Clinical Applications of Nuclear Medicine

BIOE 221: Physics and Engineering of Radionuclide based Medical Imaging (RAD221)

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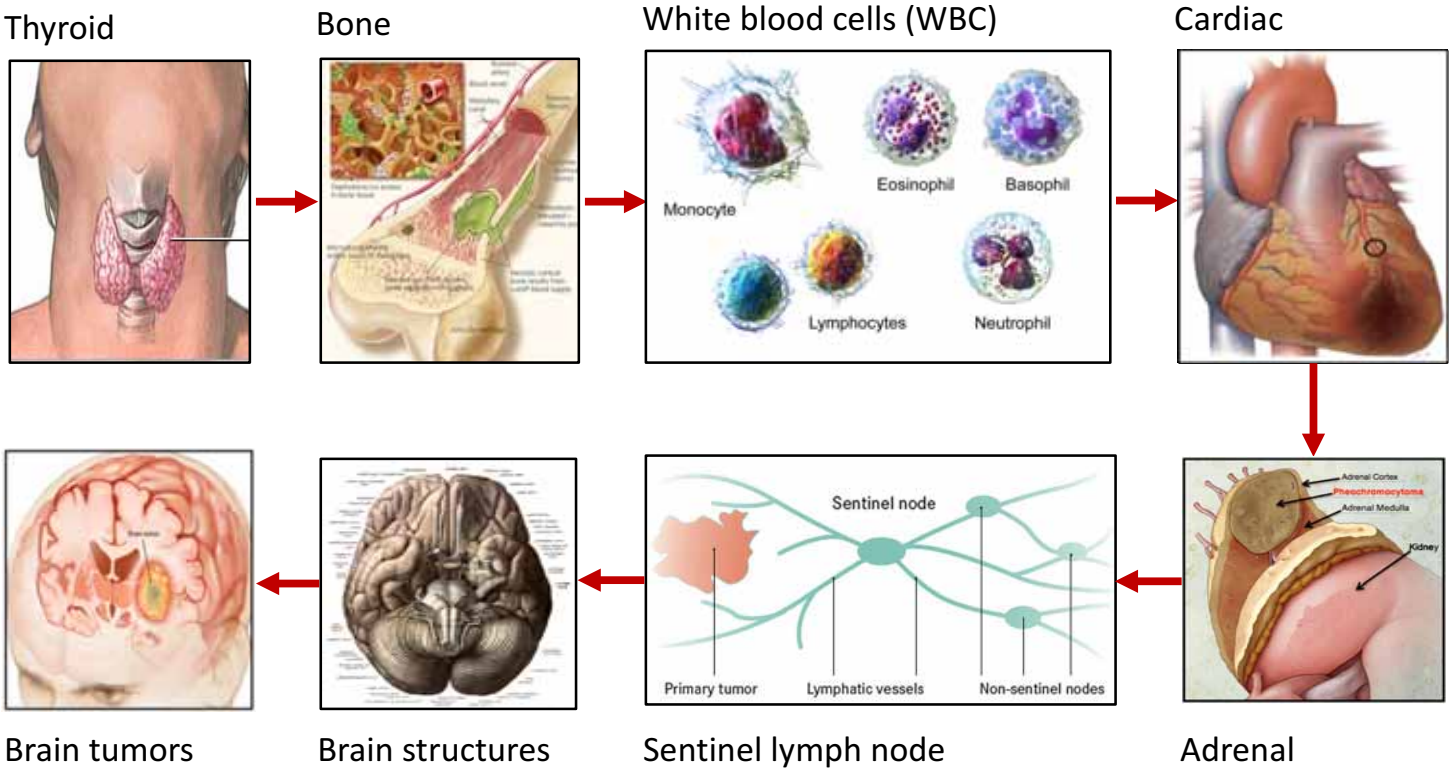
Jan 9th 2018

MIPS
Molecular Imaging
Program at Stanford

Overview of clinical applications

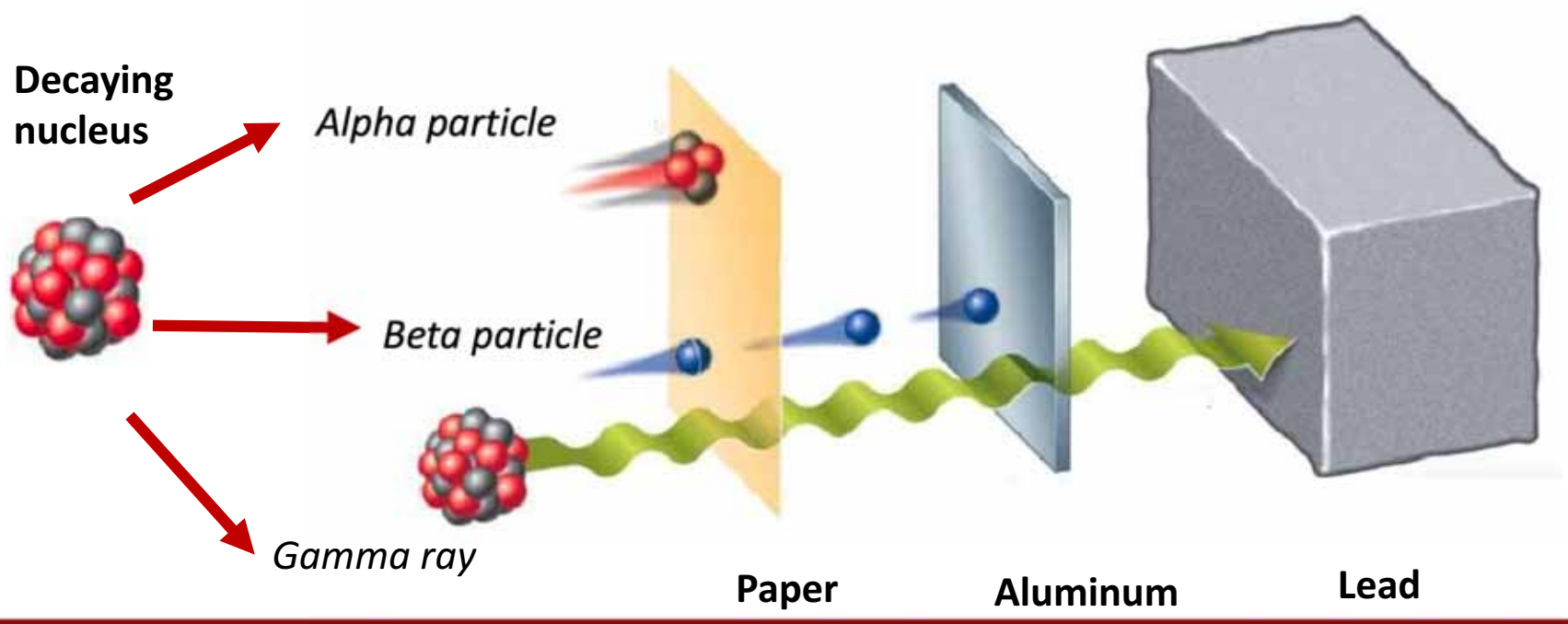


Nuclear Medicine

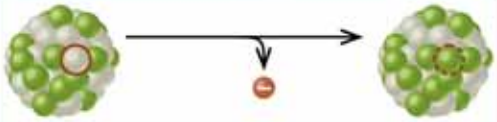
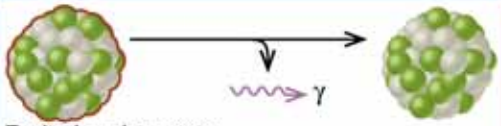
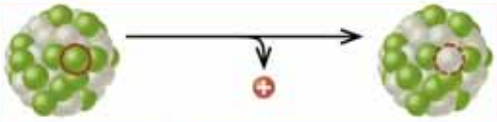
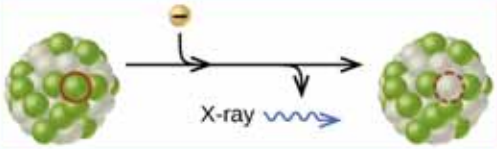
Medical specialty where unsealed **sources of radioactivity** are administered in the form of radiopharmaceuticals are used for **diagnostic and therapeutic purposes**

Radioactivity

Spontaneous decay of unstable nuclei to achieve stability



Radioactivity decay processes

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	${}^{A}_{Z}X \rightarrow {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	${}^{A}_{Z}X \rightarrow {}^{0}_{-1}e + {}^{A}_{Z+1}Y$		A: unchanged Z: increase by 1
Gamma decay	${}^{A}_{Z}X \rightarrow {}^{0}_{0}\gamma + {}^{A}_{Z}Y$		A: unchanged Z: unchanged
Positron emission	${}^{A}_{Z}X \rightarrow {}^{0}_{+1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1
Electron capture	${}^{A}_{Z}X \rightarrow {}^{0}_{-1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1

Proton
Neutron

Radionuclides used for diagnosis and treatment

Radionuclide	Physical half life	Mode of decay	Modality	Clinical Indication
Iodine (^{123}I)	13.3 h	EC	SPECT	Hyperthyroidism, Parkinson's disease, schizophrenia
Fluorine (^{18}F)	109.77 m	β	PET	Parkinson's disease, schizophrenia
Iodine (^{131}I)	8.02 d	β	SPECT	Hyperthyroidism, neuroblastoma, thyroid cancer, NHL, RIT
Phosphorus (^{32}P)	14.29 d	β	SPECT	Cystic craniopharyngioma, PVNS, polycythemia vera
Strontium (^{89}Sr)	50.57 d	β	SPECT	Painful bone metastasis
Yttrium (^{90}Y)	64.10 h	β	PET/SPECT	Hepatic metastasis, PVNS, RIT, NHL
Tin-177m (^{177m}Sn)	14.00 d	IT	SPECT	Bone tumor treatment
Samarium (^{153}Sm)	1.93 d	β	SPECT	Painful bone metastasis, synovitis
Erbium (^{169}Er)	9.40 d	β	PET	Synovitis
Rhenium (^{186}Re)	3.78 d	EC β	PET	Painful bone metastasis Painful arthiritis
Rhenium (^{188}Re)	16.98 h	β	SPECT	Painful bone metastasis RIT, rheumatoid arthiritis
Radium (^{223}Ra)	11.43 d	α	SPECT	Bone metastasis

IT; isomeric transition, EC; electron capture, NHL; non-Hodgkin lymphoma, PVNS; pigmented villonodular synovitis, RIT; radioimmunotherapy

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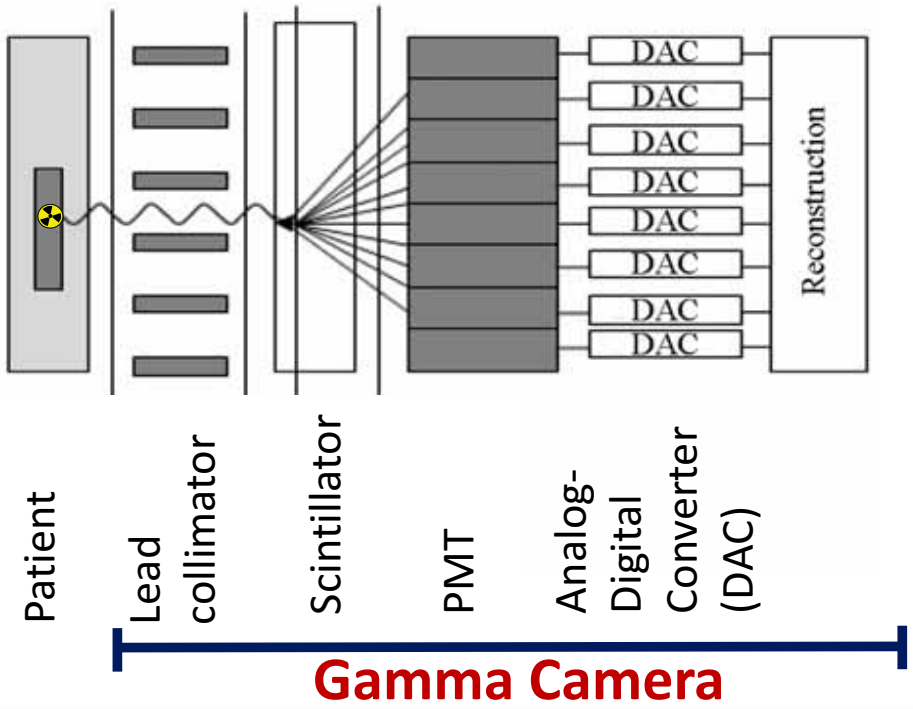
Modalities used in clinical nuclear medicine

1. 2D Planar Scintigraphy



2D planar scintigraphy single headed gamma cameras

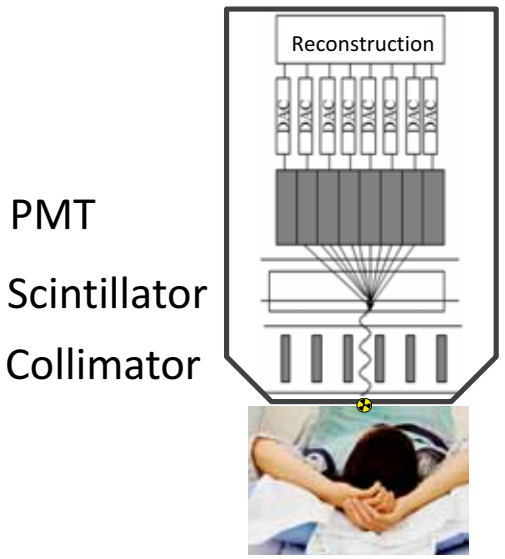
Mediso Planar line, TH and AP-R (HR/C) gamma cameras

*Mi*E, syngula scintron planar gamma camera, 40 cm FOV

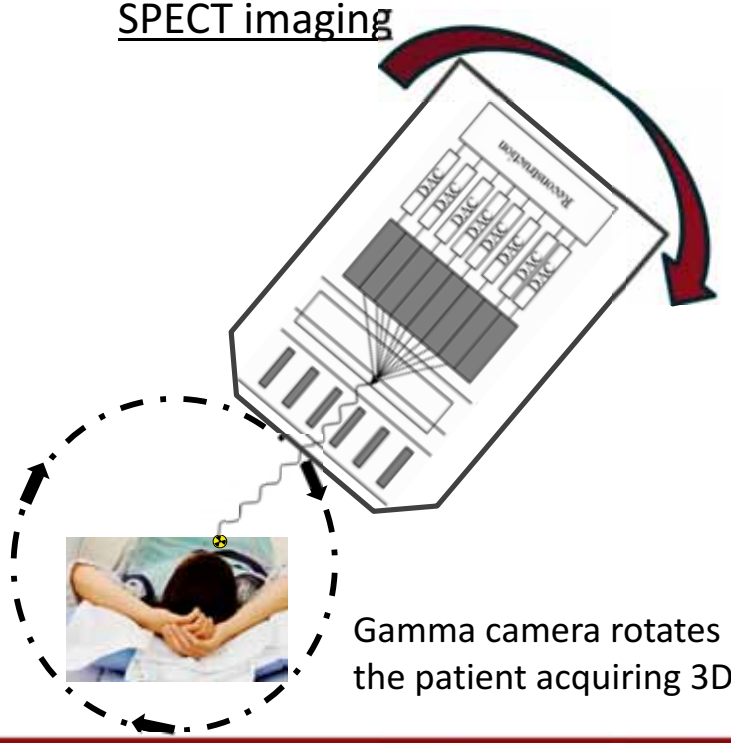
Modalities used in clinical nuclear medicine

2. Single Photon Emission Computed Tomography (SPECT)

Planar imaging

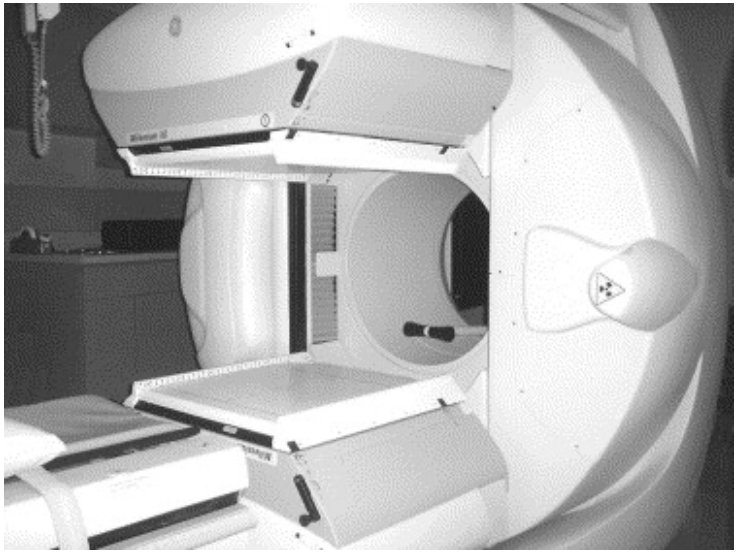


SPECT imaging



Gamma camera rotates around the patient acquiring 3D data

Single Photon Emission Computed Tomography (SPECT)

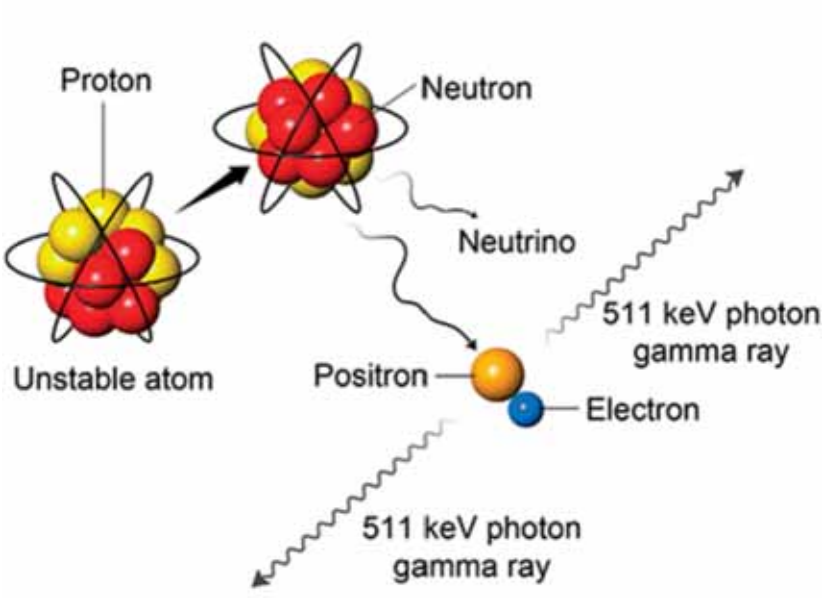


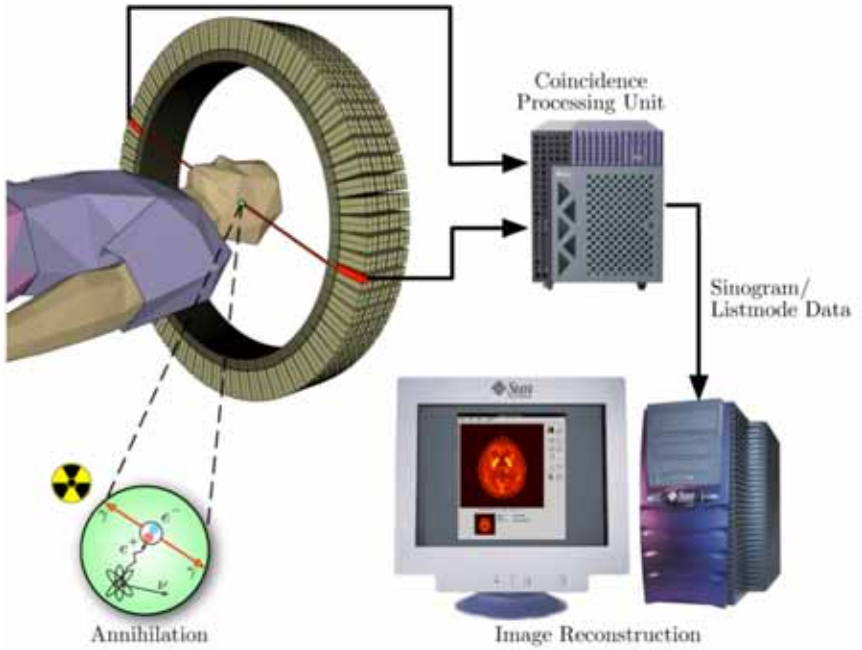
GE Discovery VG Hawkeye system
The first commercial SPECT/CT system (1999)

G-SPECT, MILabs' high performance clinical SPECT system, Innovation of the Year Award (2015)

Modalities used in clinical nuclear medicine

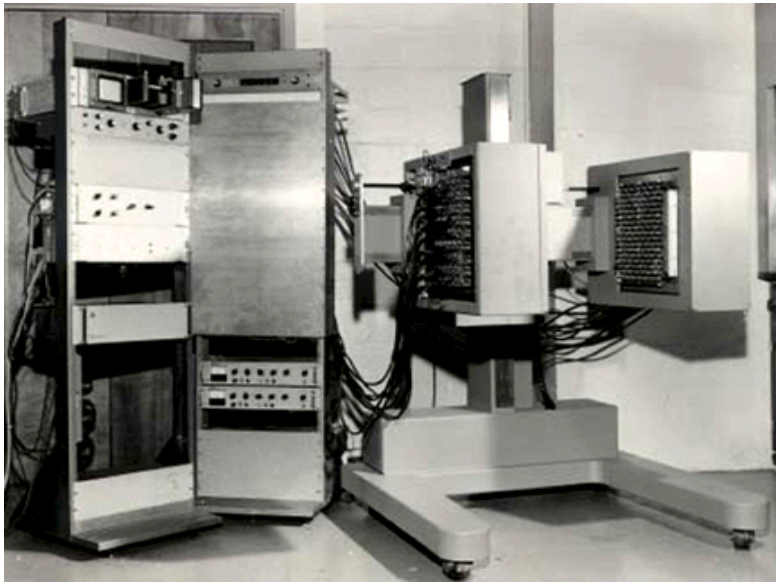
3. Positron Emission Tomography (PET)





Elsayes KM & Oldham SA *Introduction to Diagnostic Radiology* (2015)

Positron Emission Tomography (PET)



PC-1 First PET imaging device
(1968-71)

Discovery PET/CT 610, absolute sensitivity of
10.0 cps/kBq, GE Healthcare (2012)

Advances in Nuclear Medicine

Henri Becquerel
1896
Discovery of radioactivity

Marie Sklodowska Curie
1898
Discovery of radium

Georg de Hevesy
1913-23
Application of radiotracers in plant studies

Blumgart and Weiss
1927
Blood flow measurements in humans

Geiger and Müller
1928
First Geiger counter

Ernest O. Lawrence
1932

Benedict Cassen
1951
First rectilinear scanner

Hal Oscar Anger
1958
Development of the gamma camera

Kuhl and Edwards
1963
SPECT

Phelps Hoffman Ter-Pogossian
1973
PET

Nuclear Medicine

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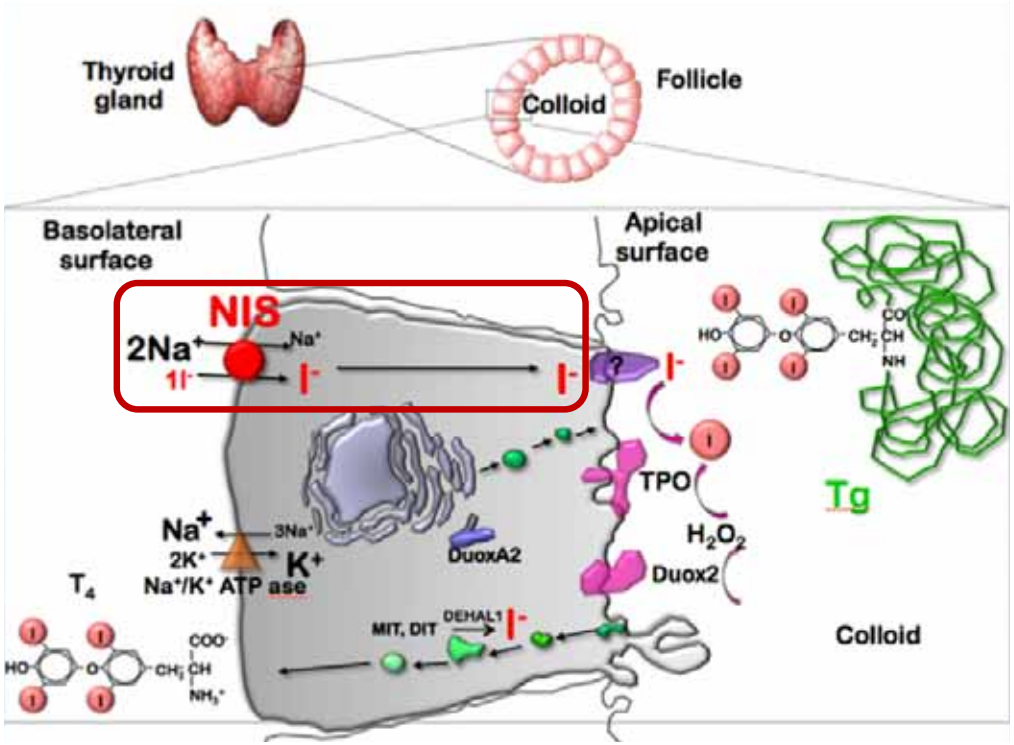
Thyroid Scintigraphy

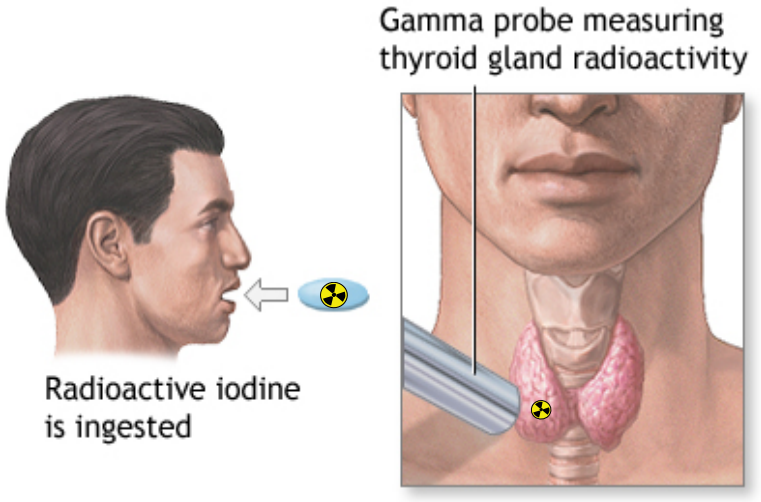


Portulano *et al Endocr Rev* (2014)

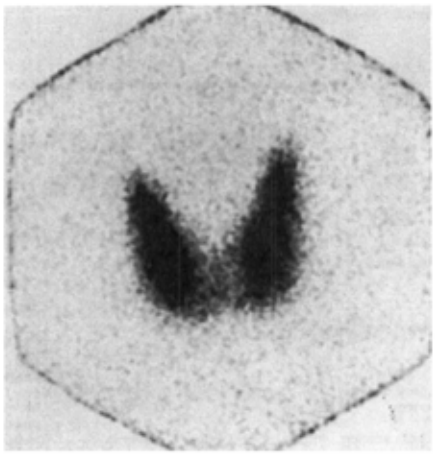
Radionuclides

- ^{131}Iodine
- ^{123}Iodine
- [^{99m}Tc]pertechnetate

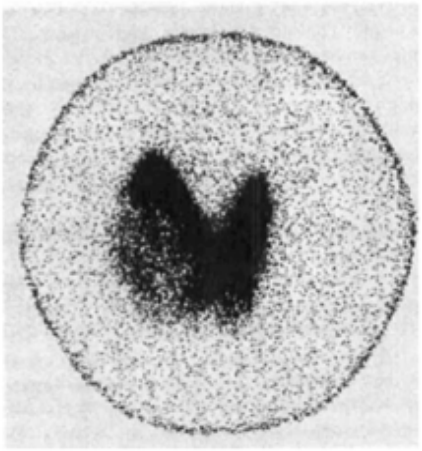
Detection of thyroid disease



Healthy



Graves disease and hypo-functioning nodule



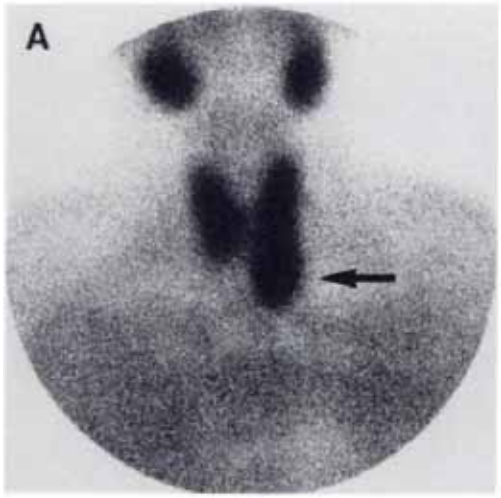
Scintiscans 3h post oral dose ^{123}Iodine (200 µCi)

Mello & McDougall. *Crit Rev Clin Lab Sci* (1992)

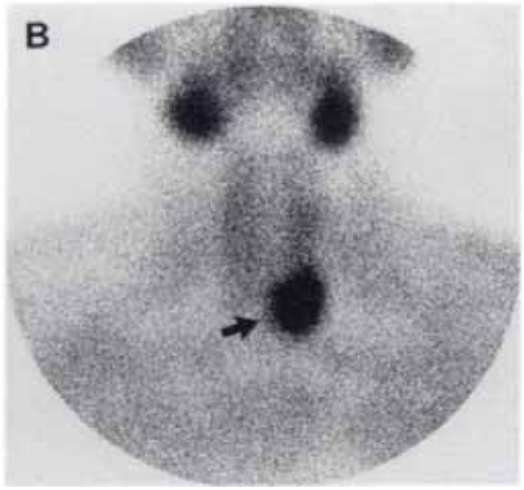
Preoperative localization of parathyroid adenomas

Patient with hyperparathyroidism

Early phase (15 min)



Late phase (2hr)



Intravenous dose of [^{99m}Tc]Sestamibi (20 -25 mCi)

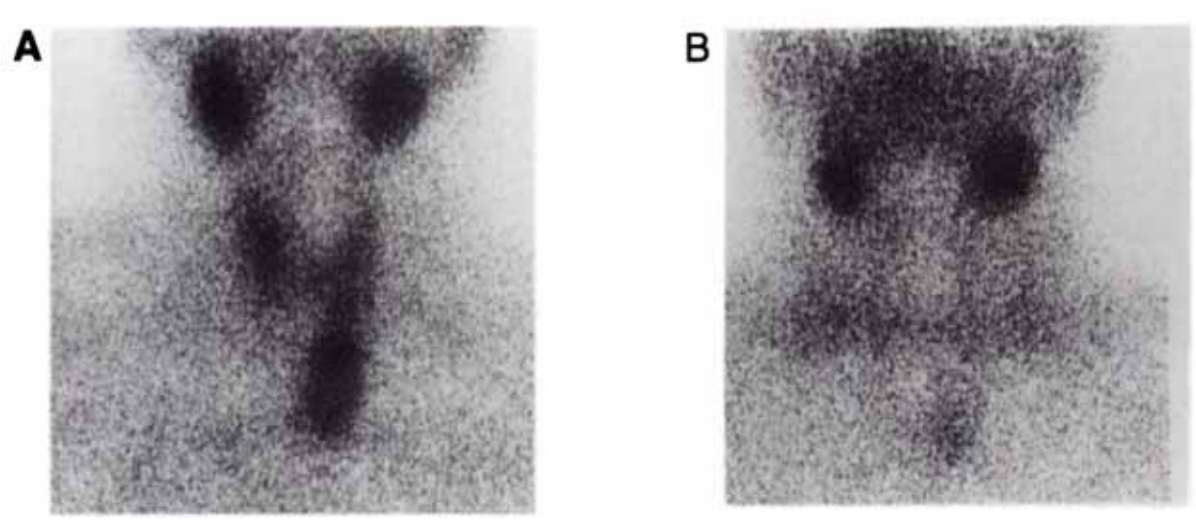
Taillefer *et al J Nucl Med* (1992)

Detection of parathyroid adenomas

Patient with a history of hypertension presented high serum calcium levels

Early phase

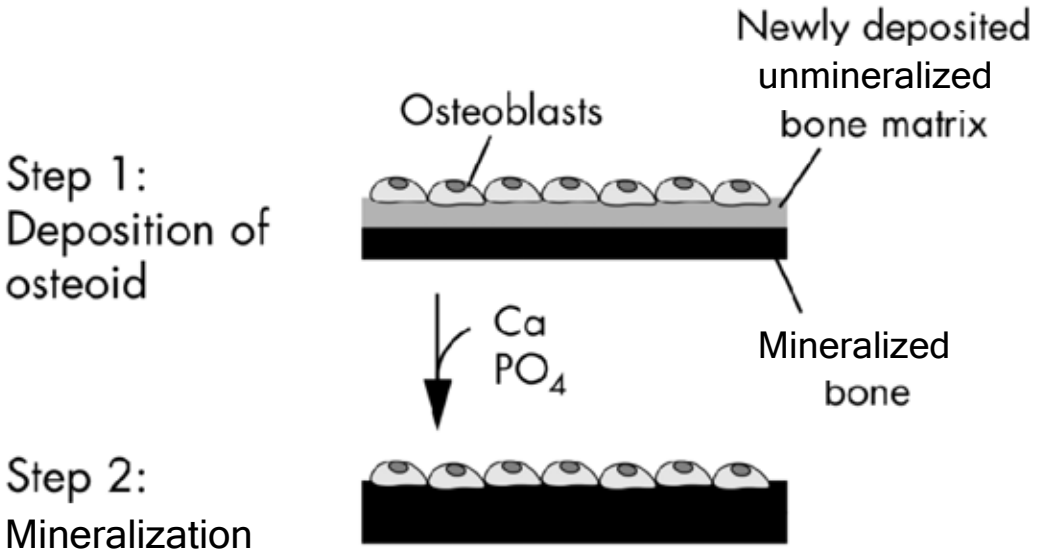
Late phase (3hr)



Intravenous dose of [^{99m}Tc]Sestamibi

Benard *et al J Nucl Med* (1995)

Bone scintigraphy to detect osteoblastic activity



Rauch & Schoenau *Arch Dis Child Fetal Neonatal Ed* (2002)

Radionuclides

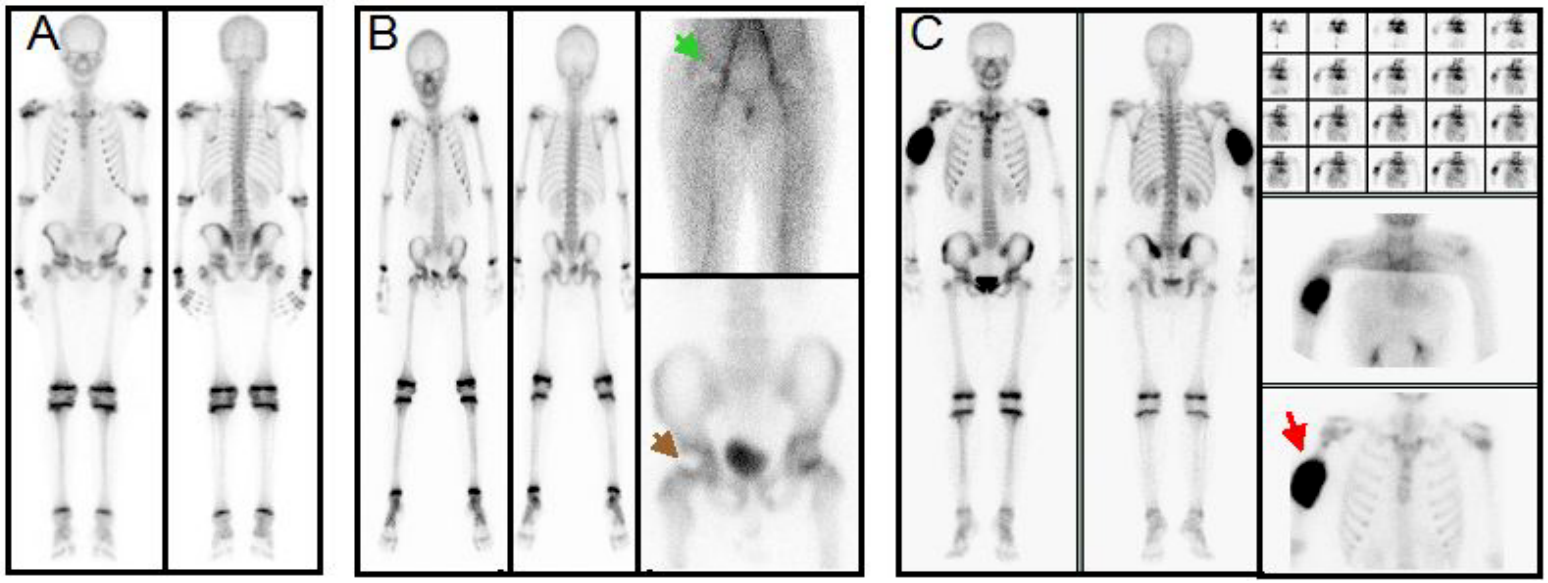
- [^{99m}Tc]methylene diphosphonate ([^{99m}Tc]MDP)
- [^{99m}Tc]medronate
- [^{18}F]Sodium Fluoride

Visualizing avascular necrosis and osteosarcoma

Healthy

Avascular necrosis

Osteosarcoma

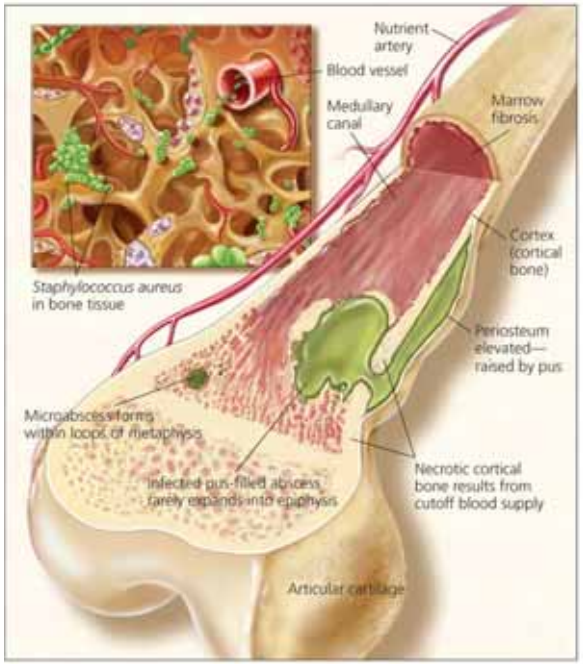


Recommended dose for children is 9.3 MBq/kg(0.25mCi/kg)

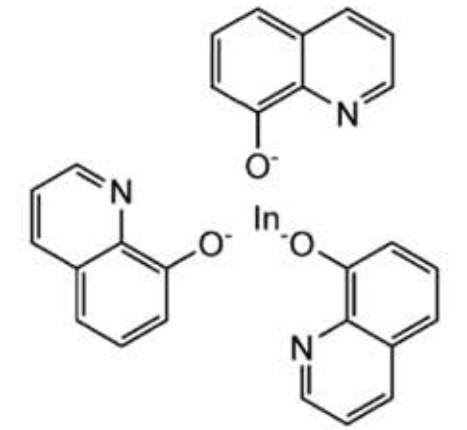
Moriguchi *et al Clinical Application of Nuclear Medicine* Ch 3 (2013)

Immunoscintigraphy for soft tissue infections

Osteomyelitis



Lydia V Kibiuik *CMI* (2010)



Radionuclides

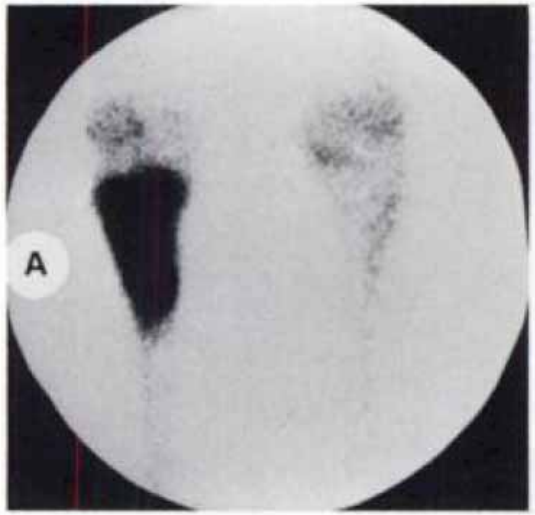
- ^{111}Indium-oxine
- ^{99m}Tc-HMPAO (hexamethylpropyleneamine oxime)

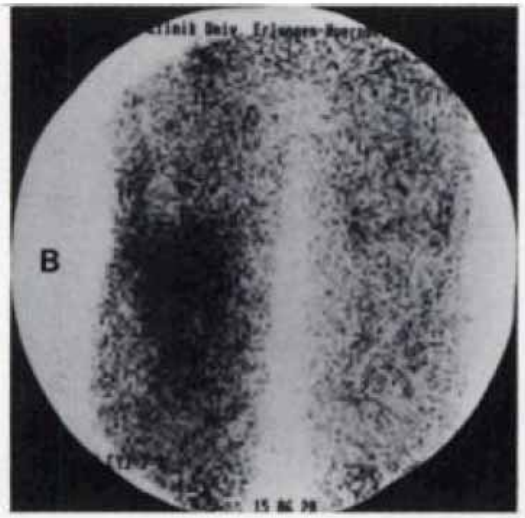
Detection of osteomyelitis using bone and immunoscintigraphy

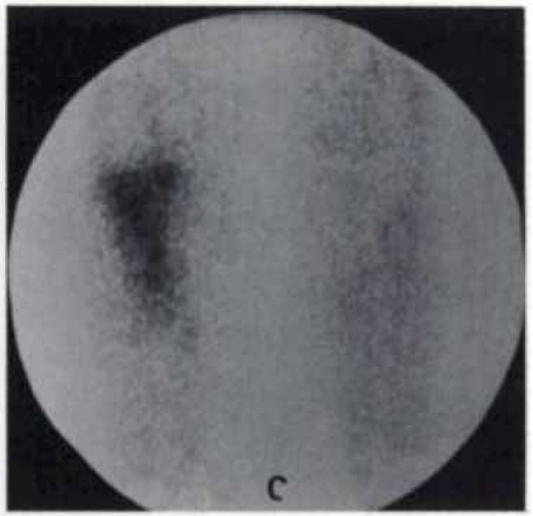
Bone

White blood cell (WBC)

WBC (mAb fragment)







[^{99m}Tc]MDP (750 MBq)

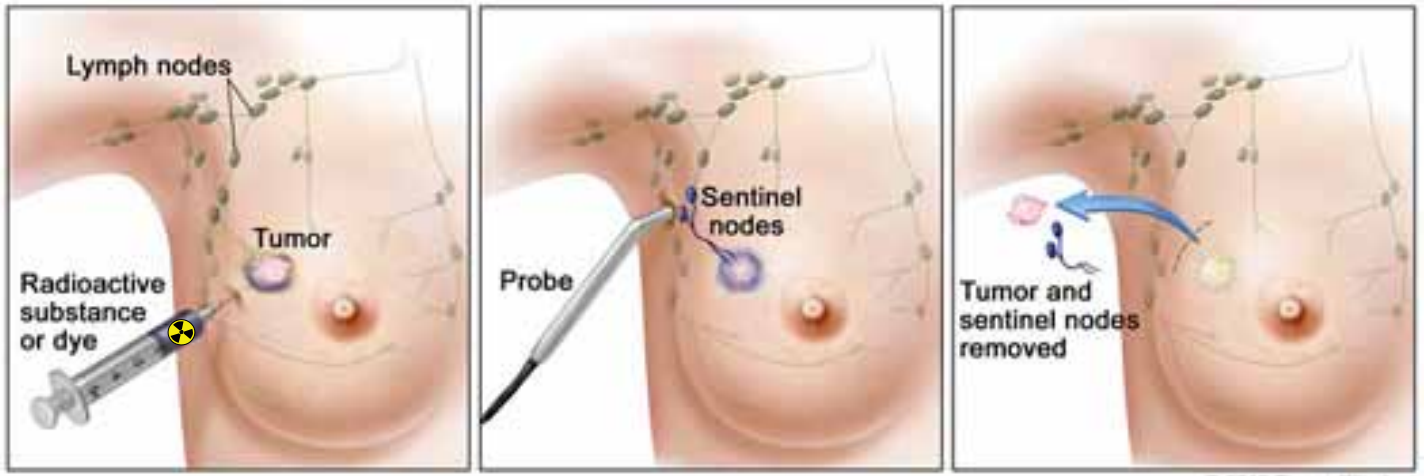
WBC labeled with
[^{111}In]oxine (20 MBq)

mAb Fab' fragment (1.25 mg) labeled with
[^{99m}Tc]pertechnetate (1000-1500 MBq)

Becker *et al*. *J Nucl Med* (1994)

Lymphoscintigraphy for sentinel lymph node mapping

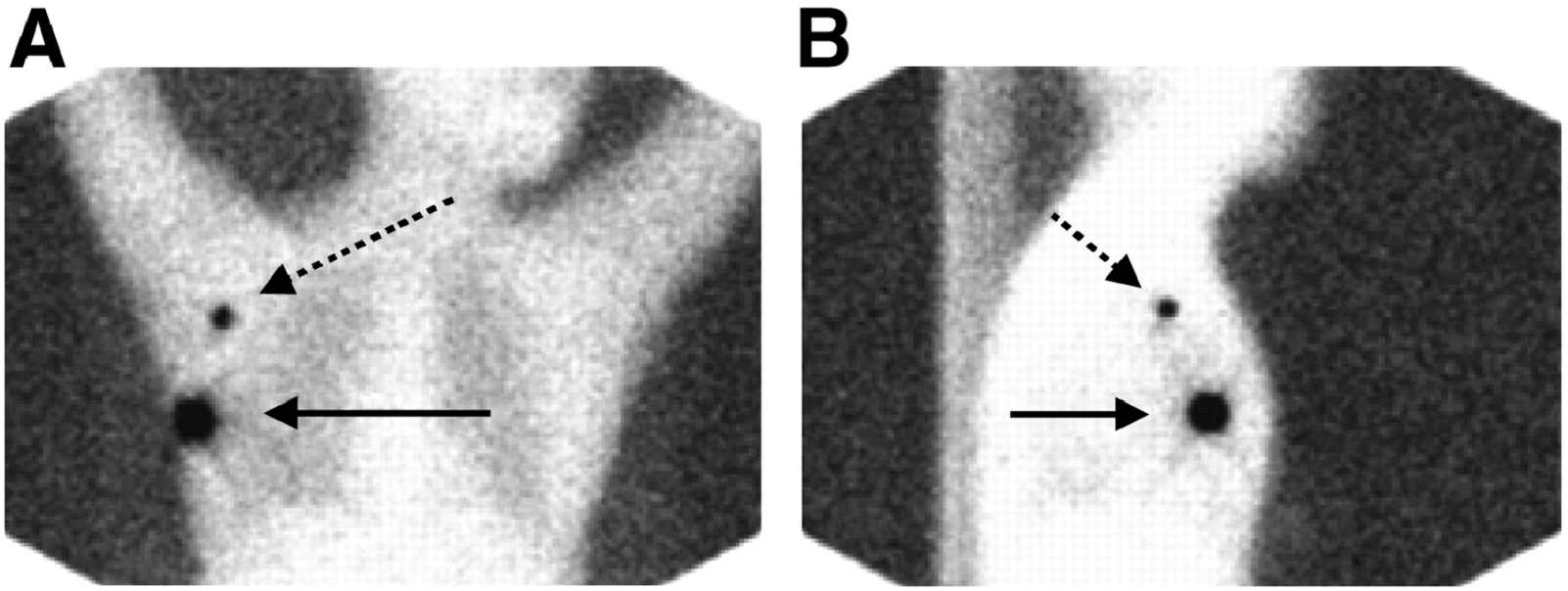
Radiolabel injection | Imaging | Therapeutic Intervention



[^{99m}Tc]sulfur-colloid (TSC)
[^{99m}Tc]tilmanocept (TcTM)

Wilson T. *National Cancer Institute* (2010)

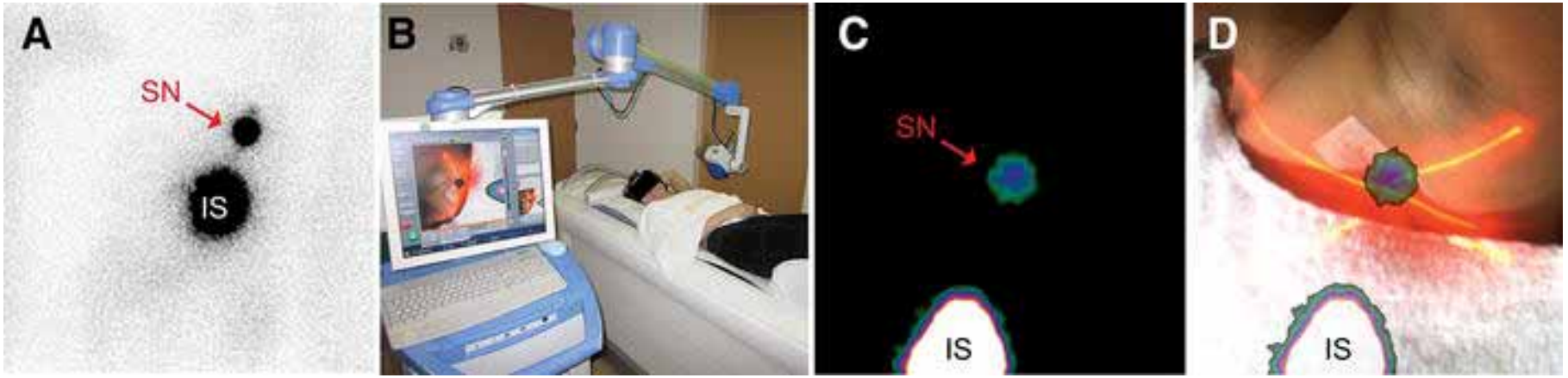
Breast lymphoscintigraphy



Lymphoscintigraphic images 30 min post intradermal TSC (0.1-0.5 mCi) injection

Pandit-Taskar *et al*. *J Nucl Med* (2006)

Radio-guided surgery using hybrid gamma-optical imaging



ICG - fluorescent dye
[^{99m}Tc]nanocolloid

Portable gamma camera

Optical and gamma-imaging

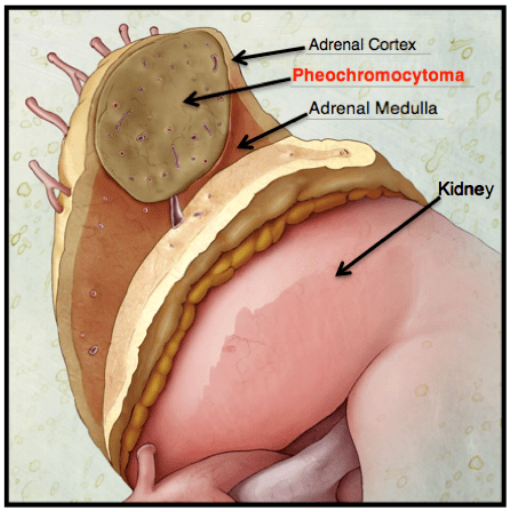
Fused image

IS – Injection site, SN – Sentinel node

Hellingman *et al Clin Nucl Med* (2016)

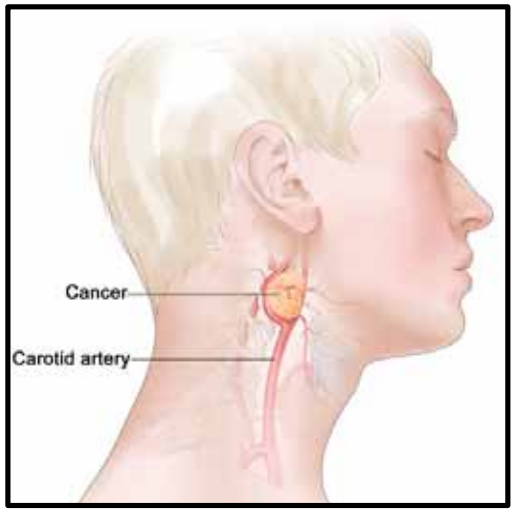
Meta[^{131}I]iodobenzylguanidine (MIBG) therapy for neuroendocrine tumors

Pheochromocytoma (PHEO)
Adrenal gland tumor



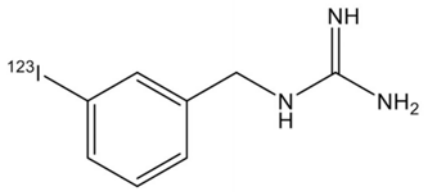
Feili A *Medical Institution*

Paraganglioma (PGL) of the head and neck

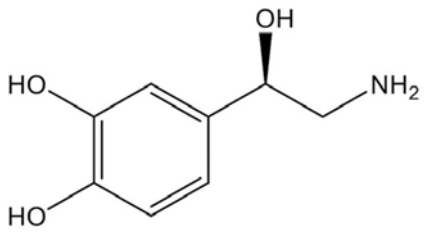


Wilson T 2013

<u>Radionuclide</u>



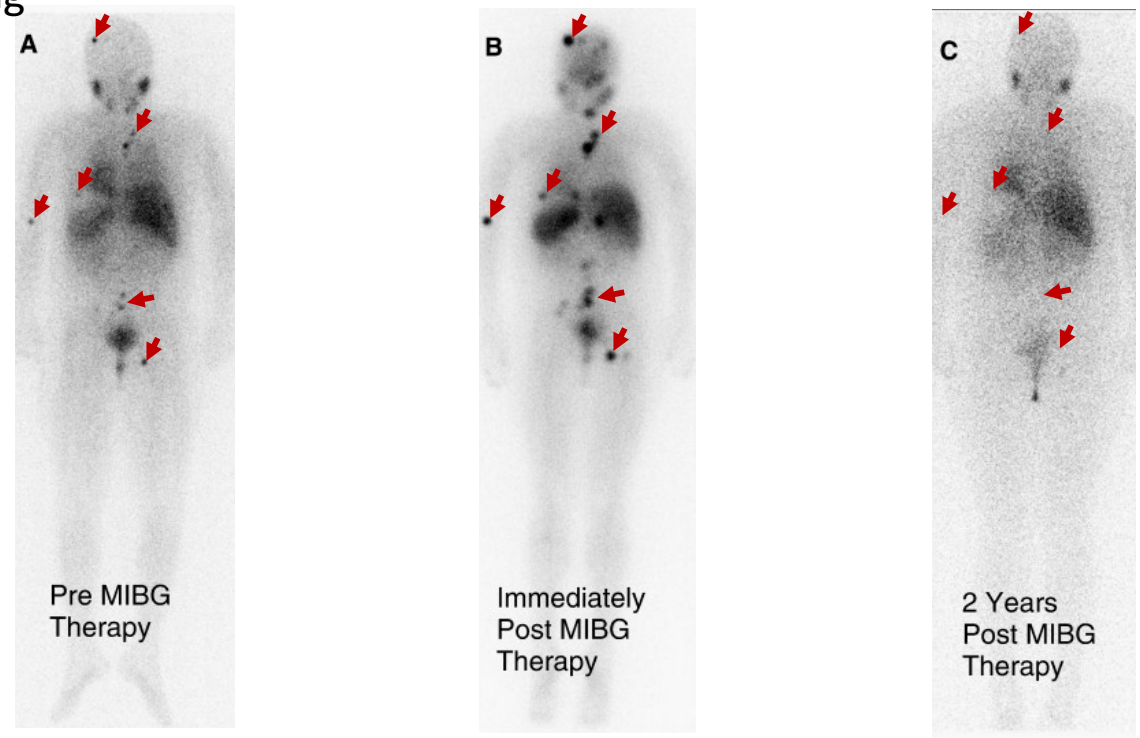
^{123}I-MIBG



Norepinephrine

[^{131}I]MIBG therapy in pediatric PHEO/PGL metastasis

SPECT imaging

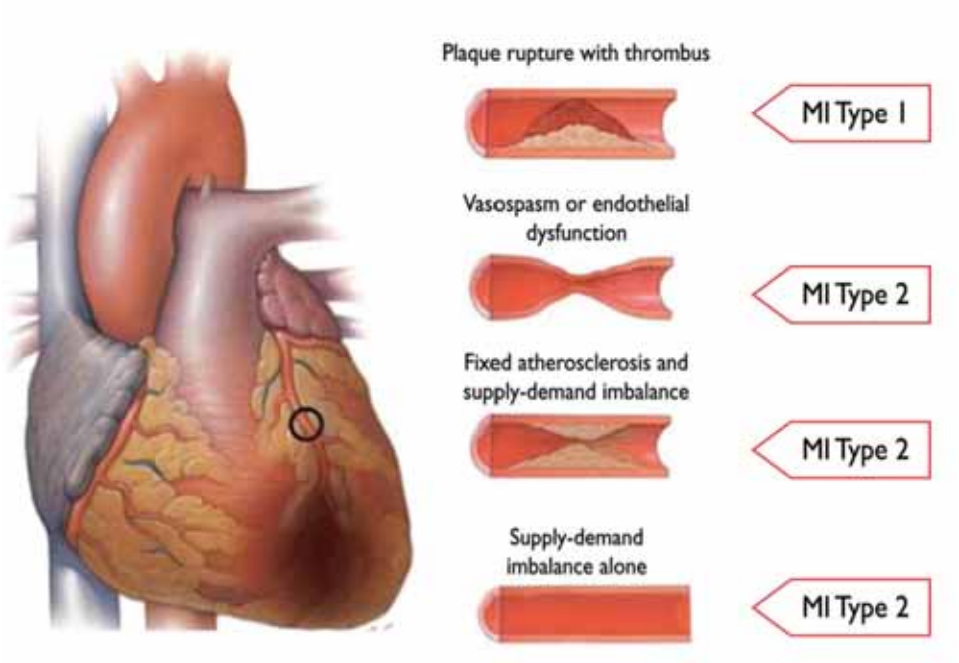


Intravenous administration of 860 mCi of ^{131}I-MIBG over 2h

Fitzgerald *et al Ann N Y Acad Sci* (2006)
Goldsby and Fitzgerald *J Nucl Med Biol* (2008)

Myocardial perfusion imaging for ischemia detection

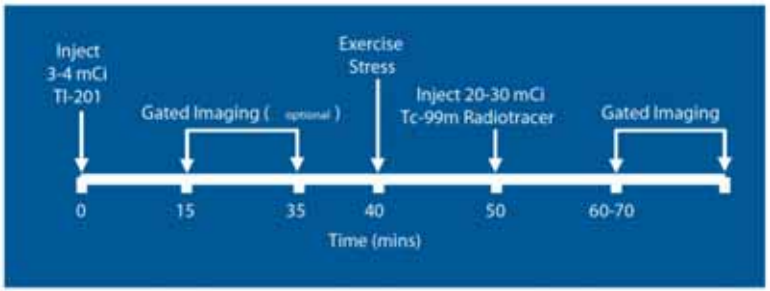
Ischemia



Thygesen *et al Circulation* (2012)

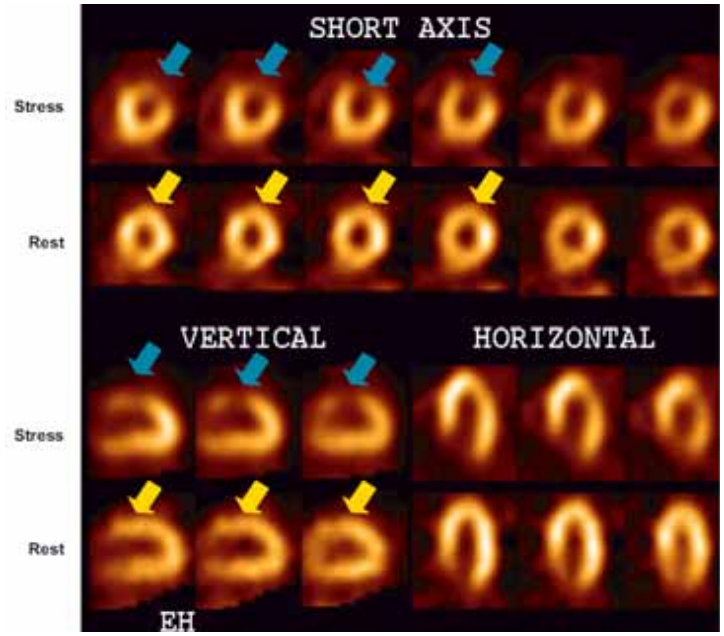
Radionuclides

- ^{201}Thallium chloride
- [^{99m}Tc]sestamibi (cardiolite)
- [^{99m}Tc]tetrofosmim (myoview)

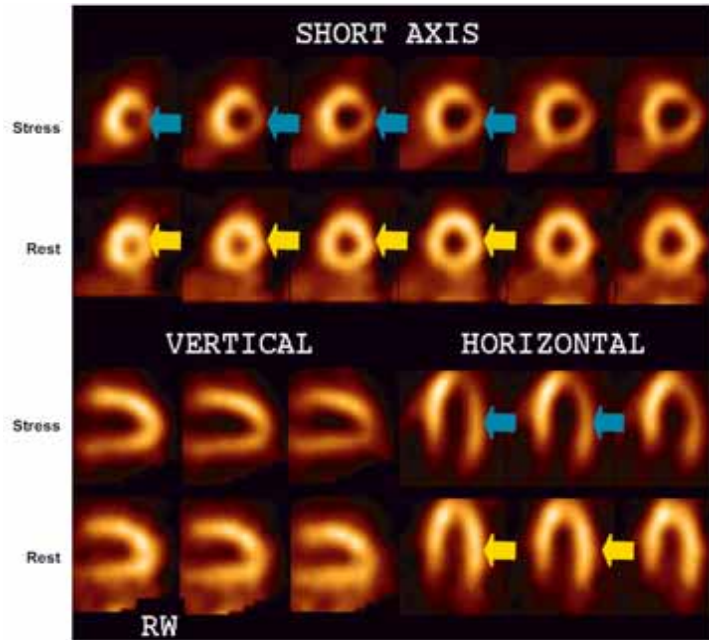


Dual Isotope ^{201}Tl/ ^{99m}Tc cardiac SPECT imaging

Case study I: patient with a clear anterior defect



Case study II: patient with a lateral defect

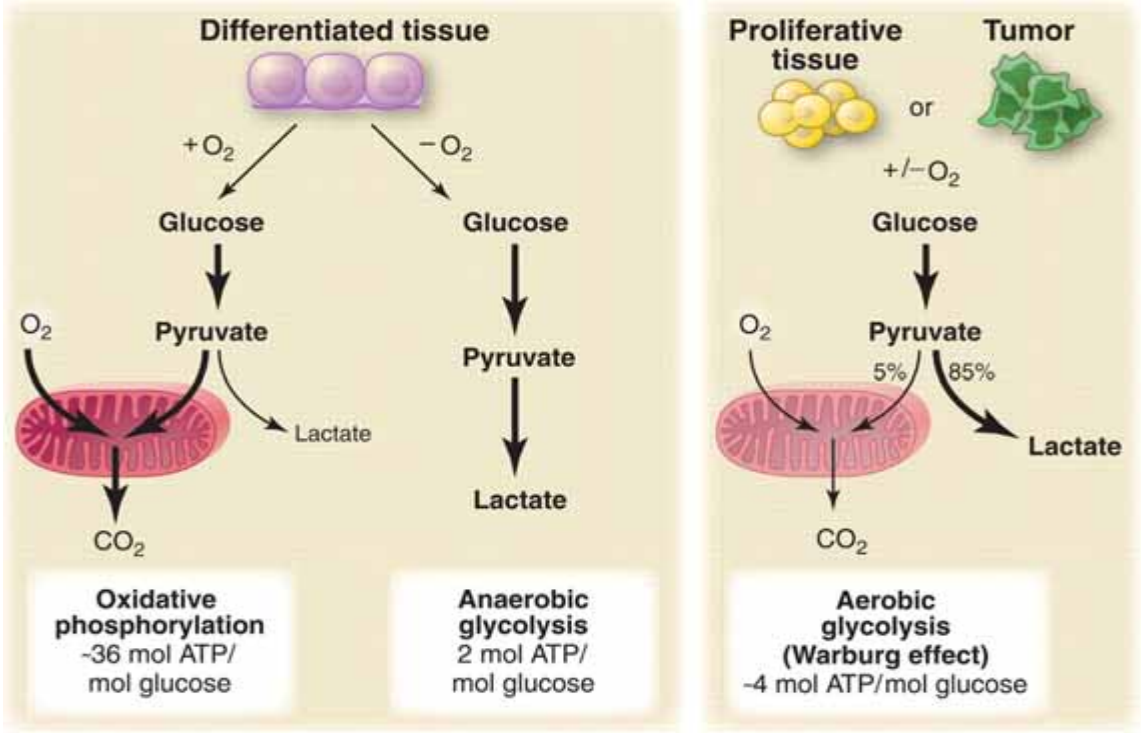


Stress - ^{99m}Tc, energy window: 126-43 keV

Rest - ^{201}Tl, energy window: 68 -77 keV

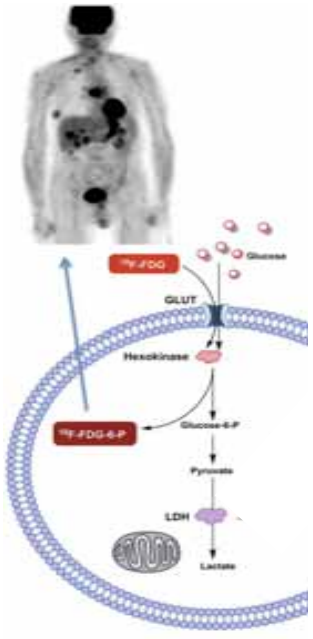
Cerqueira and Ferreira. Clin Nucl Med. Ch 4 (2007)

Utilizing metabolic reprogramming to detect tumor cells



Heiden *et al Science* (2009)

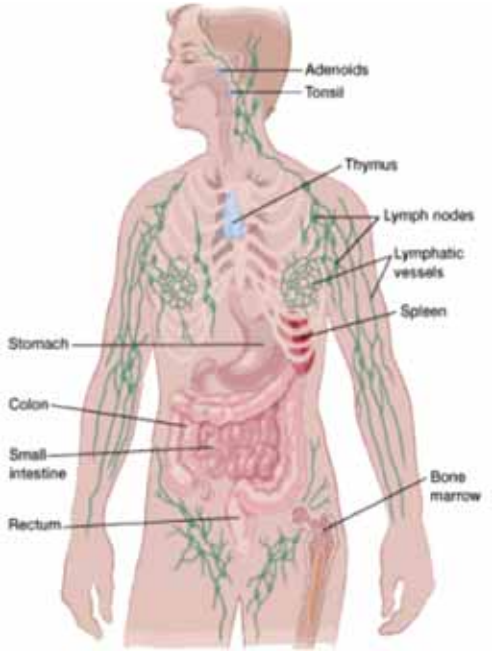
[^{18}F]FDG PET imaging



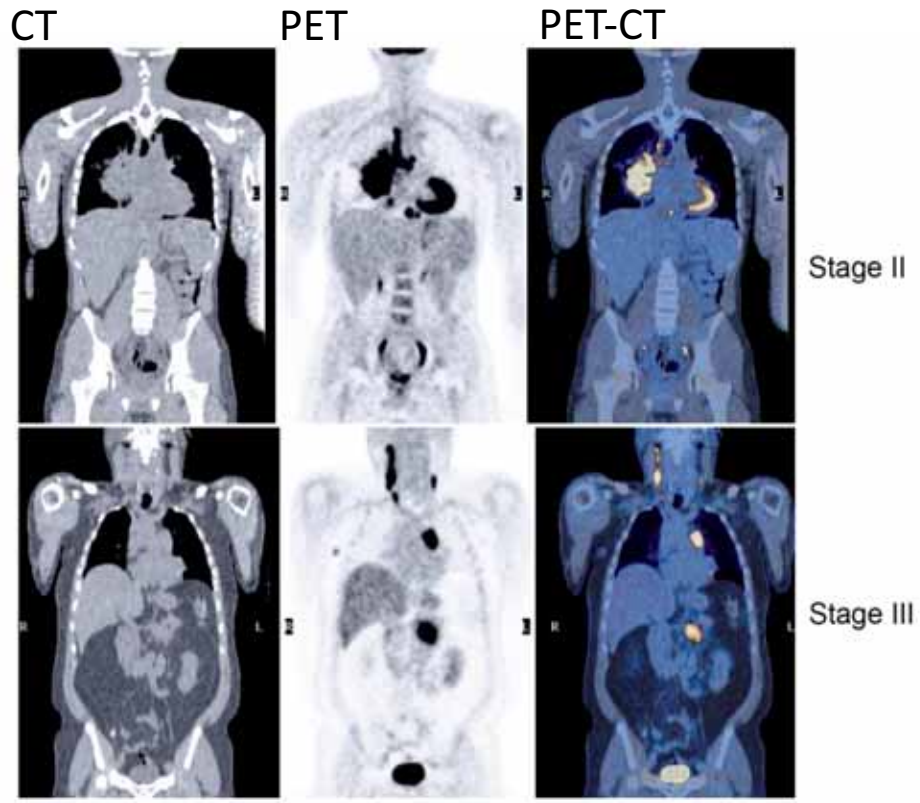
Gutte *et al J Nucl Med* (2015)

Imaging non-Hodgkin lymphoma using [^{18}F]FDG PET

Lymphatic system



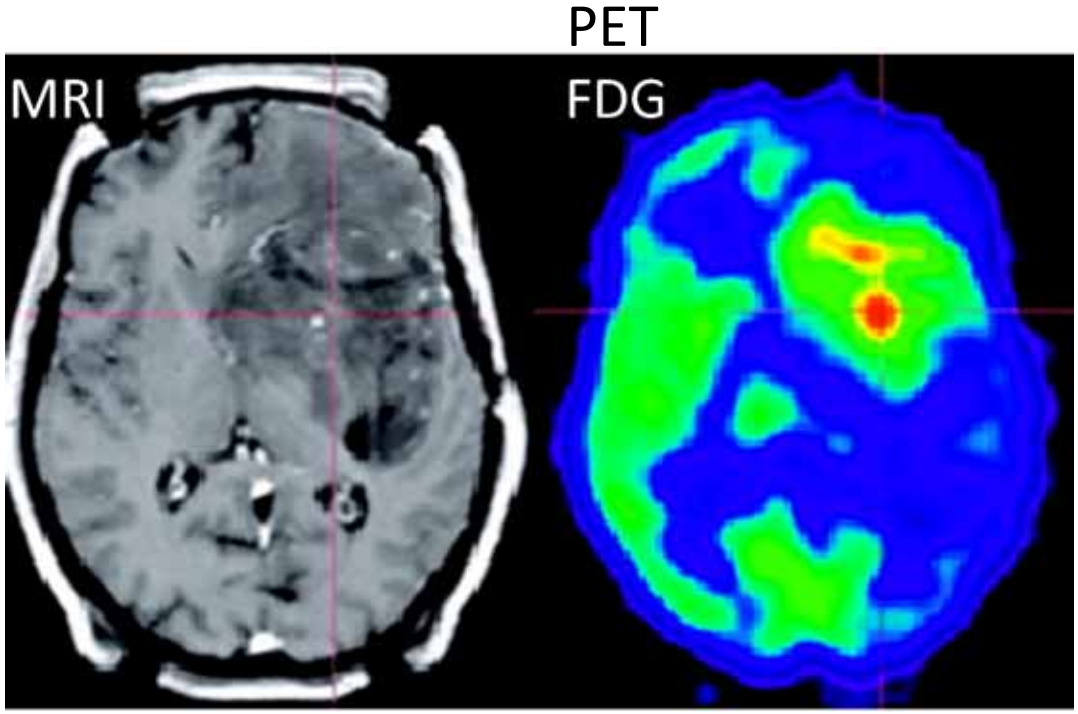
American Cancer Society (2017)



Kostakoglu *et al Clin Nucl Med* Ch 16 (2007)

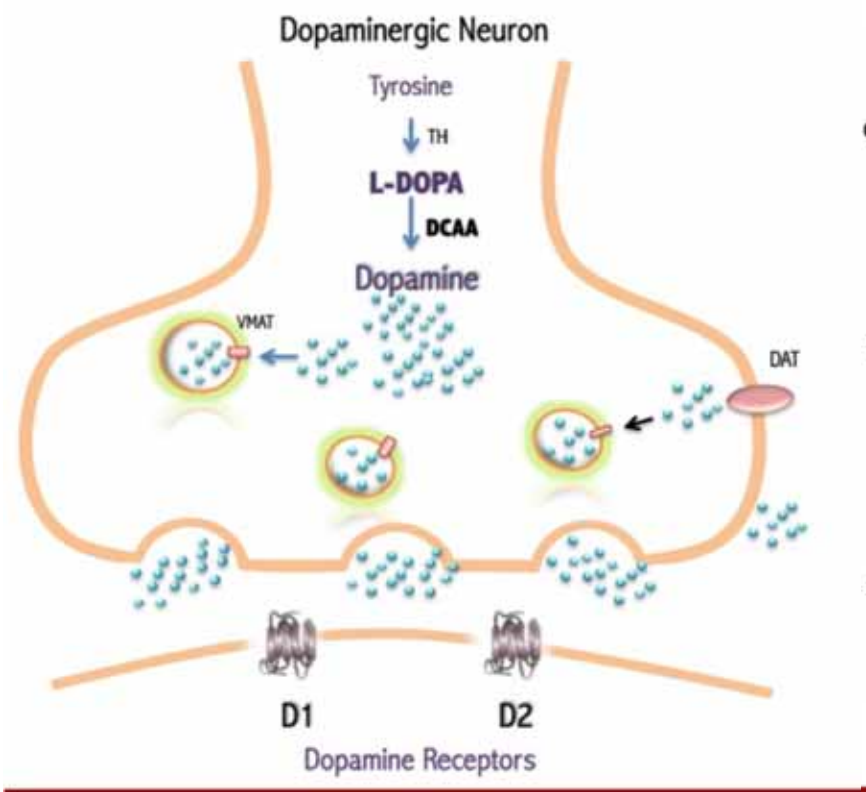
Imaging malignant glioma using [^{18}F]FDG PET

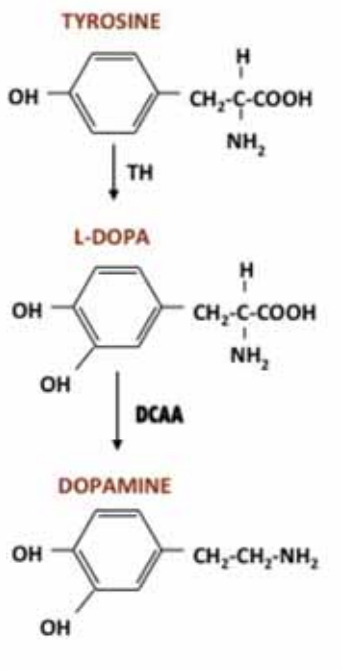
Patient with anaplastic astrocytoma



Keunen *et al Adv Drug Deliv Rev* (2014)

Detection of dopaminergic neuronal degeneration

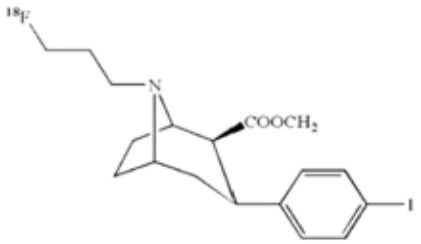




Radionuclide

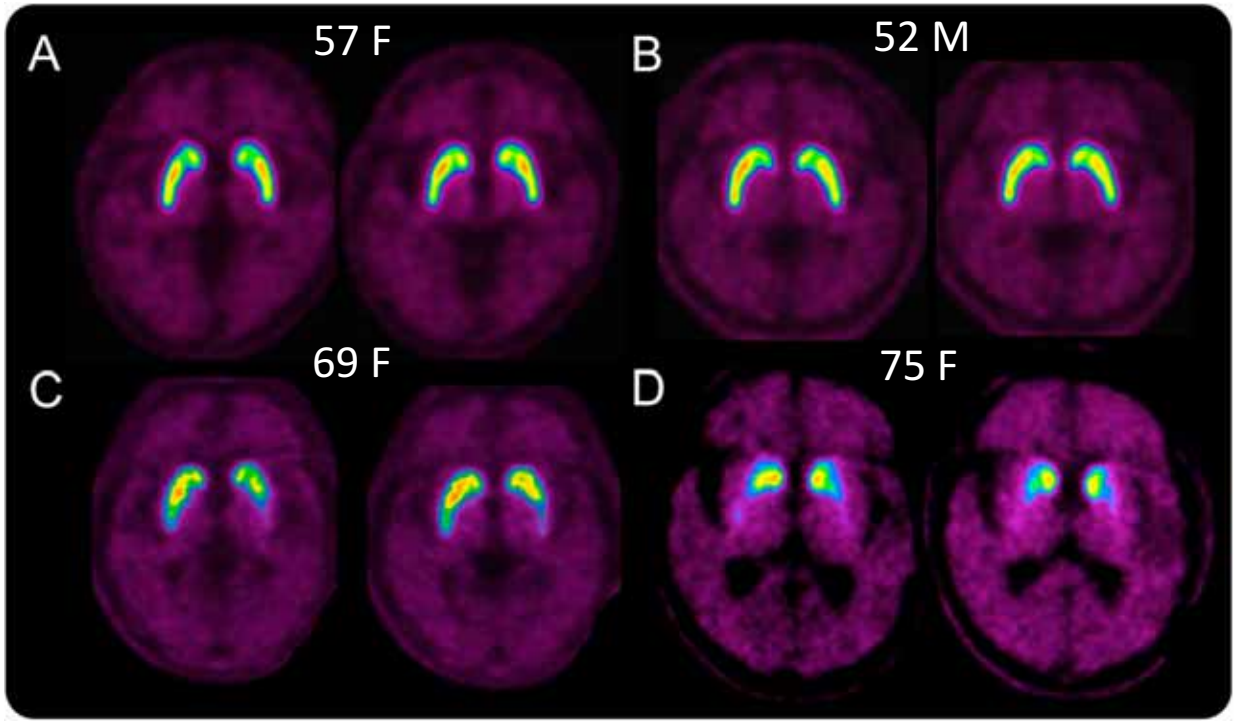
^{18}F-radiolabeled N-(3-fluoropropyl) 2β-carboxymethoxy-3β-(4-iodophenyl) nortropane

([^{18}F]FP-CIT/DaTSCAN)



Diagnosing presynaptic dopaminergic deficits using PET

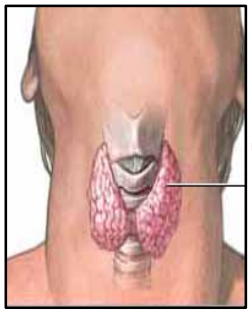
Patients with liver cirrhosis and concurrent parkinsonism



Yang *et al NeuroToxicology* (2017)

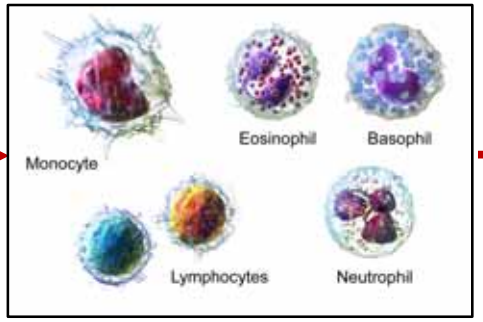
Clinical Applications of Nuclear Medicine

Thyroid

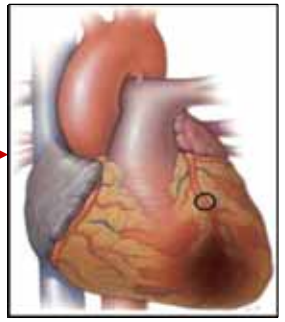


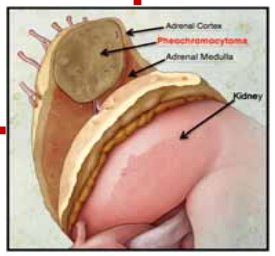
Bone

White blood cells (WBC)

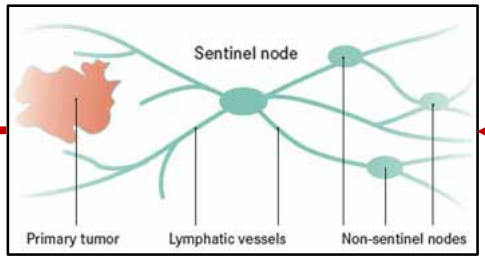


Cardiac





Adrenal



Sentinel lymph node

Brain structures

Brain tumors

Further reading

Mansi L, Lopci E, Cuccurullo V and Chiti C. Clinical Nuclear Medicine in pediatrics (2016)

Cherry S, Soreson J and Phelps M. Physics in Nuclear Medicine 4th edition (2012)

Biersack H and Freeman L. Clinical Nuclear Medicine (2007)

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