IMAGING IN NUCLEAR MEDICINE

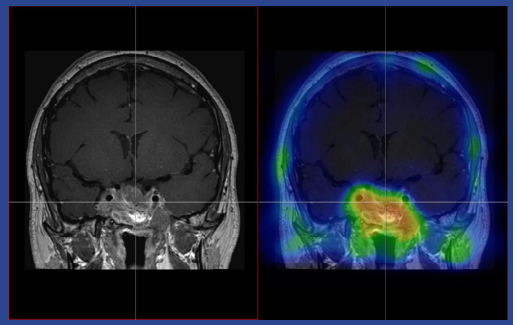
BASIC PRINCIPLES OF NUCLEAR MEDICINE
RADIOPHARMACEUTICALS
INSTRUMENTS (SPECT, PET, HYBRID EQUIPMENTS)

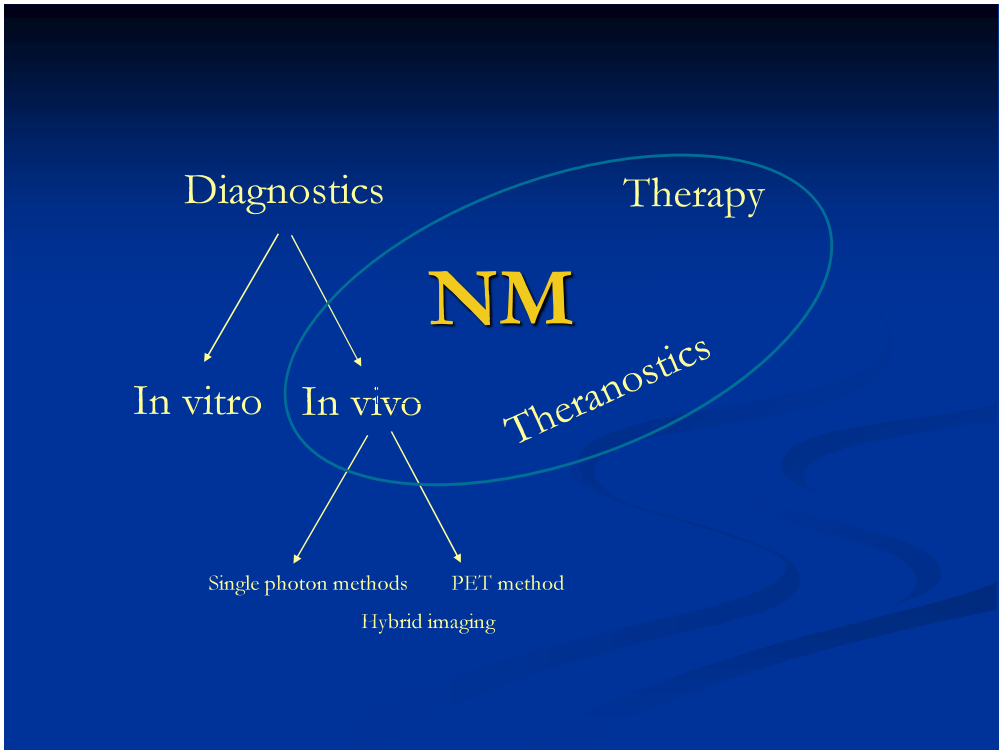
Sándor Czibor MD

SEMMELWEIS UNIVERSITY
Medical Imaging Clinic, Director: Pál Maurovich-Horvat MD, PhD
Department of Nuclear Medicine, Head: Györke Tamás, MD, PhD
http://semmelweis.hu/nuklearis-medicina/ email: titkarsag.nmt@med.semmelweis-univ.hu

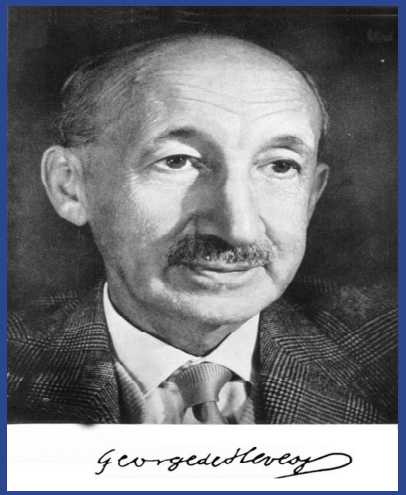
NUCLEAR MEDICINE

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



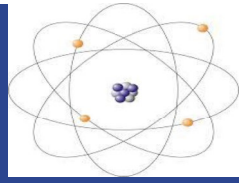


George de Hevesy (1885-1966)



- 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

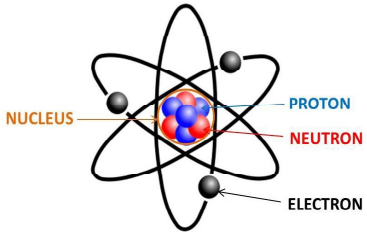


- Tracer theory
  - Radioactive compounds participate in an organism's physiological processes in the same way as nonradioactive materials
- Radiolabelling
  - The substance is "labelled" by including radionuclides in its chemical composition
  - When these decay, their presence can be determined by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

Radiopharmaceuticals

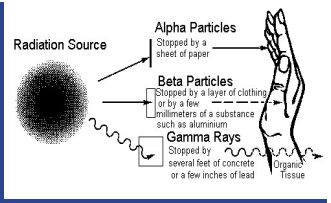
- **Organ-, tissue-, cell-, or molecule-specific compounds** labelled with radioisotopes
- Can be target-specific
- Can be traced from outside
- Functional imaging
- Intact and abnormal tissue function can be identified and characterized
- Capable for quantifying biochemical processes

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 grater than the number of protons (for large nuclei)
    - Stable nuclei: p=n or p<n
- **Radioactive isotopes**
  - Unstable nuclei → radioactive decay

Radioactive decay

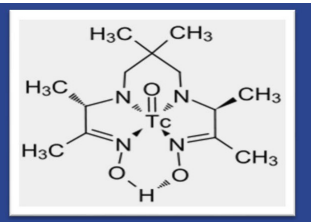


- Types
  - Proton deficiency → Beta decay (β-particle + γ-radiation)
  - Excess protons → Positrion emission (annihilation + 2 γ photons)
    → Electron capture (characteristic X-ray emission)
  - Large nuclei → Alfa radioation (α-particle)
- Ionizing radioation
  - Particle radiation (α, β, positron)
    - Depending on the type of the decay
  - Electromagnetic radiation (γ, X-ray)
    - All types of radioactive decay are typically accompanied by γ-rays

Most important radioisotopes

Nuclide	Gamma-energy (keV)	Half life ($T_{1/2}$)
Gamma emitting radioisotopes		
^{99m}Tc	140	6 h
^{131}I	364	8 day
^{123}I	159	13 h
^{67}Ga	93, 185, 296	78 h
^{111}In	172, 247	2.8 day
^{201}Tl	31, 135, 167	73.5 h
Positron emitting radioisotopes		
^{18}F	511	109.7 min
^{68}Ga	511	67.7 min
^{124}I	511	4.2 day
^{11}C	511	20.4 min
^{13}N	511	9.96 min
^{15}O	511	2.07 min

Technetium-99m (^{99m}Tc)



- Physical properties
  - Pure gamma (γ) 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

^{99m}Tc generator

TARGET → (chain reaction) → PARENT ELEMENT

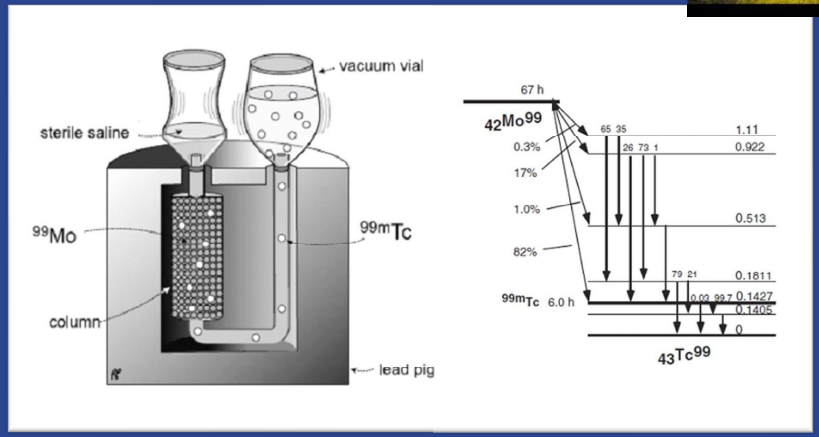
↓ (radioactive decay)

DAUGHTER ELEMENT

↓ (radioactive decay)

STABLE ENDPRUDUCT ELEMENT

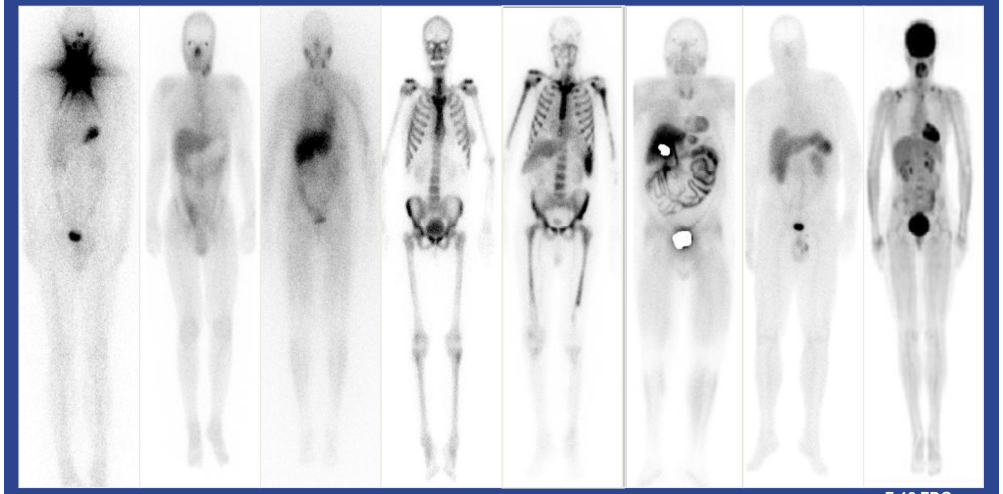
^{99m}Tc generator



Specific compounds for NM investigations

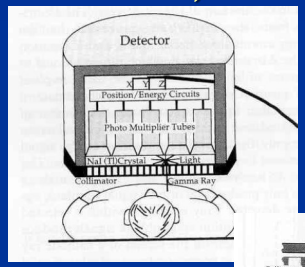
Tissue or organ	Function	Specific compound	Mechanism
Bone	Osteoblast activity	Bisphosphonates	Adsorption
Thyroid	Iodine uptake	Sodium-pertechnetate, sodium-iodine	Ion transport
Kidney	Tubular secretion	MAG3, EC	Active transport
Lung	Ventilation	Aerosols	Passive transport with diffusion
	Perfusion	Macroaggregate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

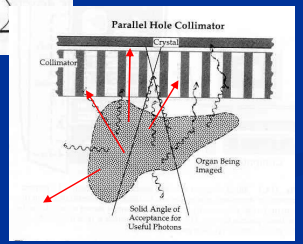
Different radiopharmaceuticals – different distributions



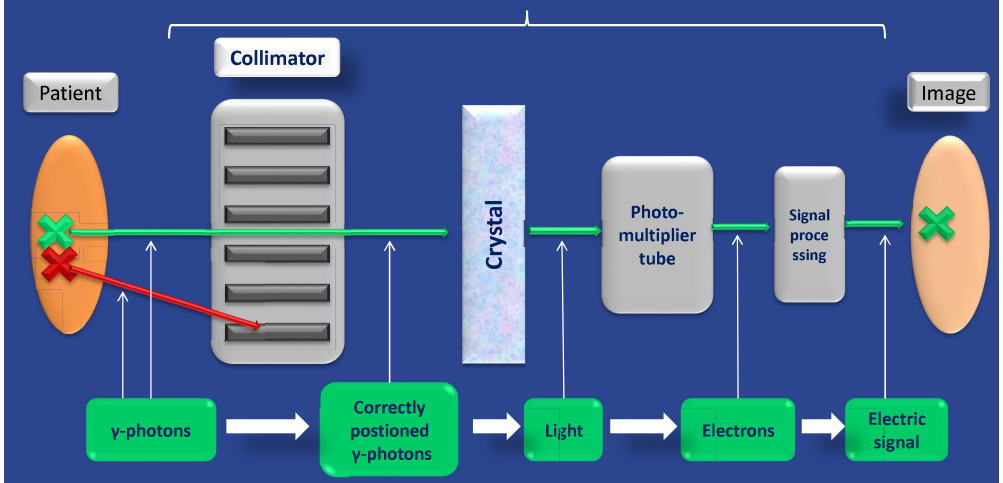
Imaging devices

- Gamma camera (Anger camera, scintillation camera)





Gamma detector



Gamma (planar) camera

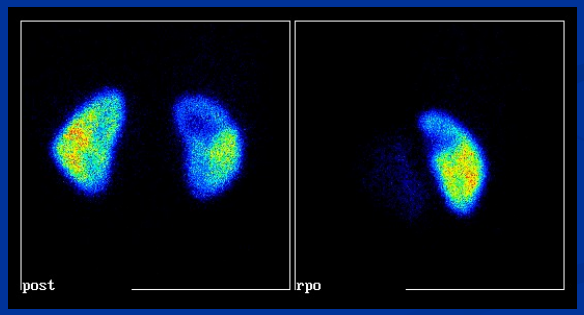
- Gamma-emitting radioisotopes
- Planar imaging
  - 1 detector head
  - 2D summation image

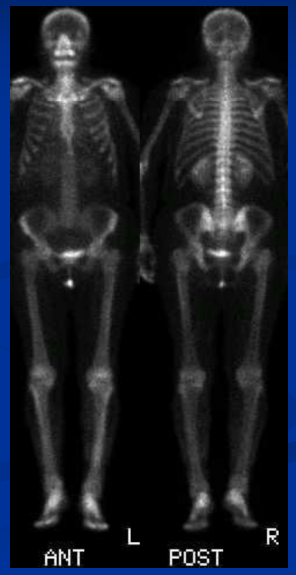
Types of studies

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

Planar investigations

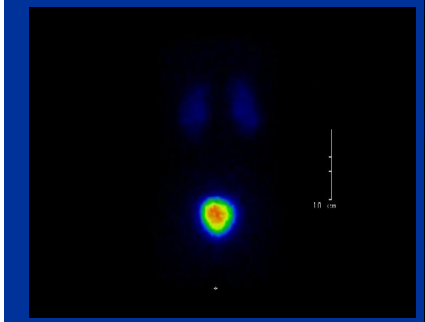
1. Static Investigation

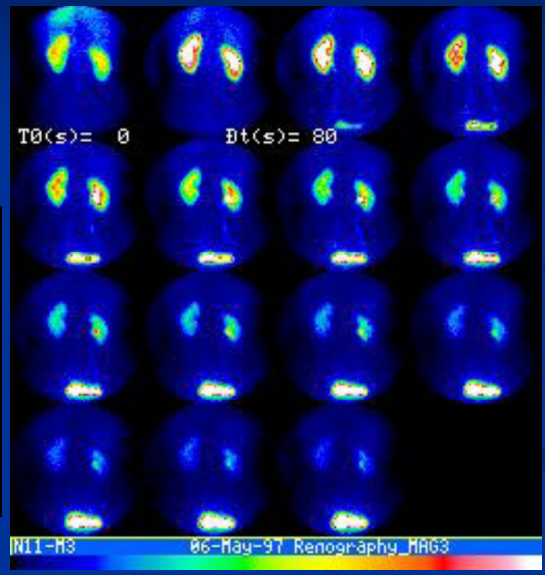




Planar investigations

2. Dynamic / functional investigations

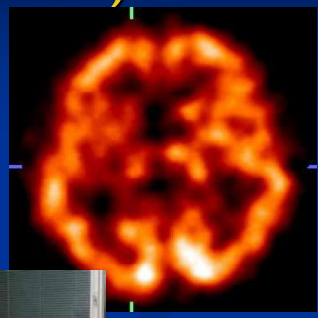




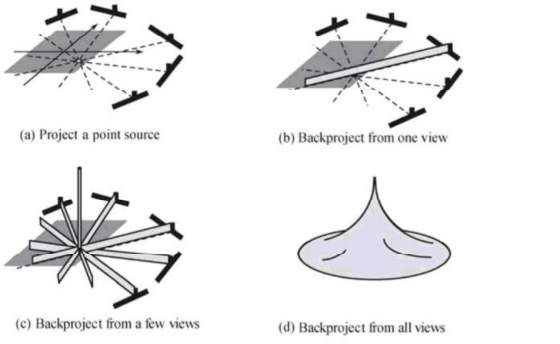
SPECT

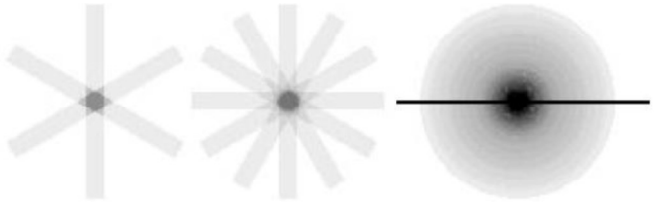
- Single Photon Emission Computed Tomography
- Gamma-emitting radioisotopes
- Cross-sectional (tomographic) imaging
  - 1 or more detector heads
  - **Rotational motion**
  - Multi-directional projection images
  - Computerized reconstruction
    - Cross-sectional images
    - 2D tomographic images in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

Single Photon Emission Computed Tomography (SPECT)



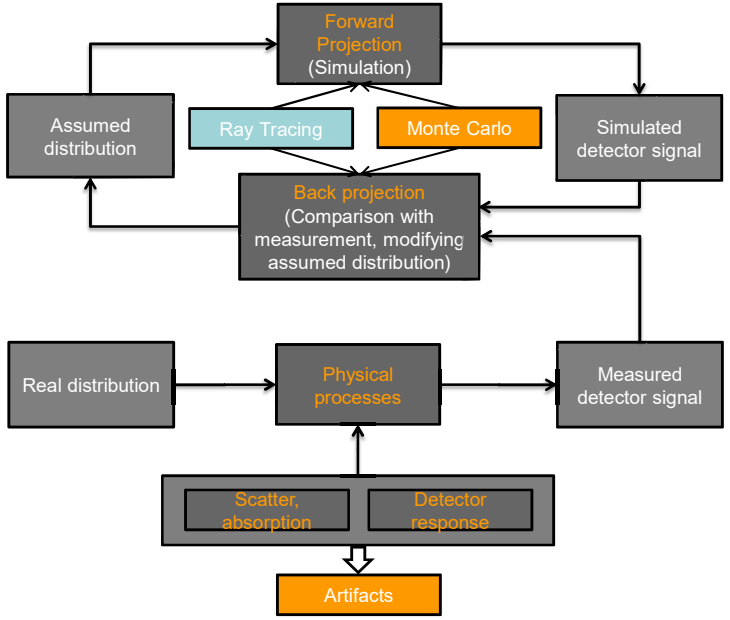
Simple Backprojection





Mediso

Iterative Reconstruction



Mediso

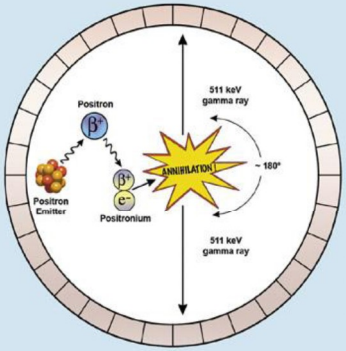
SPECT images

SPECT vs. planar imaging

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

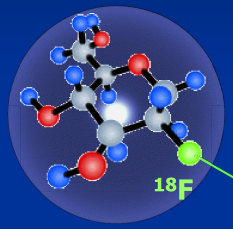
PET

- 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



β+ decay

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



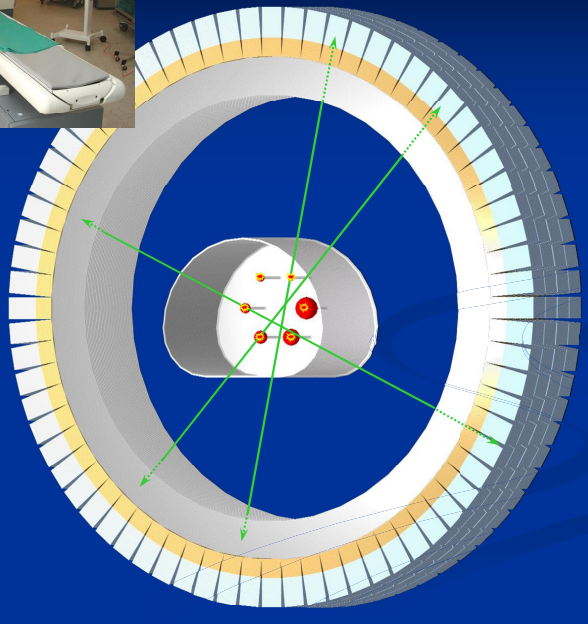
1-3 mm

e+

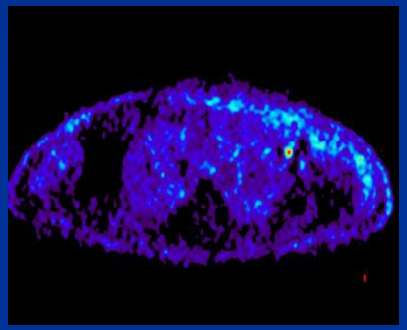
e-

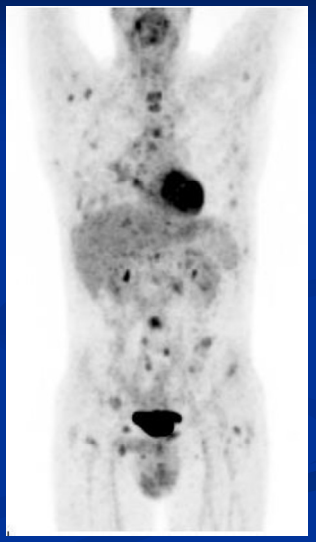
511 keV

511 keV



Positron-emission tomography (PET)





MIP (maximum intensity projection)

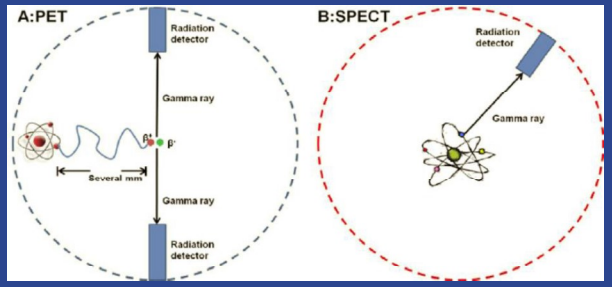
- Axial field of view: ca. 20 cm
- One bed position - acquisition time: 1-3 minutes
- Whole body examination: 4-6 bed positions (120 cm) 4-18 minutes

Why do we need PET?

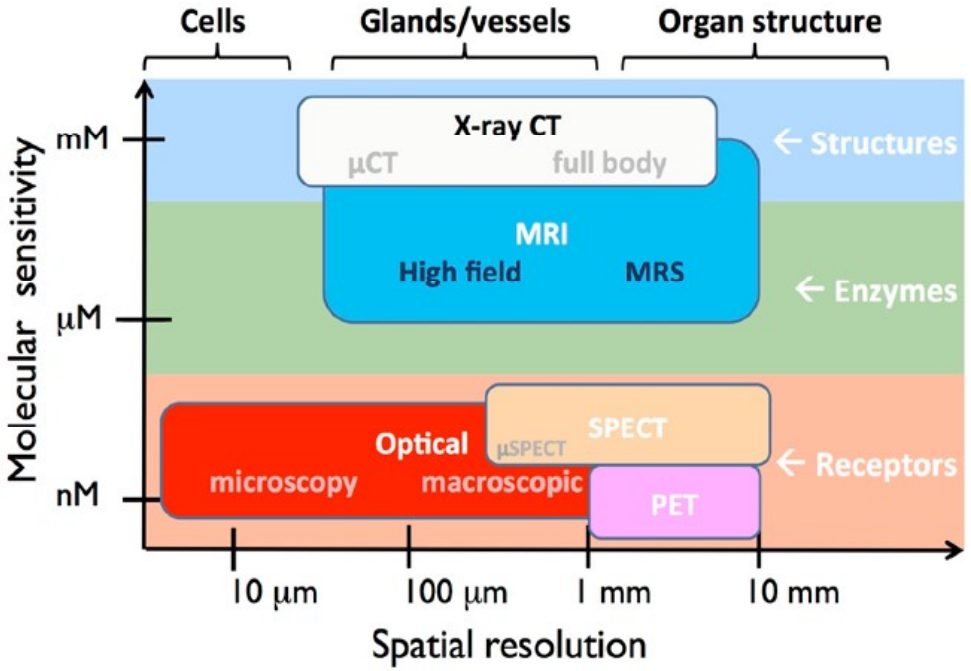
- Most important positron-emitting radionuclides and their half lives:

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

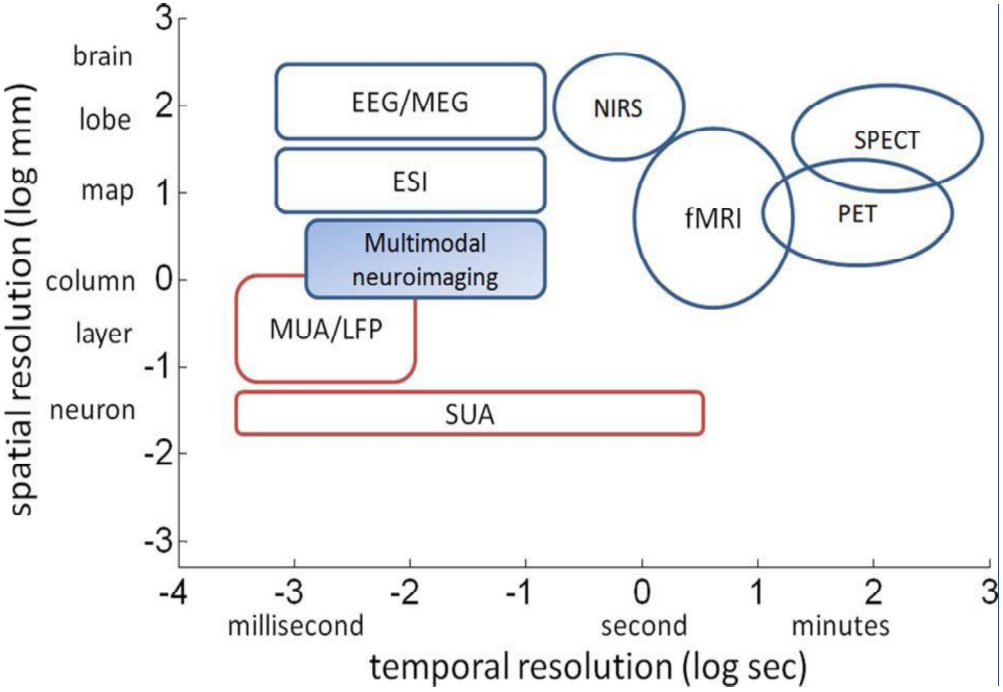
PET vs. SPECT



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



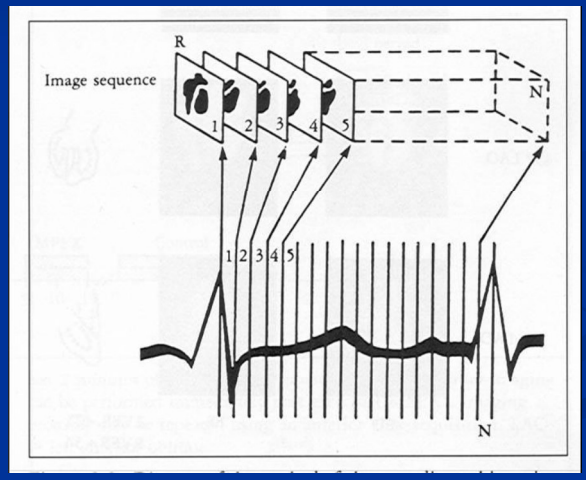
Kenneth MT et al. - Phys. Med. Biol. 60 (2015) R239–R269



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

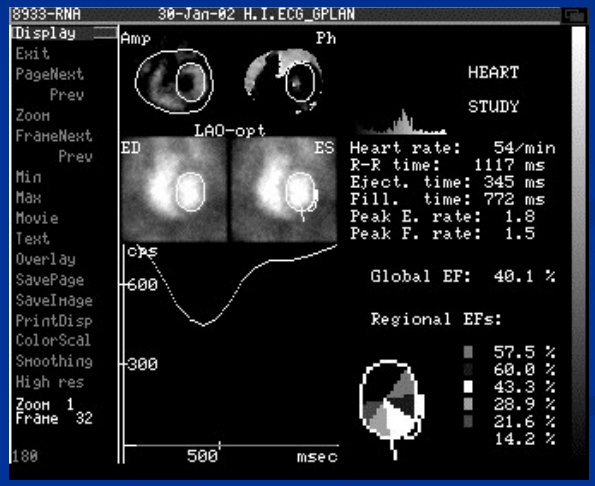
Nuclear Cardiology - Function

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

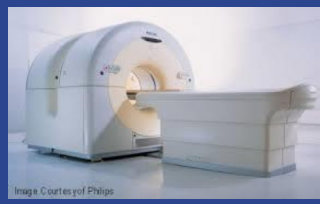


Nuclear Cardiology - Function

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

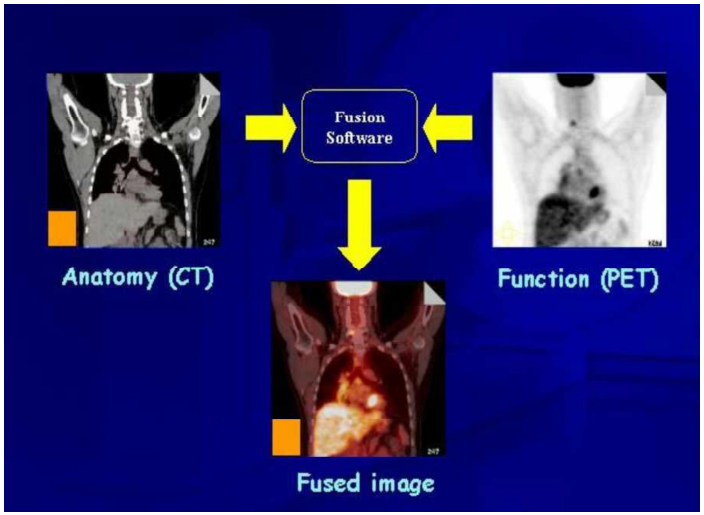


Hybrid imaging



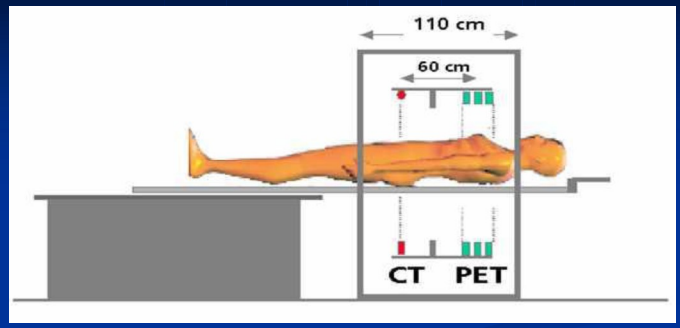
- Combines the advantages of SPECT/PET and CT (or MRI)
- Two modalities in one device (functional + morphological)
  - SPECT-CT, PET-CT, PET-MR, SPECT-PET-CT
  - Imaging at the same time (one after another), in the same position
  - Software based image fusion
- Role of CT
  - Localization
  - Attenuation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

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 registrated images

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



CT

PET, SPECT

PET-CT, SPECT-CT

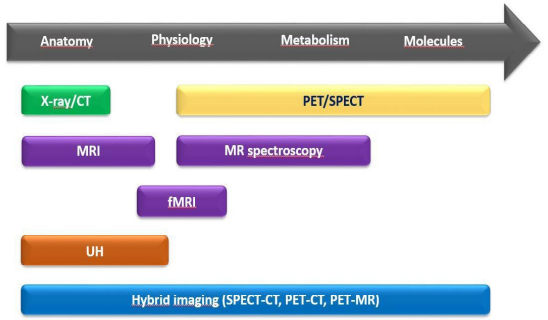
Why PET/SPECT is necessary?

Nuclear medicine (PET/SPECT)

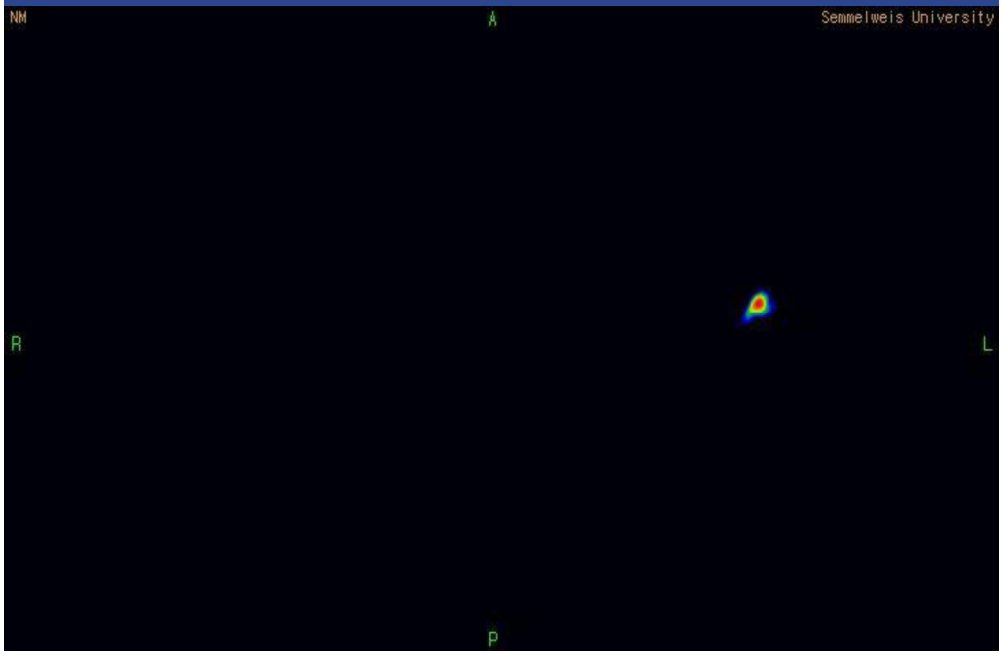
- Sensitive
  - Highest functional sensitivity imaging technique
  - Functional abnormalities can be detected earlier than morphological abnormalities
  - High biological contrast between the normal and abnormal tissues
- Specific
  - Radiopharmaceuticals accumulate specifically in pathologic tissues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

Radiology (CT)

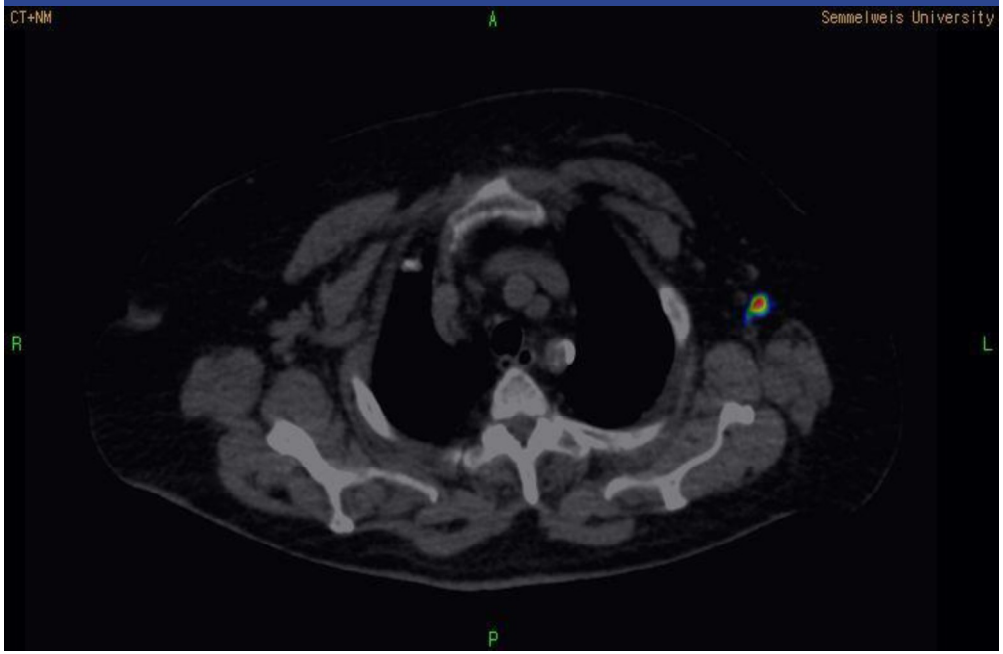
- Lower specificity
- High resolution
- Morphological information
- Localization and extent of the disease
- Short acqusition time



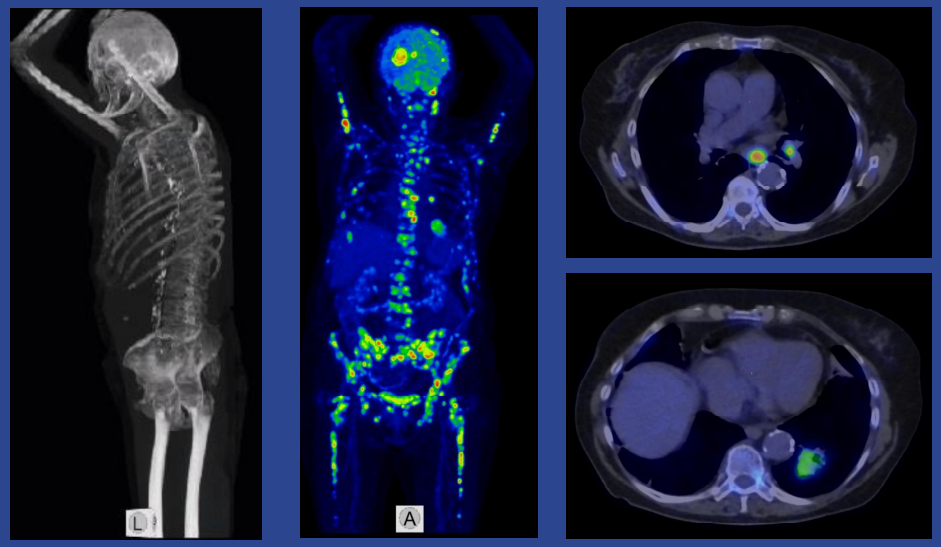
NM – What is functioning?



CT – Where is it?



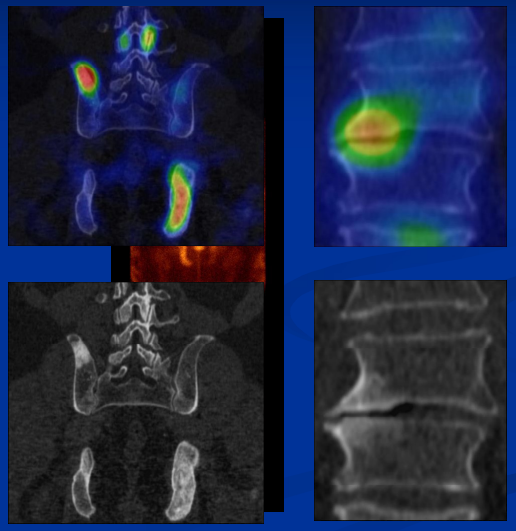
Hybrid imaging in practice



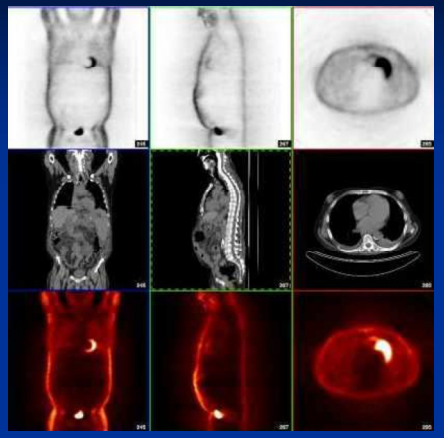
Hybrid imaging - the role of CT

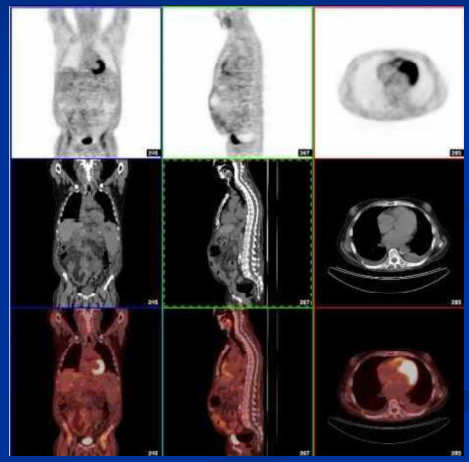
- Anatomic localisation
- Attenuation correction
  - Low dose native CT is enough
- Characterisation
- Increasing diagnostic safety
- Patient comfort
- Cooperation of radiology and NM

Characterisation

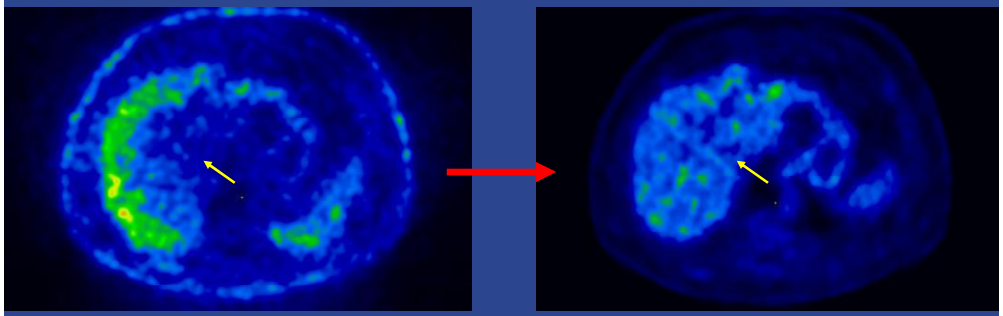


CT-based attenuation correction





CT-based attenuation correction



Hybrid imaging is popular...

NM in general

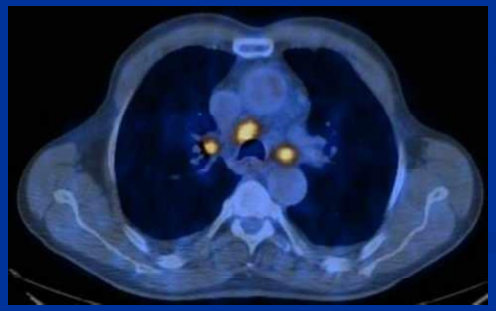
- Functional information - functional imaging

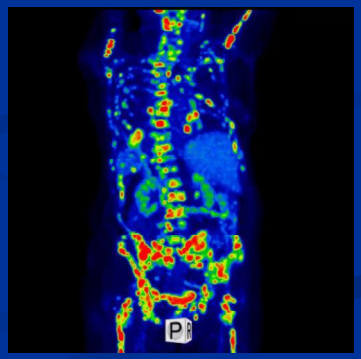
NM in general

- Functional information
- Sensitivity

High sensitivity

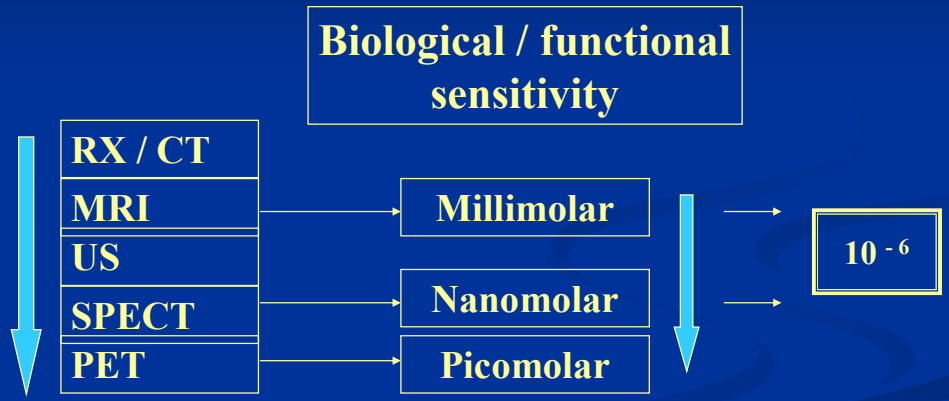
- Tracer-principle
- Functional lesions appear before morphological lesions
- High biological contrast between normal and abnormal processes





MIP (maximum intensity projection)

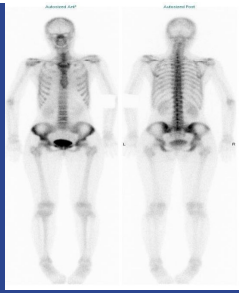
Sensitivity of imaging modalities



NM in general

- Functional information
- Sensitivity
- Specificity

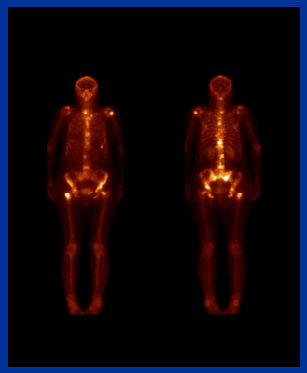
Bone scintigraphy

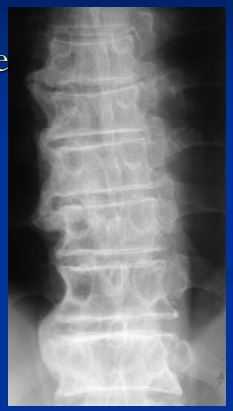


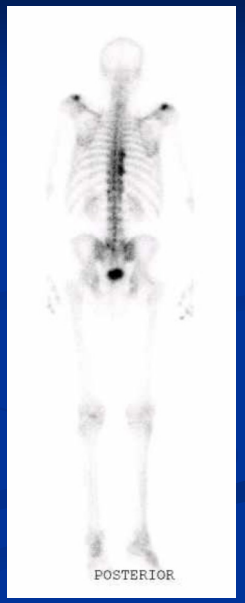
- Tc-99m-diphosphonate
  - Adsorbs to bones in proportion to ***osteoblastic activity***
- Almost every bone disease causes increased osteoblastic activity, therefore increased radiopharmaceutical uptake
- ***Very sensitive***
  - Can detect bone lesions before X-ray
    - ➢ Positive bone scan + negative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

Bone scintigraphy – aspecific

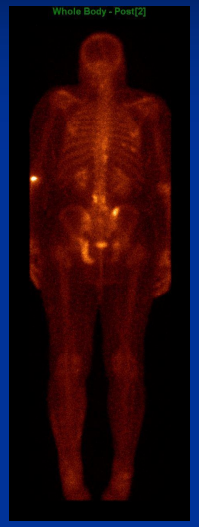
- Tc-99m-diphosphonate
- Osteoblastic function

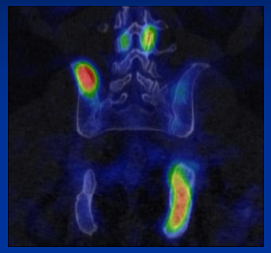


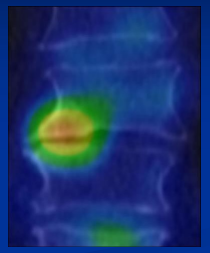


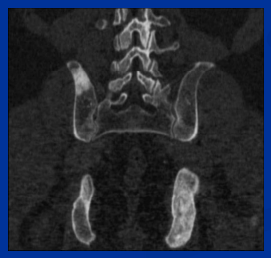


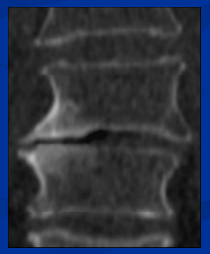
Characterisation











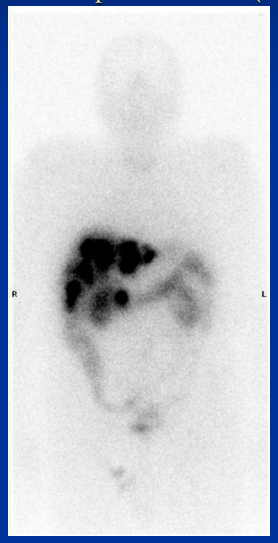
Molecular imaging

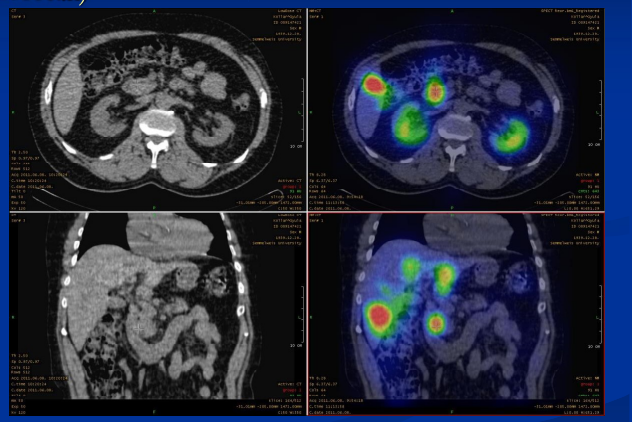
- Visualization of subcellular molecular-biochemical processes in the living organism

Molecular targets	Molecules
Enzymes, transporters	Substrates
Receptors	Ligands
Antigens	Antibodies

Somatostatin receptor-scintigraphy – specific

- ^{111}In-pentetreotide (Octreoscan)



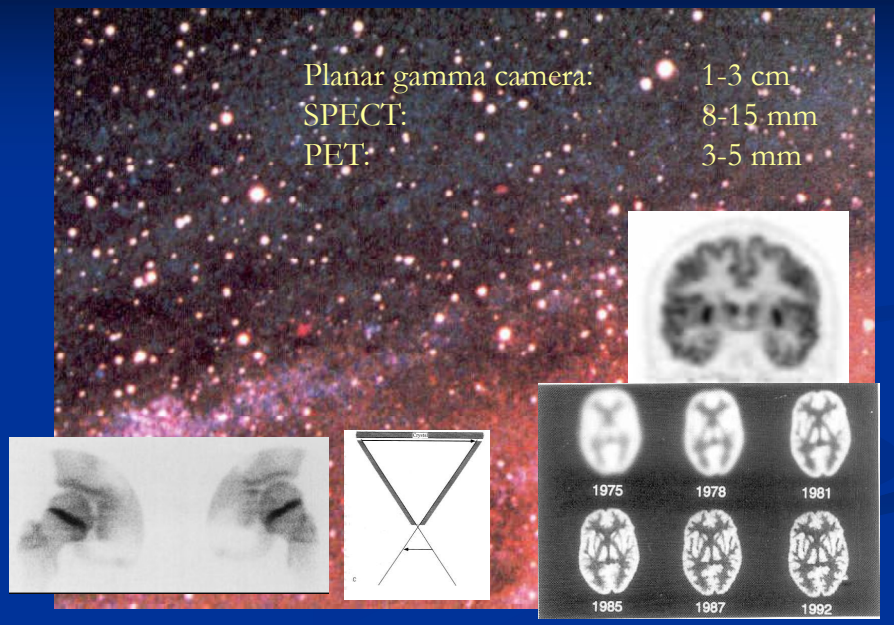


Radionuclide therapy!

NM in general

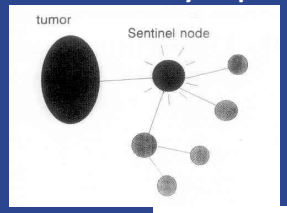
- Functional information
- Sensitivity
- Specificity
- „Bad” spatial resolution

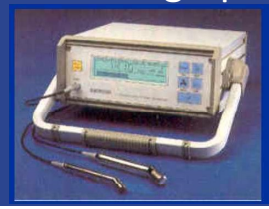
Spatial resolution…

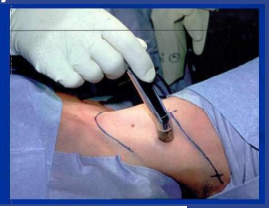


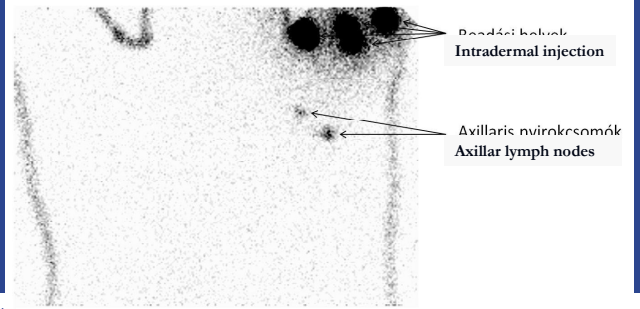
Spatial resolution

- Sentinel lymph node scintigraphy



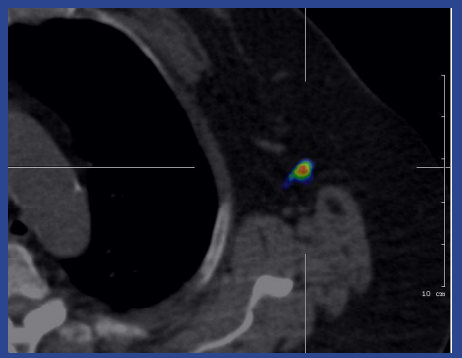


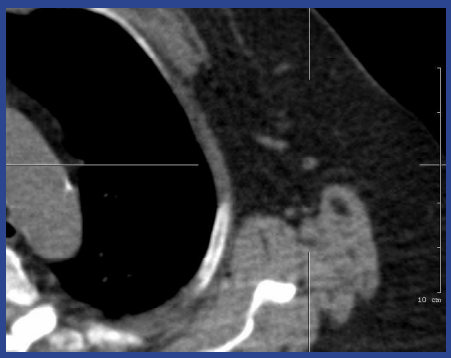




Spatial resolution

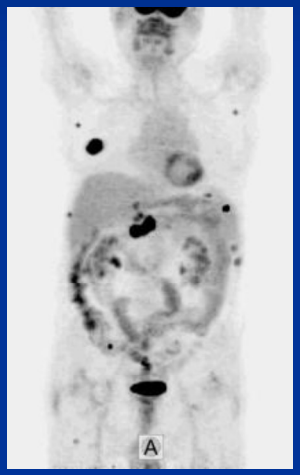
- Sentinel lymph node

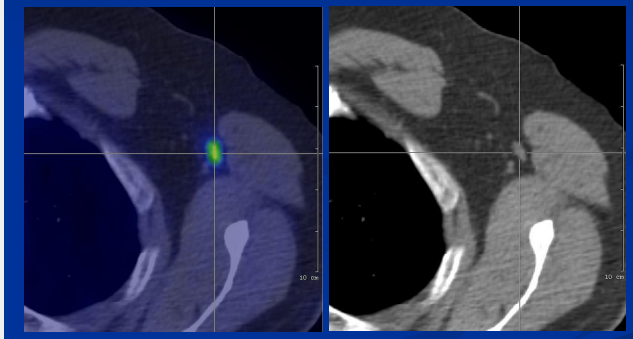




Spatial resolution - Nodal staging

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



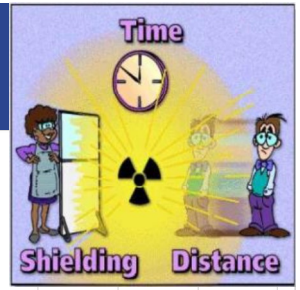


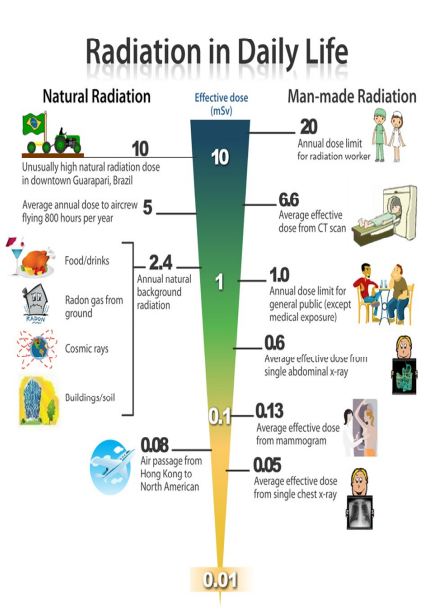
Diffuse large B-cell lymphoma, relapse after autologous stem cell transplantation

General considerations

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

Radiation protection





General considerations

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

Quantification

Quantitative: Glucose Metabolic Rate (Mr_{glu})

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

(μmoles/min/ml)

Semiquantitative: Standardized Uptake Value (SUV)

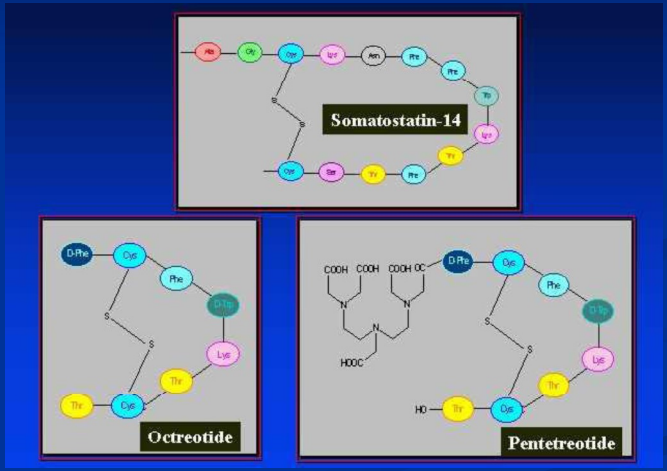
$$SUV = \frac{\text{tracer concentration (Bq/ml)}}{\text{injected dose (Bq) / body volume (ml)}}$$

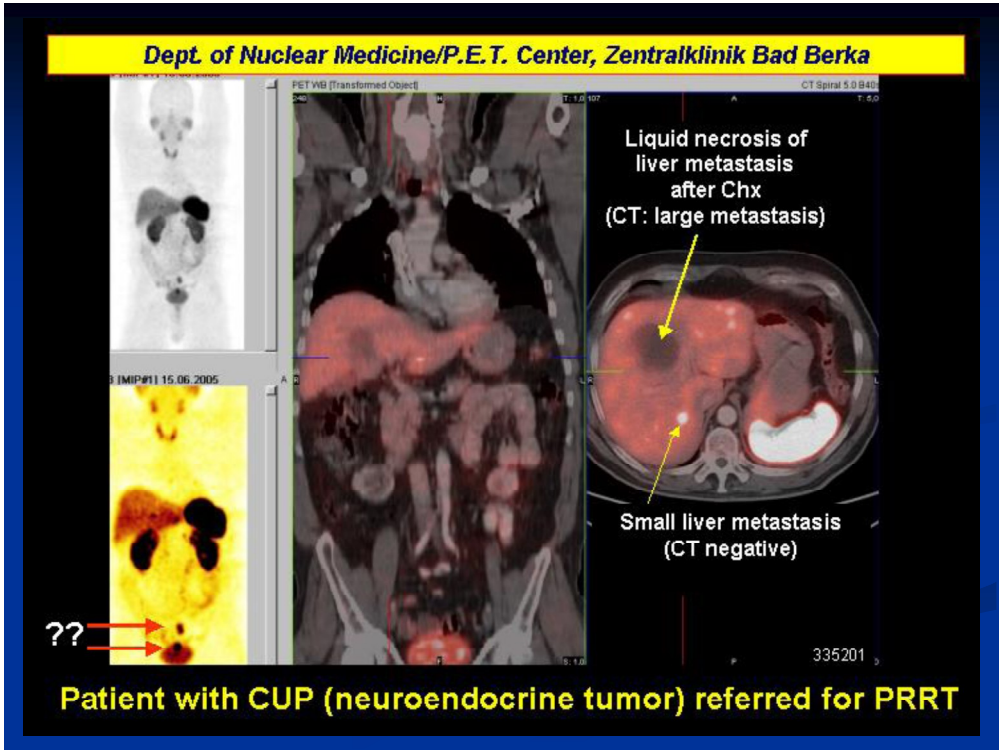
Specific applications

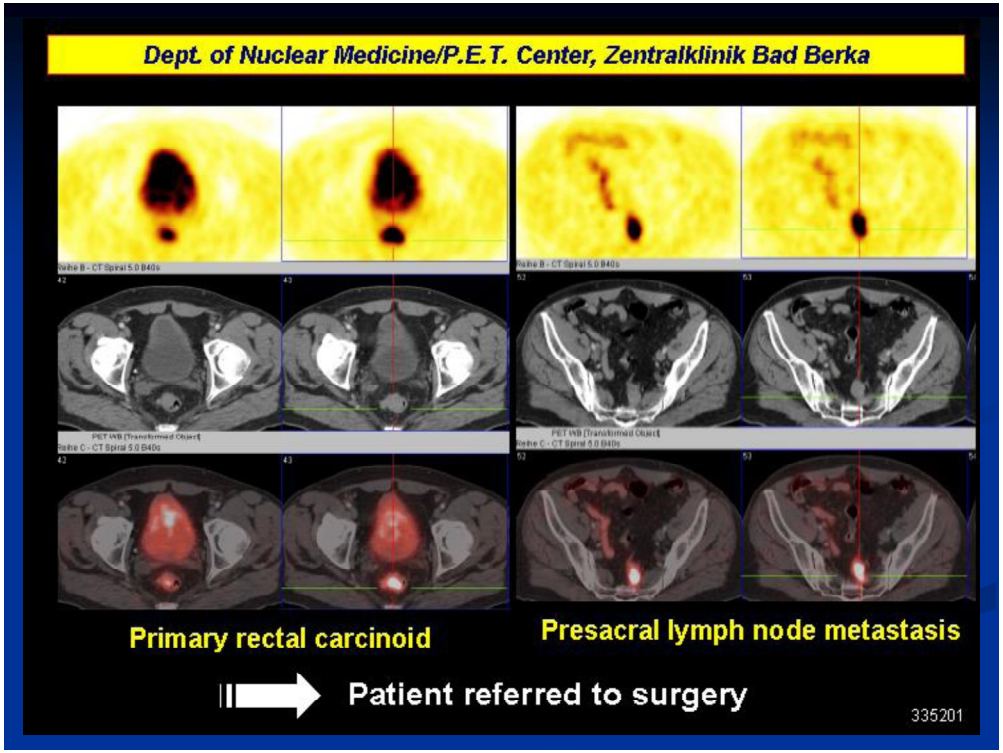
Receptors, peptides
Imaging of somatostatine receptors (SST-R)

- 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%
  - Phaeochromocytoma 73%

Basic principles of SST-R scintigraphy





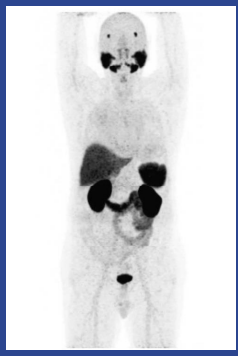


Theranostics

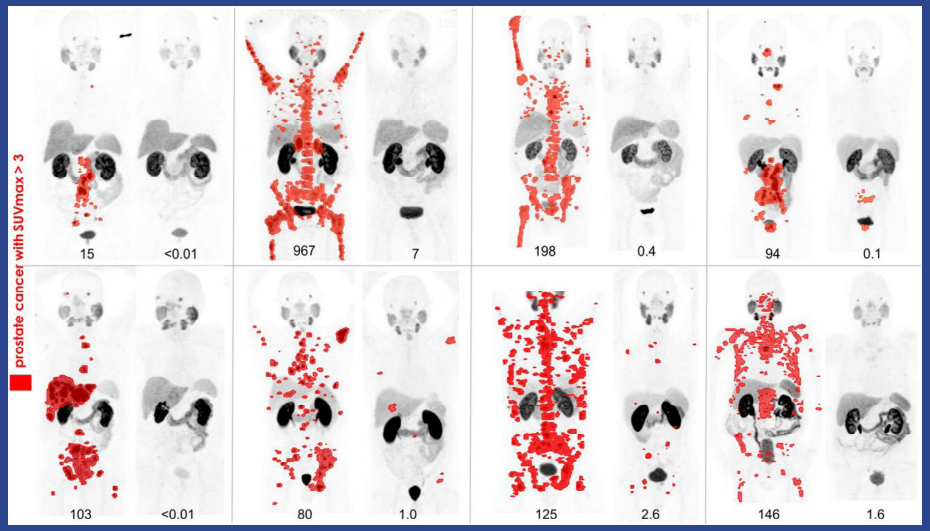
- Compounds suitable for both diagnosis and treatment, that specifically bind to target molecules
  - For diagnosis → labelled with γ- or positron-emitting radioisotopes
  - For treatment → labelled with α- or β-emitting radioisotopes
- Target specific molecules
  - ➢ Only the diseased cells are visualized → 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}F, ^{68}Ga
  - (gamma: ^{99m}Tc, ^{111}In)
- Radiotherapy:
  - ^{177}Lu, ^{131}I (beta neg.)
  - ^{225}Ac (alpha)
- Teranostics: PSMA I&T (Imaging & Therapy)



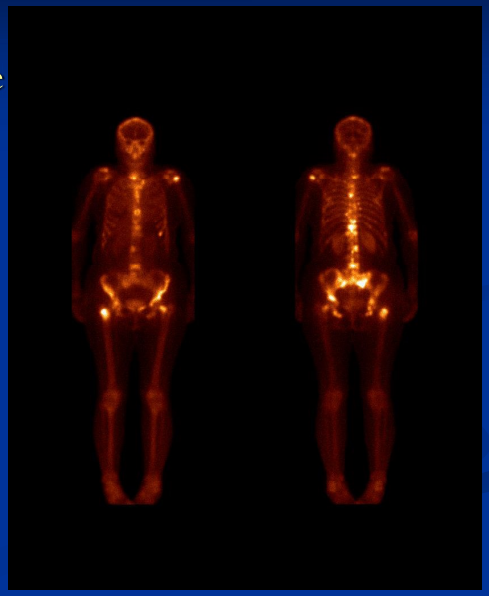
Demirci et al. Nucl Med Commun. 2016



2018 SNMMI Image of the Year: PET imaging before and after ^{177}Lu-PSMA617 therapy for metastatic prostate cancer. ^{68}Ga-PSMA11 PET maximum-intensity projection images at baseline and 3 months after ^{177}Lu-PSMA617 treatment in 8 patients who experienced prostate-specific antigen declines of ≥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).

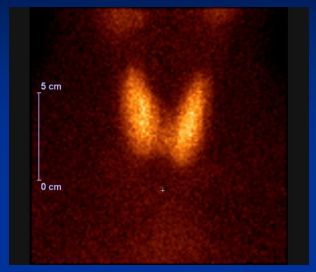
Bone scintigraphy

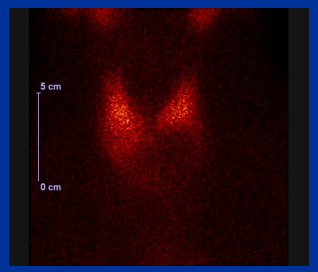
- Tc-99m diphosphonate
- Osteoblastic activity
- Osseous metastases

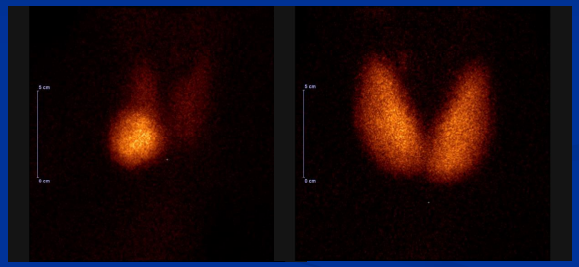


Thyroid gland

Radiopharmaceutical:
^{99m}Tc-pertechnetate



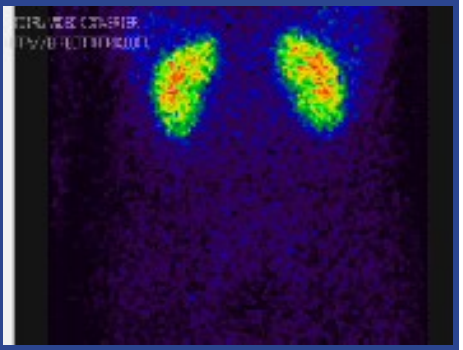




Dynamic renal scintigraphy

- 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 invastigated

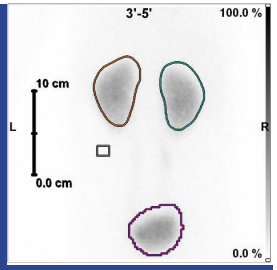
- ^{99m}Tc-MAG3
- ^{99m}Tc-EC
- ^{99m}Tc-DTPA



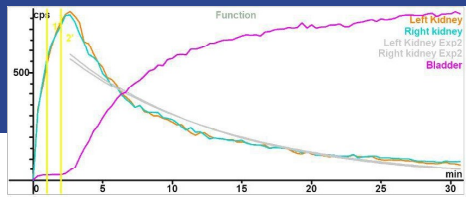
Normal dynamic renal scintigraphy

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}, $T_{1/2}$



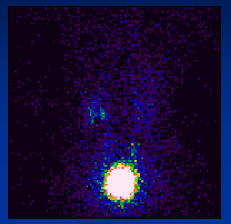
	Left	Right
T0 (sec):	0	0
Tmax:	2'40"	2'40"
Thalf:	8'06"	8'33"
Wash-out Thalf:	4'	4'
Residual Activity:	16.0 %	17.1 %
Norm.Res. Activity:	17.0 %	18.3 %
Relative Function:	49.9 %	50.1 %
Relative Perfusion:	51.9 %	48.1 %

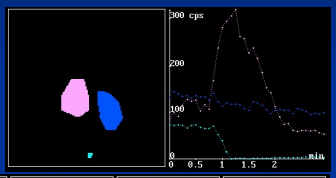


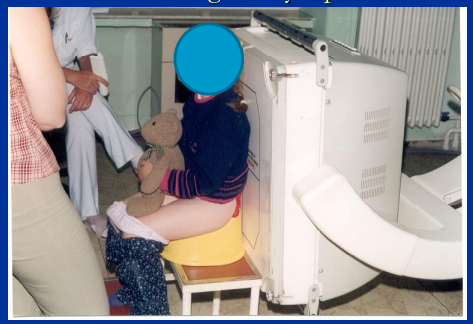
SEMMELWEIS UNIVERSITY ©
Department of Nuclear Medicine

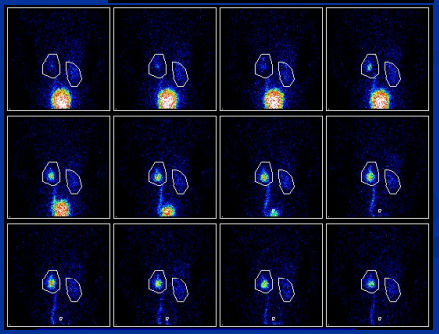
VUR – indirect radionuclide cystography

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



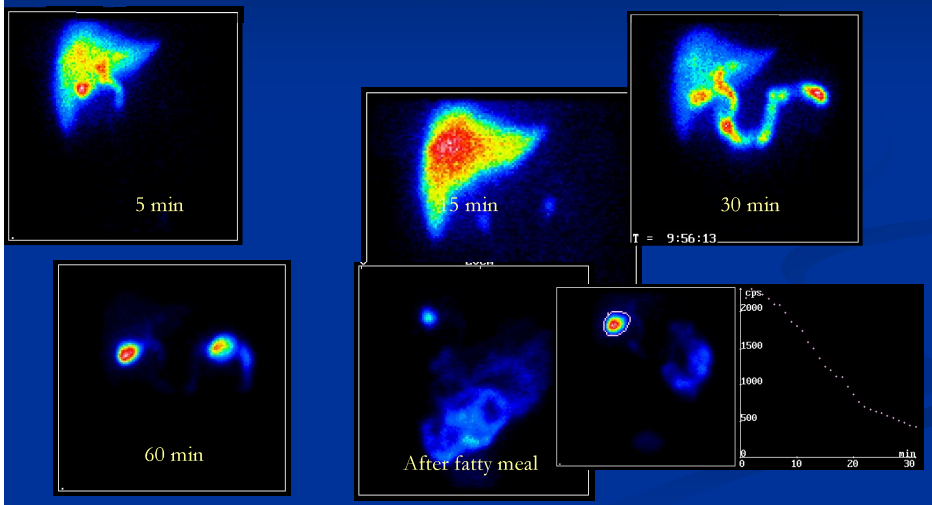






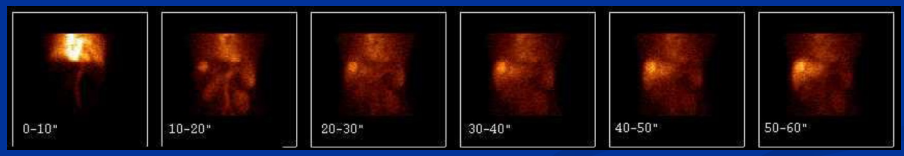
Dynamic cholescintigraphy

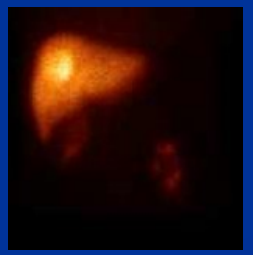
- Tc-99m HIDA (hepato-imino-diacetic acid)

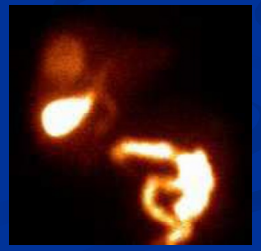


Focal hepatic lesion, incidentaloma

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

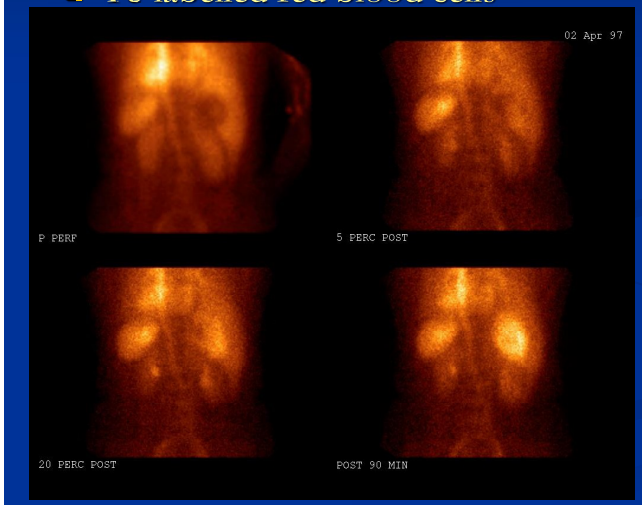


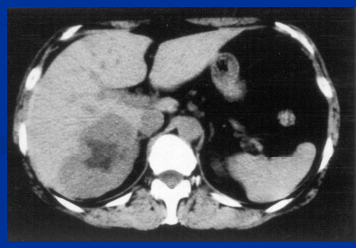




Focal hepatic lesion, incidentaloma

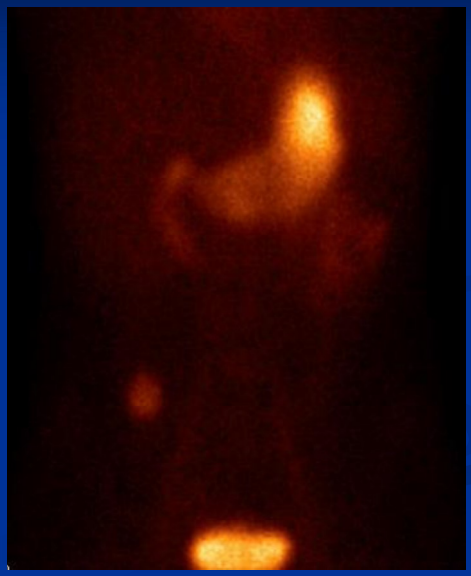
- Cavernous haemangioma
- Technetium-labelled red blood cell scintigraphy
- Tc-labelled red blood cells





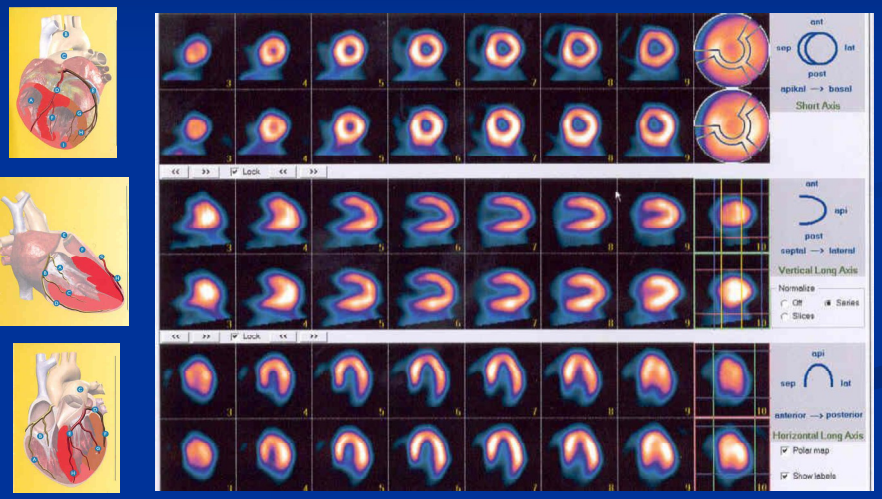
Gastrointestinal bleeding in childhood

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

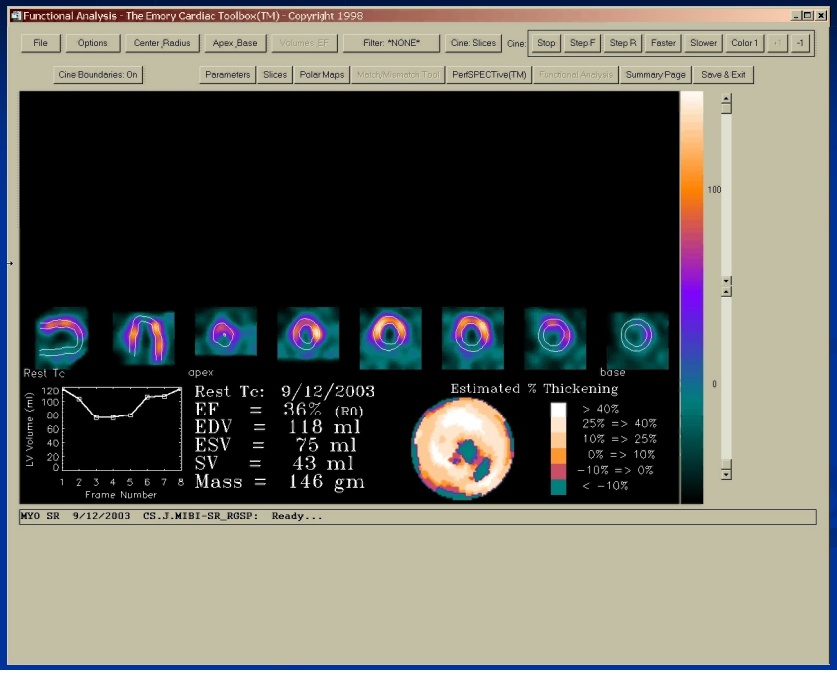


Nuclear cardiology

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

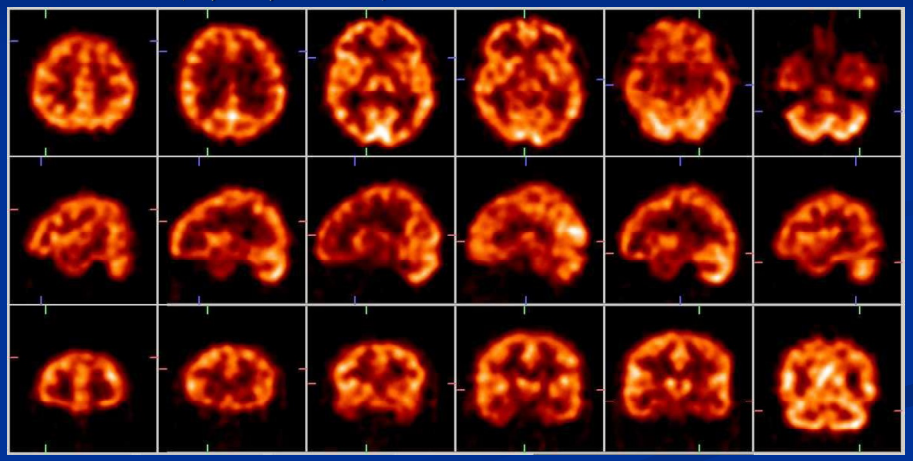


Gated MyoSPECT: wall motion presentation

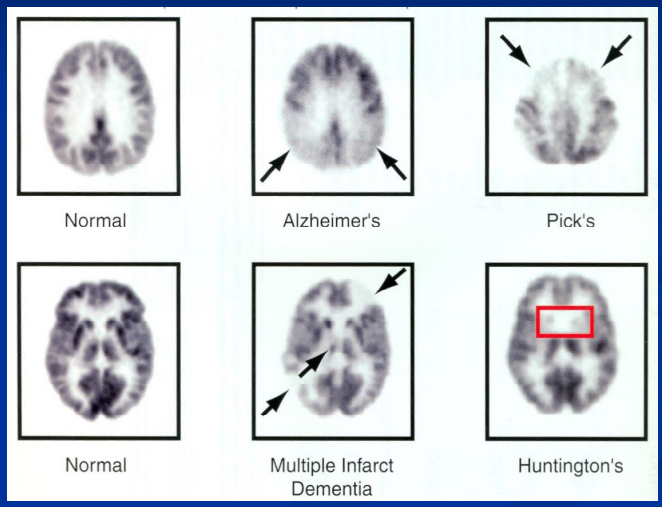


Neurology

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



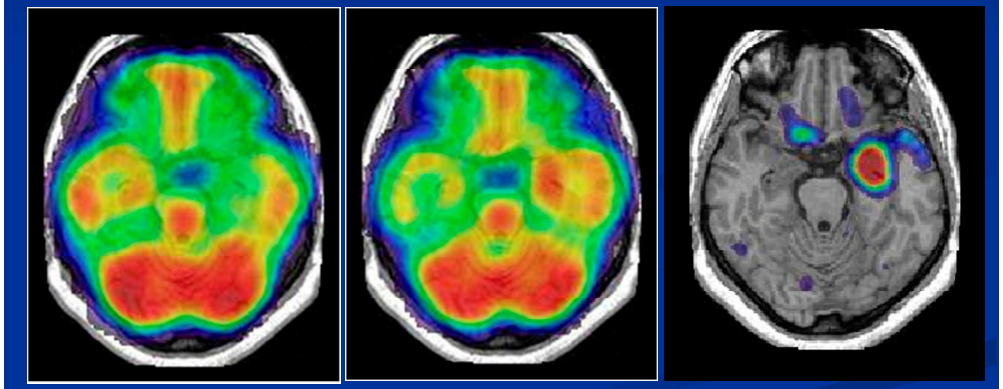
Neurology
Differential diagnosis of dementia



Brain perfusion SPECT - epilepsy

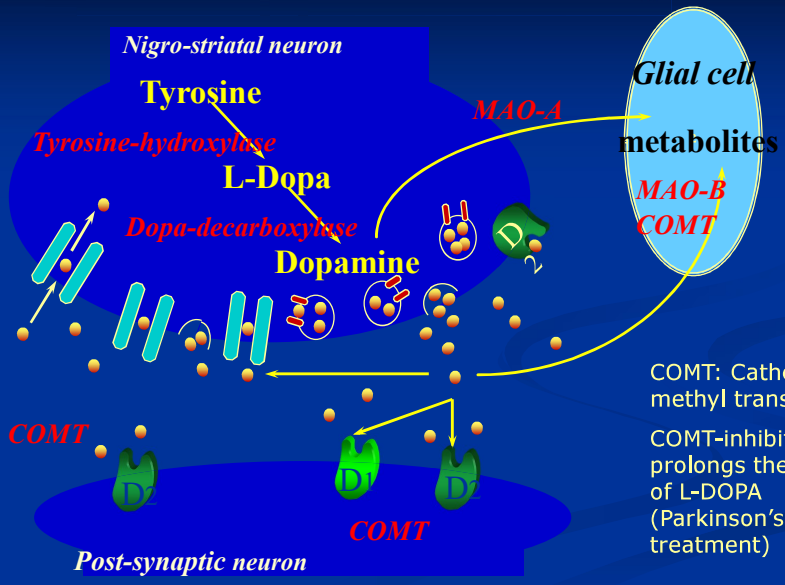
Ictal examination

- Focal epilepsy



Interictal SPECT-(PET) | Ictal SPECT | Subtraction

- Dopaminergic neurotransmission
  - Radiopharmacon-specific accumulation and binding



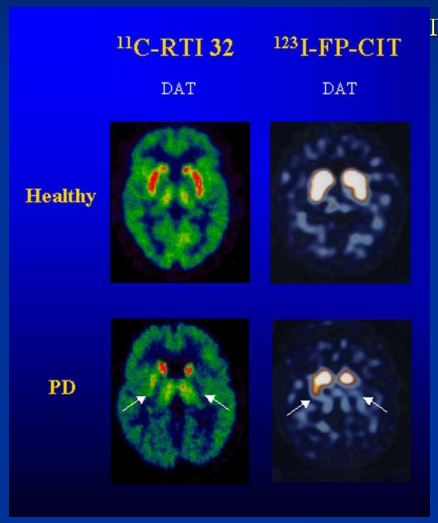
COMT: Cathecol-O-methyl transferase,

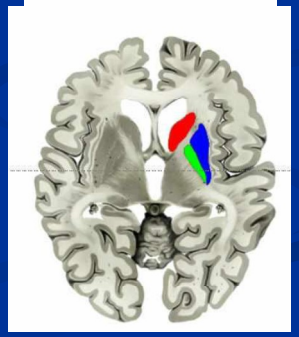
COMT-inhibitor prolongs the effect of L-DOPA (Parkinson's disease treatment)

Image: Dr. P. Remy

Dopaminergic neurotransmission

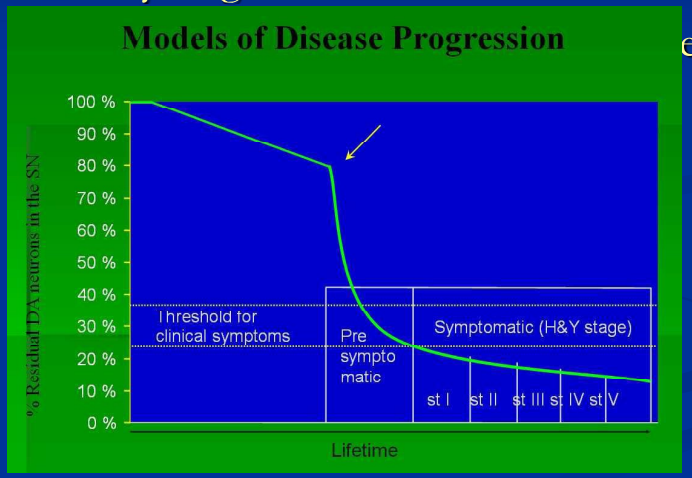
- TScan (DA ter)

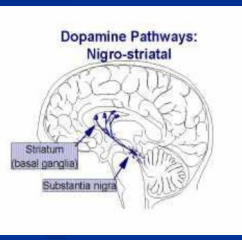




Dopaminergic neurotransmission

- Early diagnosis – DATScan

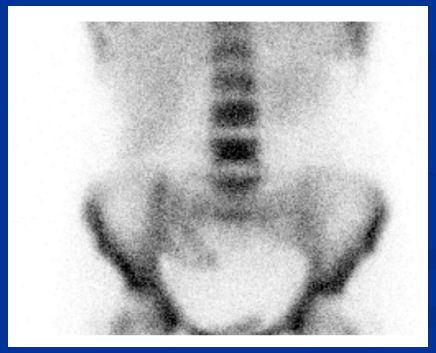




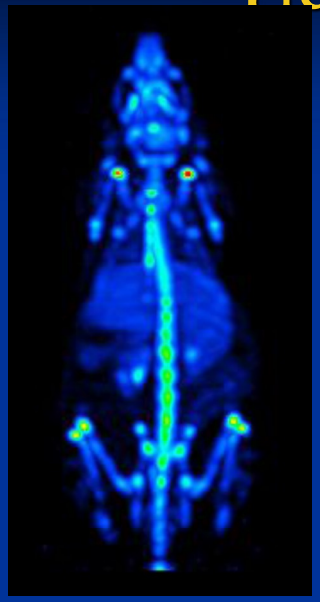
H&Y – Hoehn-Yahr scale

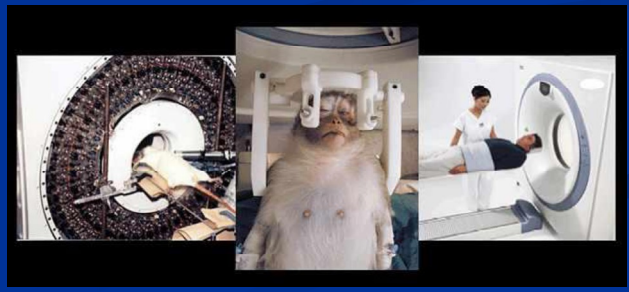
Inflammation

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

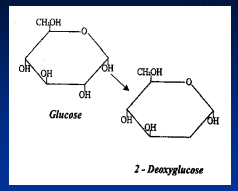


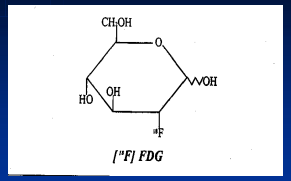
Preclinical studies





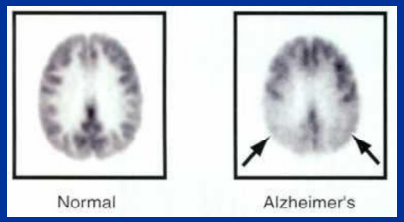
^{18}F-fluoro-deoxiglucose (FDG)

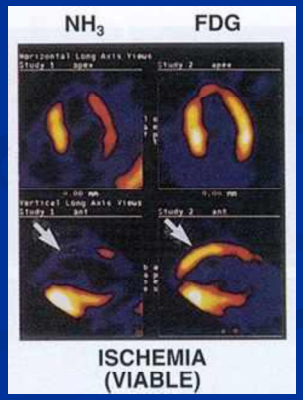




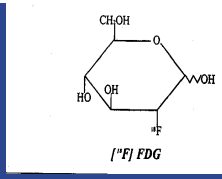
Applications:

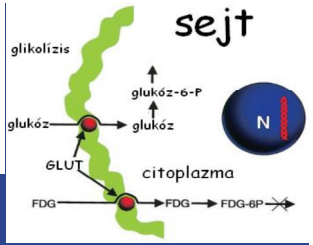
- Oncology (~ 85 %)
- Neurology (~ 10%)
- Cardiology (~ 5 %)



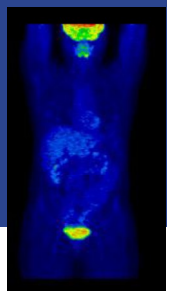


FDG-PET





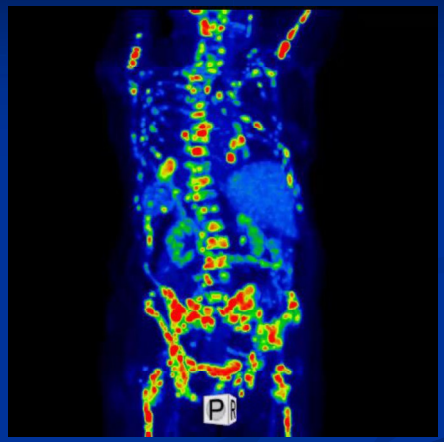
- ^{18}F-fluro-deoxy-glucose
- Tumors have a high metabolic activity (aerobic and anaerobic glycolysis) → imaging of glucose metabolism of tumors
- Glucose accumulates in several malignant tumors, but it is ***not tumor-specific!***
- Inflammation and tumors can not be differentiated
- High physiological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

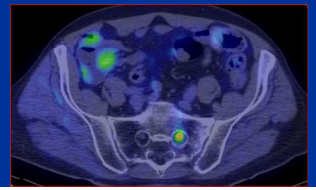


SEMMELWEIS UNIVERSITY ©
Department of Nuclear Medicine

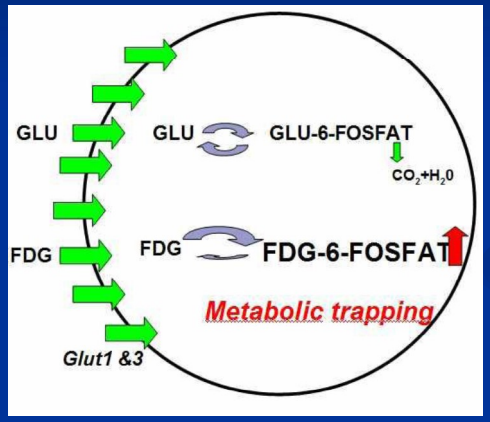
Nuclear oncology

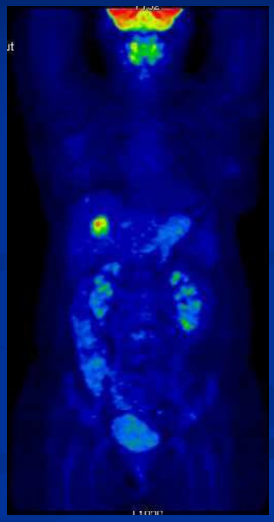
- Sensitive detection of malignant lesions
  - Based on functional, metabolic changes
  - High biological contrast
- Non-invasive characterisation of a known lesion
  - Tumor-specific
    - (^{18}**FDG-PET**, ^{99m}Tc-MIBI, ^{67}Ga)
  - Specific for a particular malignancy
    - ($^{123/131}$I, receptor-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



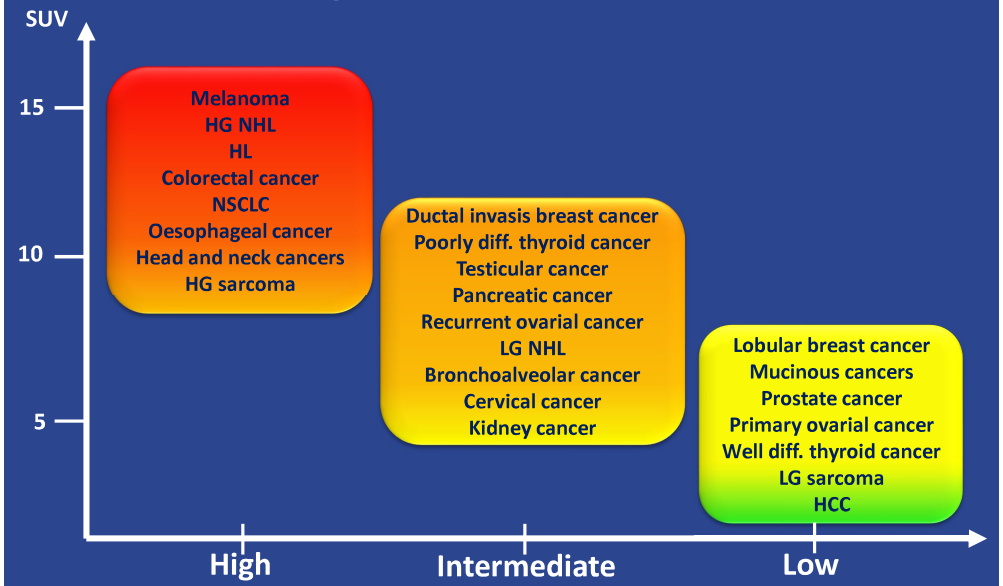


^{18}F-fluoro-deoxyglucose (FDG) in oncology



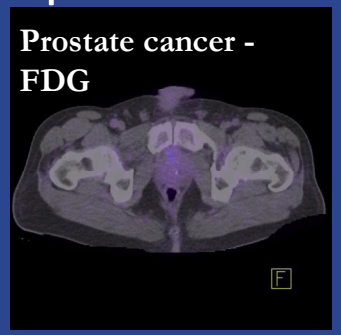


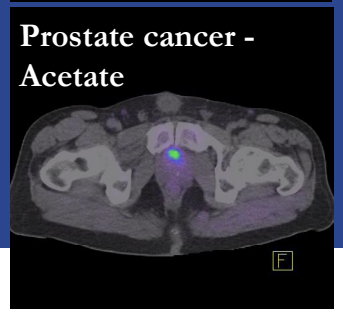
FDG-uptake in different tumors



Not every tumor takes up FDG!!!

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





PET-CT in oncolgy (1)

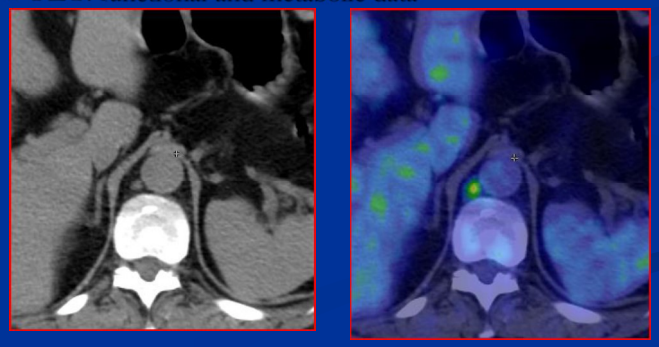
- Staging (TNM)
  - Operability, regional lymph nodes, distant metastases
  - NM performs better than morphological imaging techniques
  - PET-CT changes the stage in 20-40%
- Treatment response
  - Evaluation of response to treatment after chemo- and radiotherapy
  - Monitoring after radio-frequency 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

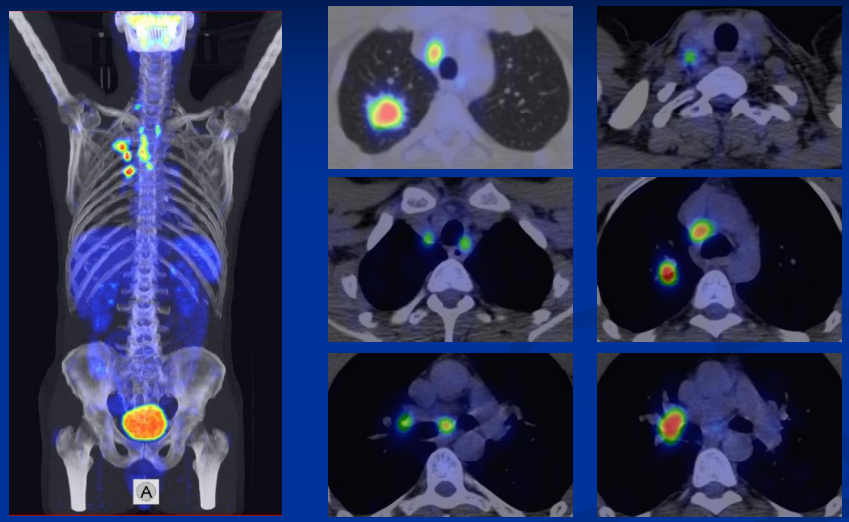
PET-CT in oncology (2)

- 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 evulate the grade of the malignancy
  - Brain tumor: low-grade vs. high-grade

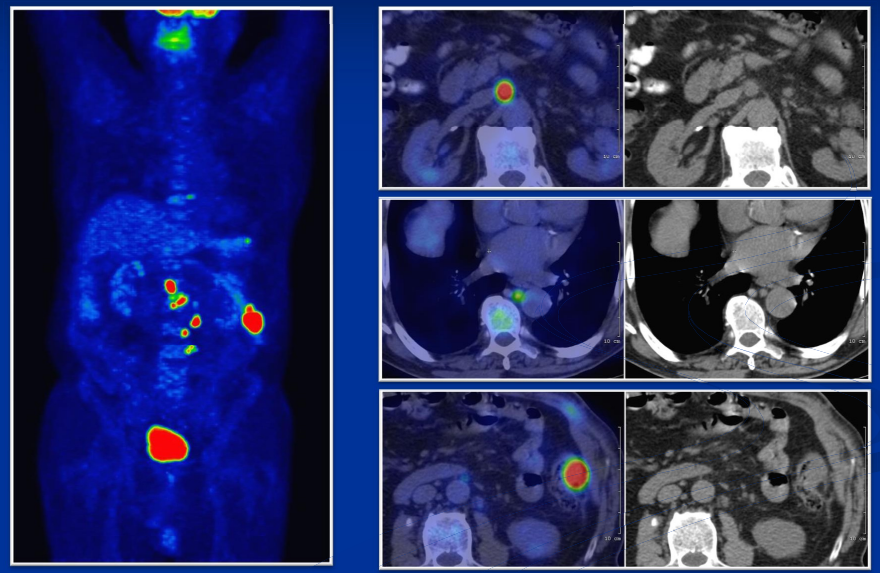
Role of PET-CT in oncology

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



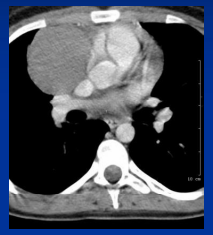


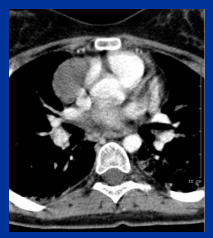
Lymphoma staging, nodal and extranodal manifestations



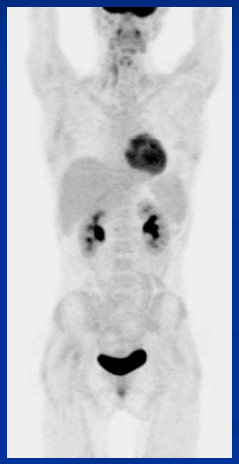
Restaging
(Residual terime, Hodgkin's disease /N.S., 15 yo female/)

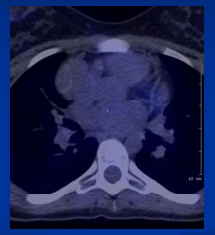
Staging CT

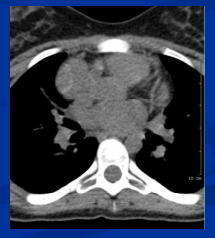




Restaging CT







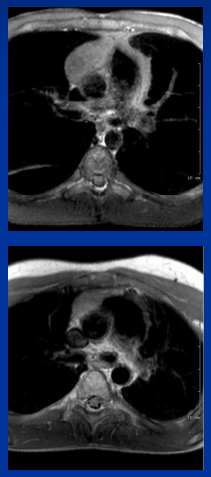
Restaging PET-CT

4,5 years of permanent CR

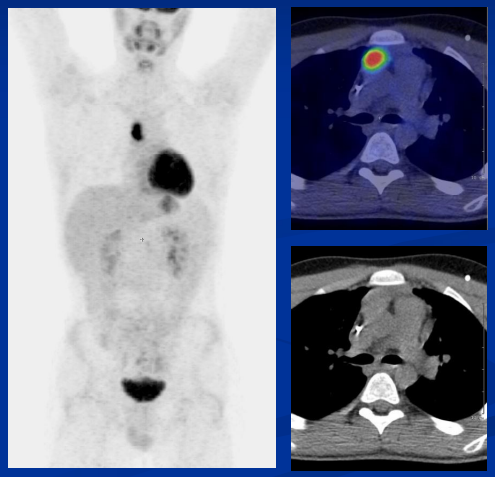
CT: Heim Pál Kórház

Restaging
(Residual terime, NHL (PMBCL)

Staging MR, T1



Restaging MR, T1

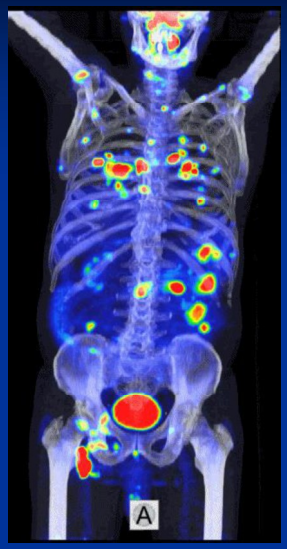


Restaging PET-CT

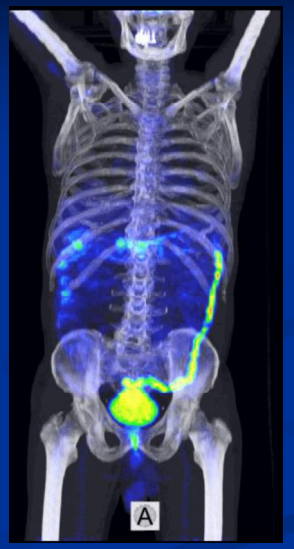
MR: Semmelweis Egyetem, MR Kutató Központ

n.b.: physiological myocardial uptake

Interim PET



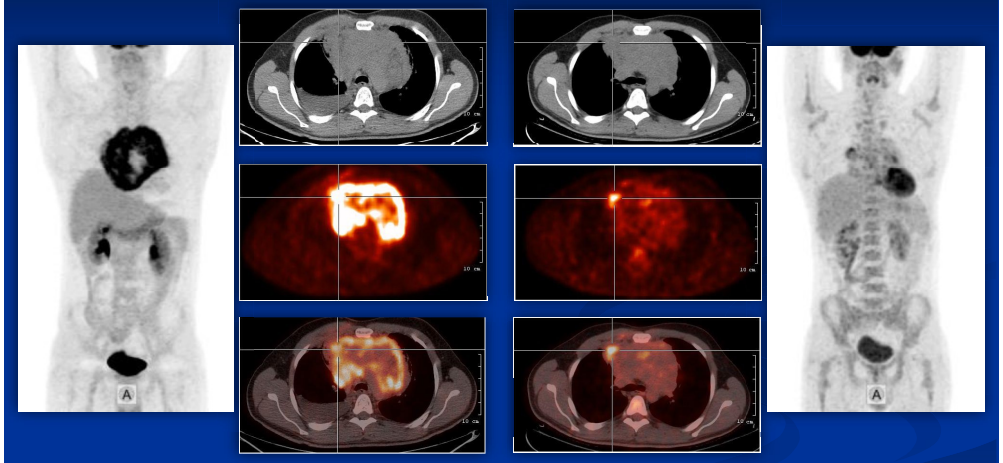
DLBCL: before treatment



After 2 cycles of R-CHOP therapy

n. b.: aspecific intestinal activity

Interim PET



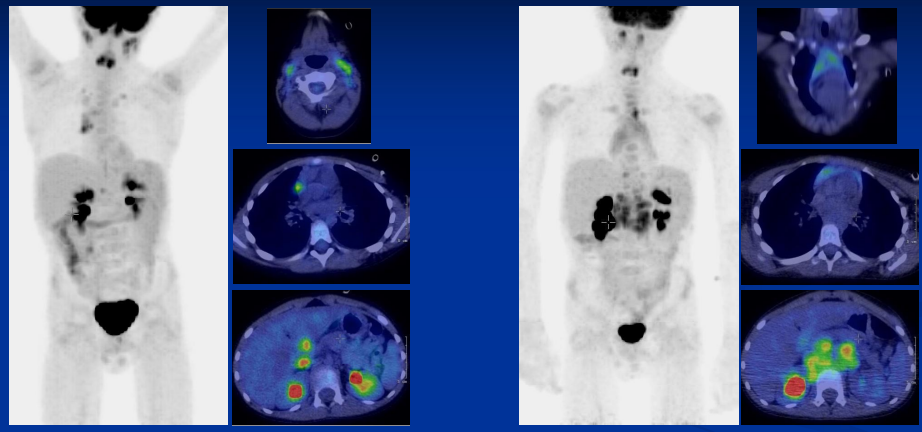
DLBCL: before treatment

After 2 cycles of R-CHOP therapy

n. b.: aspecific intestinal activity

Interim

Restaging



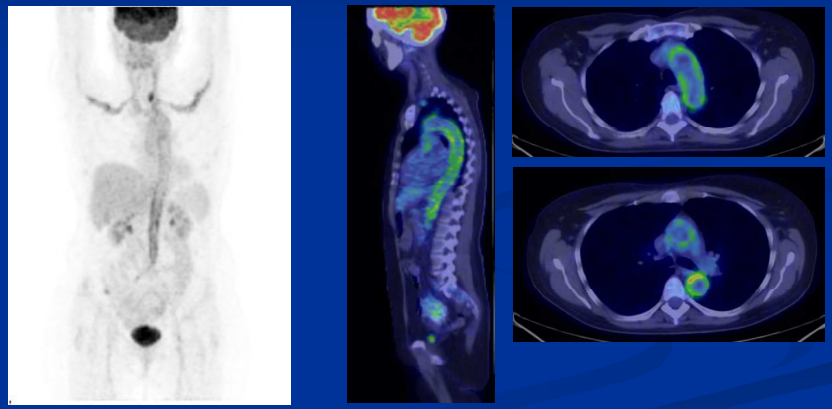
Hodgkin's disease (mixed cellularity type), 5-year-old boy

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

PET radiopharmaceuticals in oncolgy

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

Thank you for your attention!