceuticals emptied by glomerular filtration and/or tubular secretion
  - The way and time of emptying of the urine can be followed
  - The function of the renal parenchyma and the urinary flow can be investigated
- $^{99m}\text{Tc}$ -MAG3
- $^{99m}\text{Tc}$ -EC
- $^{99m}\text{Tc}$ -DTPA



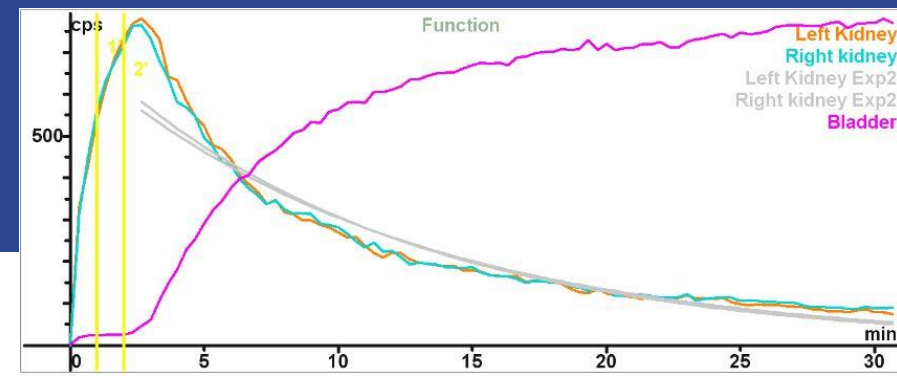
Normal dynamic renal scintigraphy

# Renogram

- Time-activity curve of the kidney region (ROI)
- The curve is determined by the
  - Blood flow
  - Function of the parenchyma
  - Urinary flow
- Quantitative parameters can be calculated
  - Relative function of the kidneys
  - $T_{\max}$ ,  $T_{1/2}$

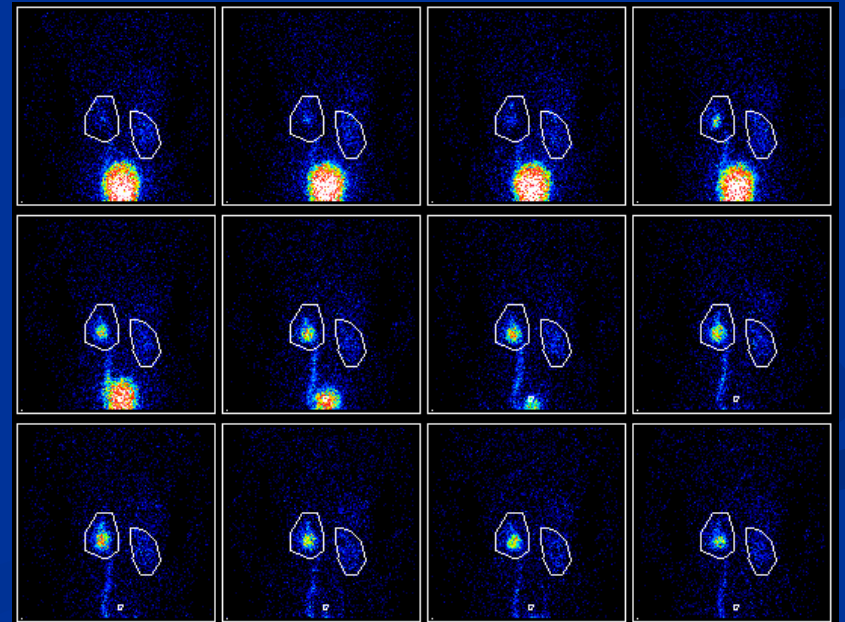
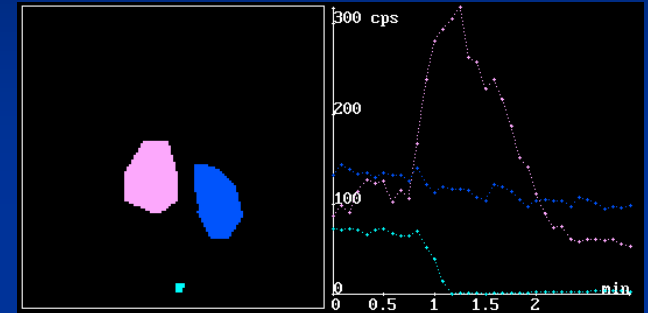
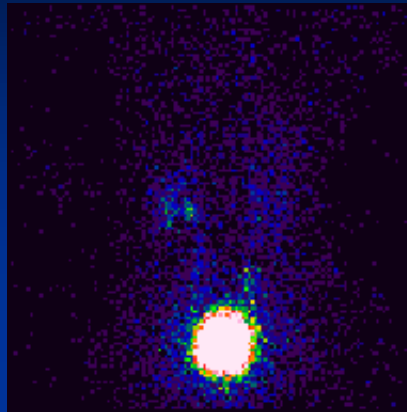


	Left	Right
T0 (sec):	0	0
Tmax:	2'40"	2'40"
Thalf:	8'06"	8'33"
Wash-out Thalf:	4'	4'
Residual Activity:	16.0 %	17.1 %
Norm.Res. Activity:	17.0 %	18.3 %
Relative Function:	49.9 %	50.1 %
Relative Perfusion:	51.9 %	48.1 %



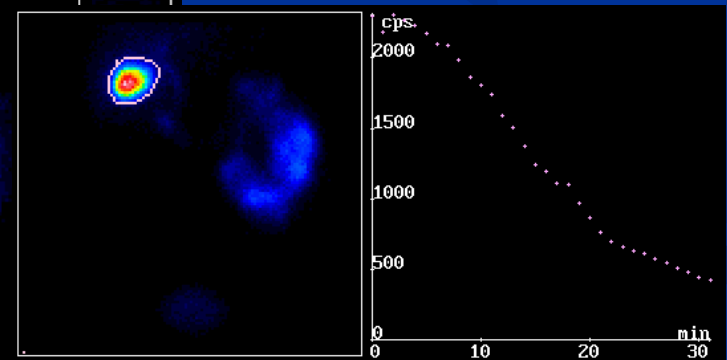
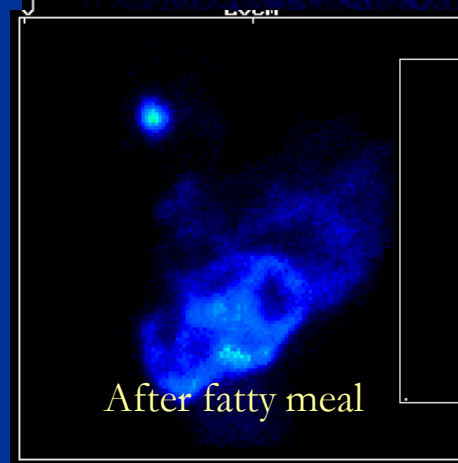
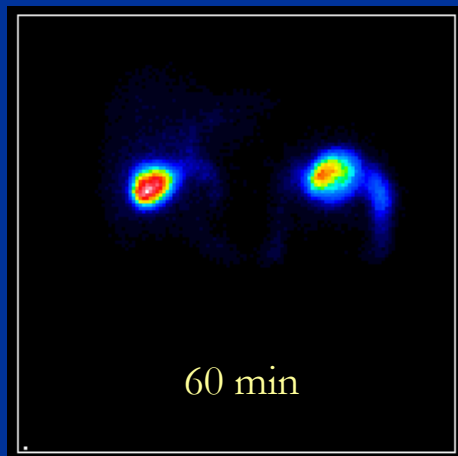
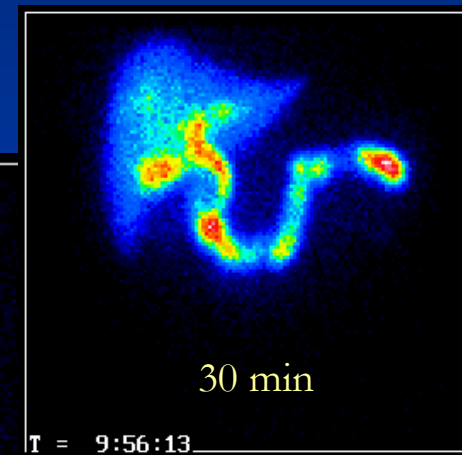
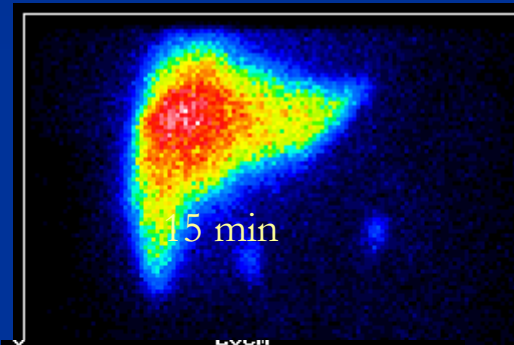
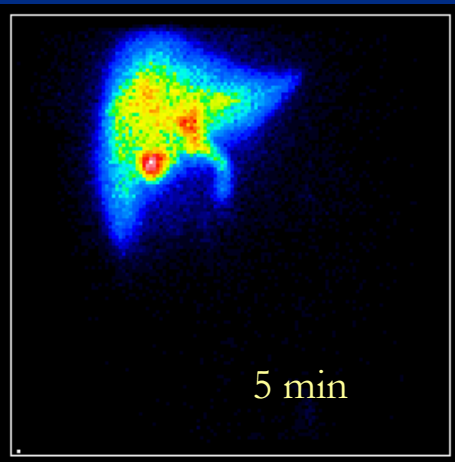
# VUR – indirect radionuclide cystography

- House-trained children
- Non-invasive
- Physiological
- Low radiation exposure
- Bladder retention and bladder filling clearly separable



# Dynamic cholescintigraphy

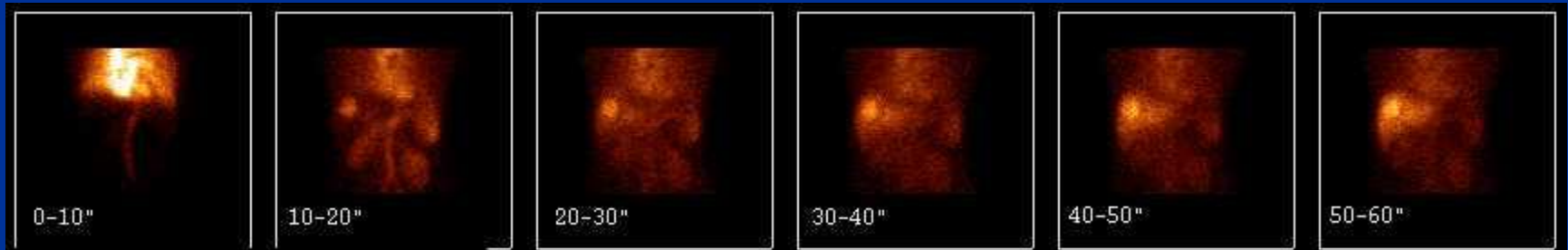
- Tc-99m HIDA (hepato-imino-diacetic acid)





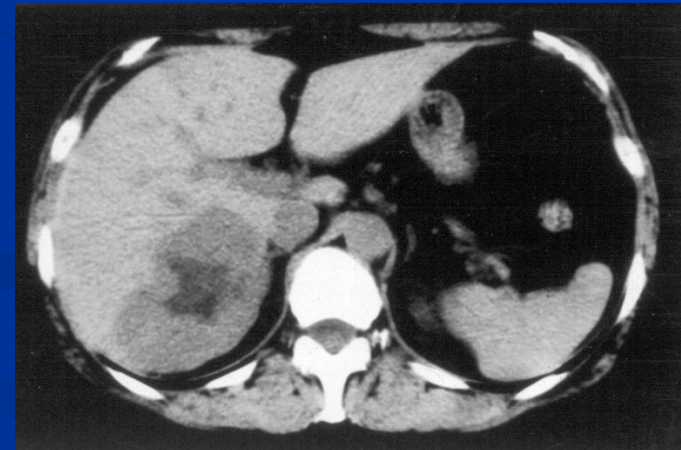
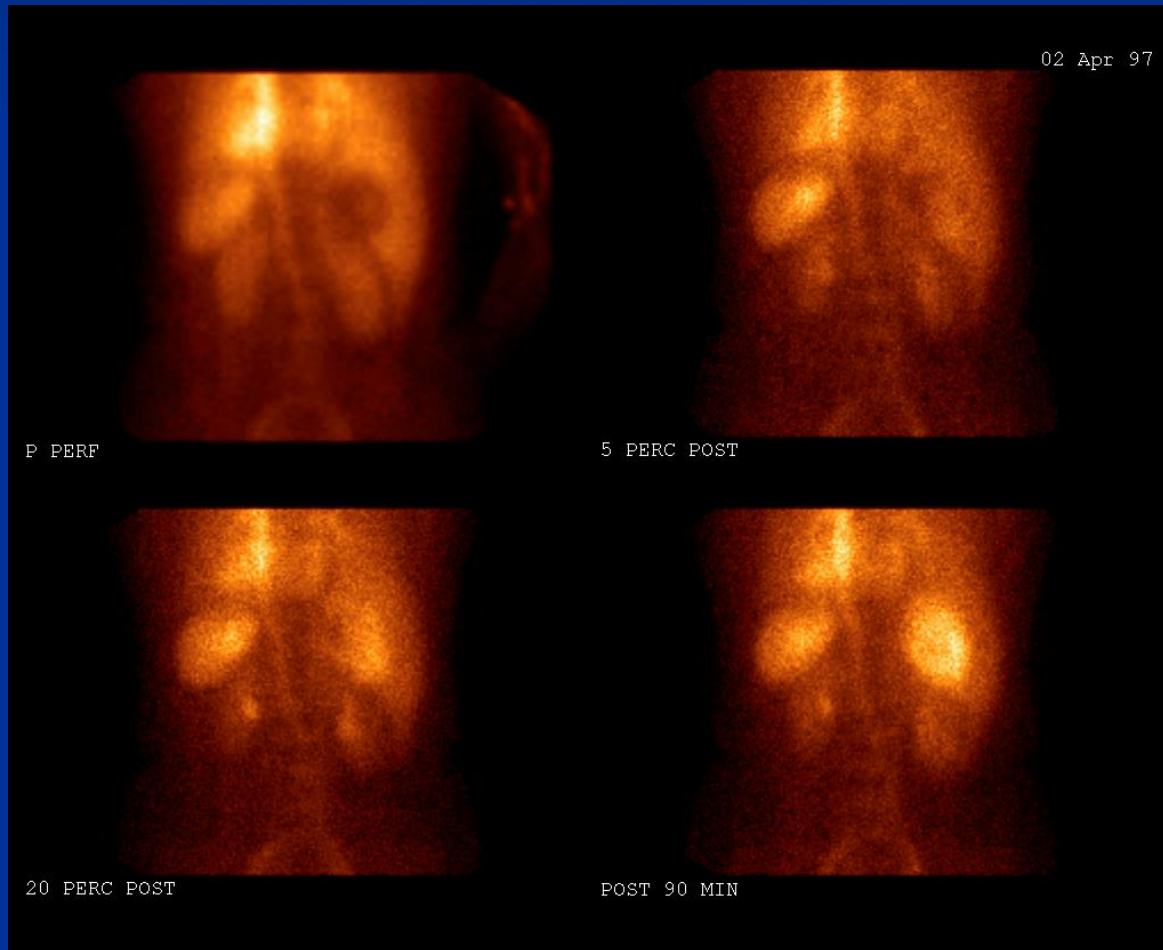
# Focal hepatic lesion, incidentaloma

- FNH (focal nodular hyperplasia)
- Cholescintigraphy
- Tc-99m HIDA



# Focal hepatic lesion, incidentaloma

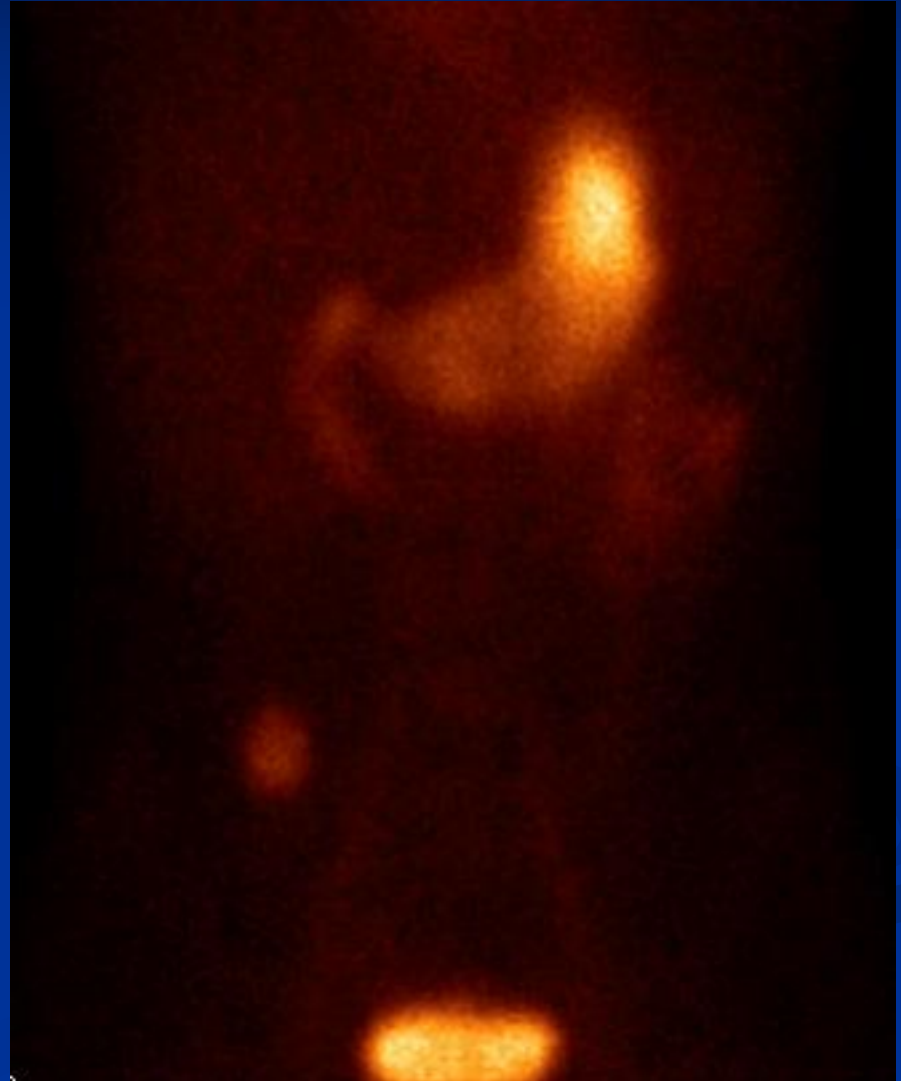
- Cavernous haemangioma
- Technetium-labelled red blood cell scintigraphy
- Tc-labelled red blood cells





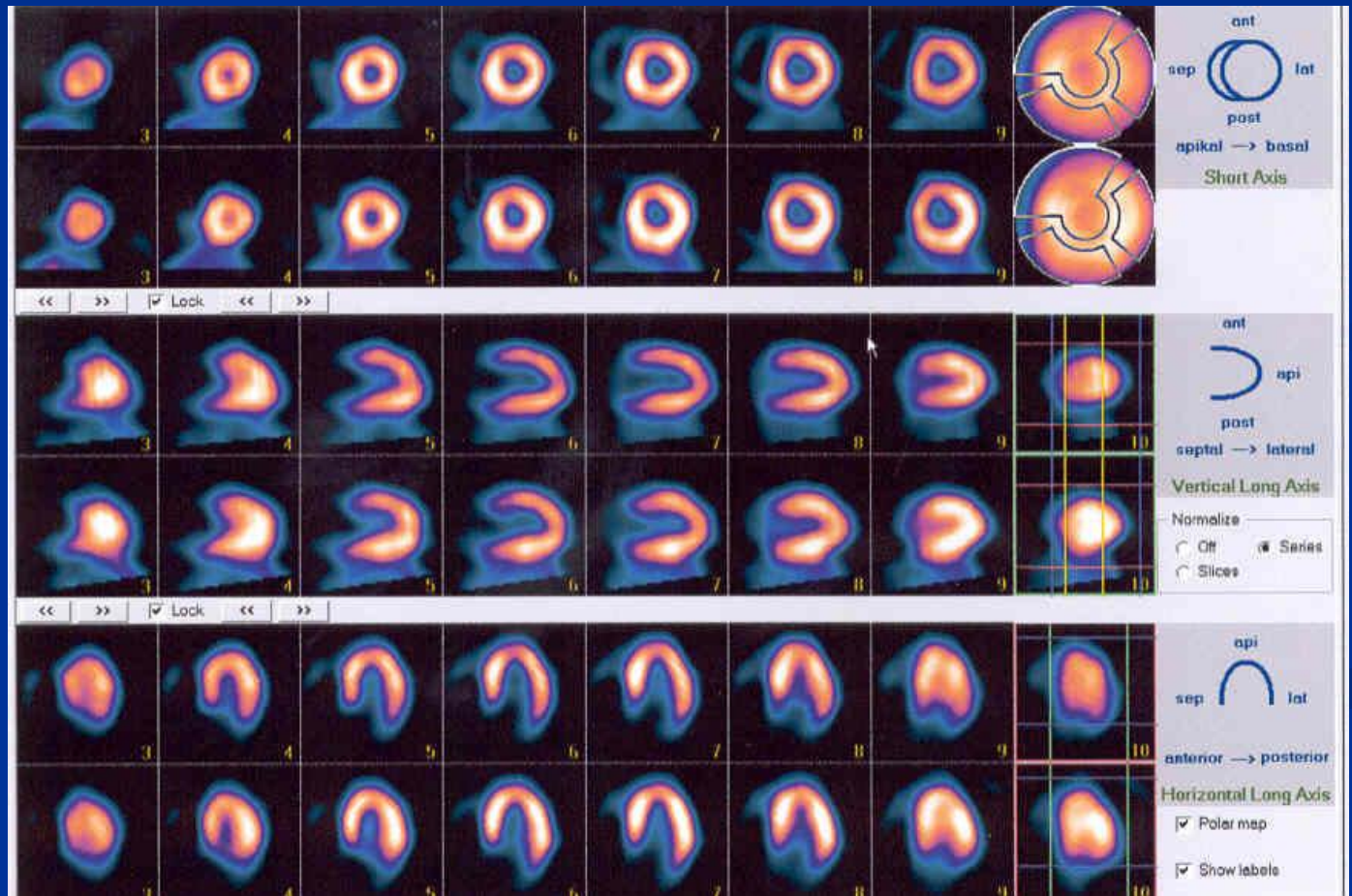
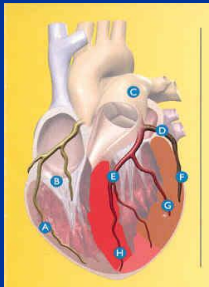
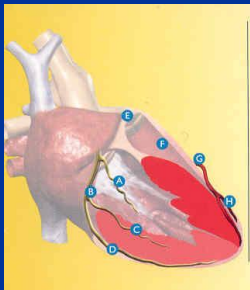
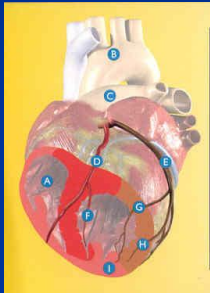
# Gastrointestinal bleeding in childhood

- Meckel's diverticulum
- $^{99m}\text{Tc}$ -pertechnetate

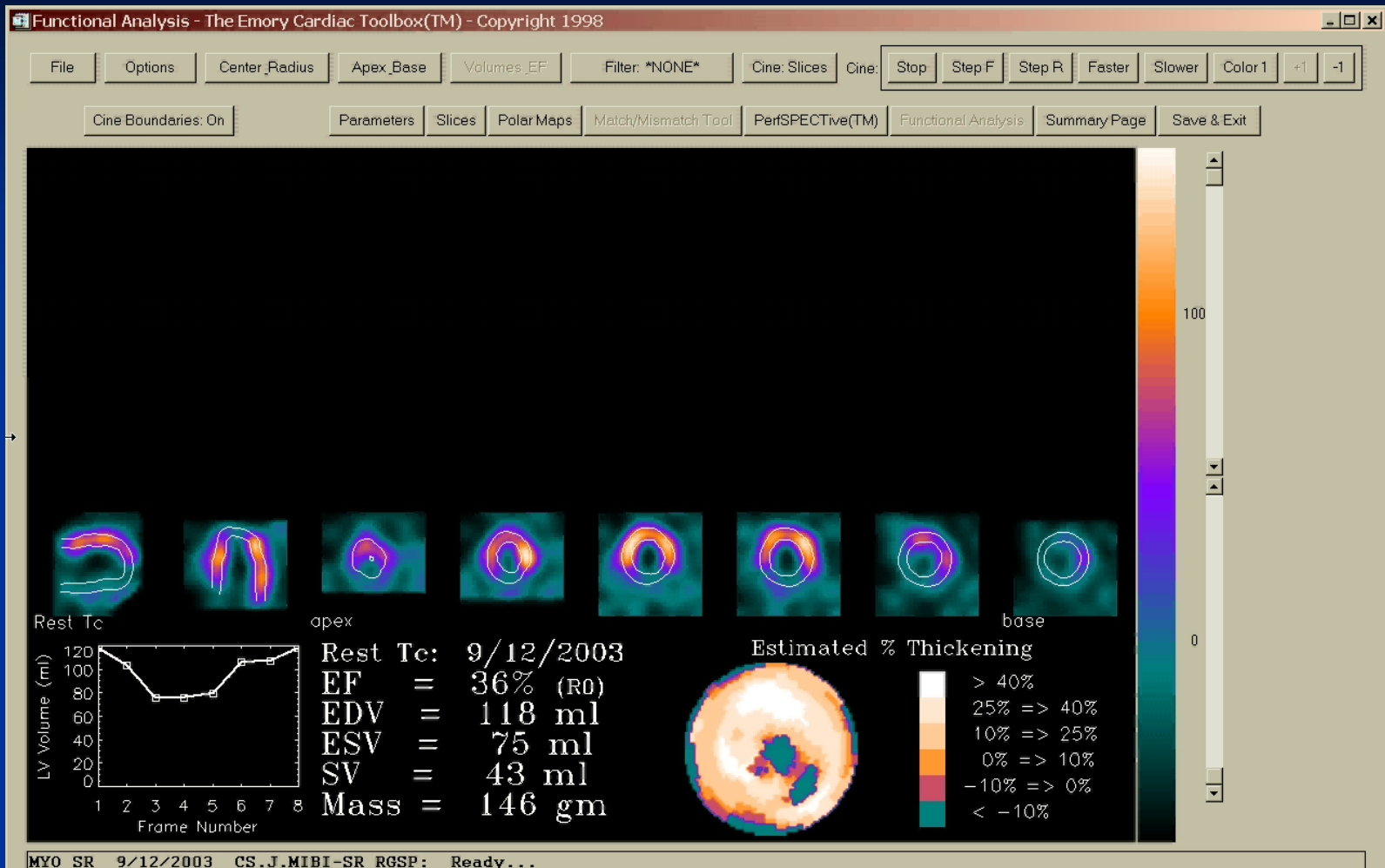


# Nuclear cardiology

- Perfusion myocardial scintigraphy
- Radiopharmaceutical:
  - Tc99m MIBI (methoxy-isobutyl-isonitrile)

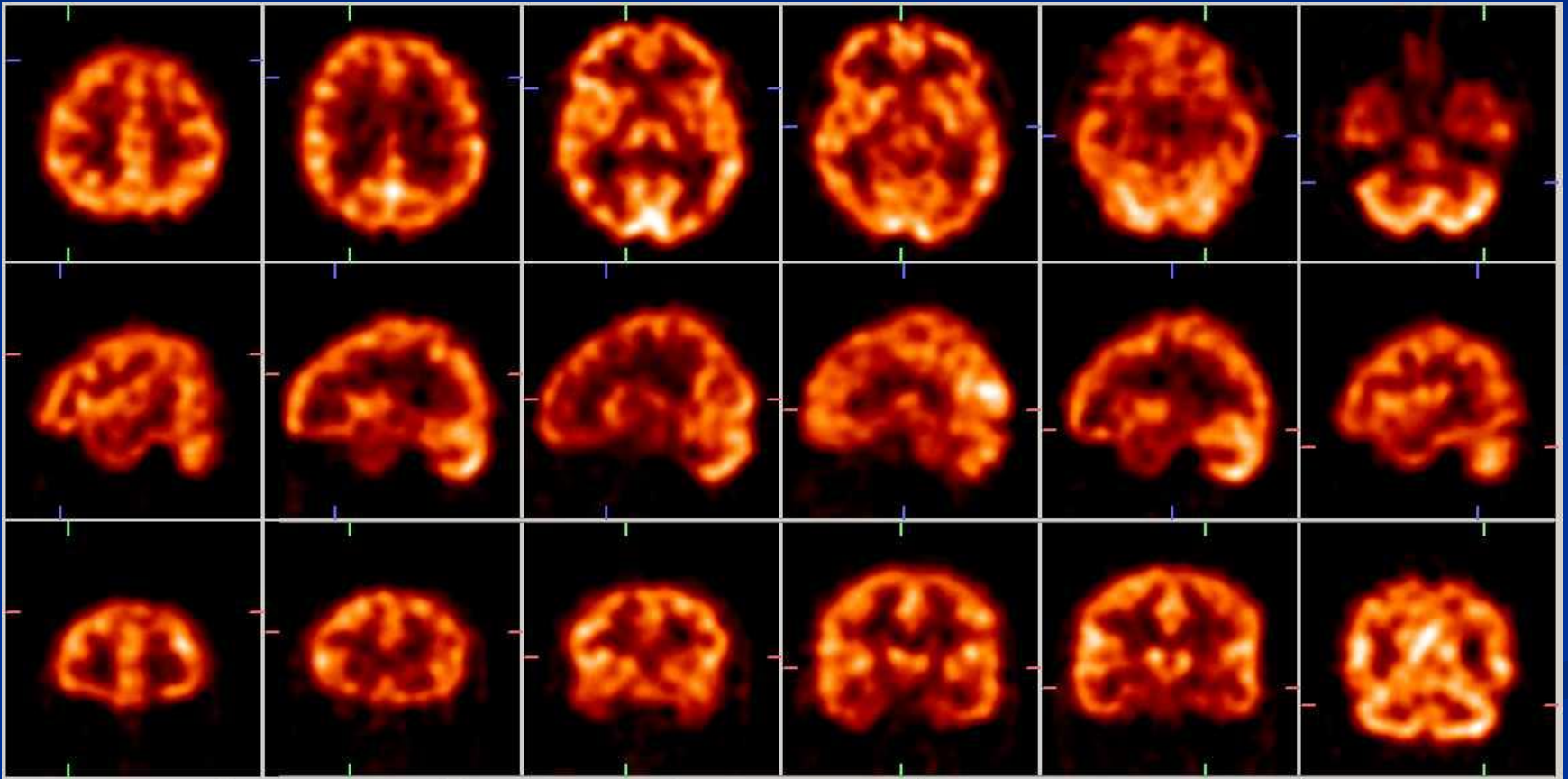


# Gated MyoSPECT: wall motion presentation



# Neurology

- Regional cerebral perfusion
- Tc-99m HMPAO (hexamethyl-propyleneamine oxime)
- Tc-99 m ECD (ethylene cysteine dimer)





# Neurology

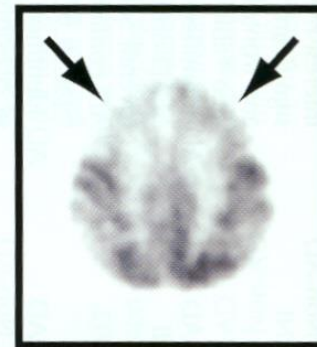
## Differential diagnosis of dementia



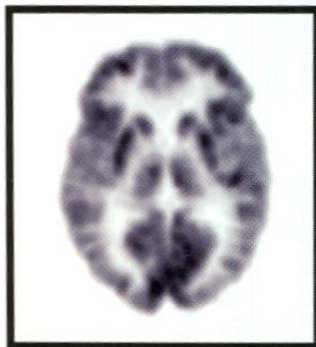
Normal



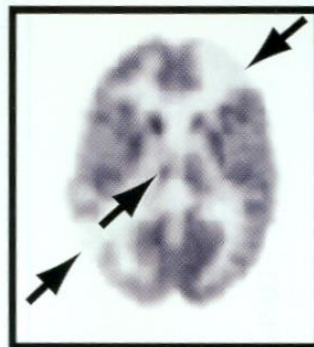
Alzheimer's



Pick's



Normal



Multiple Infarct  
Dementia

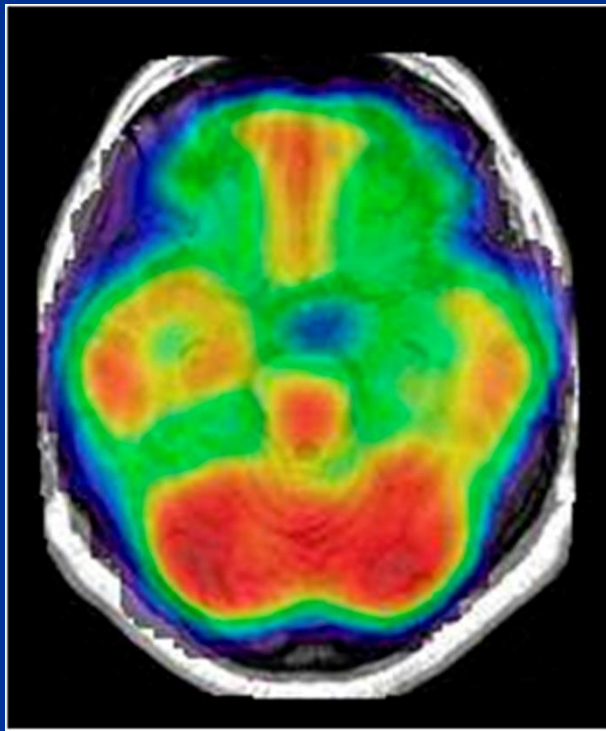


Huntington's

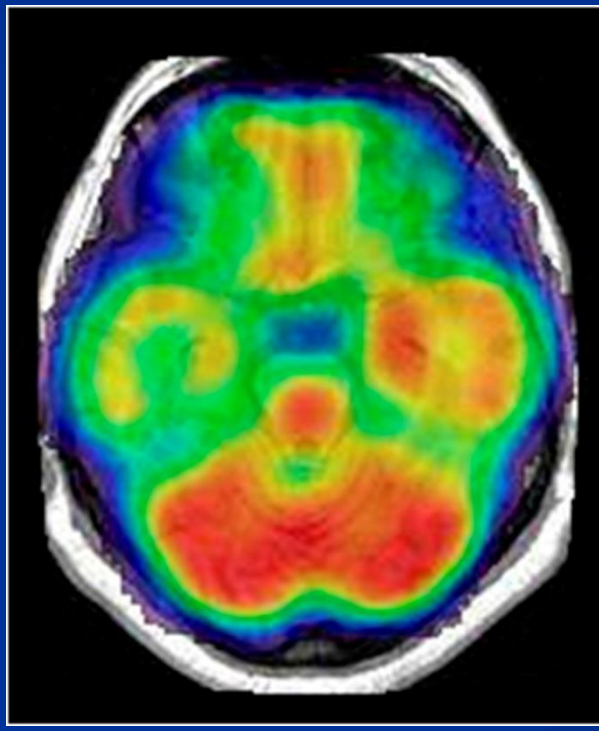
# Brain perfusion SPECT - epilepsy

Ictal examination

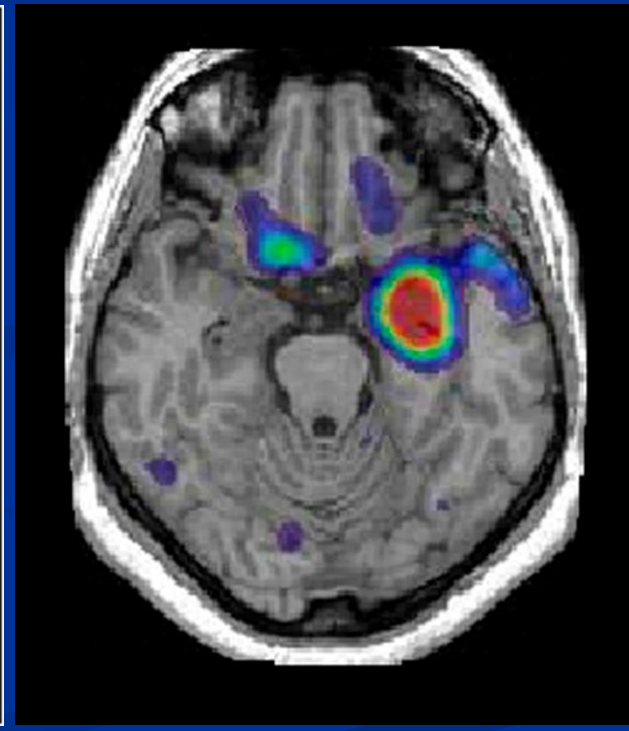
■ Focal epilepsy



Interictal  
SPECT-(PET)

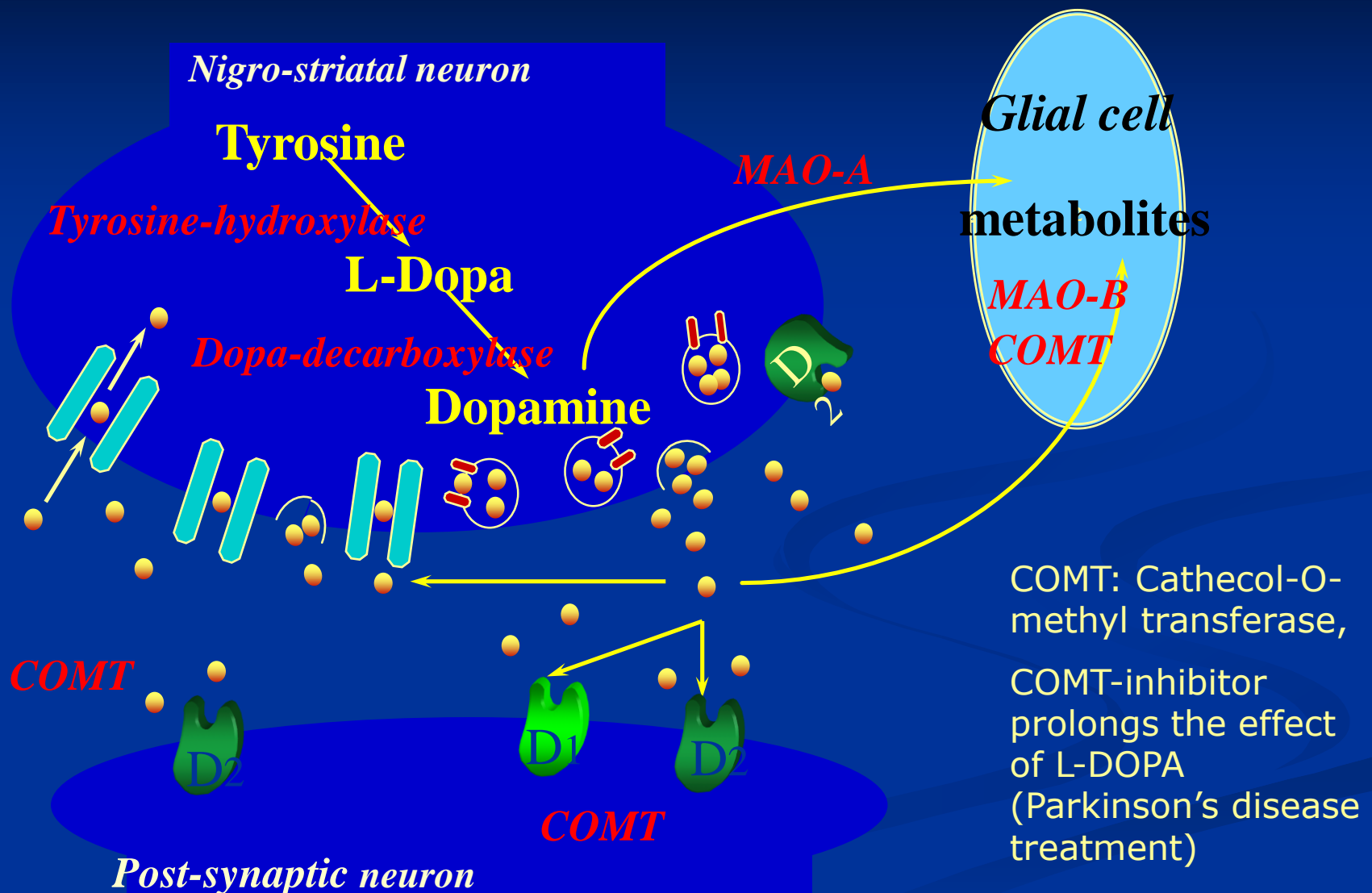


Ictal  
SPECT



Subtraction

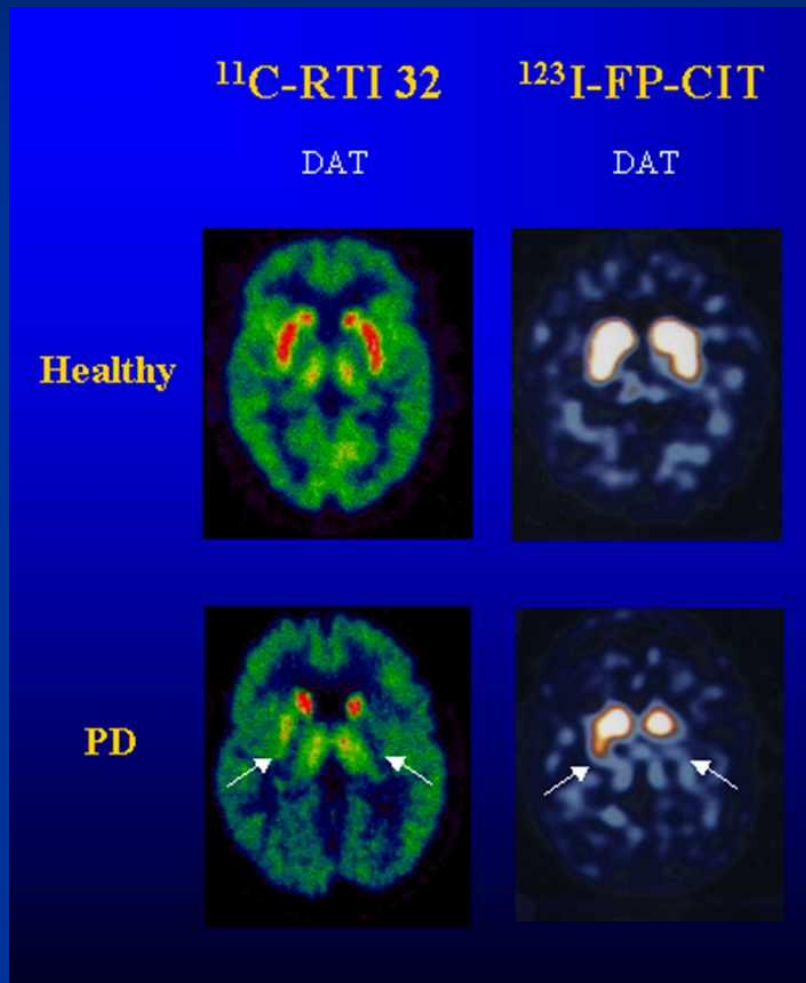
- Dopaminergic neurotransmission
  - Radiopharmaceutical-specific accumulation and binding





# Dopaminergic neurotransmission

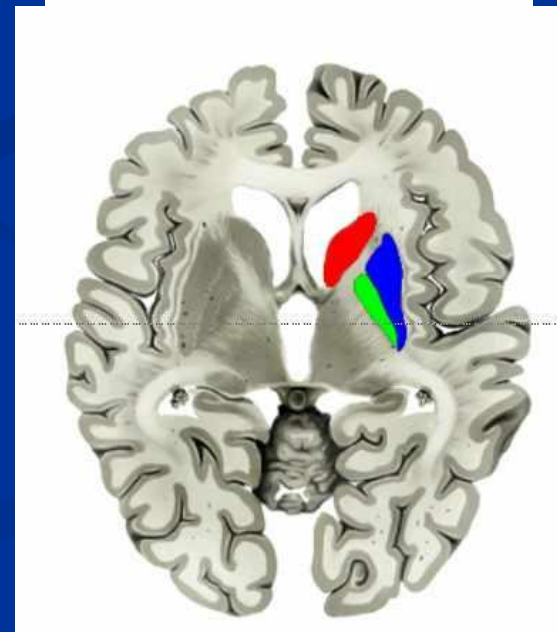
■



TSscan (DAT)



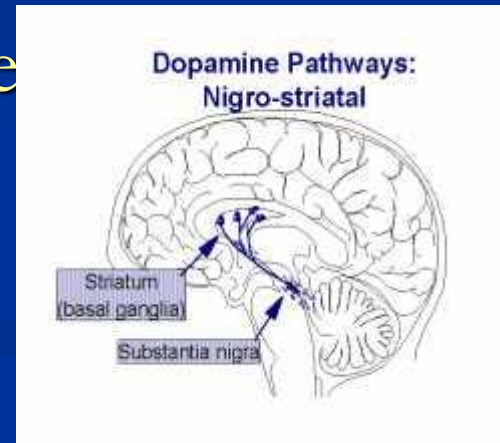
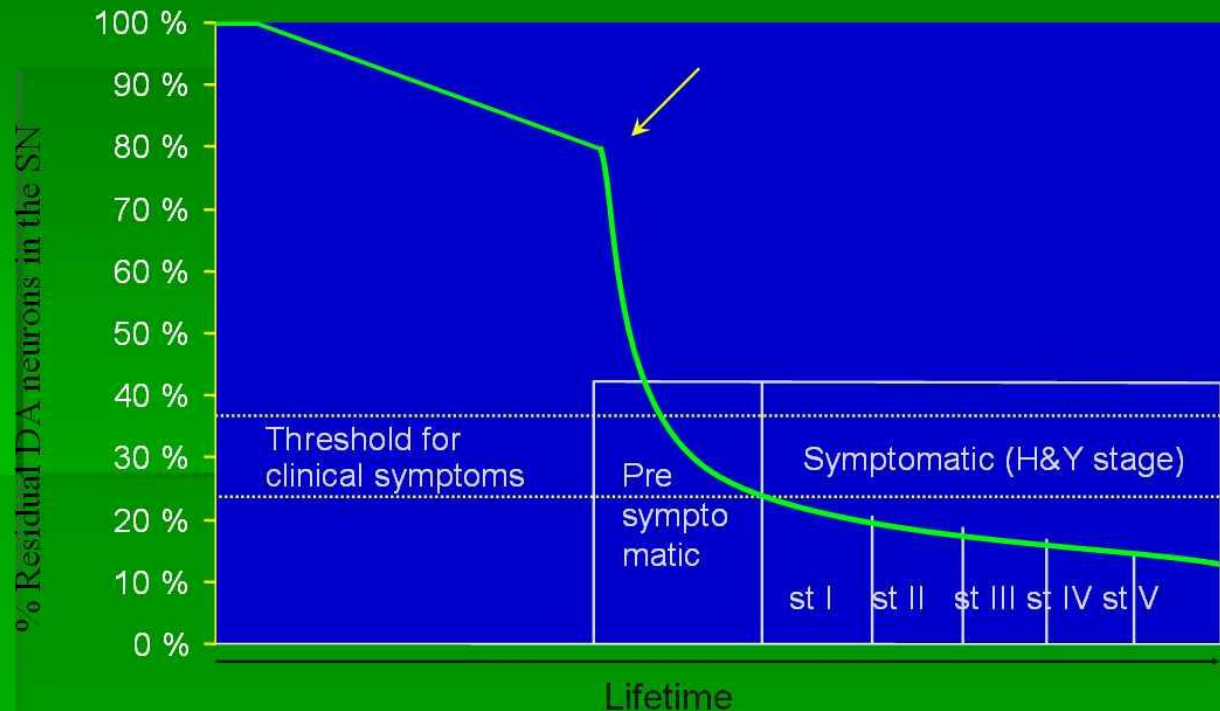
arter)



# Dopaminergic neurotransmission

## ■ Early diagnosis – DATScan

### Models of Disease Progression



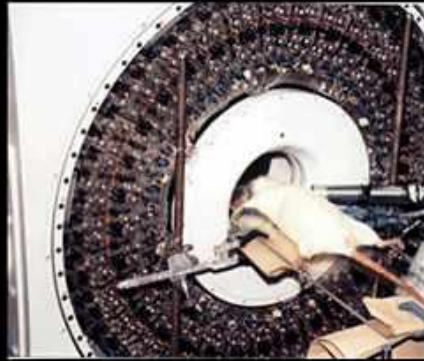
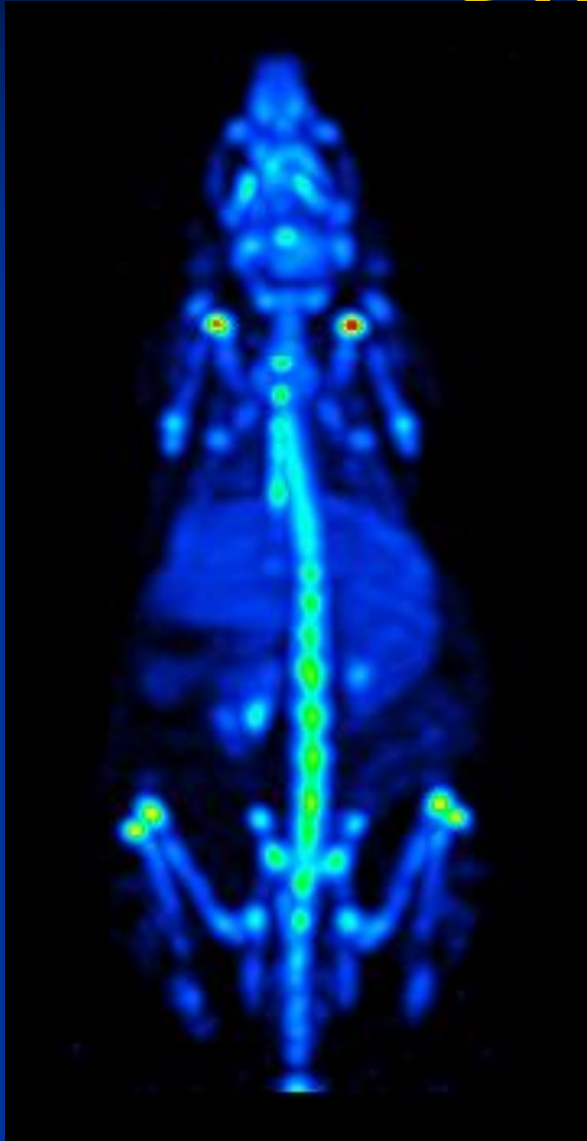
H&Y – Hoehn-Yahr scale

# Inflammation

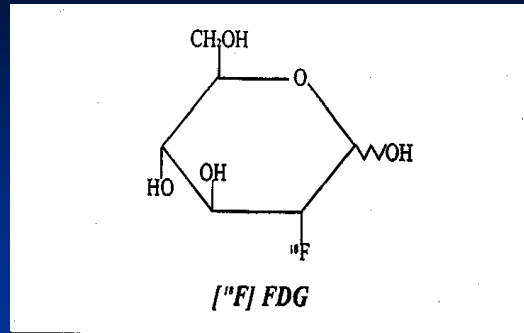
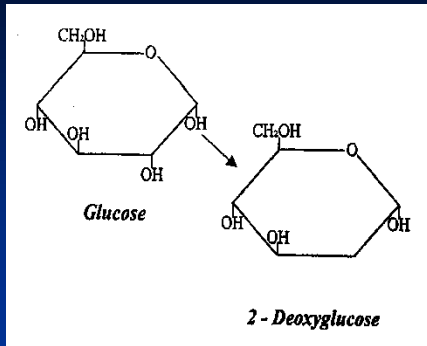
- Labelled leukocytes
- $^{67}\text{Ga}$
- Human immunoglobulin
- Labelled antibiotics
- FDG-PET



# Preclinical studies



# $^{18}\text{F}$ -fluoro-deoxiglucose (FDG)

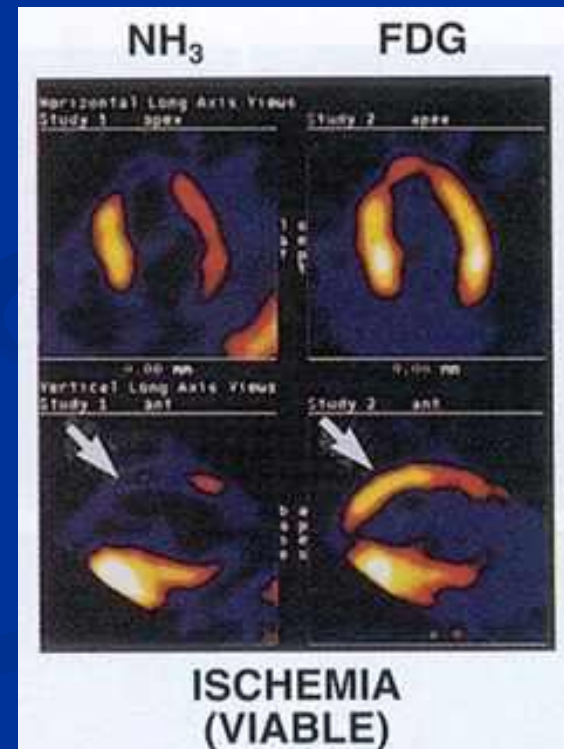


## Applications:

Oncology (~ 85 %)

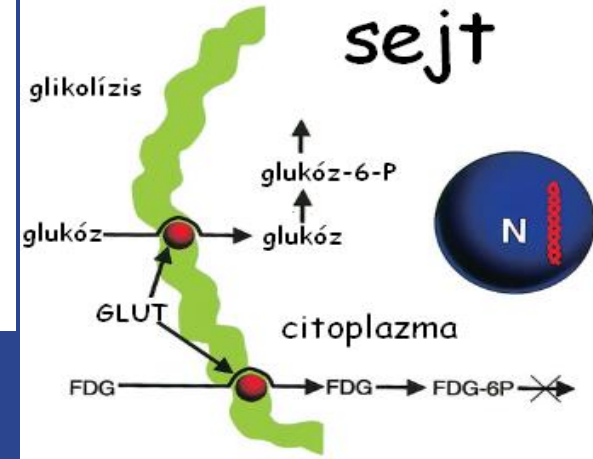
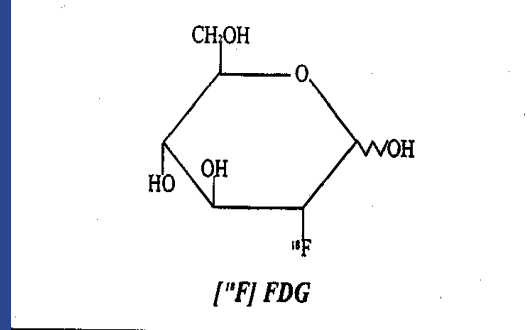
Neurology (~ 10%)

Cardiology (~ 5 %)

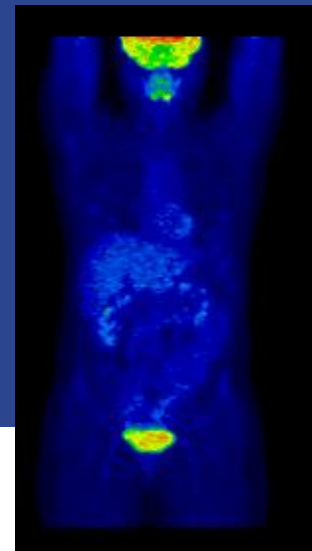




# FDG-PET

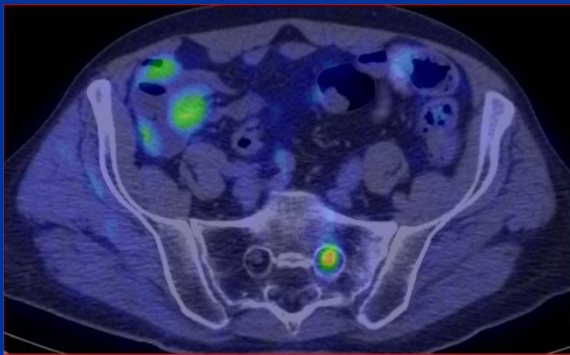
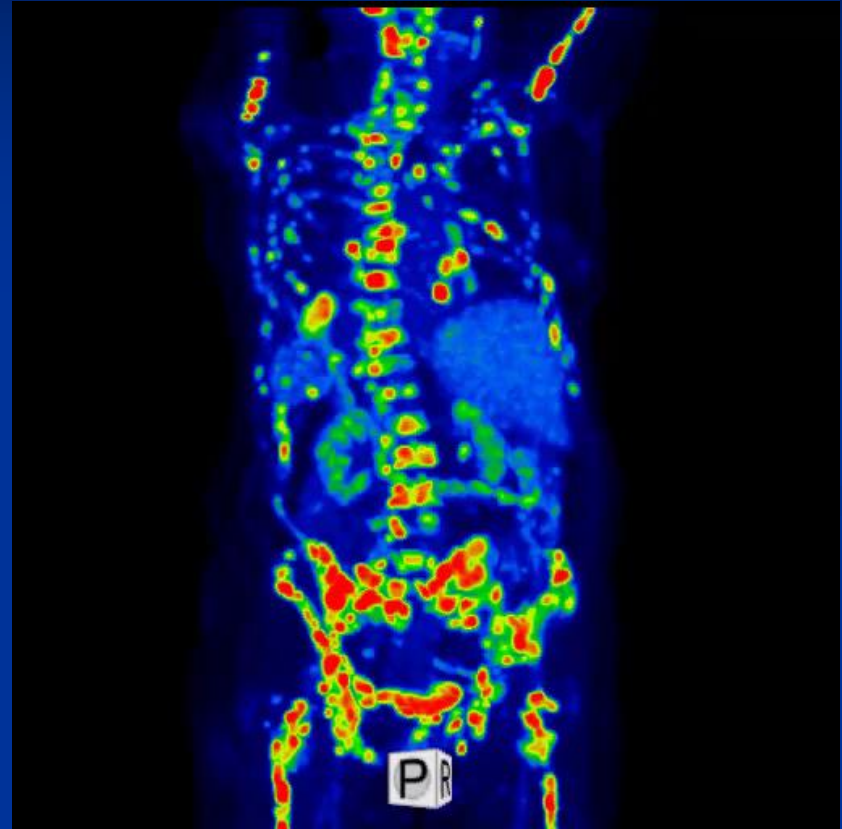


- $^{18}\text{F}$ -fluoro-deoxy-glucose
- Tumors have a high metabolic activity (aerobic and anaerobic glycolysis) → imaging of glucose metabolism of tumors
- Glucose accumulates in several malignant tumors, but it is **not tumor-specific!**
- Inflammation and tumors can not be differentiated
- High physiologic glucose uptake in the brain
- Excreted through urine



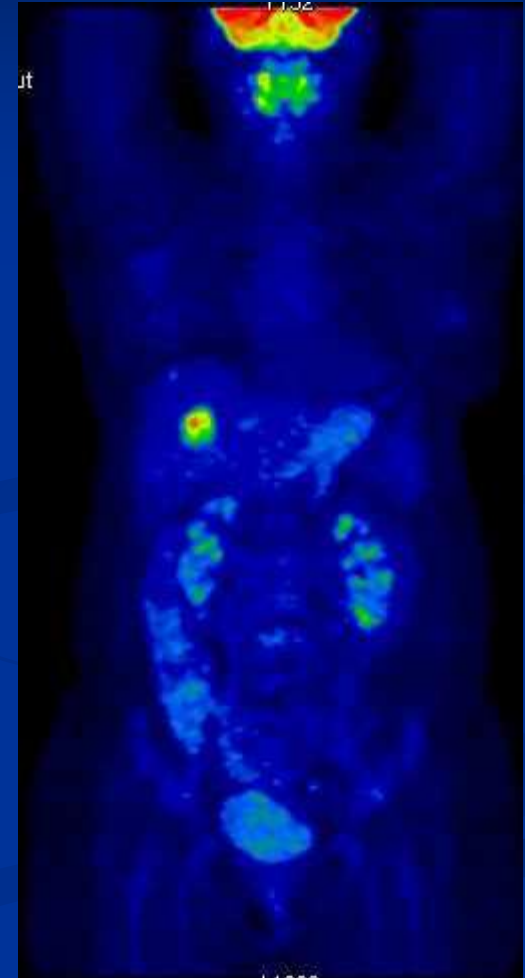
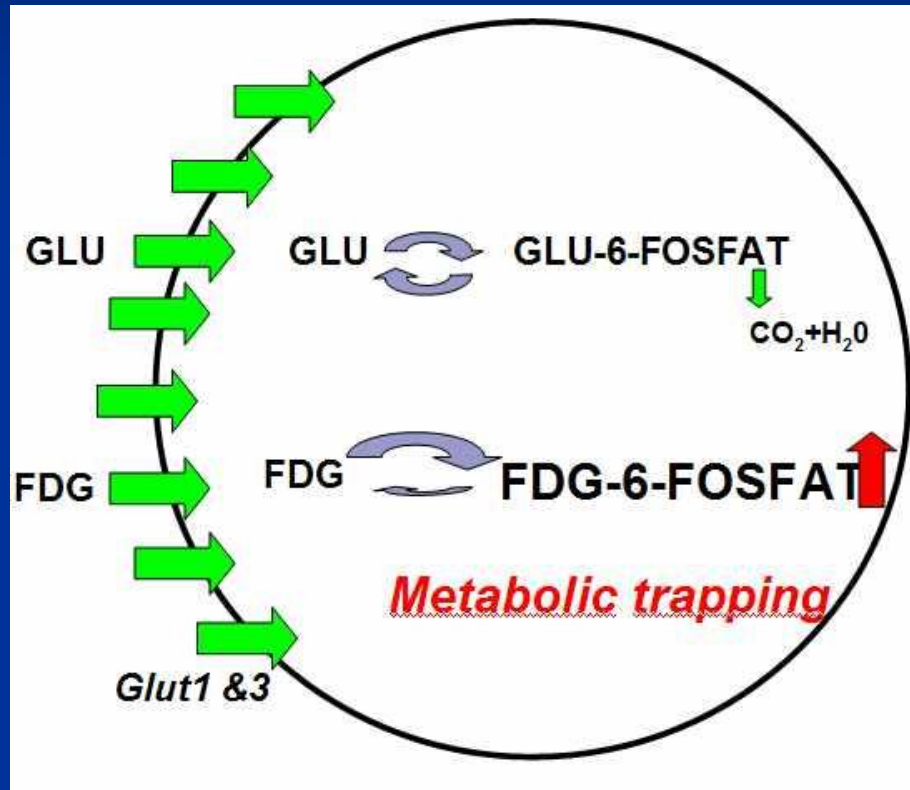
# Nuclear oncology

- Sensitive detection of malignant lesions
  - Based on functional, metabolic changes
  - High biological contrast
- Non-invasive characterisation of a known lesion
  - Tumor-specific
    - ( $^{18}\text{F}$ FDG-PET,  $^{99\text{m}}\text{Tc}$ -MIBI,  $^{67}\text{Ga}$ )
  - Specific for a particular malignancy
    - ( $^{123/131}\text{I}$ , receptor- and immunoscintigraphy)

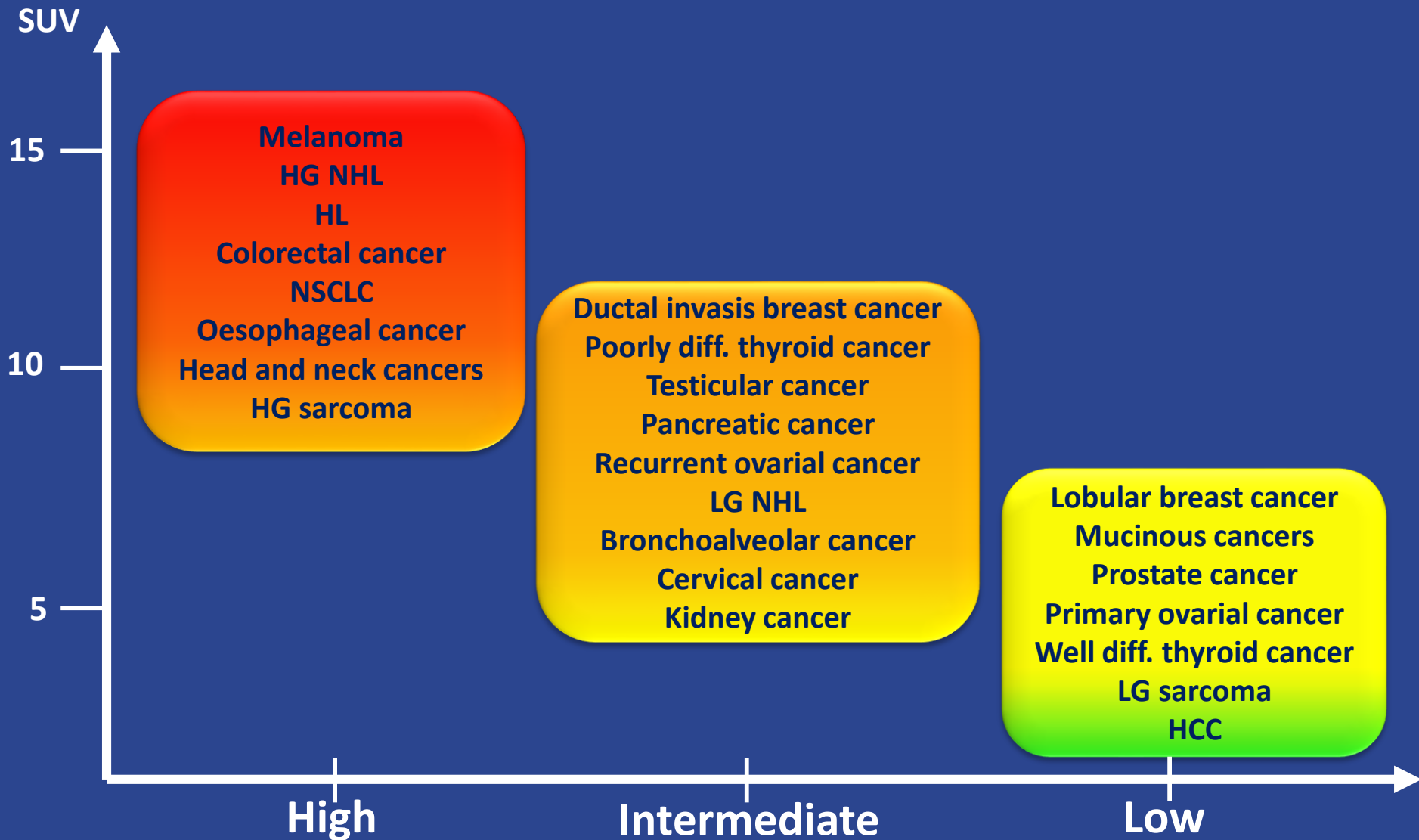




# $^{18}\text{F}$ -fluoro-deoxyglucose (FDG) in oncology



# FDG-uptake in different tumors



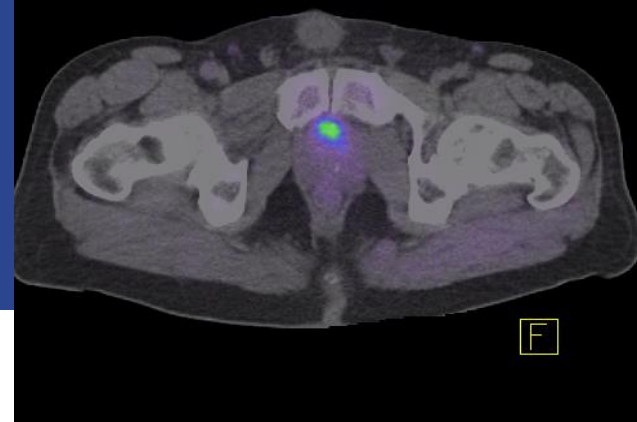
# Not every tumor takes up FDG!!!

- Prostate cancer
- Hepatocellular cancer
- Diff. neuroendocrine tumors
- Mucinous carcinoma
- Lobular breast cancer
- etc.

**Prostate cancer -  
FDG**



**Prostate cancer -  
Acetate**



# PET-CT in oncolgy (1)

- Staging (TNM)
  - Operability, regional lymph nodes, distant metastases
  - NM performs better than morphological imaging techniques
  - PET-CT changes the stage in 20-40%
- Treatment response
  - Evaluation of response to treatment after chemo- and radiotherapy
  - Monitoring after radio-frequency ablation and chemo-embolisation
  - Ineffective treatments can be discontinued
  - Overtreatment and side effects can be avoided
  - Operability can be evaluated
- Differentiation of posttreatment changes and residual tumor tissue after chemo- or radiotherapy
- Diagnosis of tumor recurrence

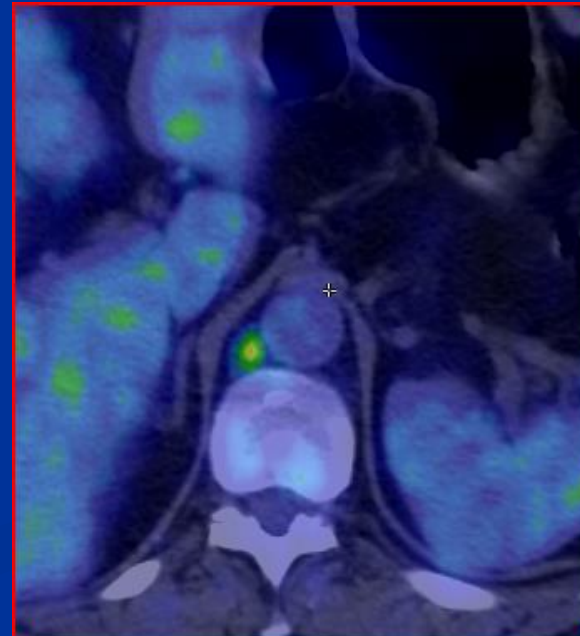
# PET-CT in oncology(2)

- Differentiation between benign and malignant lesions
  - If other modalities were unsuccessful
  - Non-invasively (if invasive methods are contraindicated)
- Radiotherapy planning
- Before biopsy
  - Before lymph node biopsy to detect the optimal location
  - To detect the region with the highest metabolic activity within a large lesion
- To evaluate the grade of the malignancy
  - Brain tumor: low-grade vs. high-grade

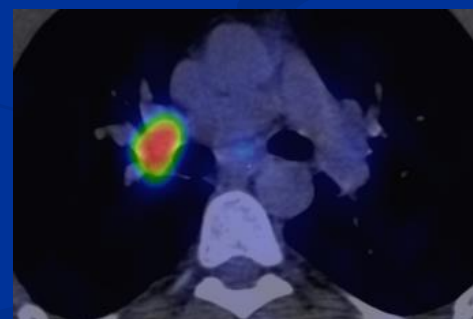
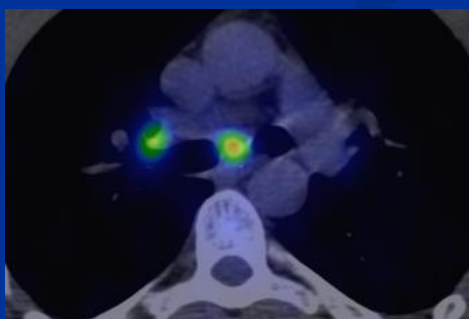
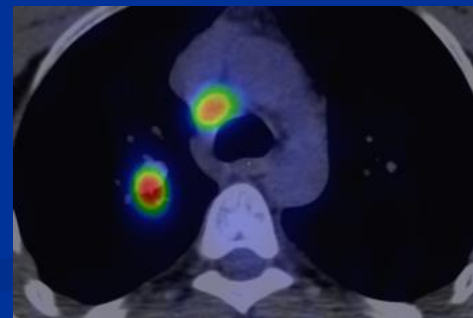
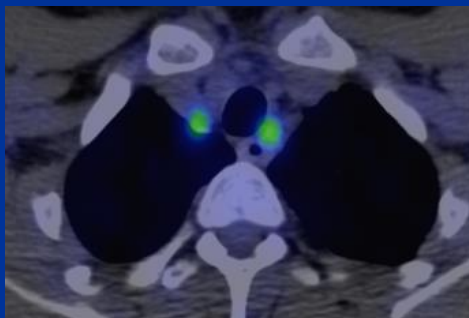
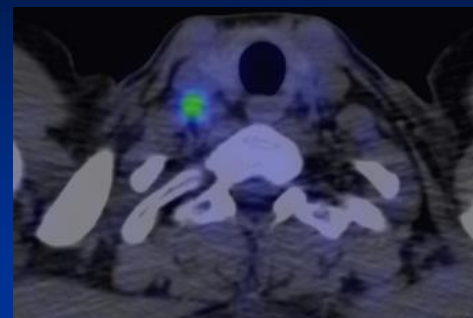
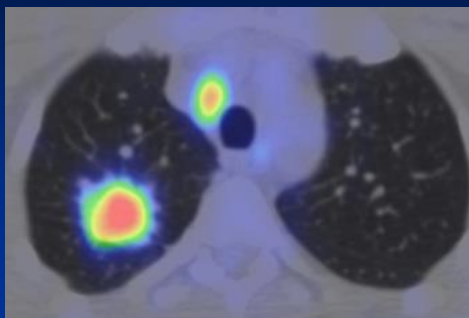
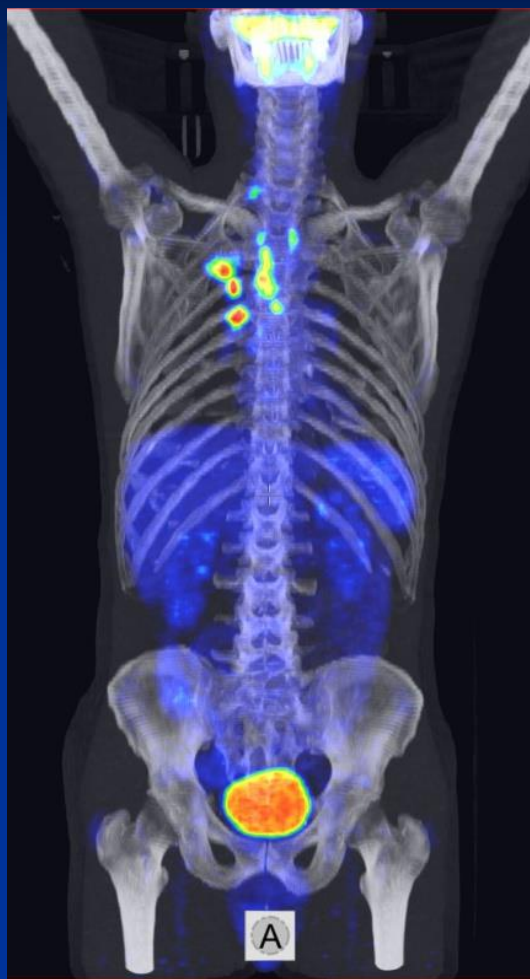
# Role of PET-CT in oncology

## ■ Staging

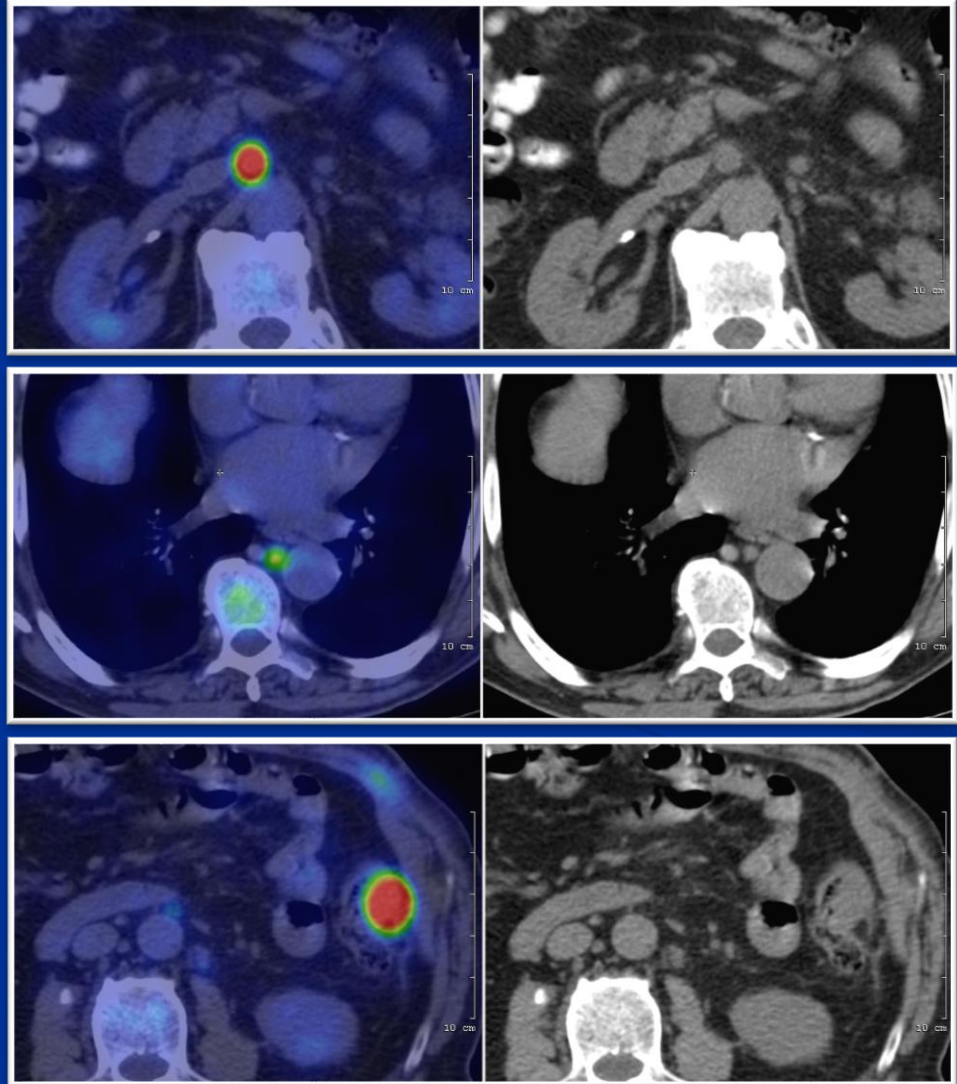
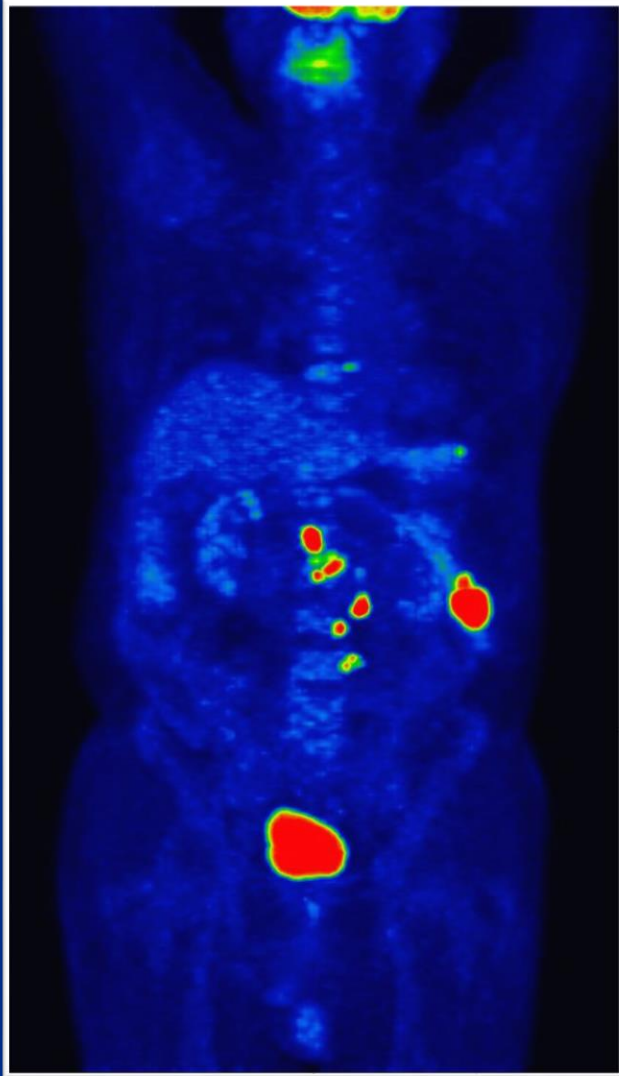
- Lymph node metastasis / lymph node involvement
  - Morphological imaging: size
  - PET: functional and metabolic data







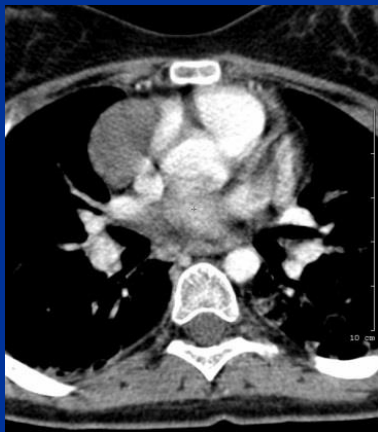
# Lymphoma staging, nodal and extranodal manifestations



# Restaging

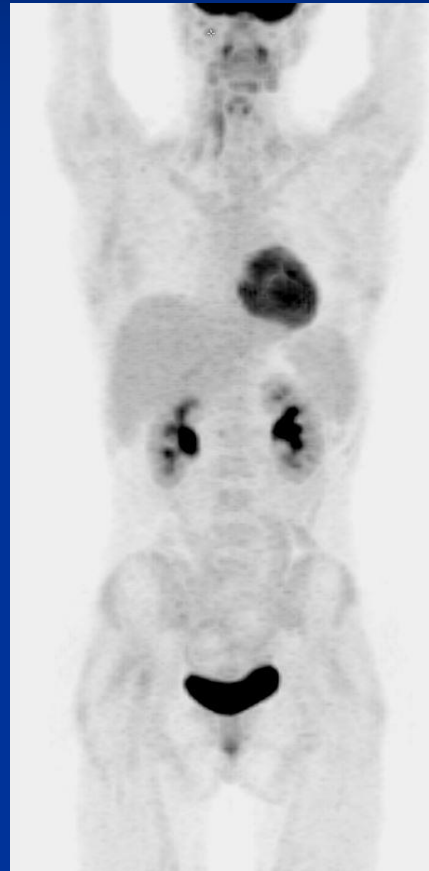
(Residual terime, Hodgkin's disease /N.S., 15 yo female/)

Staging CT



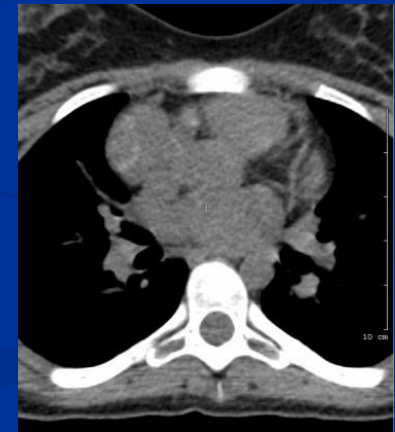
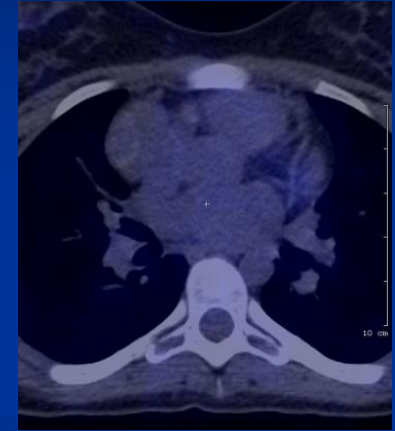
Restaging CT

CT: Heim Pál Kórház



Restaging PET-CT

4,5 years of permanent CR

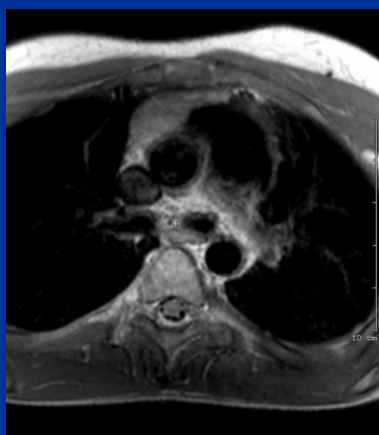
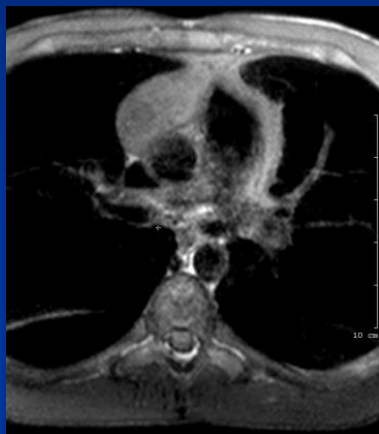




# Restaging

## (Residual terime, NHL (PMBCL))

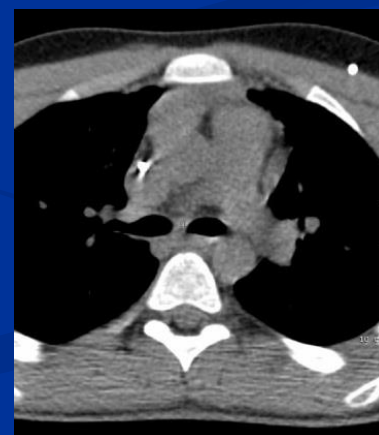
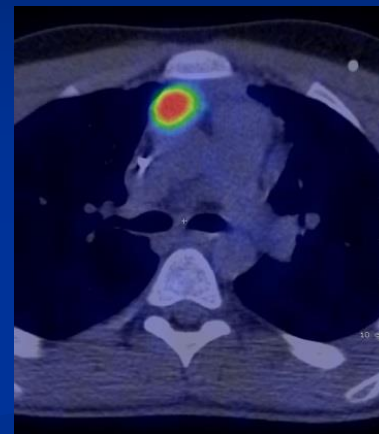
Staging MR, T1



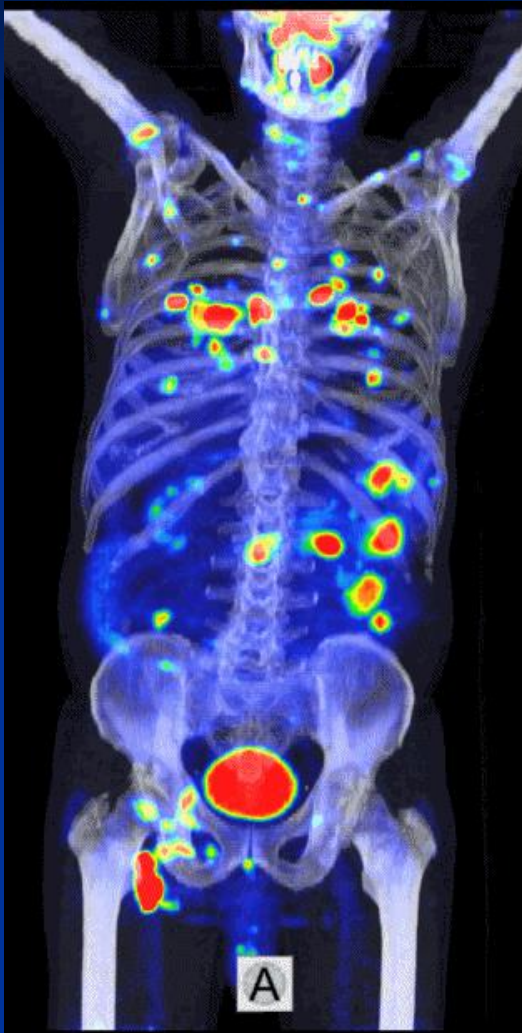
Restaging MR, T1



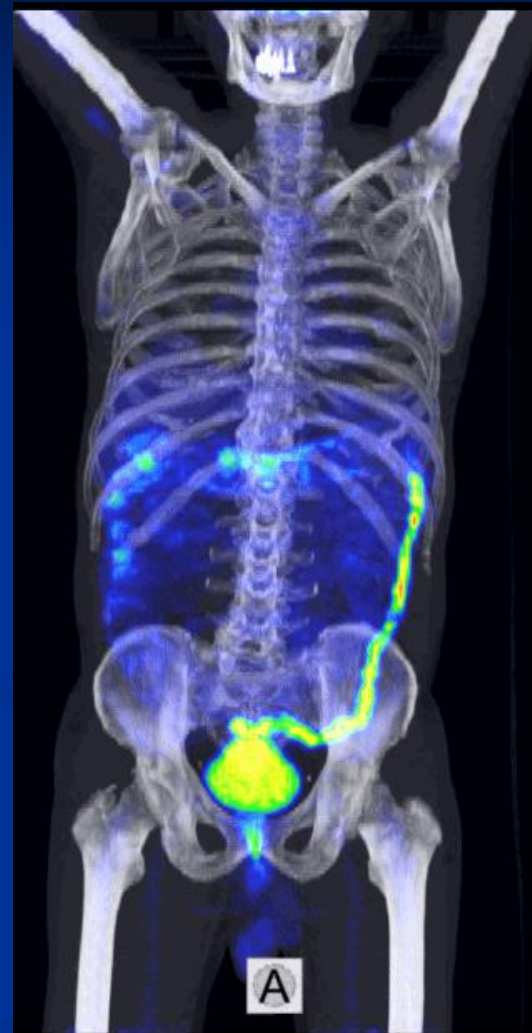
Restaging PET-CT



# Interim PET



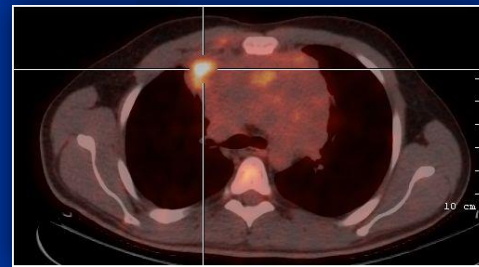
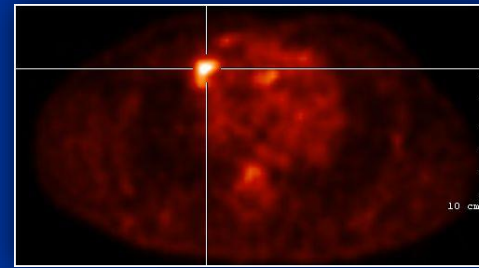
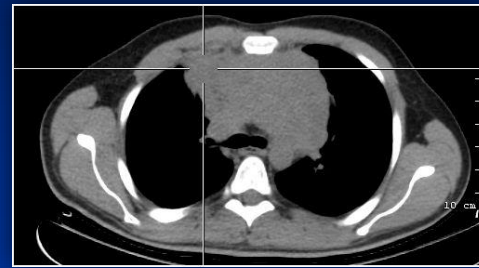
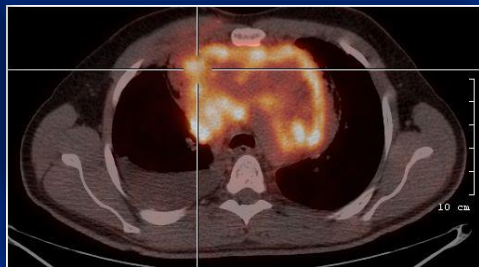
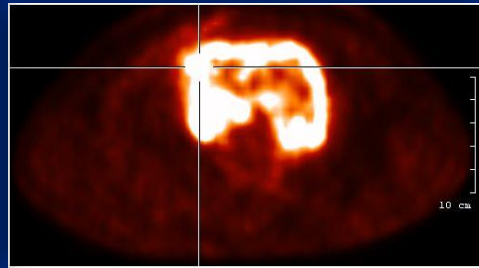
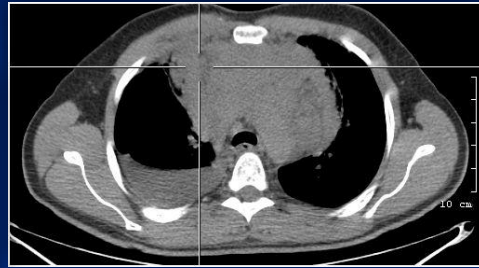
DLBCL: before  
treatment



After 2 cycles of  
R-CHOP therapy

*n. b.: aspecific intestinal activity*

# Interim PET



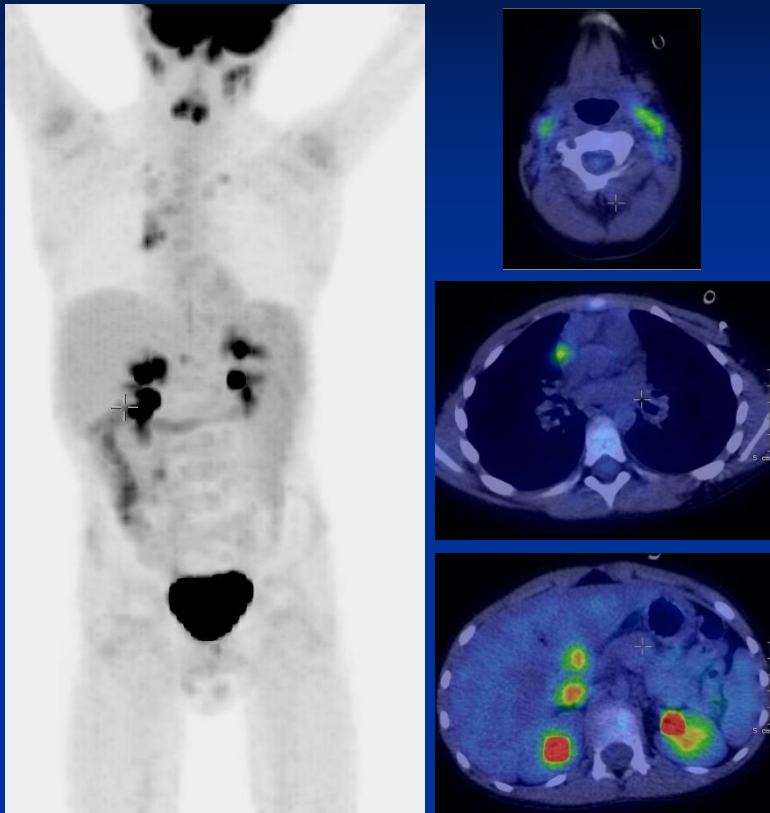
DLBCL: before  
treatment

After 2 cycles of  
R-CHOP therapy

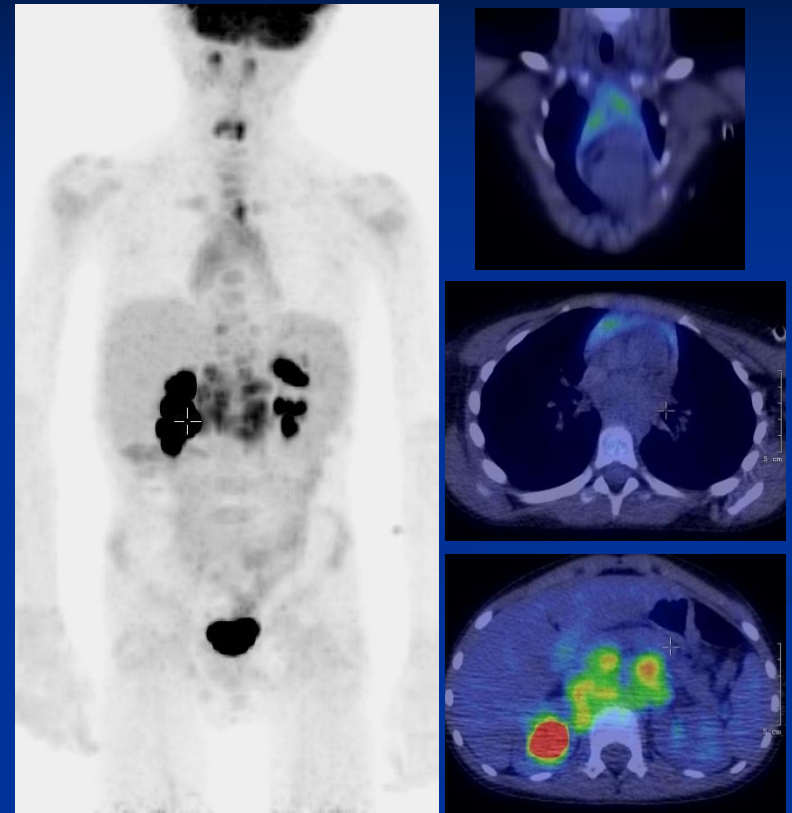
*n. b.: aspecific intestinal activity*



## Interim



## Restaging



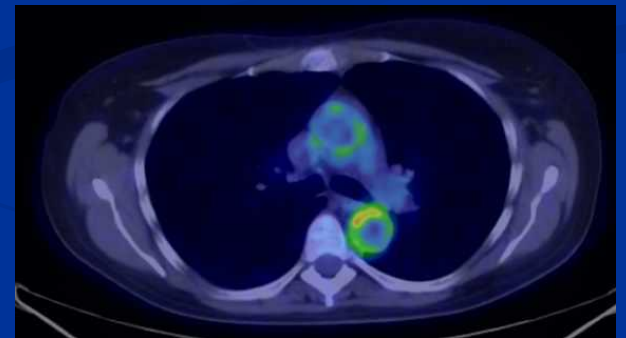
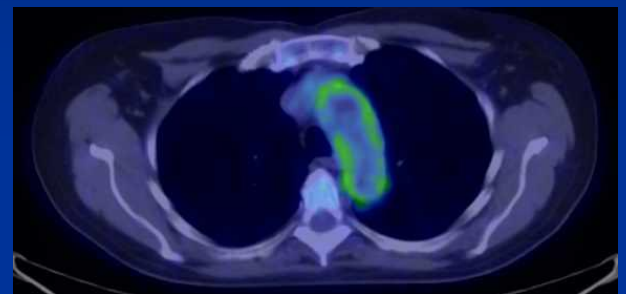
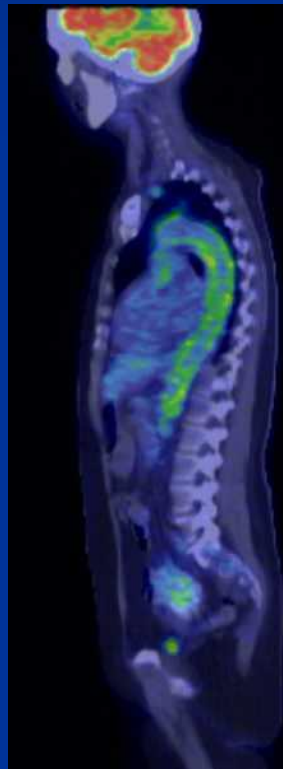
Hodgkin's disease (mixed cellularity type), 5-year-old boy

*N. b.: thymus rebound*

# Inflammation: the role of the FDG-PET in FUO

- Septic inflammation
  - Focal abdominal, thoracic, and soft tissue inflammation
  - Chronic osteomyelitis
  - Septic prosthesis loosening
- Aseptic inflammation
  - Large vessel vasculitis
  - IBD
  - Sarcoidosis
  - Painless subacute thyroiditis
- Malignant tumor, neoplastic fever
  - Hodgkin's disease, aggressive NHL
  - CRC
  - Sarcoma

# Inflammation: the role of FDG-PET in large vessel vasculitis



# PET in oncology:

- Metabolism
- Perfusion
- Oxygenisation and hypoxia
- Receptors, gene expression
- Cell proliferation
- Apoptosis
- Angiogenesis

# Some currently used PET metabolic tracers in oncology

Tracer	PET/SPECT	Process targeted	Used for
[ <sup>18</sup> F]FDG	PET	Glycolytic activity	Several cancers
[ <sup>11</sup> C]Choline	PET	Membrane synthesis	Prostatic cancer
[ <sup>18</sup> F]FLT	PET	DNA synthesis/cell proliferation	Therapeutic response
[ <sup>11</sup> C]methionine	PET	Amino acid transport	Certain cancers
[ <sup>18</sup> F]FMISO	PET	Hypoxia	Tumor hypoxia: radiation sensitivity
[ <sup>64</sup> Cu]ATSM	PET	Hypoxia	Tumor hypoxia: radiation sensitivity

FDG: Fluoro-deoxyglucose, FLT: Fluoro-deoxythymidine; FMISO: Fluoromisonidazol; ATSM: Diacetylmethylthiosemicarbazone

# PET radiopharmaceuticals in oncology

Radiopharmaceutical	Application
$^{18}\text{F}$ -FDG	Glucose transport/utilization
$^{18}\text{F}$ -sodium-fluoride	Bone metabolism
$^{68}\text{Ga}$ -PSMA	Prostate tumors
$^{18}\text{F}$ -fluorocholin	Prostate tumors
$^{124}\text{I}$	Thyroid function
$^{15}\text{O}$ -water	Blood circulation
$^{18}\text{F}$ -misonidazol	Tumor hypoxia
$^{11}\text{C}$ -methionin	Aminoacid synthesis
$^{11}\text{C}$ -thymidin	DNS synthesis
$^{18}\text{F}$ -FLT	DNS synthesis
$^{68}\text{Ga}$ -SMS	Tumor receptors
$^{18}\text{F}$ -fluorouracil	Chemotherapeutic agents



# Thank you for your attention!



# Radionuclide therapy

Benign and malignant thyroid diseases (differentiated thyroid cc., hyperthyreosis, struma)		$^{131}\text{I}$ -NaI
Painful bone metastases: palliative treatment		$^{89}\text{Sr}$ -chlorid
		$^{186}\text{Re}$ -HEDP
		$^{153}\text{Sm}/^{90}\text{Y}$ EDTMP
Radiosynovectomy	Large joints	$^{90}\text{Y}$ -colloid
	Medium and small joints	$^{186}\text{Re}$ -sulfid
Pheochromocytoma, neuroblastoma, medullar thyroid cc.		$^{131}\text{I}$ -MIBG
Carcinoid		$^{90}\text{Y}$ -somatostatin analogue
Hepatocellular carcinoma		$^{131}\text{I}$ -lipiodol
Radioimmunotherapy (lymphoma)		$^{131}\text{I}/^{90}\text{Y}$ -antibody
Polycythaemia vera, essential thrombocytaemia		$^{32}\text{P}$ -Na-phosphate

# Molecular imaging (MI)

- Rapidly developing research and clinical discipline
- In the living organisation shows the characteristics and quantification of the cellular and subcellular biologic pathways.
- Represents the cellular and molecular pathways and patomechanisms in vivo.

# Goal

- Demonstrates the pathomechanism of diseases in the living cells.
- The „classical” conventional imaging techniques show the results of the molecular changes in the form of macroscopic pathologic lesions.

Imaging technique	Spatial resolution	Depth problem	Time resolution	Sensitivity (mmol/l)	Human imaging	Main indications
PET	1-2 mm	No	10 s-min	$10^{-11}$ - $10^{-12}$	Yes	Metabolism, Reporter/gene expression
SPECT	1-2 mm	No	Min	$10^{-10}$ - $10^{-11}$	Yes	Reporter/gene expression
Optical bioluminescence imaging	3-5 mm	1-2 cm	Sec-min	Unknown estimated: $10^{-15}$ - $10^{-17}$	Limited	Reporter/gene expression, cellular circulation
Optical fluorescence imaging	2-3 mm	<1 cm	Sec-min	Unknown estimated: $10^{-9}$ - $10^{-12}$	Limited	Reporter/gene expression, cellular circulation
MR	25-100 $\mu$ m	No	Min-h	$10^{-3}$ - $10^{-5}$	Yes	Morphologic, gene expression