EUROPEAN SOCIETY OF RADIOLOGY

eBook for Undergraduate Education in Radiology

CHAPTER: Nuclear Medicine

Preface

Undergraduate teaching of radiology in Europe is provided according to national schemes and may vary considerably from one academic institution to another. Sometimes, the field of radiology is considered as a "cross-cutting discipline" or taught within the context of other clinical disciplines, e.g., internal medicine or surgery.

This e-book has been created in order to serve medical students and academic teachers throughout Europe to understand and teach radiology as a whole coherent discipline, respectively. Its contents are based on the *Undergraduate Level of the ESR European Training Curriculum for Radiology* and summarize the so-called ***core elements*** that may be considered as the basics that every medical student should be familiar with. Although specific radiologic diagnostic skills for image interpretation cannot be acquired by all students and rather belong to the learning objectives of the *Postgraduate Levels of the ESR Training Curricula*, the present e-book also contains some ***further insights*** related to modern imaging in the form of examples of key pathologies, as seen by the different imaging modalities. These are intended to give the interested undergraduate student an understanding of modern radiology, reflecting its multidisciplinary character as an organ-based specialty.

We would like to extend our special thanks to the authors and members of the ESR Education Committee who have contributed to this eBook, to Carlo Catalano, Andrea Laghi and András Palkó who initiated this project, and to the ESR Office, in particular Bettina Leimberger and Danijel Lepir, for all their support in realising this project.

We hope that this e-book may fulfil its purpose as a useful tool for undergraduate academic radiology teaching.

Minerva Becker

Chapter Outline

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eBook for Undergraduate Education in Radiology

Based on the ESR Curriculum for Undergraduate Radiological Education

Chapter: **Nuclear Medicine**

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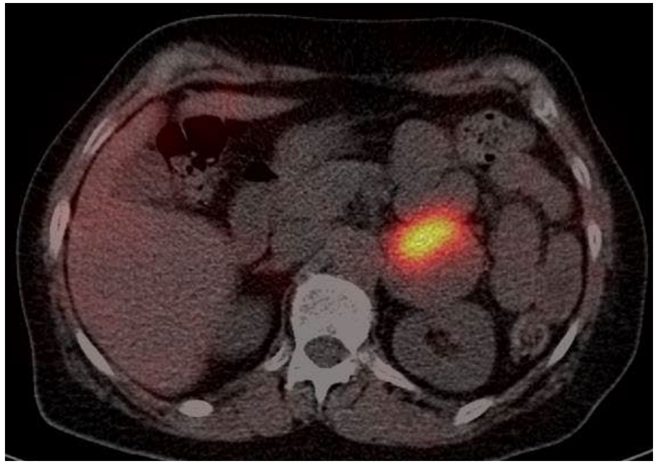
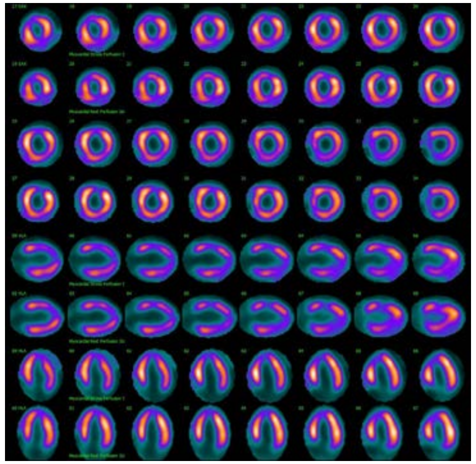
Introduction

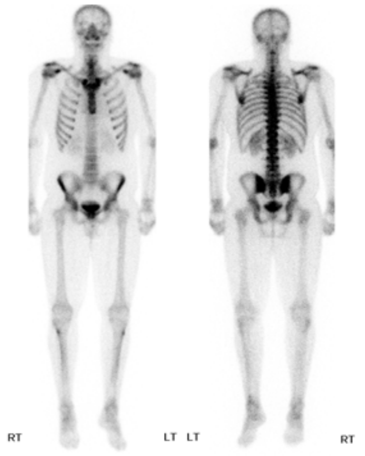
What is Nuclear Medicine

Nuclear Medicine is the practice of using small quantity of unsealed radioactive sources to diagnose, monitor disease and provide targeted therapy.

Most imaging modalities, such as computed tomography (CT) or magnetic resonance imaging (MRI) demonstrate body anatomy. Nuclear medicine is one of the few imaging modalities that demonstrate body physiology, so called 'functional' imaging. For example, a whole-body bone scan shows bone turnover. This allows nuclear medicine to have a wide range of applications across many body systems, and pathologies.







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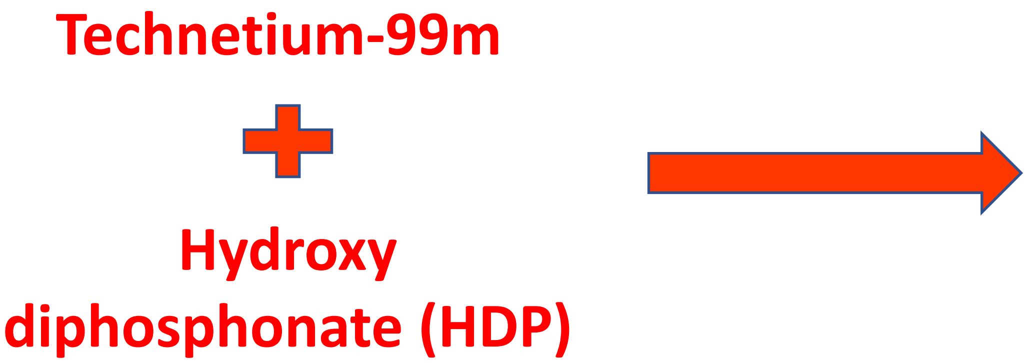
Terminology

- A radiopharmaceutical combines a radionuclide and pharmaceutical.
- A radionuclide is an unstable form of an element that emits radiation from its nucleus as it decays to a more stable form. The emitted radiation from the patient is used to create the image in nuclear medicine. Elements used for diagnostic imaging usually either emit beta particles (positrons or electrons) or gamma rays.
- Pharmaceuticals have properties that help to target specific organs/tissues or molecular pathways.
- Technetium-99m is the most used radionuclide in nuclear medicine and can be combined with a wide range of pharmaceuticals which enables targeting of different organs and physiological processes.



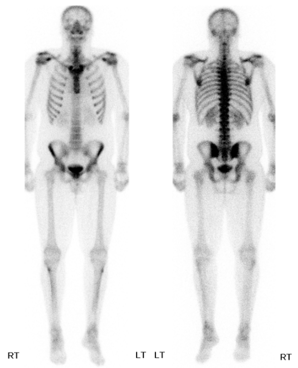


Figure 1. [^{99m}Tc]Tc- HDP whole body bone Scan

Radiopharmaceuticals

Radionuclide	Half-life	Pharmaceutical	Clinical Indication
Technetium-99m ([^{99m}Tc]Tc)	6 hours	Pertechnetate	Thyroid imaging, Meckel scan
		Methyl diphosphonate (MDP) or hydroxydiphosphonate (HDP)	Bone scan for cancer staging, arthropathy
		Diethylene-triamine-pentaacetate (DTPA)	Renal imaging, lung ventilation imaging (aerosol)
		Sestamibi	Cardiac, parathyroid
		Macroaggregated albumin (MAA)	Lung perfusion imaging
		Technegas	Lung ventilation imaging
		Mercaptoacetyltriglycine (MAG 3)	Renal
		2,3 dimercaptosuccinic acid (DMSA)	Renal

Table 1. Commonly used radiopharmaceuticals

Chapter Outline

Radiopharmaceuticals

Radionuclide	Half-life	Pharmaceutical	Clinical Indication
Iodine-123 ($[^{123}I]I$)	13.2 hours	-	Thyroid imaging
		Ioflupane	Brain- parkinsonian syndromes
		Metaiodobenzylguanidine (MIBG)	Neuroectodermal tumour imaging
Iodine-131 ($[^{131}I]I$)	8 hours	-	Thyroid imaging and treatment
Indium-111 ($[^{111}In]In$)	2.8 days	Octreotide, Pentetreotide	Neuroendocrine tumour
Krypton-81m ($[^{81}Kr]Kr$)	13 seconds	-	Lung ventilation imaging

Table 2. Commonly used radiopharmaceuticals

Nuclear Medicine (NM) Imaging

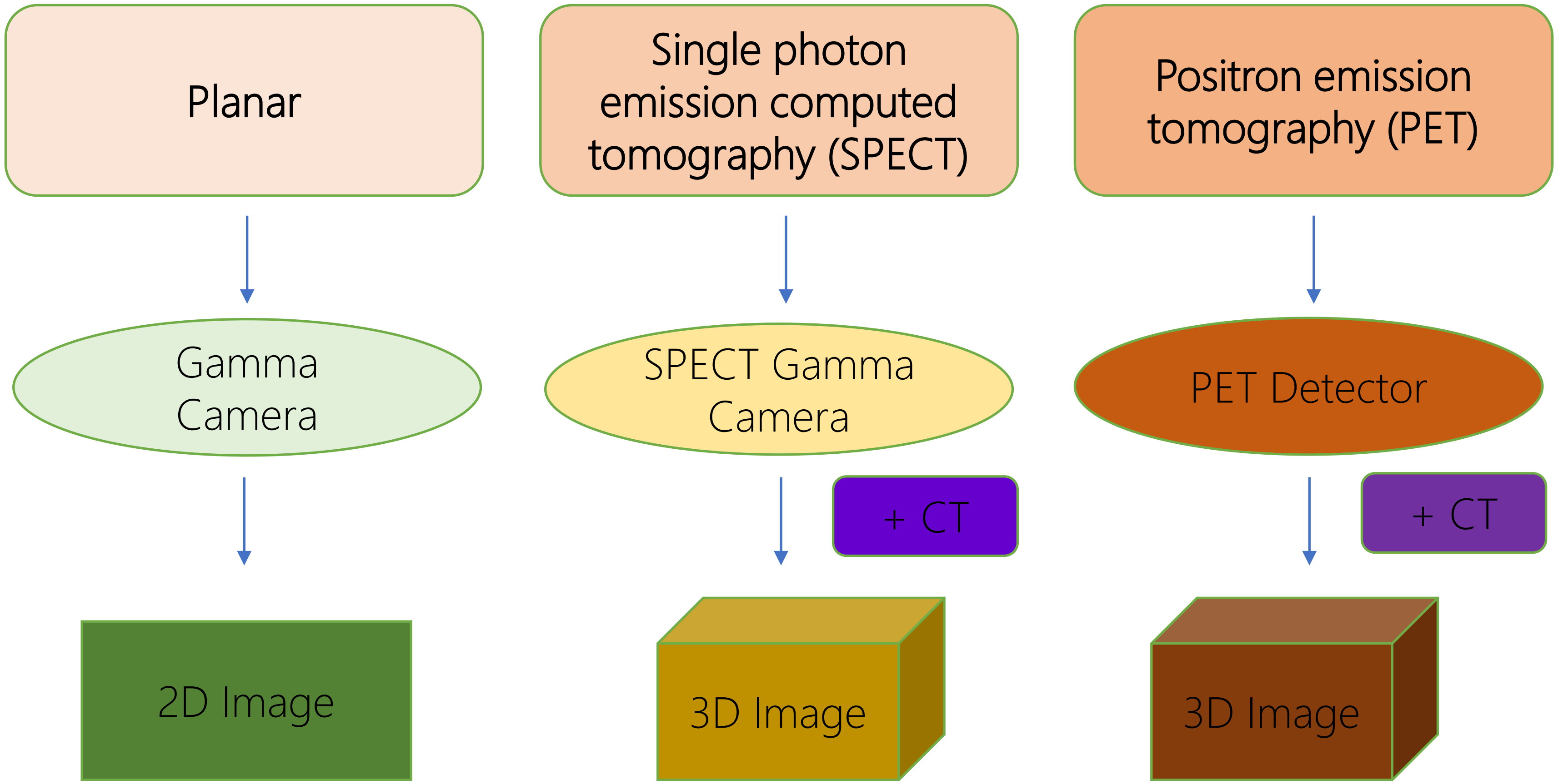


Figure 2. NM Imaging Modalities

Gamma Camera

1. Radionuclides decay releasing gamma photons.
2. Collimators are made of lead with holes. These only accept gamma photons that travel parallel to the collimator holes.
3. A scintillation crystal is fluorescent; i.e., when a gamma photon interacts, it releases light photons. The amount of light is proportional to the deposited energy of the gamma photons.
4. Photomultiplier tubes detect the light photons from the crystal and convert these into an electrical signal.
5. A computer processes the electrical signal to calculate the energy of the received photons and their x, y coordinates within the patient to form the final images.

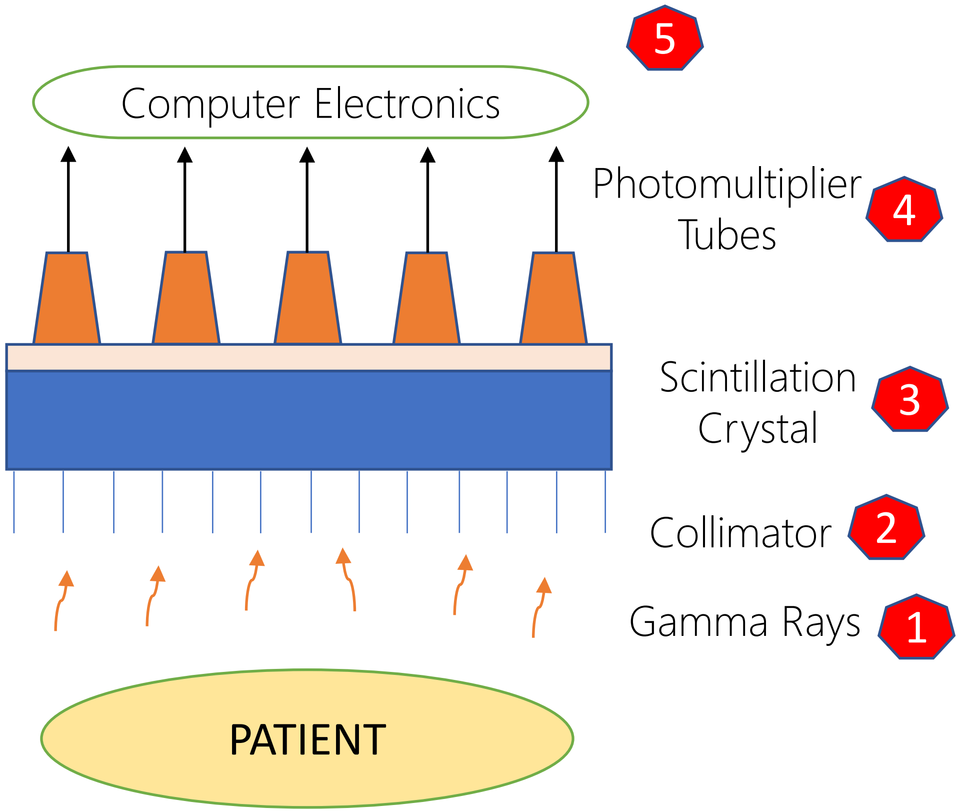


Figure 3. Gamma Camera Flowchart

Planar Imaging

- 2D imaging technique
- Typically, anterior and posterior views
- Oblique views - depending on clinical indication
- Commonly used applications include bone, kidneys, thyroid, hepatobiliary and gastrointestinal tract imaging

Static

- Radiopharmaceutical is injected intravenously/ingested, and images are acquired after a certain time period delay called 'uptake time'
- The uptake time and scan duration is dependent upon the half life of the radionuclide and the study being performed. E.g., 2-3 hours for a Technetium-99m labelled DMSA renal scan compared to 4-6 hours for an Iodine-123 thyroid uptake scan
- Static imaging is used to gain information about the organ of interest based on size, morphology, intensity and position of radiopharmaceutical uptake

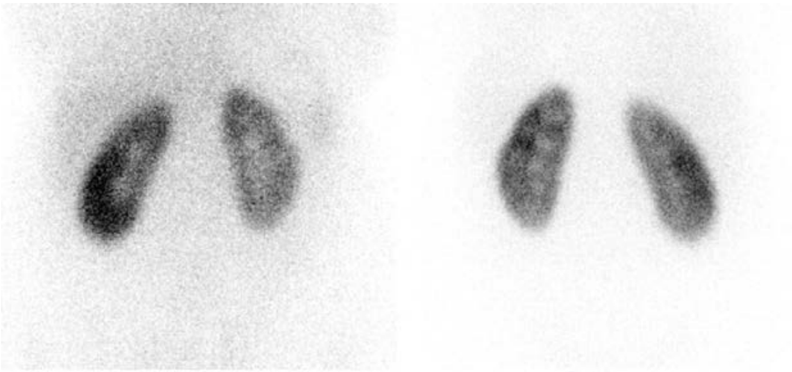


Figure 4. [^{99m}Tc]Tc- DMSA renal scan anterior and posterior views

Planar Imaging

Dynamic

- Distribution of radiopharmaceuticals change with time due to their inherent properties
- Images are usually acquired immediately post injection with series of frames over time
- Time interval between frames varies between different studies
- Functional assessment of a system is provided based on radiopharmaceutical distribution over time

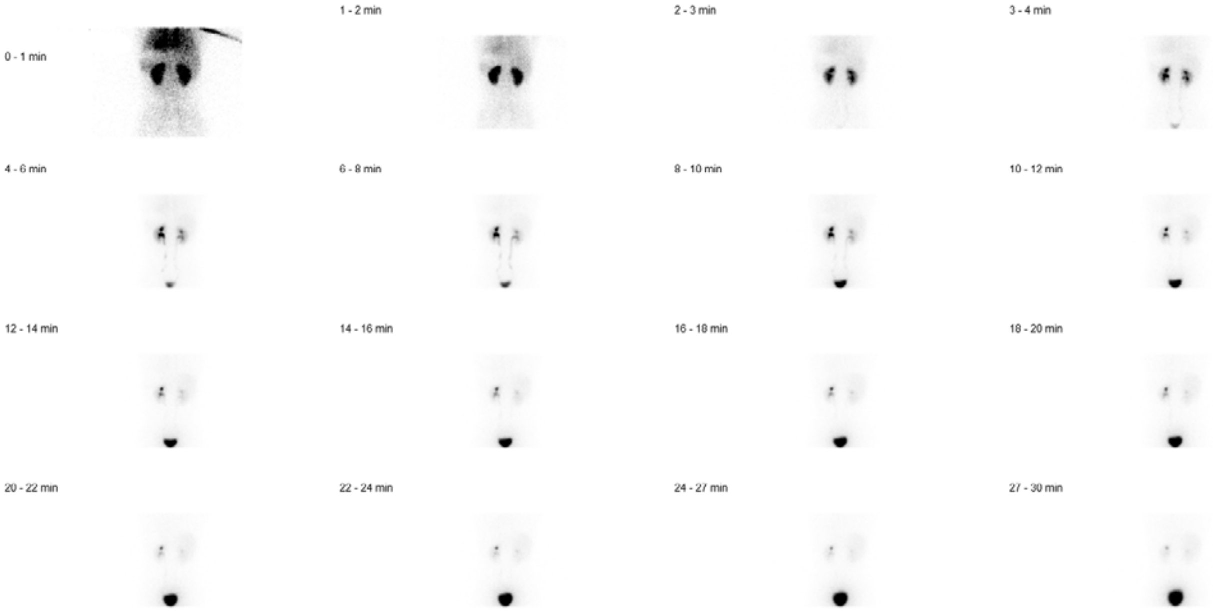


Figure 5. [^{99m}Tc]Tc-MAG3 Renogram

Chapter Outline

SPECT and SPECT/CT Imaging

Single photon emission computed tomography (SPECT) is an extension of conventional gamma camera imaging.

Typically, two gamma camera heads rotate around the patient on a gantry acquiring a series of planar images which are reconstructed into 3D images.

Computed Tomography (CT) images may be acquired alongside SPECT. These permit attenuation correction and localisation of sites of radiotracer uptake in the body.

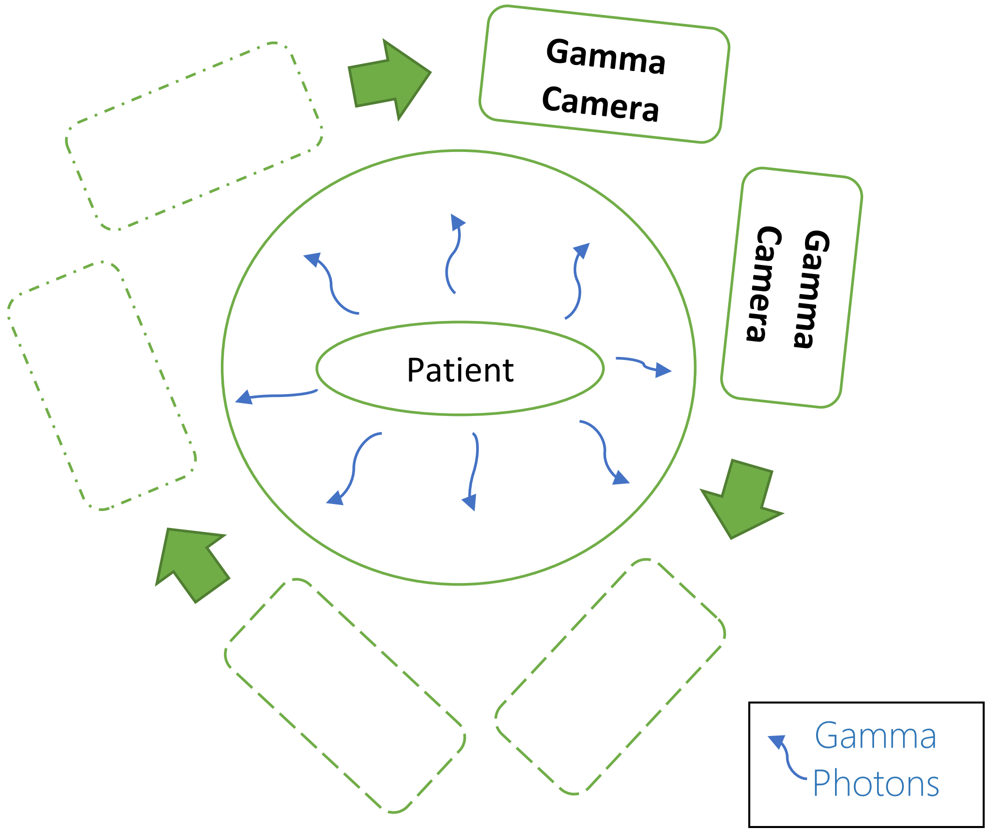


Figure 6. Schematic diagram of SPECT scanner

SPECT Applications

Commonly used applications include cardiac, bone, parathyroid, pulmonary, and brain imaging.

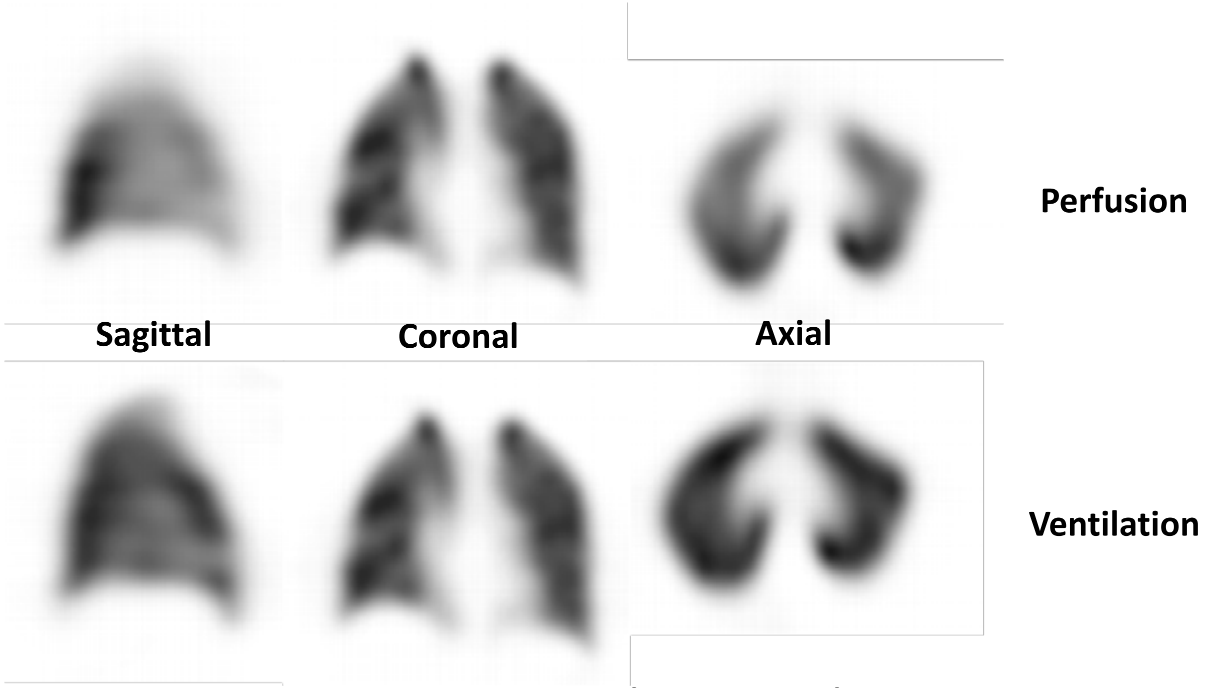


Figure 7. Ventilation/Perfusion (V/Q) SPECT

V/Q SPECT demonstrating normal distribution of radiopharmaceutical

Chapter Outline

Comparison of SPECT and Planar Imaging

Planar	SPECT
Poorer contrast and spatial resolution compared to SPECT	Better contrast and spatial resolution compared to planar
Use gamma emitting radionuclide	Use gamma emitting radionuclide
Generally shorter image acquisition times depending on study type	Longer image acquisition times
Poorer localization compared to SPECT(2D)	Localization at depth as a tomographic technique (3D)

Table 3. Comparison of SPECT and Planar Imaging

Chapter Outline

Positron Emission Tomography (PET) Imaging

PET imaging uses radionuclides that are proton rich (nucleus contains a relatively large number of protons compared to neutrons) and decay by positron emission.

The positron-emitting radionuclide undergoes β⁺ decay with a proton converted to a neutron, a positron and a neutrino. The positron (e^+) is the antiparticle of the electron (e^-) with the same mass and electrical charge as the electron. However, the charge is positive.

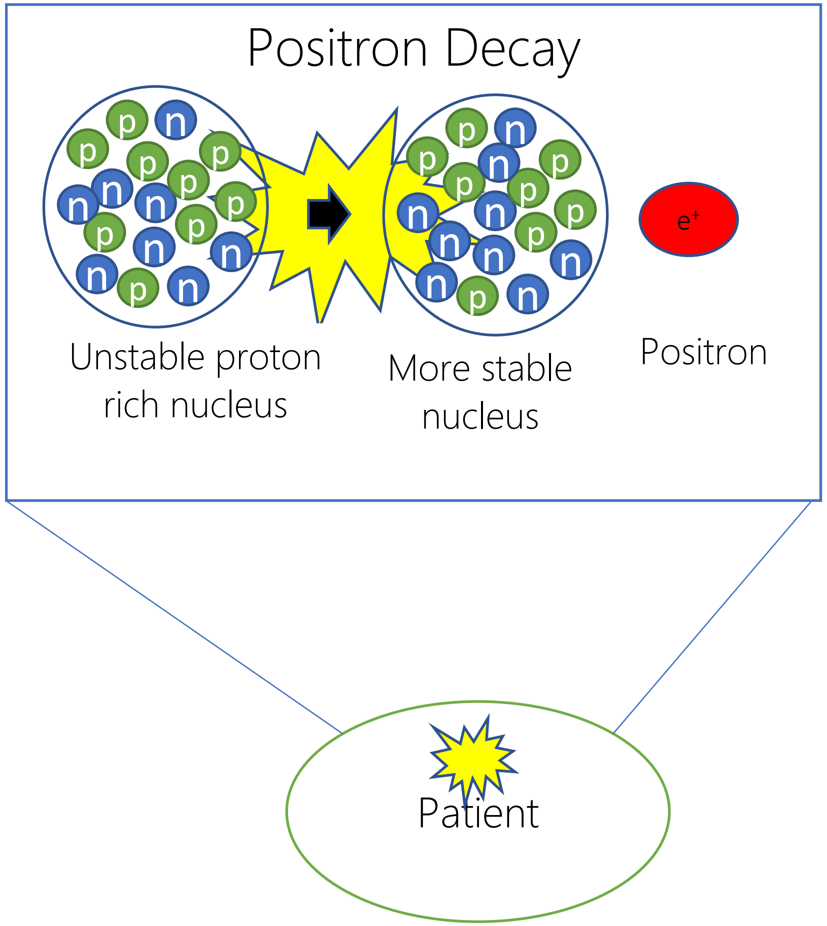


Figure 8. PET scanner

Chapter Outline

PET Imaging

Positrons travel a short distance through tissue and annihilate with electrons (*see Figure 8, slide 18*).

This annihilation process, produces two photons of 511 kiloelectron volts (keV) energy which travel in opposite directions (at 180° to each other) and are detected by opposed radiation detectors.

The near simultaneous detection of the two photons allows the localization of their origin to a line joining the detectors which is called annihilation coincidence detection.

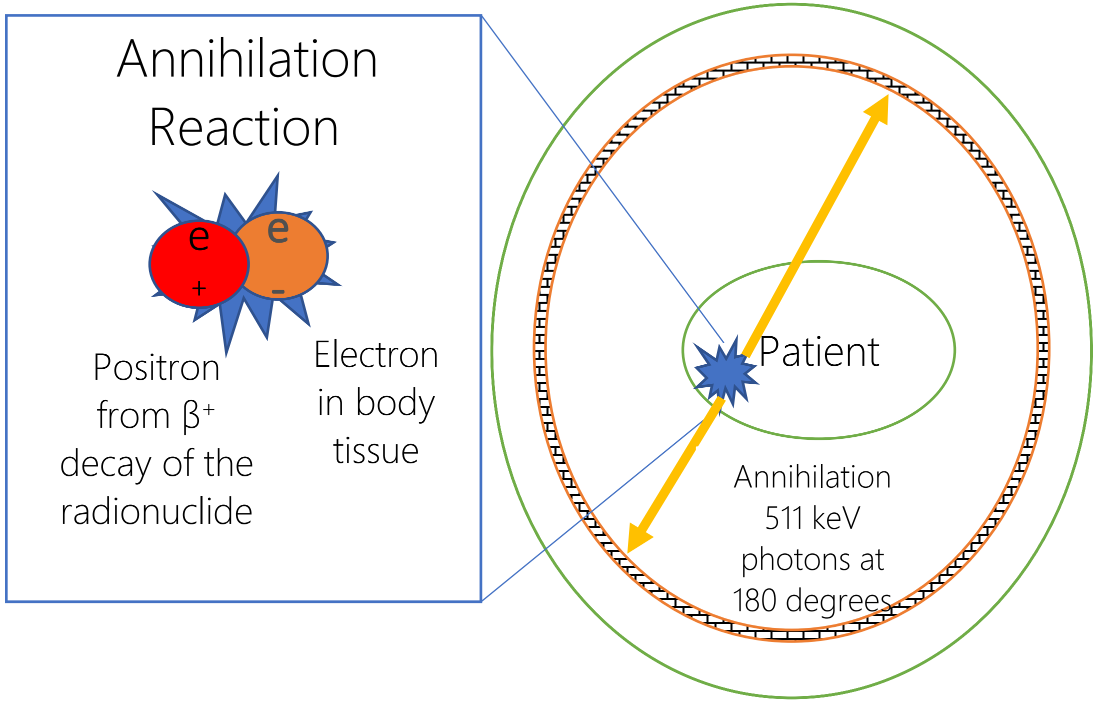


Figure 9. PET scanner

PET Imaging

- PET is combined with CT for attenuation correction and anatomical localization.

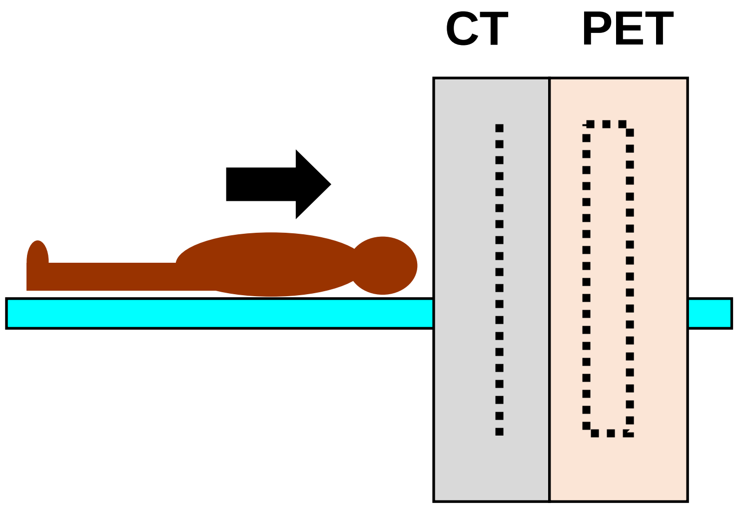


Figure 10. Diagram of PET/CT scanner

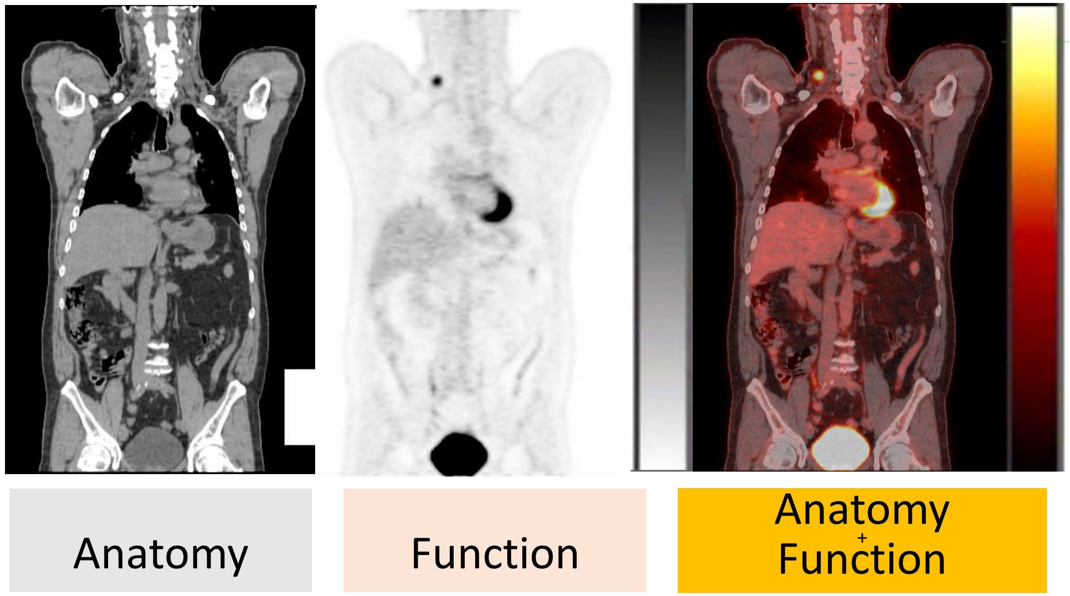


Figure 11. [^{18}F]FDG PET/CT Coronal CT, PET and fused

Chapter Outline

Positron Emitting Tracers-Common Clinical Examples

Radionuclide	Physical Half-life (mins)	Production method	Pharmaceutical	Physiological process	Clinical application
Fluorine-18 ([^{18}F]F)	110	Cyclotron	Fludeoxyglucose (FDG)	Glucose metabolism	Oncology, infection
			Fluorocholine	Cell membrane metabolism	Prostate cancer Parathyroid imaging
			Prostate-specific membrane antigen (PSMA-1007) DcF-PyL	PSMA expression	Prostate cancer
Gallium-68 ([^{68}Ga]Ga)	68	Generator	Dotatate	Somatostatin receptor expression	Neuroendocrine tumour
			PSMA-11	PSMA expression	Prostate cancer

Table 4. Commonly used positron emitting tracers

Comparison of SPECT and PET Imaging

SPECT	PET
Lower cost compared to PET	More expensive compared to SPECT
Use gamma emitting radionuclide	Use positron emitting radionuclide
1-3 large detectors	Ring of multiple detectors
Poorer spatial resolution 10-15 mm	Higher spatial resolution 5-8 mm
Can be combined with CT for attenuation correction and anatomical localisation	Can be combined with CT for attenuation correction and anatomical localisation

Table 5. Comparison of SPECT and PET Imaging

Chapter Outline

Applications of Planar, SPECT and PET

Bone	Brain	Oncology
Metastatic disease Metabolic disease Rheumatology Infection Trauma	Dementia Movement disorder Seizure Tumour	Sentinel lymph node Solid organ tumors Prostate cancer: PSMA receptor Neuroendocrine tumors: somatostatin receptor Therapy

Cardiac	Liver/Spleen	Renal
Ventricular function Perfusion Infarct	Function Blood volume	Function Morphology/Scarring Obstruction/Blood flow

Blood	Lungs	Thyroid	GI
Inflammation Infection Red cell mass	Perfusion Ventilation	Function Metastatic disease	Transit Bleeding

Figure 12. Nuclear Medicine Applications

Chapter Outline

Bone Scan

Indications:
Oncology (staging some cancers), rheumatology, bone and joint infections, painful joint prosthesis, metabolic bone disease

Route: Administered intravenously

Radiopharmaceutical:
Technetium-99m ([^{99m}Tc]Tc) labelled bisphosphonates such as ([^{99m}Tc]Tc - HDP (hydroxyethylene diphosphonate) or MDP (methylene diphosphonate) which bind to calcium and hydroxyapatite crystals in bone in proportion to local *vascularity and osteoblastic* activity.

Image acquisition:

- Anterior and posterior whole body planar: Acquired 3-4 hours post-injection for optimal concentration of radiopharmaceutical by osteoblasts and clearance from tissues
- Dynamic: 3 phases: selected cases e.g. infected prosthesis
  - Flow phase (2-to-5 second images obtained for 60 seconds immediately after injection)
  - Blood pool phase (5 minutes after injection)
  - Delayed phase (3-4 hours after injection)

Chapter Outline

Bone Scan

Planar Normal Case example

Biodistribution in the skeleton should be homogenous and almost symmetrical for left and right sides.

Excretion route is renal so there is visualization of kidneys and bladder.

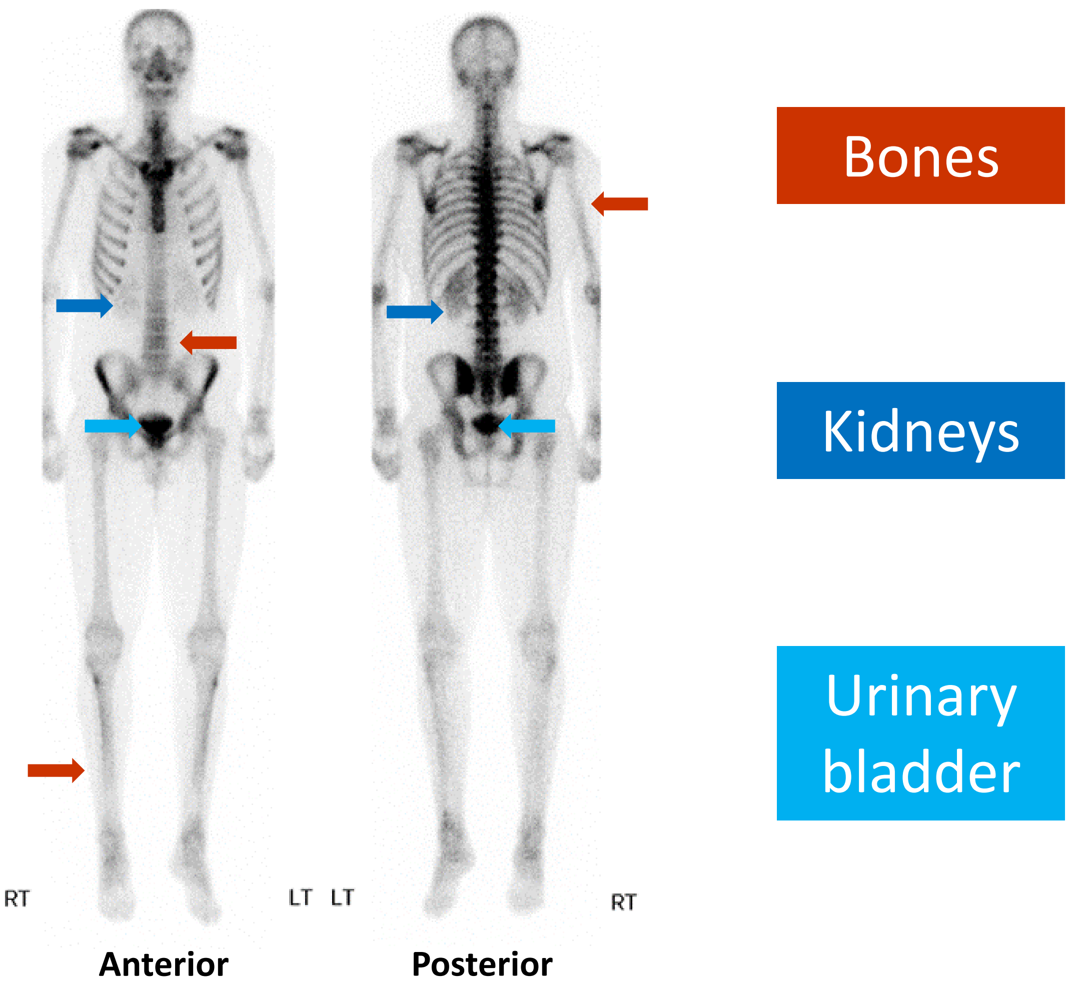


Figure 13. Normal [^{99m}Tc]Tc- HDP whole body bone scan

Bone Scan

Dynamic: Normal Case example

1st phase (Flow phase)

Dynamic study to demonstrate the presence of blood flow in the affected area (e.g., inflammation/infection of a joint replacement). 2-to-5 second images are obtained for 60 seconds after injection radiopharmaceutical. Focused on region of interest/clinical concern e.g., hip.

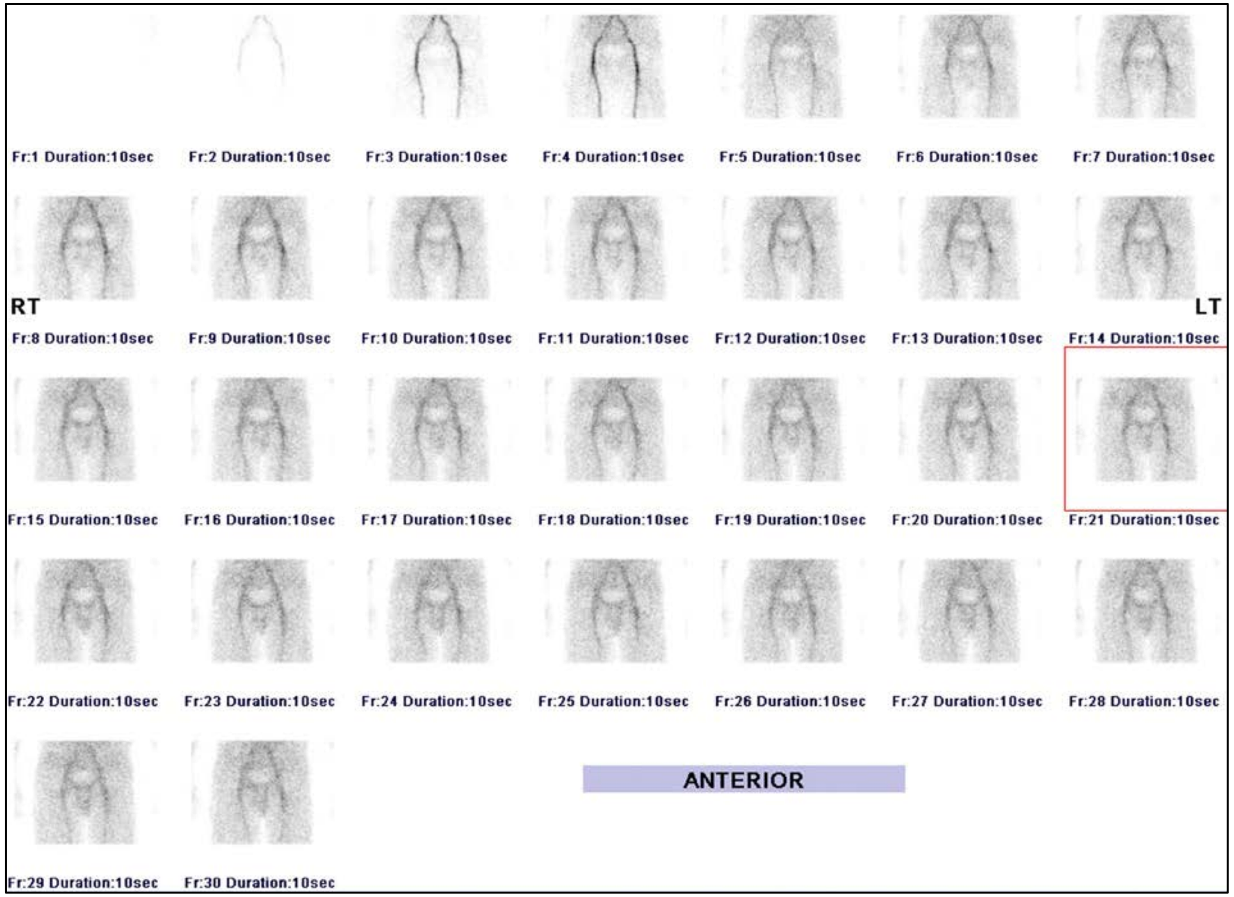


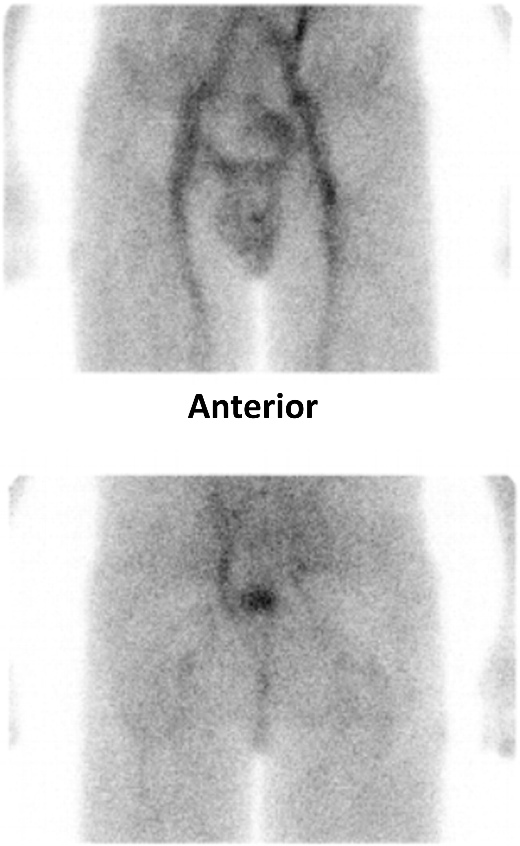
Figure 14. Normal perfusion phase of dynamic bone scan of the hip area

Bone Scan

Dynamic: Normal Case example

2nd phase (Blood pool):

Early static views to visualize the distribution of radiopharmaceutical into the extra-cellular space. Focused on region of interest/clinical concern.



3rd phase (Delayed phase):

2-4 hours later, static view- vertex to toes.

Figure 15. Normal blood pool phase of the hip area and whole body bone scan

Bone Scan

Case: Metastatic disease

63 years old male with prostate cancer.

There is intense radiopharmaceutical uptake within axial and appendicular skeleton including the right sacrum, left acetabulum, and vertebral bodies, and ribs, skull in keeping with osteoblastic metastatic disease.

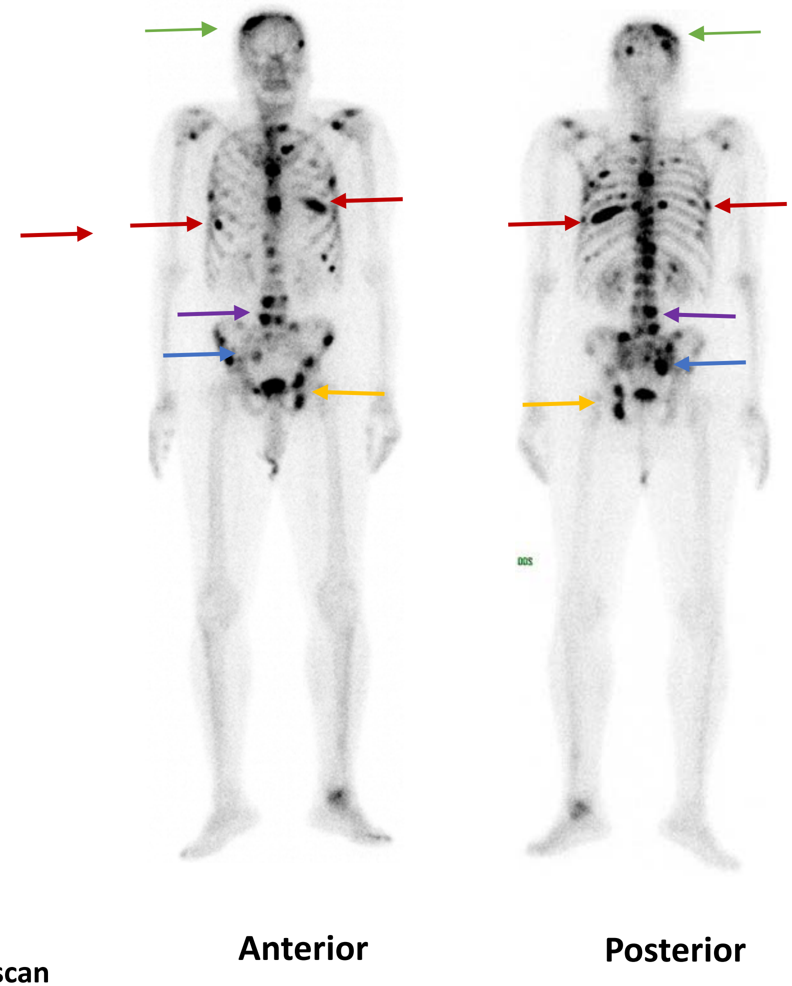


Figure 16. [^{99m}Tc]Tc- HDP body bone scan

Chapter Outline

Bone Scan

Case: “Superscan”

74 years old male. Known history of prostate malignancy.

Diffuse slightly heterogeneous increased radiopharmaceutical uptake throughout the imaged skeleton, including the skull and long bones. Although there is some activity in the urinary bladder, there is only very faint activity in the kidneys.

The overall appearances would be in keeping with a superscan, indicating diffuse metastatic bone involvement, given the history of prostate malignancy.

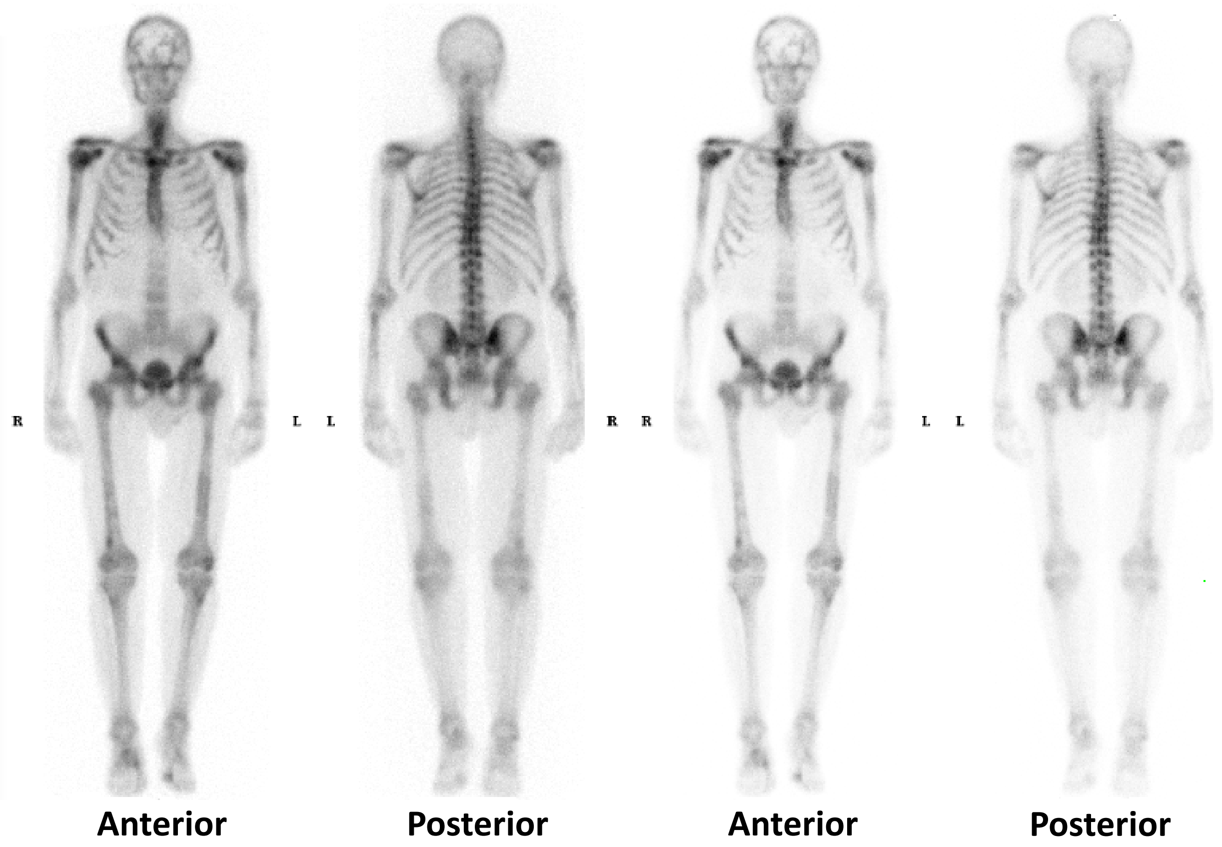


Figure 17. [^{99m}Tc]Tc- HDP whole body bone scan

Bone Scan

Case: Paget's disease

84 years old male, raised ALP.

Patchy increased uptake within the skull, intense uptake within the entire mandible, L3 vertebral body pedicles and spinous process, and also within the right hemipelvis. There is associated expansion of the right hemipelvis. The appearances are in keeping with polyostotic Paget's.

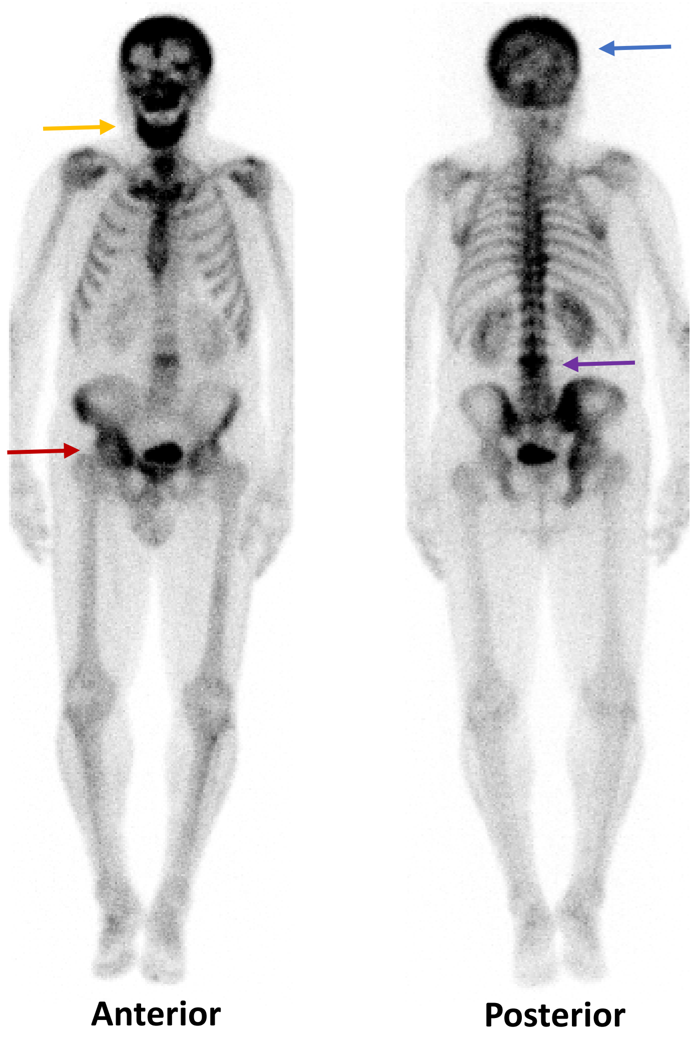


Figure 18. [^{99m}Tc]Tc- HDP whole body bone scan

Chapter Outline

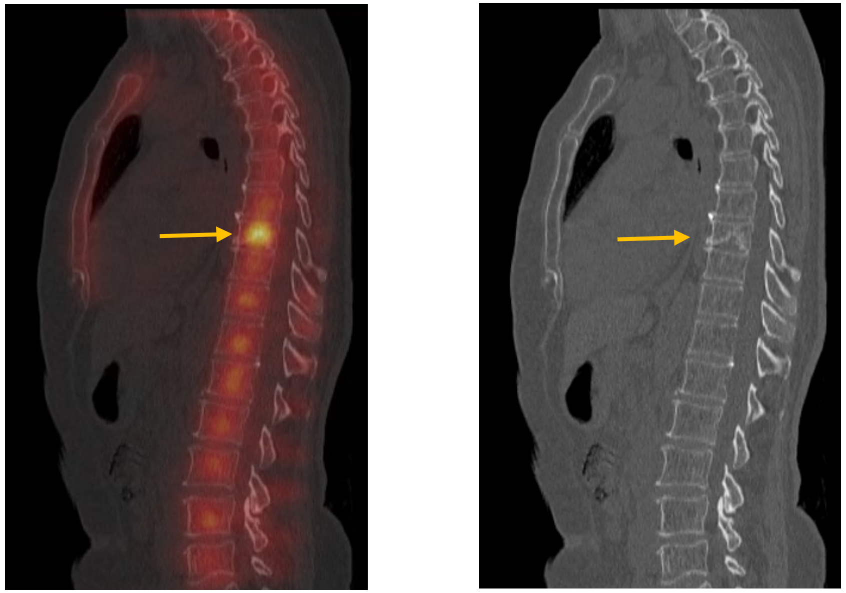
Bone Scan

Case: breast cancer vertebral metastasis

54 years old female. Known breast cancer. Mid thoracic back pain.

Anterior Posterior

Figure 19. [99mTc]Tc- HDP whole body bone scan



Sagittal SPECT/CT fused Sagittal CT bone window

Figure 20. [99mTc]Tc- HDP SPECT/CT

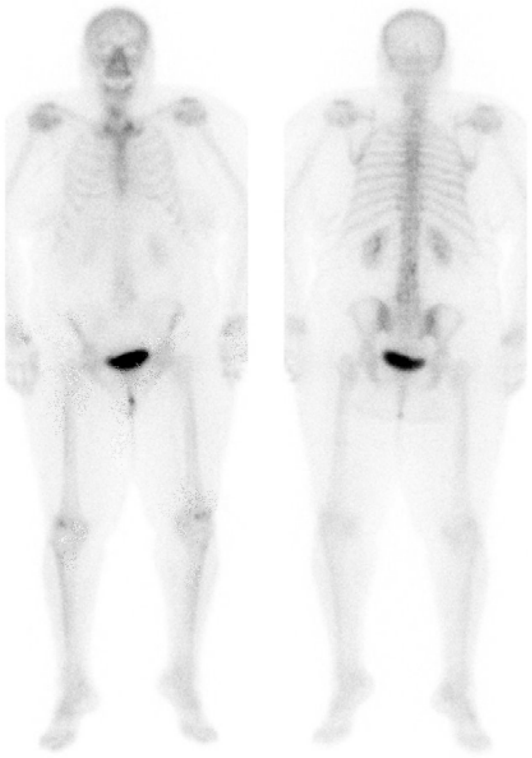
Increased uptake within the T9 vertebral body demonstrated on the posterior view whole body bone scan is subtle (blue arrow). The subsequent SPECT/CT allows better localisation to the T9 vertebral body as well demonstrating the vertebral body height loss/collapse (yellow arrow).

Bone Scan

Case: Bone SPECT/CT for pain generators

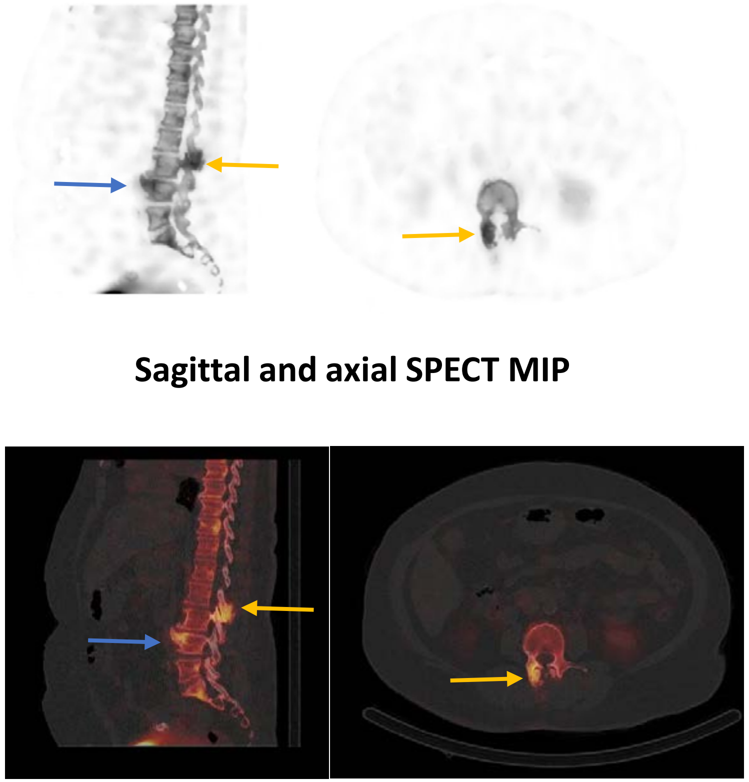
32 years old female. Lower back pain.

No significant uptake demonstrated on whole body scan to explain the patient's symptoms. The subsequent SPECT/CT demonstrates increased uptake at the L3/L4 disc space (blue arrow) and right L2/L3 facet joint (yellow arrow) which are likely to be the main osseous pain generators.



Anterior **Posterior**

Figure 21. [99mTc]Tc- HDP whole body bone scan



Sagittal and axial SPECT MIP

Sagittal and axial SPECT/CT fused

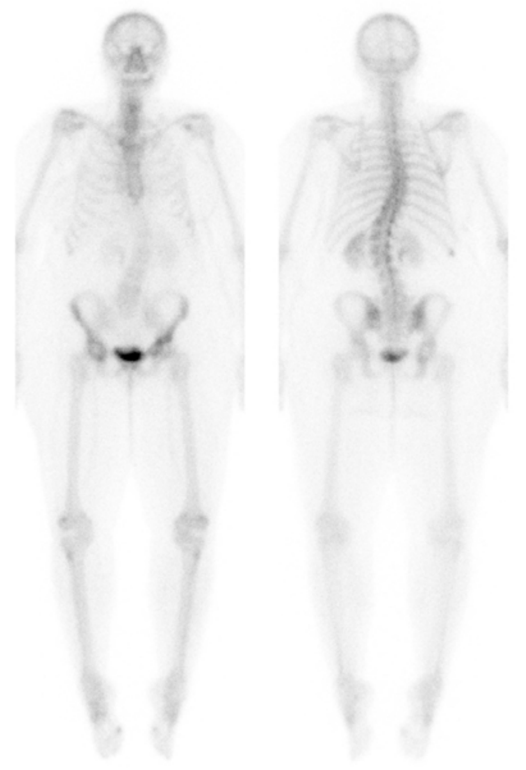
Figure 22. [99mTc]Tc- HDP SPECT/CT

Bone Scan

Case: Lytic metastatic disease from breast cancer

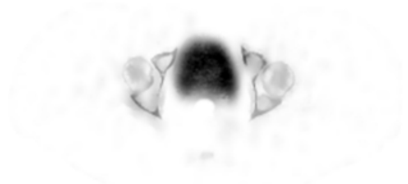
62 years old female. Breast cancer 10 years. Presenting with bilateral hip pain

No significant uptake demonstrated on whole body scan to explain the patient's symptoms. The subsequent SPECT/CT demonstrates lucent lesions within bilateral acetabuli which do not demonstrate increased uptake, in keeping with osteoclastic metastatic disease.

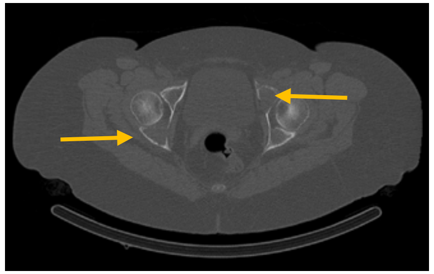


Anterior **Posterior**

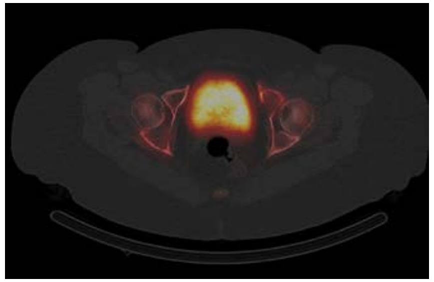
Figure 23. [^{99m}Tc]Tc- HDP whole body bone scan



Axial SPECT MIP



Axial CT Bone window



Axial SPECT/CT Fused

Figure 24. [^{99m}Tc]Tc- HDP SPECT/CT

Bone Scan

Strengths and limitations:

- Uptake of Technetium-99m is based on vascularity and osteoblastic activity. Other bone lesions such as infection and trauma can also demonstrate high uptake. Therefore, bone scans are sensitive but nonspecific so correlation with other modalities may be needed.
- Lytic lesions (e.g. myeloma and certain tumor metastases e.g. renal cell) may not be visible on bone scintigraphy as bone scans assess osteoblastic activity and these are typically osteoclastic.

Chapter Outline

Thyroid Scintigraphy

Radiopharmaceutical	Production	Emission and half life	Mechanism	Uses	Pros/Cons
[^{99m}Tc]Tc- pertechnetate	Generator	Gamma rays, 6 hours	trapped by normal follicular cells	Thyroid uptake and imaging	Rapid examination, poor image quality when low uptake
Iodine-123 ([^{123}I]I)	Cyclotron	Gamma rays, 13 hours	trapped by normal follicular cells, organified and stored in colloid space	Thyroid uptake and imaging Thyroid cancer metastases	Relatively expensive and unavailable as cyclotron, better image quality when uptake is low
Iodine-131 ([^{131}I]I)	Reactor	Beta and gamma rays, 8.06 days	trapped by normal follicular cells, organified and stored in colloid space	Hyperthyroidism / thyroid cancer treatment	

Table 6. Radiopharmaceuticals used in thyroid scintigraphy

Thyroid Scan

Route: Administered intravenously

(Both [^{123}I]I and [^{99m}Tc]Tc-pertechnetate)

Image acquisition:

- Anterior, left anterior oblique and right anterior oblique views
- [^{123}I]I: Either at 4-6 or 24 hours after administration
- [^{99m}Tc]Tc-pertechnetate): 20 minutes after administration

Certain medications can interfere with thyroid uptake of the radiopharmaceutical

No iodine-containing contrast for 6 weeks prior

No iodine-containing medications for 4 weeks prior

No amiodarone for 3-6 months prior

Thyroid Scan

Normal Case

Tc99m thyroid scan.

Diffuse homogenous uptake within both lobes of the thyroid gland.

Mild homogenous uptake noted within the salivary glands.

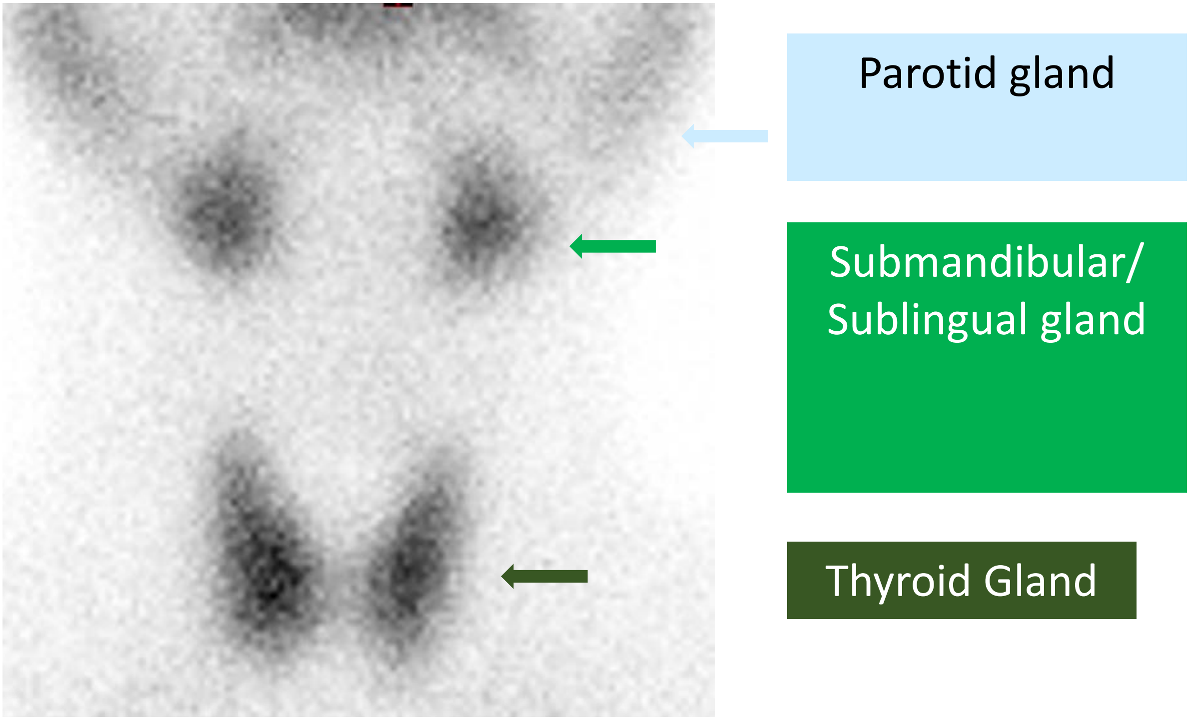


Figure 25. Normal [^{99m}Tc]Tc Thyroid scan

Thyroid Scan

Case: Graves' Disease

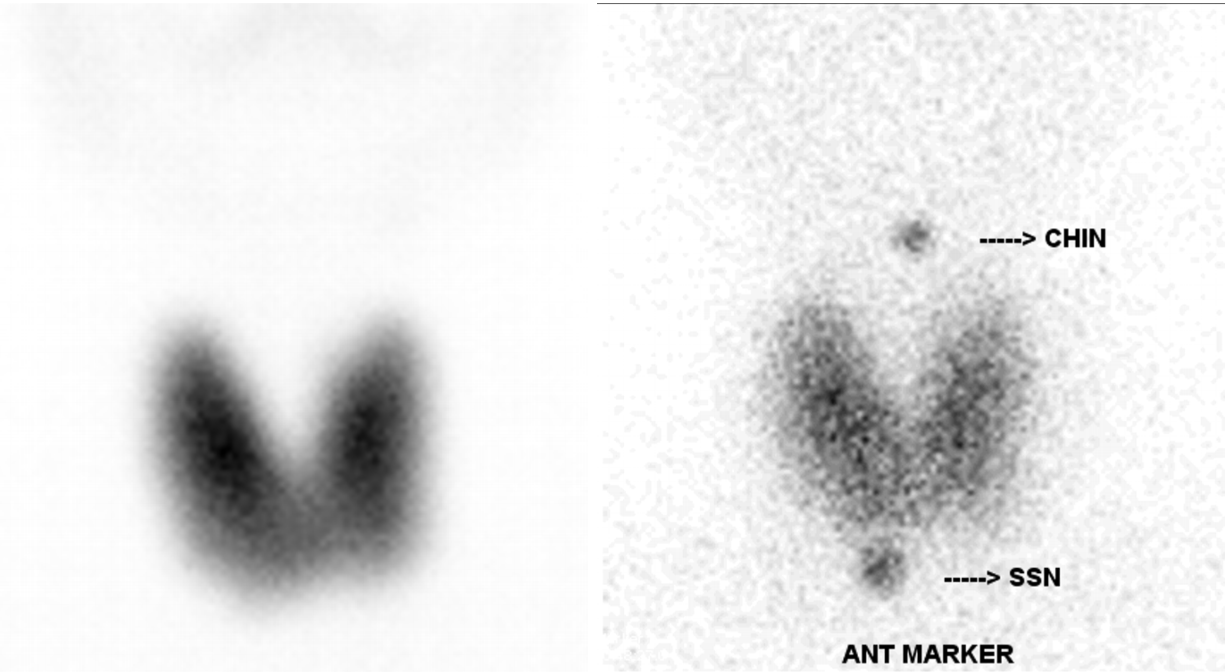
Tc99m thyroid scan.

Diffuse and relatively uniform uptake by the entire enlarged thyroid gland.

Background salivary activity is suppressed.

The percentage uptake is 25.9% (normal range 0.45-3.5%).

Chin and suprasternal (SSN) markers for anatomical localization.



Anterior

Figure 26. [^{99m}Tc]Tc Thyroid scan

Chapter Outline

Thyroid Scan

Differential diagnosis of hyperthyroidism

Thyroid Scintigraphy is the key test for differentiating causes of hyperthyroidism due to different patterns of uptake:

A. Graves' disease – homogenous increased uptake

B. Toxic multinodular goitre – multifocal uptake, often heterogenous

C. Autonomous toxic nodule – uptake in a single, often enlarged, nodule

D. Subacute thyroiditis – no uptake

A 'cold' focal area with reduced uptake is concerning for a malignant nodule. In these cases, ultrasound is needed to better characterize the nodule and determine whether biopsy is required.

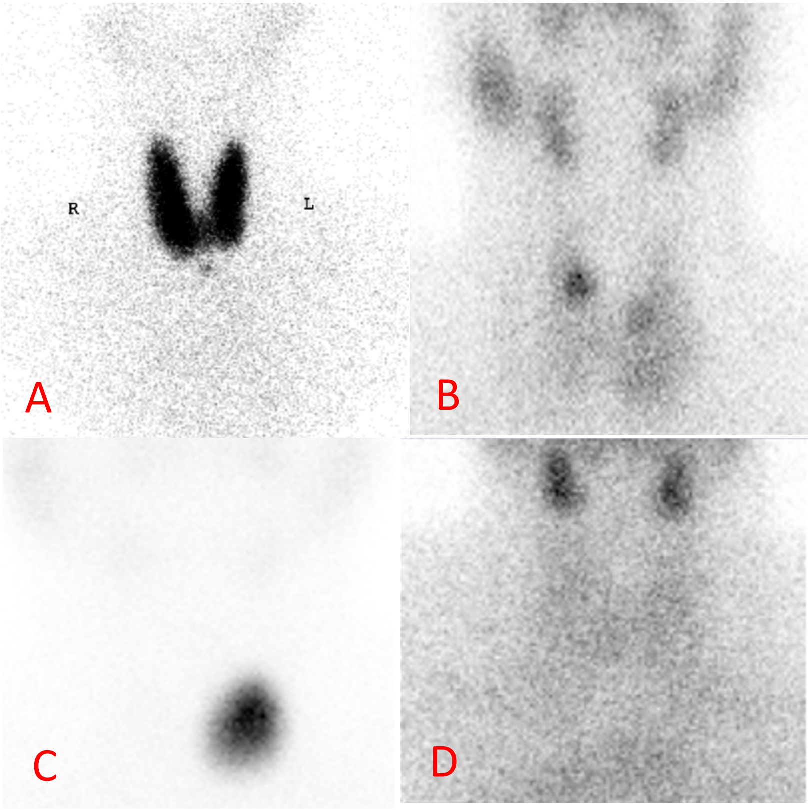


Figure 27. [^{99m}Tc]Tc Thyroid scans

Ventilation/Perfusion (V/Q) Scan

Indications:

Diagnosis of acute pulmonary embolism with normal chest radiograph
Workup of patients with pulmonary hypertension to determine whether the cause is due to chronic thromboembolic disease
Quantification of differential lung function preoperatively (for example prior to pneumonectomy in lung cancer patients)

- Pregnant patient should be counselled regarding radiation doses. Typically, radiation dose to maternal breast tissue is greater for CTPA compared to V/Q scan; doses to fetus are equivalent).

- If performing V/Q scan for acute pulmonary embolism, make sure chest radiograph has been performed and reviewed within 12 to 24 hours prior to lung scintigraphy. This is because there are other causes of perfusion defects which can be excluded on chest radiograph such as atelectasis, pneumonia, etc.

Chapter Outline

Ventilation/Perfusion Scan

Radiopharmaceutical and Route:

Perfusion:

Technetium-99m labelled human albumin (MAA) administered intravenously: These lodge in patent precapillary arterioles and capillaries and occlude the arteries temporarily reflecting regional perfusion.

Ventilation:

Krypton-81 gas administered as an aerosol for ventilation. This is inhaled until it reaches a steady state in the alveoli and then continuously during the scan. It reflects regional ventilation.

[^{99m}Tc]Tc labelled aerosols, DTPA or Technegas accumulate in bronchiole and alveoli.

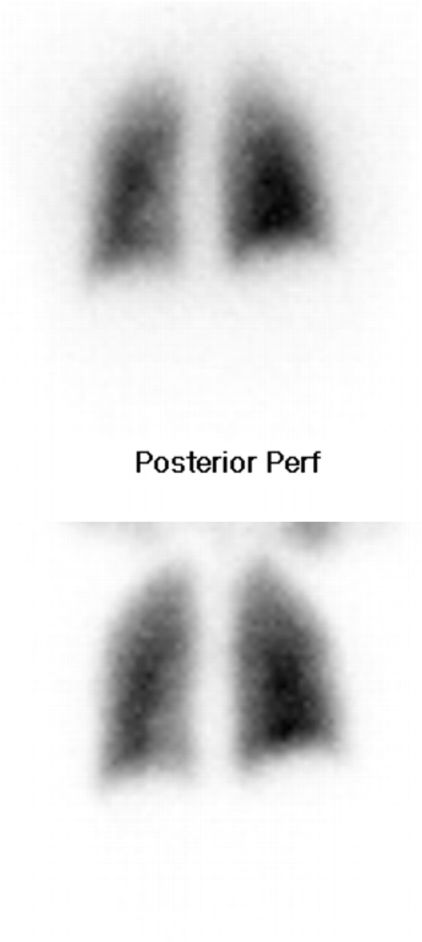


Figure 28. Planar images from a Normal V/Q scan

Ventilation/Perfusion Scan

Image acquisition:

- Imaging starts with the ventilation scan, immediately followed by the perfusion scan.
- Perfusion imaging and ventilation using $[^{81}Kr]Kr$ gas can be imaged at the same time as the perfusion study due to different energy windows of $[^{81}Kr]Kr$ (190 keV) and $[^{99m}Tc]Tc$ (140 keV)
- If DTPA or Technegas are used the ventilation and perfusion will need to be acquired separately due to the same radionuclide being used
- SPECT imaging with additional CT component (Planar if SPECT not available)

EANM guideline for ventilation/perfusion single-photon emission computed tomography (SPECT) for diagnosis of pulmonary embolism and beyond, 2019

Ventilation/Perfusion Scan

Normal Case

Diffuse homogenous uptake within both lungs.

No mismatch between perfusion and ventilation imaging.

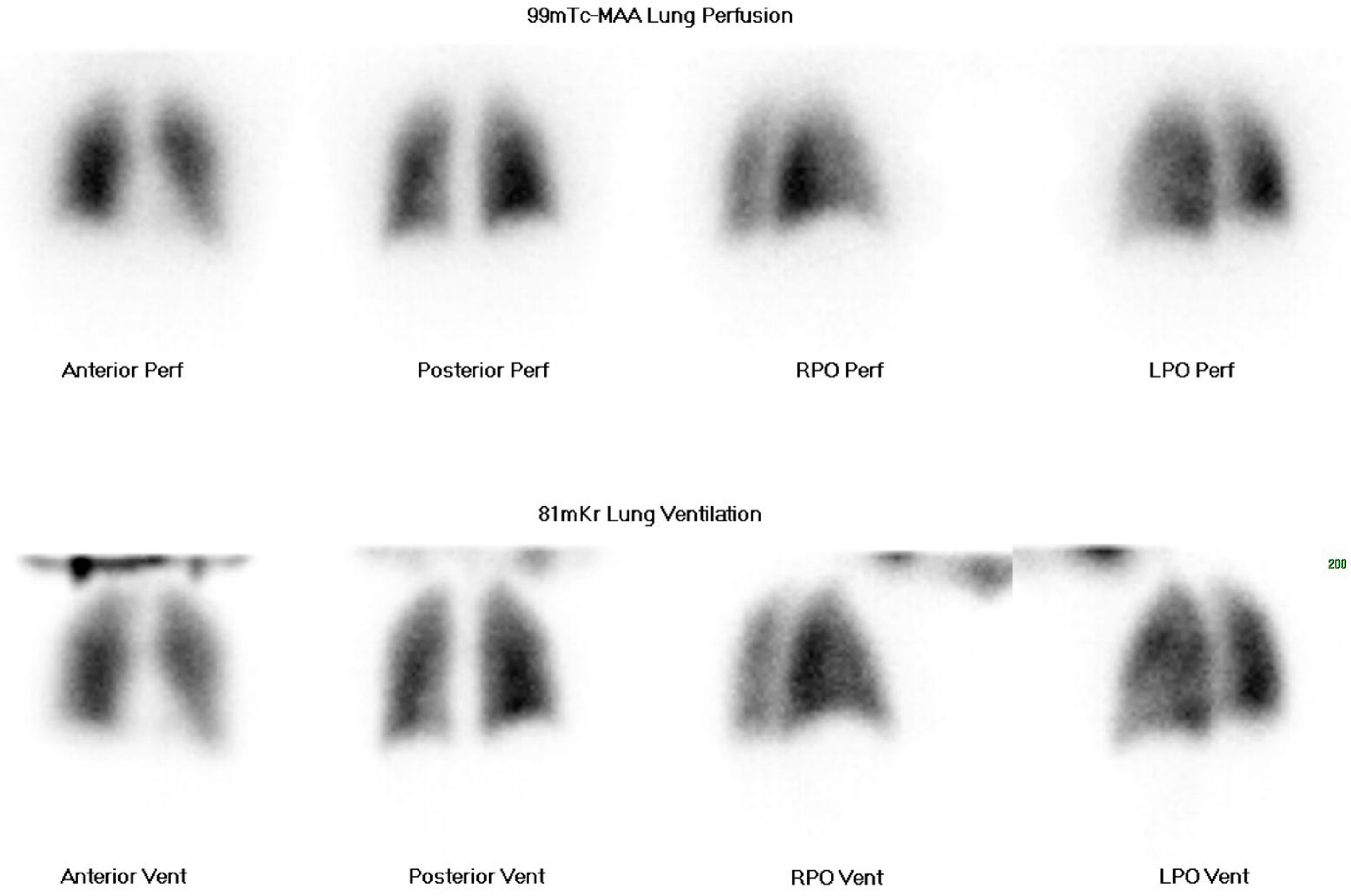


Figure 29. Planar images from a Normal V/Q scan

Ventilation/Perfusion Scan

Case: Bilateral subsegmental pulmonary emboli

24 years old female. Focal segmental glomerulosclerosis with nephrotic syndrome. Previous pulmonary embolism. Similar pain and worsening shortness of breath whilst on apixaban.

SPECT Perfusion **SPECT Ventilation** **Axial CT Lung Window**

Figure 30. V/Q SPECT/CT

On the simulated planar imaging, there is no obvious mismatched defect.

On the SPECT/CT, there are bilateral subsegmental wedge shaped perfusion defects in the lateral segments of both lower lobes and posterior segment of the right lower lobe (blue arrows), which are mismatched and with no corresponding CT abnormality.

Comparison of V/Q Scan and CTPA

V/Q scan	CTPA
Can be used in patients with contrast nephropathy and renal impairment	Quicker, Readily available
Reduced radiation burden to radiosensitive breast tissue in pregnant women	Alternative explanations for the patient's symptoms e.g. pneumothorax
Diagnosis of chronic thromboembolic pulmonary hypertension	If there is PE, can demonstrate findings of right heart strain

Table 7. Comparison of V/Q scan and CTPA
Abbreviations: CT pulmonary angiogram (CTPA); pulmonary embolism (PE)

Chapter Outline

Dimercapto Succinic Acid (DMSA) Renal Scan

Indications:

Detection of focal renal parenchymal abnormalities including assessment of renal scarring
Differential renal function estimation
Assessment of the horseshoe, solitary or ectopic kidney

Route: Administered intravenously

Image acquisition:

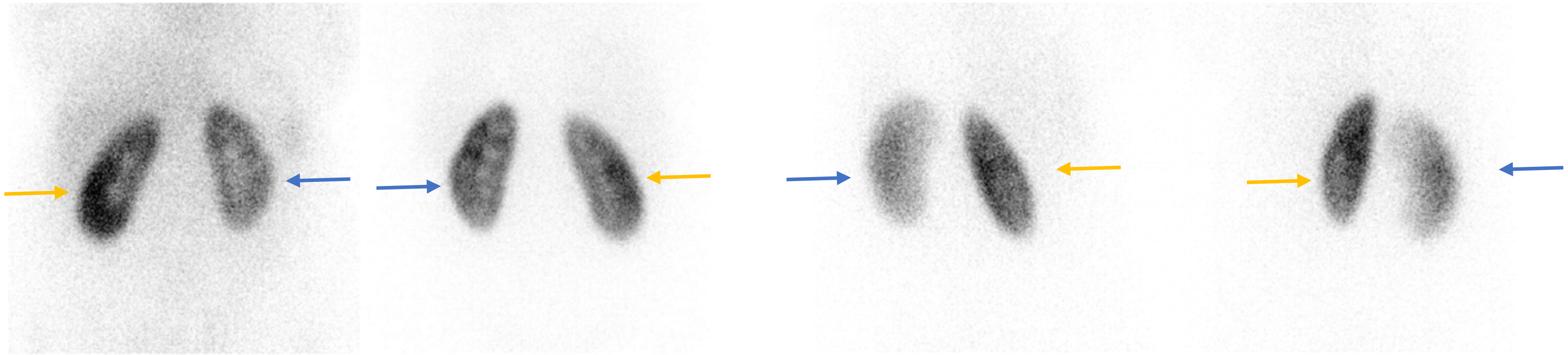
- Static planar 2-3 hours post-injection
- Views: anterior, posterior and 45 degree left and right posterior oblique

Radiopharmaceutical:

Technetium-99m labelled-DMSA (2, 3-dimercaptosuccinic acid) is protein-bound and removed from plasma, and concentrates in the proximal tubules of the renal cortex

DMSA Renal Scan

Normal Case



Anterior | Posterior | Right posterior oblique (RPO) | Left posterior oblique (LPO)

Figure 31. Normal [^{99m}Tc]Tc- DMSA

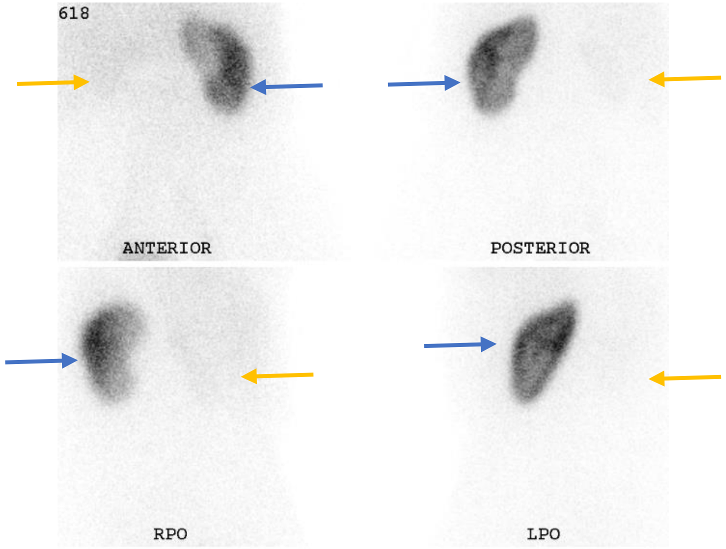
Relative higher radiopharmaceutical uptake within the right kidney (yellow arrow) compared to the left kidney (blue arrow) due its superficial position i.e. closer to the gamma camera. Otherwise, both kidneys have a normal contour and exhibit homogenous radiopharmaceutical uptake. No photopenic defects to suggest cortical scarring.

Chapter Outline

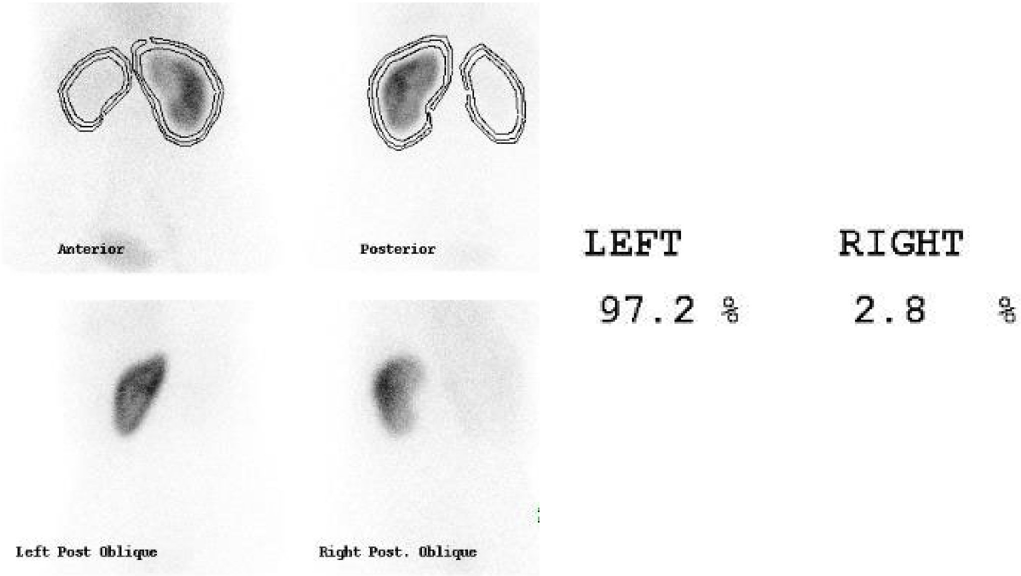
DMSA Renal Scan

Case: Non-functioning right kidney with a likely hypertrophied left kidney

59 years old female. Severe right hydronephrosis with 1.3 cm stone. DMSA to assess renal function.



Standard views of DMSA



Standard views of DMSA with region of interest marked and split function

Figure 32. [^{99m}Tc]Tc- DMSA

The right kidney is barely visible above background (yellow arrow) and the faint outline is smaller than the left kidney. The left kidney is large (blue arrows) likely due to compensatory hypertrophy, with a regular contour and no regions of photopenia to indicate scarring. Split function = right kidney 2.8%, left kidney 97.2%.

DMSA Renal Scan

Case: Horseshoe Kidney

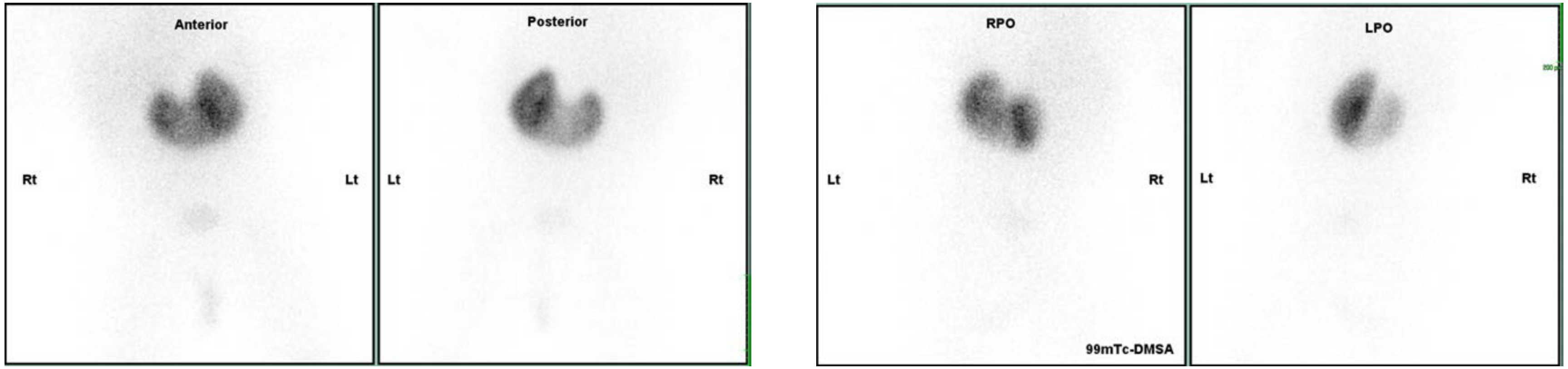


Figure 33 [^{99m}Tc]Tc- DMSA

Horseshoe kidney configuration with no evidence of scarring.

DMSA Renal Scan

Usefulness of the test compared with other imaging modalities:

More accurate assessment of divided renal function compared to a renogram (*see next section*).

Other imaging modalities such as ultrasound and CT can assess renal size but cannot quantitatively assess function.

Pyelonephritis may also be identified as defects and mimic scars.

Renal: Renogram

Indications:
Assessment of renal perfusion
Evaluation of divided renal function
Possible obstruction
Assessment of the urinary tract post-surgery e.g. post pyeloplasty for pelviureteric junction (PUJ) obstruction

Radiopharmaceutical:
[^{99m}Tc]Tc- Mercaptoacetyltriglycine (MAG3):

Agent undergoes both glomerular filtration and tubular excretion

[^{99m}Tc]Tc- Diethylene-triamine-pentaacetate (DTPA):

Alternative agent but less used in clinical practice, undergoes glomerular filtration only

Route: Administered intravenously

Image acquisition:
Dynamic planar imaging for 30 minutes
Then static images acquired pre-micturition, post-micturition and delayed 2-hours post-micturition
Furosemide injected to assess for obstruction – timing varies between institution
Computer processing of data to provide time activity curve

Chapter Outline

Renal: Renogram

Normal Case

Time activity curve is a representation of the uptake and excretion of the radiopharmaceutical by the kidneys as a graph.

Renogram has three phases:

A - Vascular (flow phase) - shows blood flow and initial uptake of radiopharmaceutical by the kidneys, usually lasts 30 to 60 seconds (yellow arrow)

B - Cortical transit (tissue-function phase) - radiopharmaceutical concentrates in renal tubules, peaks at 3-5 minutes (pink arrow).

C - Excretory (drainage phase) – downslope in the renogram indicating excretion of radiopharmaceutical by the kidneys. It usually starts at 4-8 minutes after radiotracer injection (purple arrow).

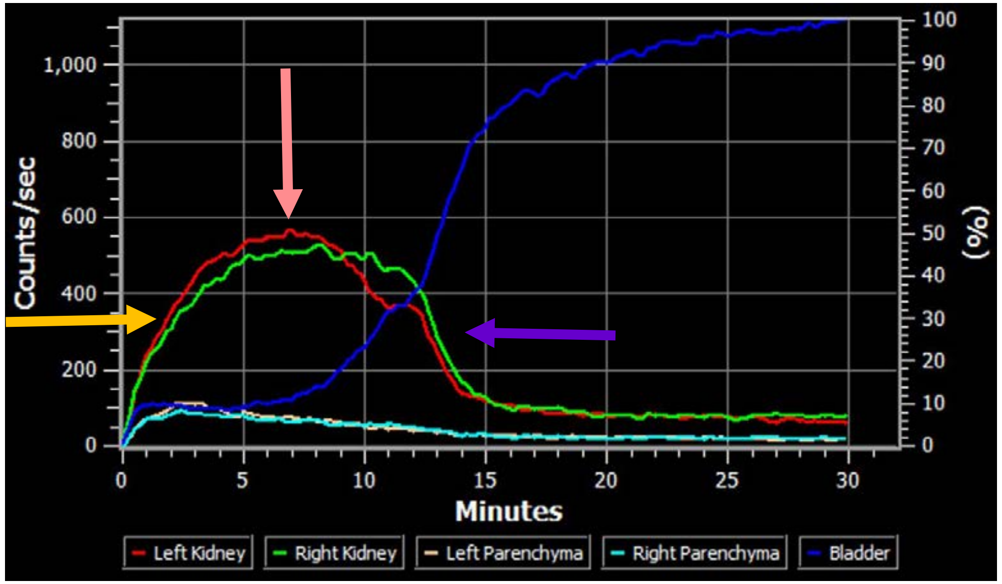


Figure 34. Normal [^{99m}Tc]Tc- MAG3 Renogram Time Activity Curve

Both kidneys show prompt tracer uptake, normal transit, excretion and drainage. The time activity curves are normal. Normal study with no evidence of obstruction.

Renal: Renogram

Case: Right kidney pelviureteric junction obstruction

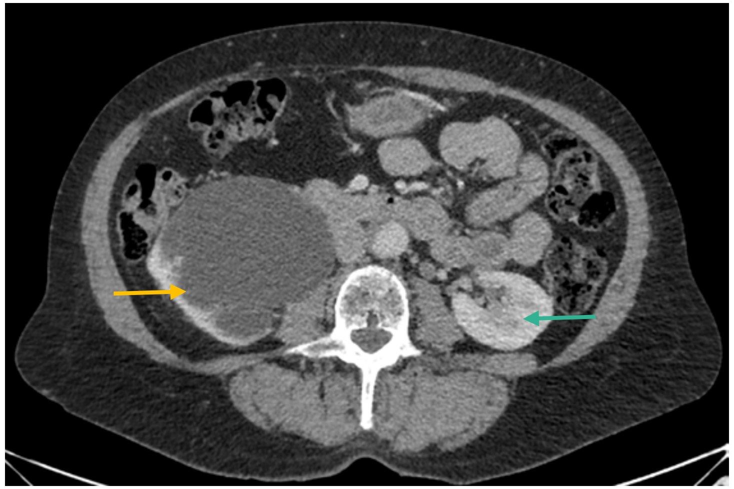


Figure 35. Axial Post Contrast CT

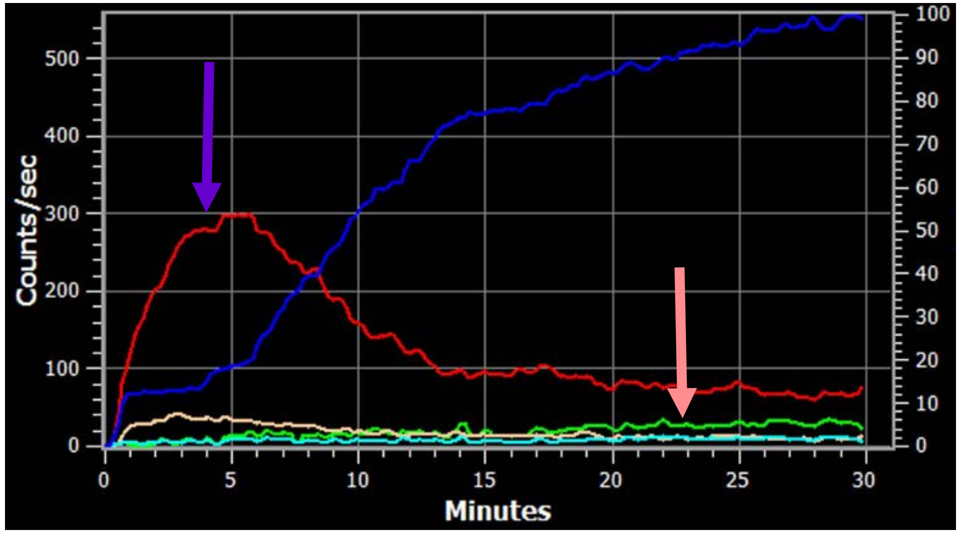


Figure 36. [^{99m}Tc]Tc- MAG3 Renogram Time Activity Curve

CT abdomen and pelvis demonstrated right sided hydronephrosis (yellow arrow). Normal appearance of left kidney (green arrow).

On the renogram there is delayed uptake, cortical transit, excretion and limited drainage of the right kidney demonstrated by the flattened amplitude of the time-activity curve (green curve, pink arrow). Appearances are in keeping with a very high-grade/near complete obstruction. The left kidney shows prompt tracer uptake, normal transit, excretion and drainage (red curve, purple arrow). The blue curve represents tracer within the urinary bladder.

Renal: Renogram

Case: Right kidney pelviureteric junction obstruction

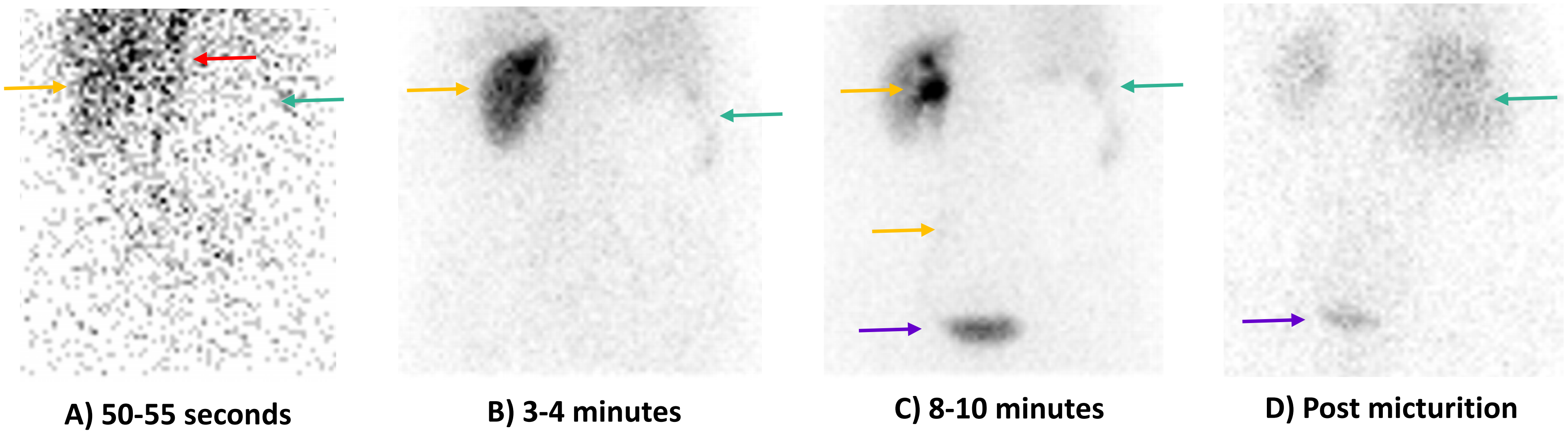


Figure 37. [^{99m}Tc]Tc- MAG3 Renogram Dynamic Study

A) In the initial vascular (flow) phase - radiopharmaceutical within the abdominal aorta and left kidney. No activity demonstrated in the right kidney.

B) Cortical transit (tissue-function) phase - radiopharmaceutical concentrates in renal tubules of the left kidney. Faint rim of cortical uptake around the grossly distended pelvis of the right kidney.

C) Excretory (drainage) phase - radiopharmaceutical demonstrated within the left renal pelvis, ureter and bladder in keeping with excretion of radiopharmaceutical by the left kidneys. Increasing activity within the right kidney cortex but no radiopharmaceutical within the renal pelvis or ureter.

D) Low level activity within the dilated right pelvicalyceal system on the post micturition.

Appearances are in keeping with a very high-grade/near complete obstruction.

Renal: Renogram

Usefulness of the test compared with other imaging modalities:

Dynamic test hence useful for assessment of urine passage and check for high-grade obstruction which can lead to obstructive uropathy and nephropathy.

CT and MR urogram demonstrate anatomical abnormality but renogram provides functional assessment helping to determine degree of impaired drainage and split function.

Chapter Outline

Myocardial Perfusion Imaging

Indications:
To identify the presence, site and grade the severity of coronary artery disease
Select patients who will benefit from revascularization e.g., PCI/CABG
Assess response post revascularization or medical treatment

Radiopharmaceutical:

Technetium-99m labelled Tetrofosmin (Myoview) or Sestamibi - lipophilic cationic agents which passively diffuse and accumulate in the mitochondria of viable myocardial tissue

Route: Administered intravenously

Image acquisition:
Two components: stress and rest. Depending on institutions performed on same day or separate days

Rest: Imaging 45-60 minutes post radiopharmaceutical injection

Stress: Exercise test or pharmaceutical stress agents given prior to radiopharmaceutical. Either adenosine, regadenoson, or dobutamine are used depending on their background medial history and medications.

SPECT Imaging

Additional CT component acquired for attenuation correction

Myocardial Perfusion Imaging

Pharmaceutical stress agent:

A stress myocardial perfusion scan assesses blood flow to the myocardium under stress.

Stress test can use exercise (e.g., bicycle or treadmill). If patients are unable to exercise, the heart can be stressed by taking a pharmaceutical stress agents that increases heart rate or dilate coronary arteries like physical exercise.

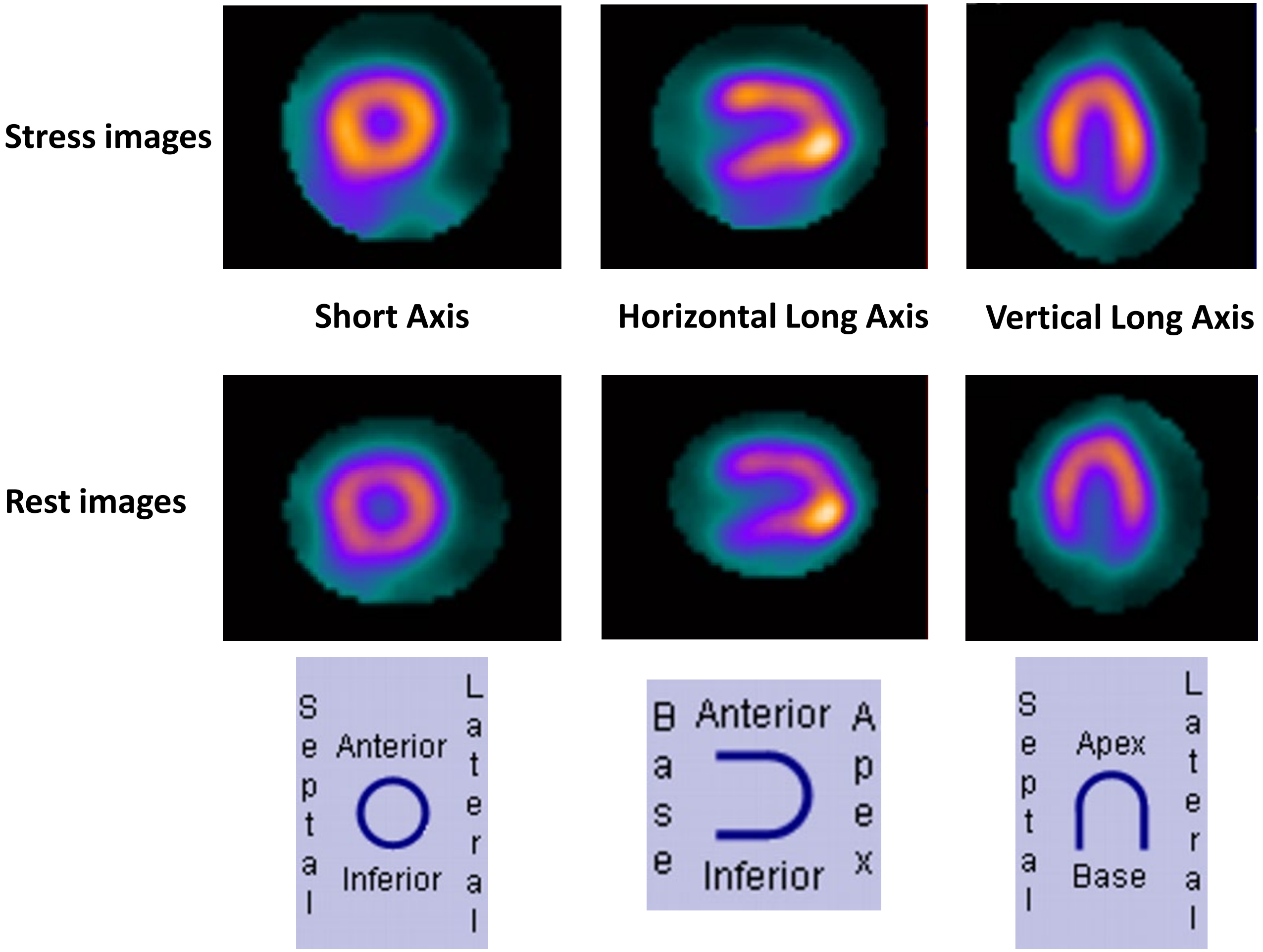
The table lists the main pharmaceutical stress agents and mechanism of action.

Pharmaceutical Stress Agent	Mechanism of Action
Regadenoson	Specific A2A adenosine receptor agonist Vasodilator (direct)
Adenosine	Nonspecific adenosine receptor agonist Vasodilator (direct)
Dipyridamole	Prevent the intracellular reuptake and deamination of adenosine Vasodilator (indirect)
Dobutamine	β1- and β2-receptor agonist Sympathomimetic

Table 8. Pharmaceutical stress agents for cardiac imaging

Myocardial Perfusion Imaging

Normal Case Example



Both stress and rest images demonstrate normal radiopharmaceutical distribution. Short, horizontal long and vertical long axis represent the different reconstructed SPECT views of the myocardium.

Figure 38. Normal [^{99m}Tc]Tc Myocardial Perfusion Imaging

Chapter Outline

Myocardial Perfusion Imaging

Case:

68 years old male. Assessment of coronary artery disease.

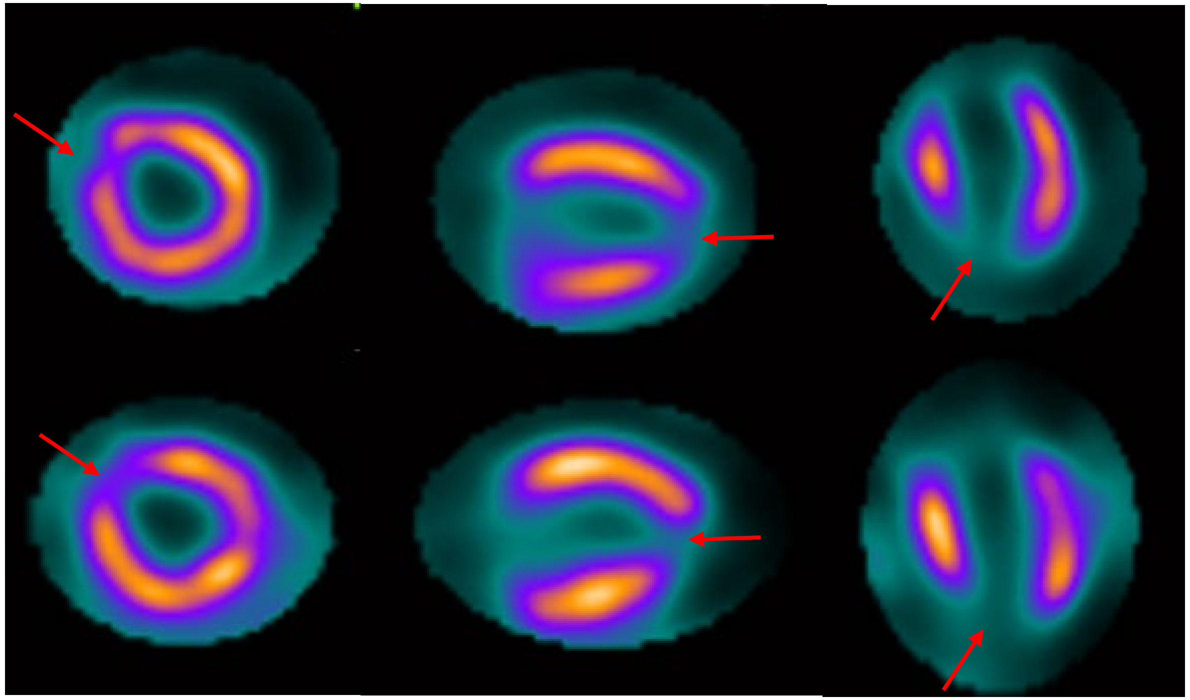


Figure 39. [^{99m}Tc]Tc Myocardial Perfusion Imaging

On the stress component, there is severe reduction of tracer uptake at the apex (red arrows) with the rest component demonstrating that this is largely fixed in keeping with an distal left anterior descending infarct.

Myocardial Perfusion Imaging

Studies	Usefulness of the test compared with other imaging modalities
Myocardial Perfusion Imaging (MPI)	Functional assessment compared to anatomical information gained from coronary angiogram or CT coronary angiogram MPI provides limited quantification of perfusion and limited spatial resolution
PET perfusion imaging (Rubidium-82 or Nitrogen-13)	Better spatial resolution and decreased noise compared to SPECT but not widely available
Cardiac MRI	High spatial resolution, can perform quantification of perfusion, and avoids ionizing radiation. Detailed characterization of myocardial tissue can be performed but expensive and limited availability
CT coronary angiogram	Provides anatomical information by visualizing the coronary artery lumen and assessing coronary artery stenosis but does not provide functional information
Stress echocardiogram	Widely available, bedside test, inexpensive, however operator dependent, lack of reproducibility

Table 9. Comparison of different cardiac imaging modalities

Metaiodobenzylguanidine (MIBG)

Indications:
Detection, localization, staging and follow-up of neuroendocrine tumours: Phaeochromocytomas, Neuroblastomas, Carcinoid tumours, etc.
Iodine-131 labelled MIBG is used for treatment of certain neuroendocrine tumours

Radiopharmaceutical:

Iodine-123 labelled with MIBG (meta-iodobenzylguanidine).

MIBG is an analogue of noradrenaline and guanethidine and enters neuroendocrine cells by an active uptake mechanism via the adrenergic transporters and stored in neurosecretory granules

Route: IV slowly over 4 minutes

Image acquisition:
Early planar 4 hours post injection
Delayed planar 24 hours post injection
+/- SPECT/CT at 24 hours

Chapter Outline

MIBG Scan

Normal Case

[^{123}I]I-MIBG scan.

Diffuse homogenous uptake within liver and urinary bladder.

Mild homogenous uptake within the salivary glands.

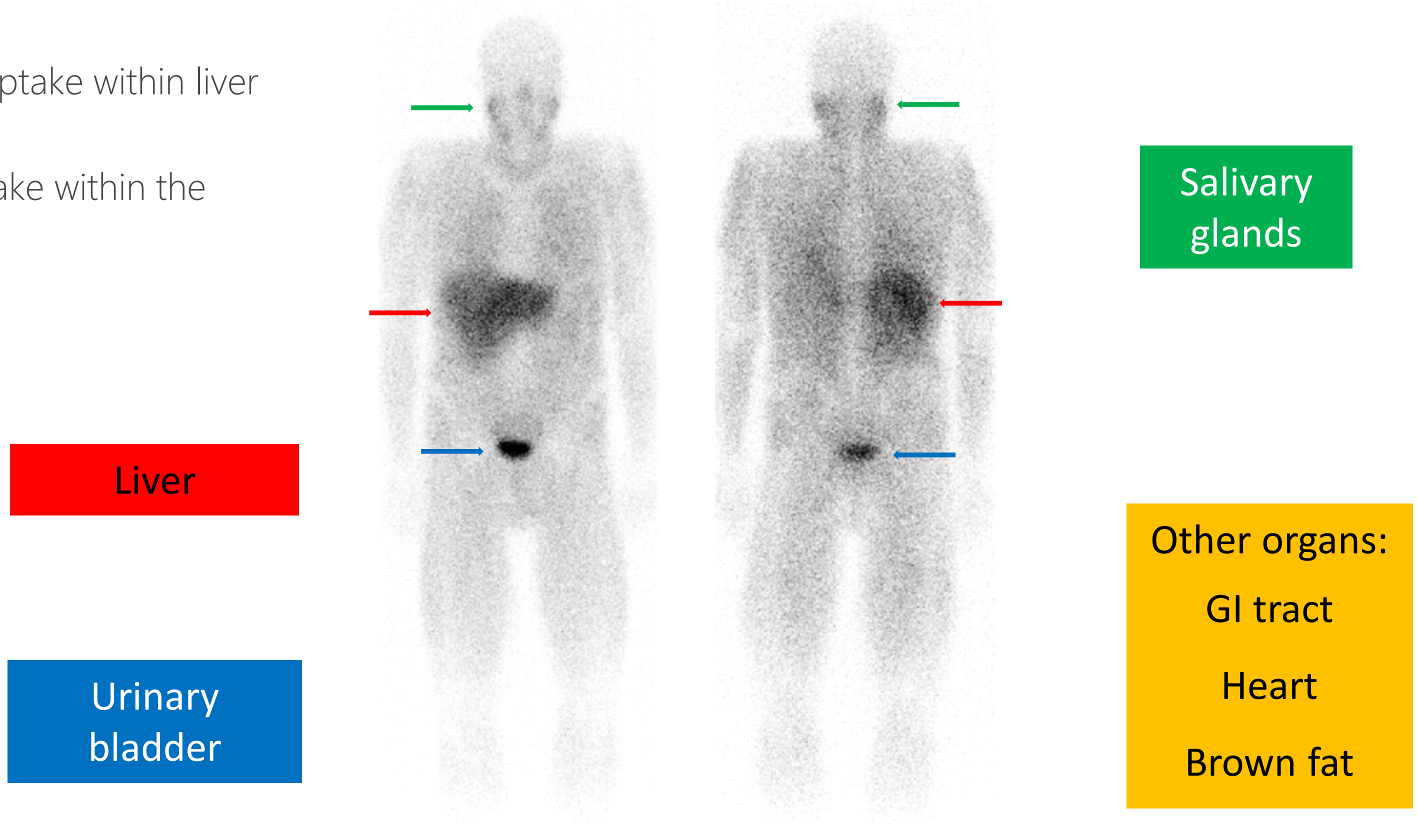


Figure 40. Normal [^{123}I]I-MIBG Scan

Chapter Outline

MIBG SPECT/CT

Case: Left phaeochromocytoma

61 years old female. Left suprarenal mass measuring 5 cm. Indeterminate on CT with no arterial enhancement but functional studies suggest phaeochromocytoma.

Figure 41. [^{123}I]I-MIBG with SPECT/CT

SPECT/CT

On the whole-body planar imaging, there is intense asymmetric increased MIBG uptake localizing to the left adrenal gland persisting on the 24-hour imaging (yellow arrow).

On the SPECT/CT, there is intense radiopharmaceutical activity anteromedially within a 5 cm left adrenal mass (blue arrows).

Chapter Outline

MIBG

Usefulness of the test compared with other imaging modalities:

Generally considered an accurate test for visualization of neuroendocrine tumors

Important functional study when findings are suspected on conventional anatomic imaging (CT/MRI)

MIBG is useful for suspected adrenal and abdominal tumors versus [^{68}Ga]Ga-DOTA peptide PET/CT for extra abdominal neuroendocrine tumors (*see PET study section*)

DaT Scan

Indications:

Diagnosis of Parkinson's disease and other neurodegenerative parkinsonian syndromes (e.g. dementia with Lewy bodies, progressive supranuclear palsy, and multiple system atrophy)

Differentiating between dementia with Lewy bodies and other dementias

Differentiating between parkinsonism due to presynaptic degenerative dopamine deficiency and other forms of parkinsonism e.g. drug induced, psychogenic or vascular

Radiopharmaceutical:

Iodine-123 DaTSCAN (Ioflupane or FP-CIT) administered intravenously

Bind to presynaptic dopamine active transporters within the nigrostriatal pathway

Loss of nigrostriatal dopaminergic nerve terminals in patients with parkinsonian syndromes. Uptake of the radiopharmaceutical corresponds to the integrity of these transporters

Route: Administered intravenously

Image acquisition:

Imaging is performed 3-6 hours post-injection
Patient positioned supine in a headrest
Trans axial tomographic slices acquired

DaT Scan

Normal Case

Normal radiopharmaceutical uptake within bilateral caudate and putamina; the basal ganglia nuclei have a normal 'comma' morphology (blue circle).

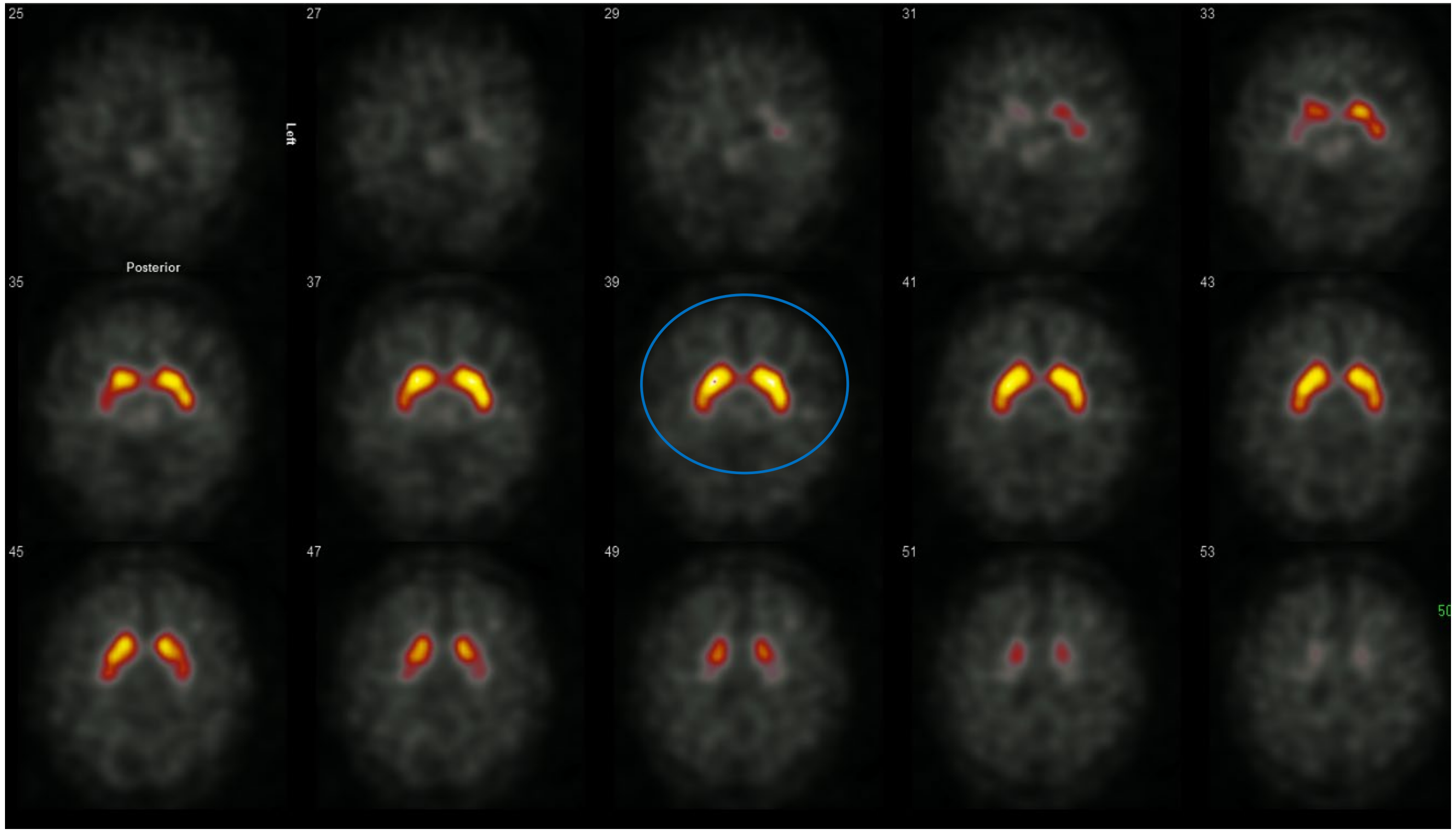


Figure 42. Axial SPECT images from DaT Scan

Chapter Outline

DaT Scan

Case: Parkinson's disease or a parkinsonian syndrome

72 years old male. Left hand tremor predominantly at rest, then began to involve right hand more recently.

Significantly reduced uptake of radiopharmaceutical in the bilateral putamina (blue arrow), worse on the right, with some reduction in uptake in the right caudate head (green arrow). Both basal ganglia are shaped like a dot rather than a comma; the "dot sign".

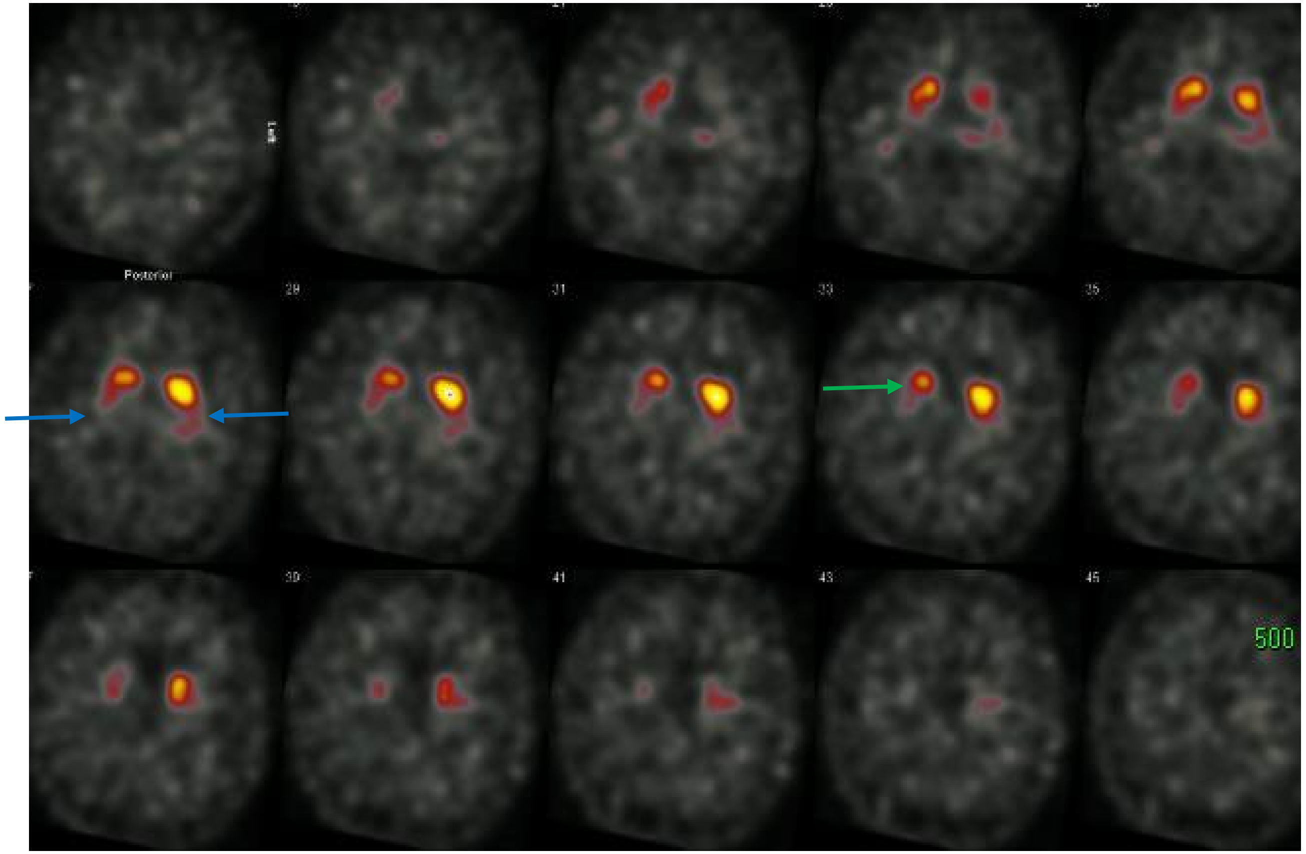


Figure 43. Axial SPECT images from DaT Scan

DaT Scan

Usefulness of the test compared with other imaging modalities:

Used synergistically with other tests depending on clinical indication e.g. MRI brain or FDG PET/CT.

Only readily available test to assess for presynaptic dopaminergic neuronal loss making it useful for its primary indication.

If there is concern over vascular parkinsonism (especially if there are clinical risk factors or unilateral abnormal findings on a DaT scan), an MRI would be helpful to assess for an ipsilateral infarct.

MRI or perhaps even FDG PET/CT may be used together with DaT scan when trying to discriminate causes of dementia.

Chapter Outline

FDG PET Scan

Indications:

- Provides a measure of glucose consumption and mainly used to detect malignancies
- Oncology - Malignancy staging and restaging, determining metabolic activity of cancer, monitoring the effects of therapy, detecting tumout recurrence, and radiation therapy planning
- Inflammation/Infection - Fever of unknown origin and vasculitis
- Neurology - Dementia and localisation of seizure foci
- Cardiology – Cardiac infection and inflammation, assessment of myocardial hibernation

FDG PET/CT: EANM procedure guidelines for tumour imaging: version 2.0, 2015

FDG PET Scan

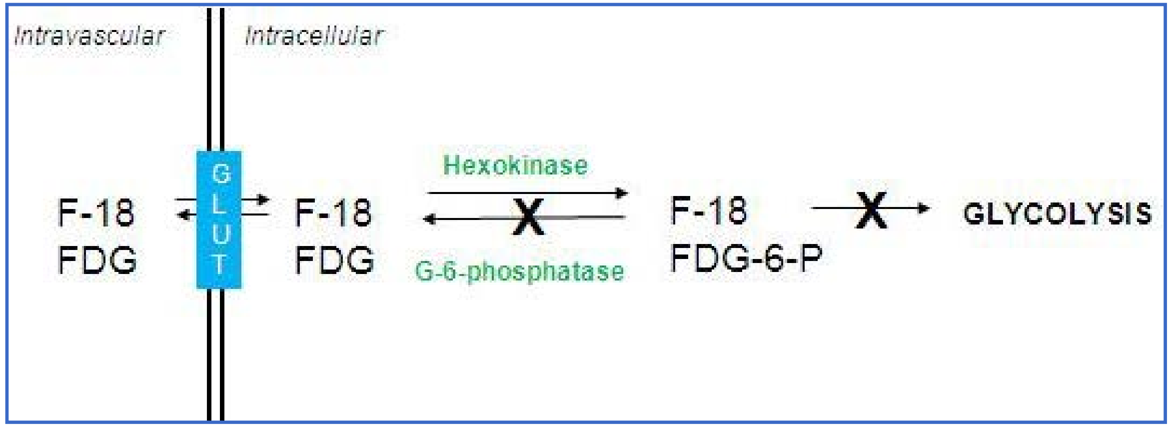
Radiopharmaceutical:

Fluorine-18 labelled fluorodeoxyglucose (FDG), Glucose analogue

Cyclotron produced

Half-life 110 minutes

FDG is metabolized to FDG-6-Phosphate. FDG enters cells via GLUT transporters similar to glucose but accumulates intracellularly after initial phosphorylation as it cannot undergo further metabolism. The higher the metabolic activity of the cells, the higher the FDG uptake. Malignant cells increase GLUT and hexokinase activity



Route: Administered intravenously

Figure 44. Schematic Diagram of Fluorine-18 FDG uptake in cells

FDG PET Scan

Image acquisition:

- Fast 4-6 hours prior to scan - optimize glucose and insulin levels
- No intense physical exercise 24 prior to scan - reduce muscle FDG uptake
- Patient should rest in a room for a period of 30 min to 1 hour - reduce muscle FDG uptake
- Patient should void before start of images - reduced FDG concentration in urinary bladder
- Imaging is performed 60 minutes post-injection
- Images acquired depending on protocols; either whole body (From the top of the head through the feet), torso imaging (from the top of the head/base of skull to mid-thigh)
- Combined with low dose CT for attenuation correction and localization

FDG PET/CT: EANM procedure guidelines for tumour imaging: version 2.0, 2015

Chapter Outline

FDG PET Scan

Blood glucose and insulin

- Both glucose and FDG are actively transported into cells, so glucose levels in blood will affect the uptake of FDG.
- High blood glucose levels will result in lower uptake of FDG.
- It is important that blood glucose levels are within a normal range before $[^{18}F]FDG$ administration.

- Patients must fast for 4-6 hours prior to a FDG PET scan.
- The preparation for diabetic patients is complicated and depends on the type of medications and if on insulin.
- A recent medical history is vital prior to imaging.

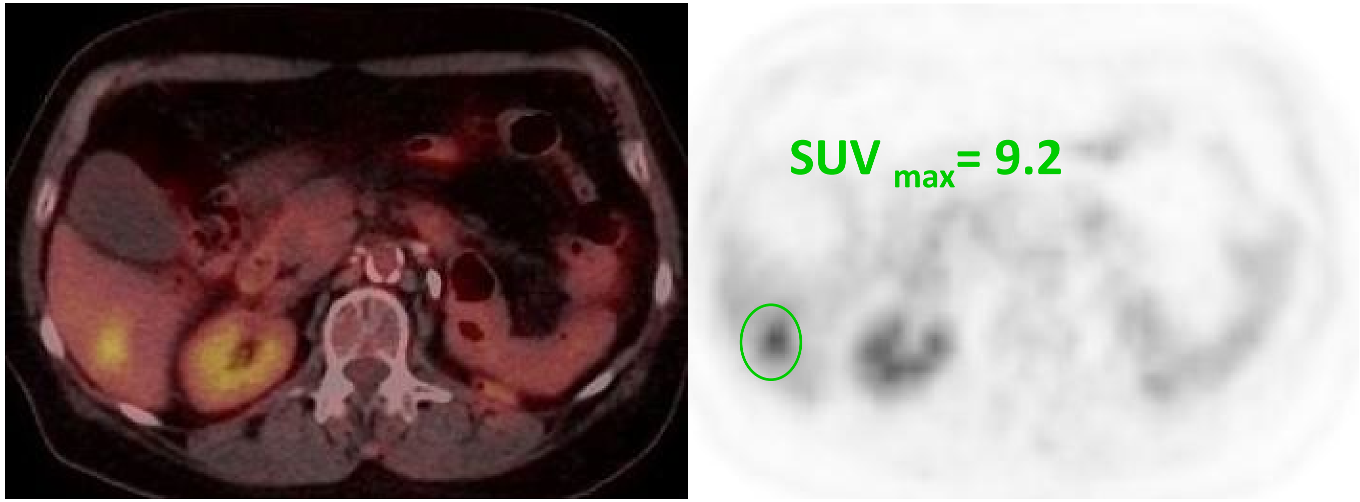
FDG PET Scan

SUV:

- The standardized uptake value (SUV) is a semiquantitative measure used to quantify activity on PET/CT scans

$$SUV = \frac{\text{Standardised uptake value } \textit{tracer uptake}}{\textit{injected activity/pt wt x 1000}}$$

- Maximum SUV of a region of interest is used to assess lesions (SUVmax) which can be compared to background activity in normal tissues (e.g., liver or mediastinal blood pool)



The green circle demonstrates a region of interest drawn around the focus demonstrating high tracer uptake within the liver allowing for SUV measurement.

Figure 45. Axial fused and PET images from $[^{18}F]$FDG PET/CT Scan

Chapter Outline

FDG PET Scan

SUV:

Factors affecting SUV	blood glucose insulin levels at time of injection time period between FDG administration and scanning
High SUV	most high-grade malignancies, infectious and inflammatory processes
Low SUV	specific malignancies (prostate, hepatocellular carcinoma, lung adenocarcinoma spectrum lesions, neuroendocrine tumours) and histological subtypes (low grade, mucinous/lobular tumours), smaller tumours (particularly below 6 mm)

Table 10. SUV

FDG PET Scan

Normal Case Example

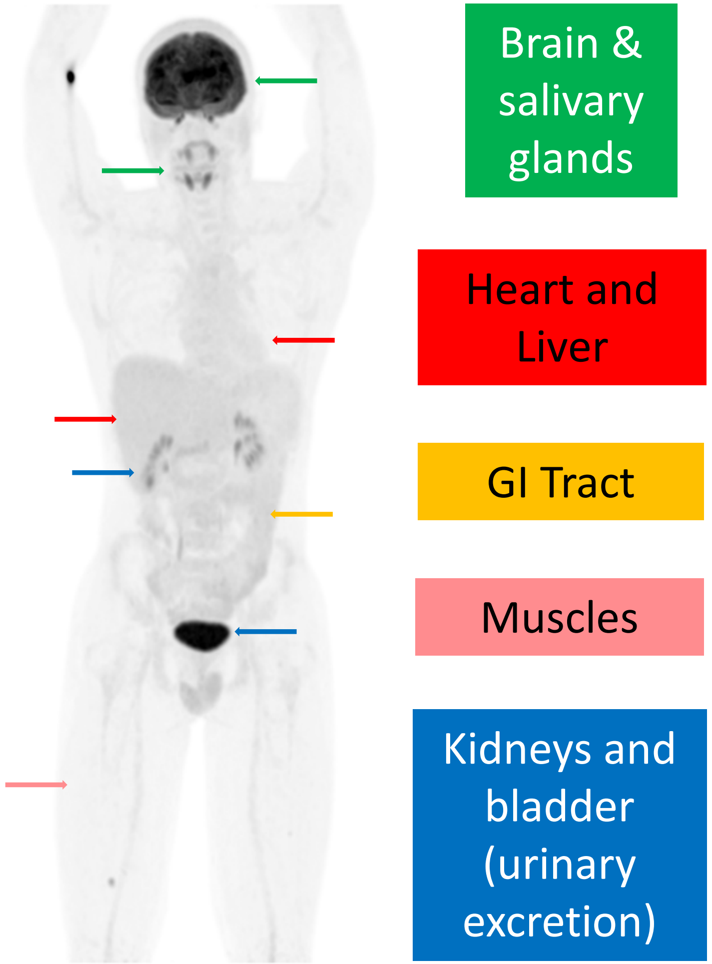


Figure 46. MIP image from [^{18}F]FDG PET Scan

Normal Physiological Uptake

- Brain: Intense FDG uptake as glucose is main substrate for metabolism.
- Urinary tract (kidneys, ureters and bladder): High uptake as excretion route is renal.
- Myocardium: variable and dependent on insulin/glucose levels and the patient's fasting status (low post fast). Myocardium usually prefers fatty acid for its metabolism.
- Gastrointestinal tract: Uptake is variable, diffuse mild to moderate uptake is normal. Metformin can increase FDG uptake.
- Liver: Low/moderate, diffuse homogeneous uptake.
- Salivary glands, tonsils, thyroid: Mild to moderate symmetric uptake.
- Muscles: FDG uptake is usually low. FDG accumulation in muscles can be increased following exercise and with elevated insulin.
- Brown fat: Metabolically active adipose tissue usually located within supraclavicular, axillary, mediastinal and paravertebral regions, observed if the patient is cold and more so in younger patients.

Chapter Outline

FDG PET/CT

Case: Lung cancer with osseous metastatic disease

82 years old male. CT Thorax demonstrated solitary pulmonary nodule

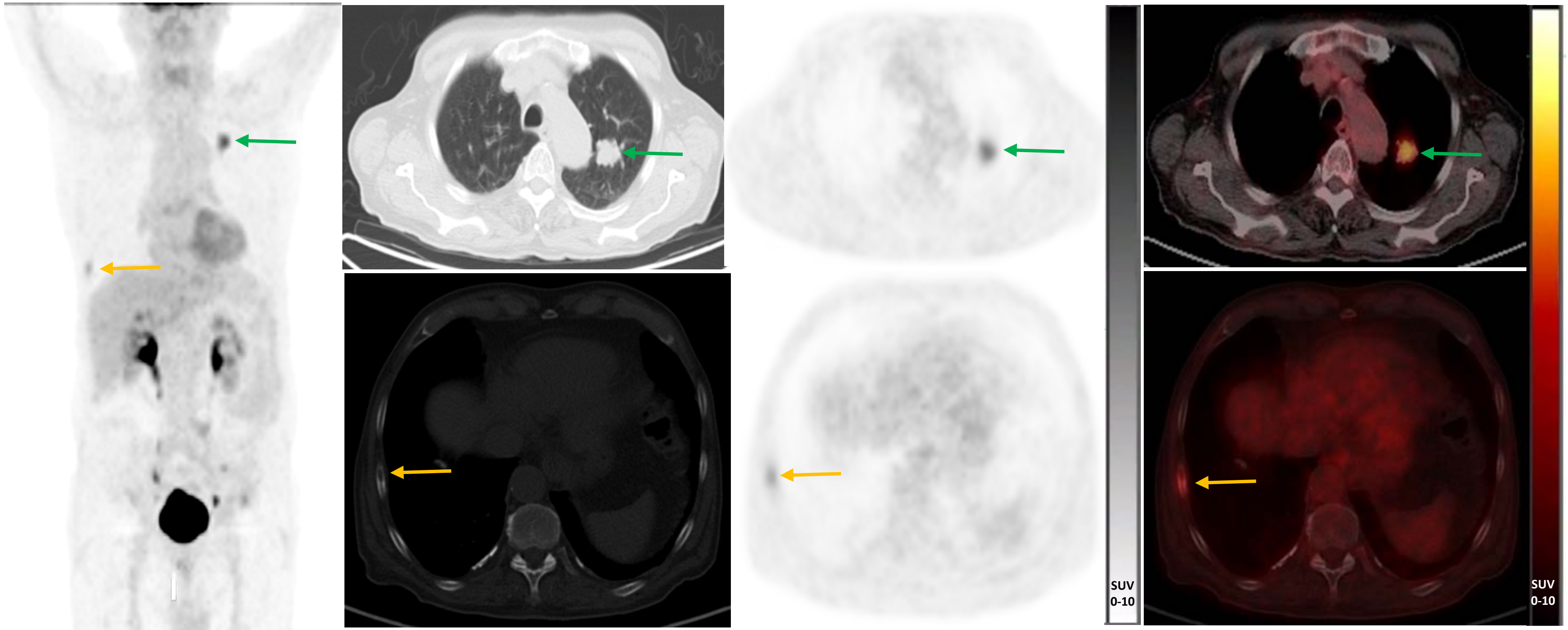


Figure 47. [^{18}F]FDG PET/CT Scan

A spiculated left apical nodule demonstrates (green arrow) increased metabolic activity (SUV-max 6.3). In addition, there is a metabolically active lytic lesion in the right 8th rib consistent with a bone metastasis (yellow arrow). No metabolic active lymph nodes demonstrated.

FDG PET/CT

Case: Diffuse Large B Cell Lymphoma

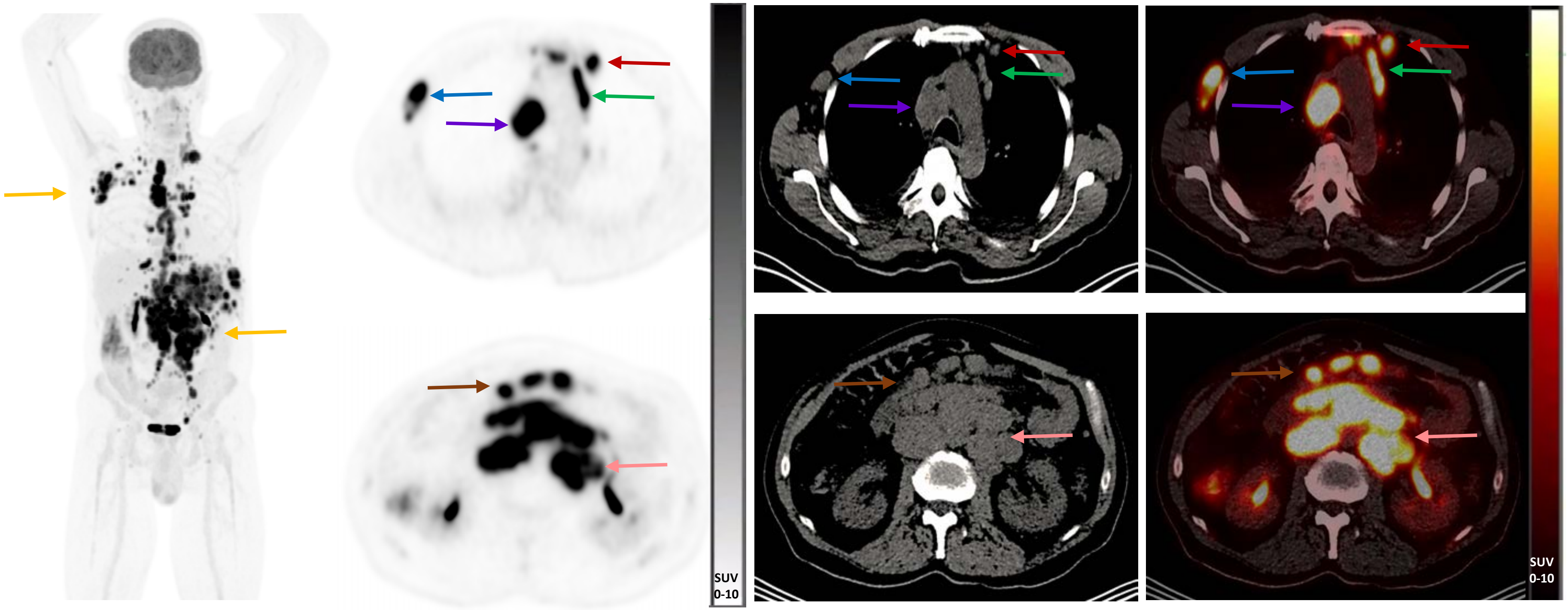


Figure 48. [^{18}F]FDG PET/CT Scan

The MIP image demonstrates multiple metabolically active foci corresponding to multiple intensely metabolically active lymph nodes above and below the diaphragm (yellow arrow). The axial images show paratracheal, prevascular, internal thoracic, axillary, para-aortic, and mesenteric nodal disease.

Chapter Outline

FDG PET/CT

Case: Non Hodgkin Lymphoma pre and post 6 cycles of chemotherapy

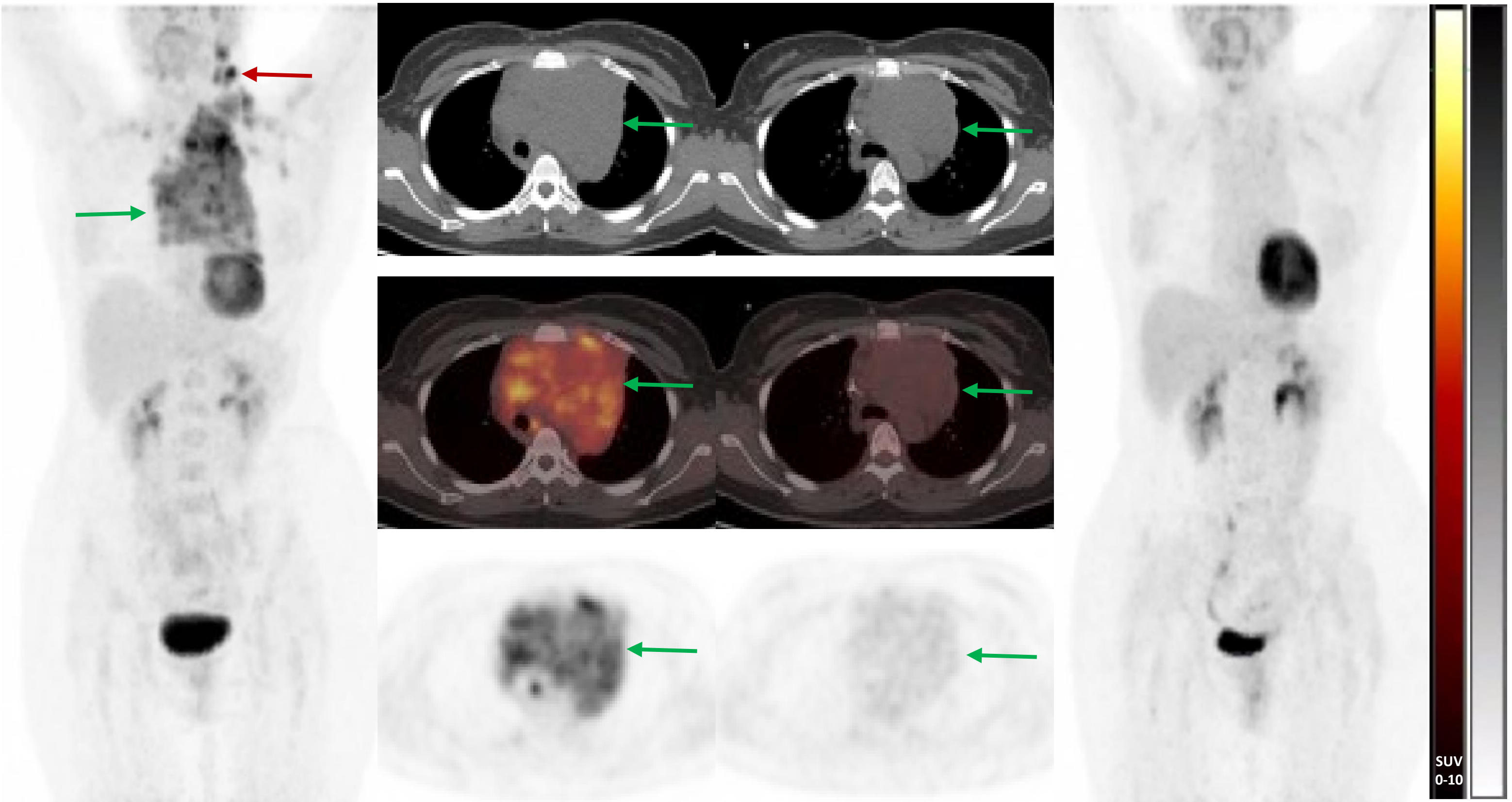


Figure 49. [18F]FDG PET/CT Scan

The left sided images demonstrates multiple metabolically active foci corresponding to multiple intensely metabolically active lymph nodes within the left neck (red arrow) and mediastinum (green arrow) which have resolved the subsequent right sided images post 6 cycle of chemotherapy.

Chapter Outline

FDG PET/CT

Deauville scale

- 5-point scale
- Used in the initial staging and treatment response assessment of Hodgkin lymphoma and certain non-Hodgkin lymphomas including the diffuse large B cellular lymphoma
- Grade visual assessment of [^{18}F]FDG uptake comparing with two reference points: mediastinal blood pool and the liver.
- Scale:

1	No uptake i.e. indiscernible from background level or no residual uptake
2	Uptake ≤ mediastinal blood pool (MBP)
3	Uptake > MBP ≤ liver
4	Uptake moderately higher than liver
5	Uptake markedly greater than liver and/or new lesions

Table 11. Deauville scale

FDG PET/CT

Pros	Cons
Anatomical and functional imaging on a single study (however the CT component is a low-dose study compared to standard CT imaging)	False positives in oncology scans: infectious and inflammatory processes, and sarcoid-like reaction in malignancy, ureteric activity mimicking lymph nodes
Detects metastatic disease that would have been missed on conventional CT/MRI Imaging which is crucial for management decisions	False negatives: Histology (low grade, necrotic or mucinous tumours, certain cancers such as prostate, hepatocellular carcinoma), small tumours

Table 12. Pros and Cons of FDG PET/CT

Chapter Outline

PSMA PET Scan

Indications:

- Staging of high-risk primary prostate cancer prior to prostatectomy
- Detectable PSA post-prostatectomy in the setting of persistent elevation of PSA (≥ 0.2 ng/ml) post prostatectomy, to assess for residual or otherwise occult disease, not identified pre-operatively
- Localization of disease in biochemical recurrence after radical prostatectomy, and radial radiotherapy if it will affect subsequent patient management decisions.
- Patient selection for Lutetium-177 labelled PSMA radionuclide therapy in metastatic castration-resistant prostate cancer

PSMA PET Scan

Radiopharmaceutical:

Prostate-specific membrane antigen (PSMA) a transmembrane glycoprotein that is expressed on the cell surface in normal prostate tissue.

PSMA expression is increased in prostate cancer especially higher-grade tumors.

PSMA can be labelled with Gallium-68 (Ga68), a positron emitter. There are radiotracers such as Fluorine-18 which can be labelled to PSMA with similar biodistribution but difference in binding affinities and nonspecific uptake.

Eluted from a Germanium-68 (^{68}Ge)/^{68}Ga generator

Half-life of 68 minutes

Route: Administered intravenously

Image acquisition:

Imaging is performed approximately 45–75 minutes after radiopharmaceutical administration.

PET images acquired from the pelvis to the head to minimize misregistration between the CT/MRI and PET components of the study due to filling of the bladder during acquisition.

Chapter Outline

68Ga PSMA PET Scan – Normal Distribution

Salivary glands

Liver and spleen

Pancreas & small bowel

Kidneys and bladder (urinary excretion)

Figure 50. MIP image from [^{68}Ga]Ga-PSMA-11 PET Scan

Normal Physiological Uptake is related to PSMA expression tissues and radiotracer excretion.

- Salivary glands: Physiological uptake related to PSMA expression.
- Liver and spleen: Moderate, diffuse homogeneous uptake.
- Pancreas and small bowel loops, particularly duodenum: Increased radiopharmaceutical uptake. PSMA expression for dietary folate absorption
- Urinary tract (kidneys, ureters and bladder): High activity as excretion route is renal.

Chapter Outline

PSMA PET Scan

Case: Prostate cancer recurrence with lymph node and osseous metastatic disease

76 years old male. Rising PSA 129 post previous radiotherapy for prostate cancer.

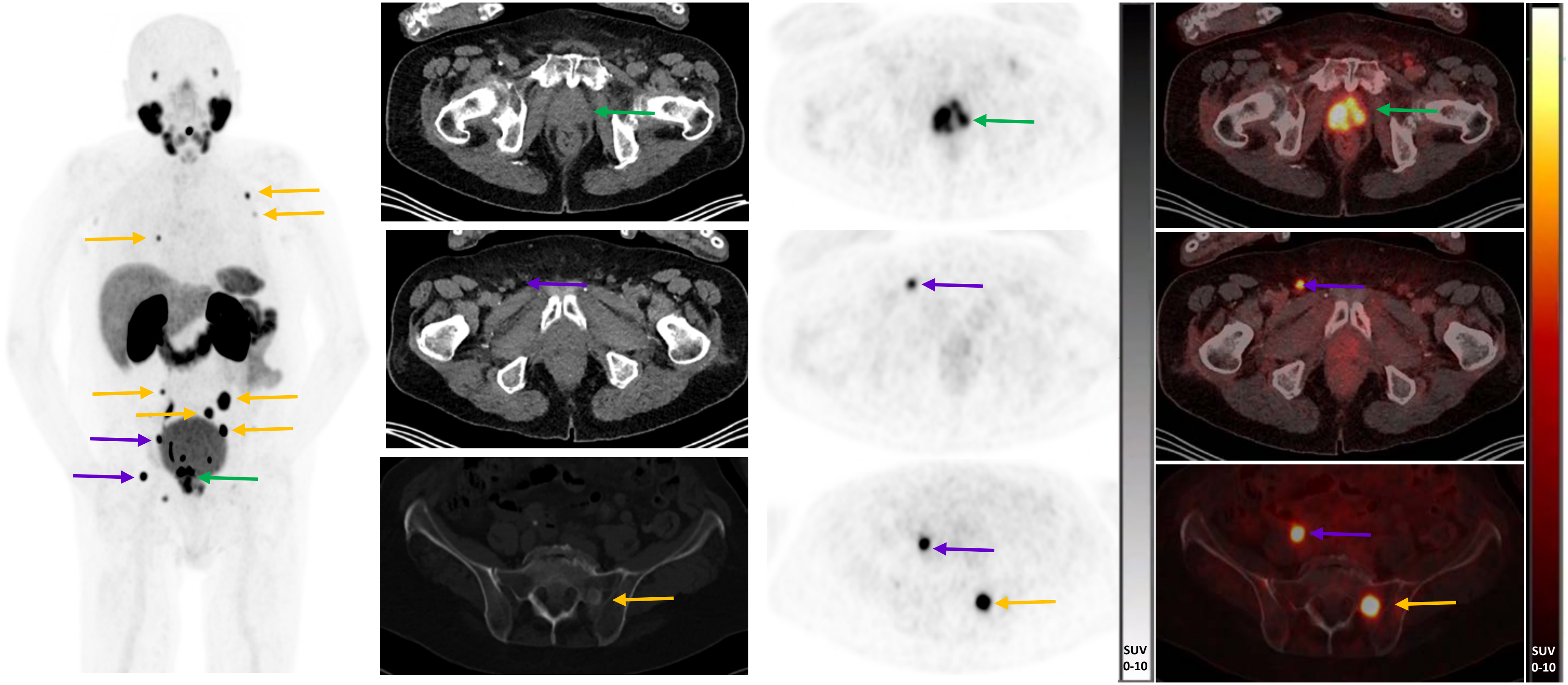


Figure 51. [68Ga]Ga-PSMA-11 PET/CT Scan

PSMA avid disease in the prostate (green arrow) with small volume right inguinal and pelvic nodal disease (purple arrow), as well as multiple bone metastases (yellow arrow) .

PSMA PET Scan

Usefulness of the test compared with other imaging modalities:

Pelvic MRI is superior to other imaging modalities for local regional staging of prostate cancer.

[^{68}Ga]Ga- PSMA PET/CT allows comprehensive metastatic disease assessment of the prostate, lymph nodes, soft tissues and bones. High sensitivity of PSMA PET, allows identification of small-volume disease, compared with conventional imaging.

Other PET radiopharmaceuticals for Prostate cancer include Fluciclovine, and radiolabelled Choline (Fluorine-18 or Carbon-11). Evidence suggest PSMA PET has superior diagnostic performance compared to the above pharmaceuticals.

False negative - 10% prostate cancer can be PSMA negative

False positives

- Infection/inflammatory process e.g. prostatitis
- Bone conditions e.g. fracture, Paget's disease, fibrous dysplasia
- Benign tumours e.g. adrenal adenoma
- Other malignancies expressing PSMA e.g. breast, lung, colorectal

Chapter Outline

DOTATATE PET Scan

Indications:

Neuroendocrine tumors (NET) localisation of primary tumour and detect sites of metastatic disease (staging)

Follow-up imaging to detect residual, recurrent or progressive disease (restaging)

Selection of patients for somatostatin receptor-targeted peptide receptor radionuclide therapy

Also used for assessment of pheochromocytoma, paraganglioma, neuroblastoma, and meningioma.

Procedure guidelines for PET/CT tumour imaging with 68Ga-DOTA-conjugated peptides: 68Ga-DOTA-TOC, 68Ga-DOTA-NOC, 68Ga-DOTA-TATE, 2010

Route: Administered intravenously

Radiopharmaceutical: Somatostatin receptors (SSTRs) are present on the cell surface of neuroendocrine cells

DOTATATE is a somatostatin analogue, binds to SSTR type 2

Gallium-68 is labelled with DOTATATE. Other pharmaceutical including DOTATOC and DOTANOC which have affinity for different somatostatin receptors.

Image acquisition:

Imaging is performed approximately 45–60 minutes after radiopharmaceutical injection.

DOTATATE PET Scan

Normal Case

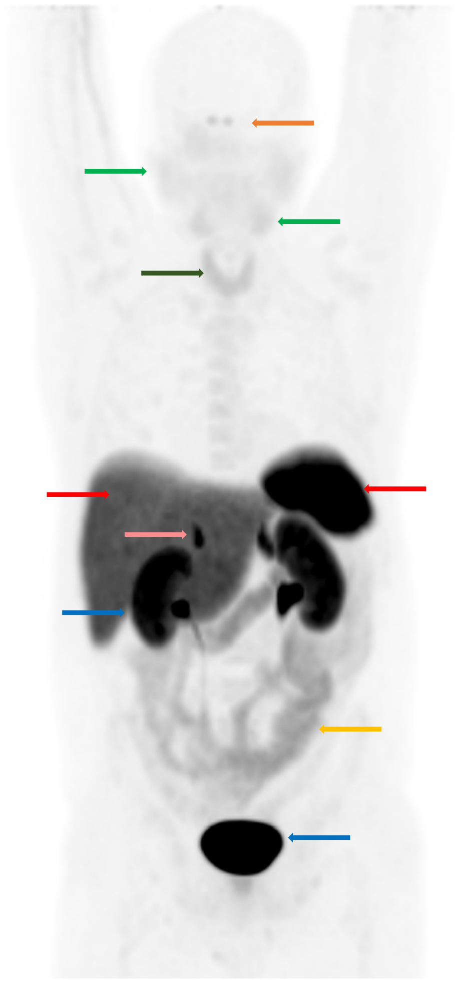


Figure 52. MIP image from [[68]Ga]Ga-DOTATATE PET Scan

Salivary glands
Pituitary Gland
Thyroid Gland
Spleen and Liver
Bowel
Adrenal Gland
Kidneys and bladder

Normal Physiological Uptake

Related to **specific receptor binding** and **nonspecific tissue handling of the peptide**

- Spleen: Highest intensity physiologic uptake, SSTR expression
- Kidneys: Glomeruler filtration, partially reabsorption in the proximal convoluted tubule, resulting in high activity in the collecting system and bladder, retained activity in the renal parenchyma
- Pituitary, thyroid and adrenal glands: SSTR expression
- Liver: Moderate, diffuse homogeneous uptake
- Salivary glands: SSTR expression
- GI Tract: Variable physiologic radiopharmaceutical uptake

Chapter Outline

DOTATATE PET Scan

Case: Pancreatic neuroendocrine tumour

42 years old male. Lesion within the pancreas on CT and MRI.

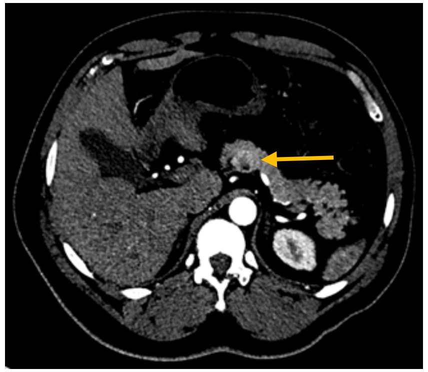


Figure 53. Axial image from Post Contrast CT

A lesion at the neck of the pancreas demonstrating peripheral arterial enhancement with a small low density/cystic focus posteriorly (yellow arrow). The lesion demonstrates diffuse intense increased DOTATATE uptake in keeping with a neuroendocrine tumour (green arrow).

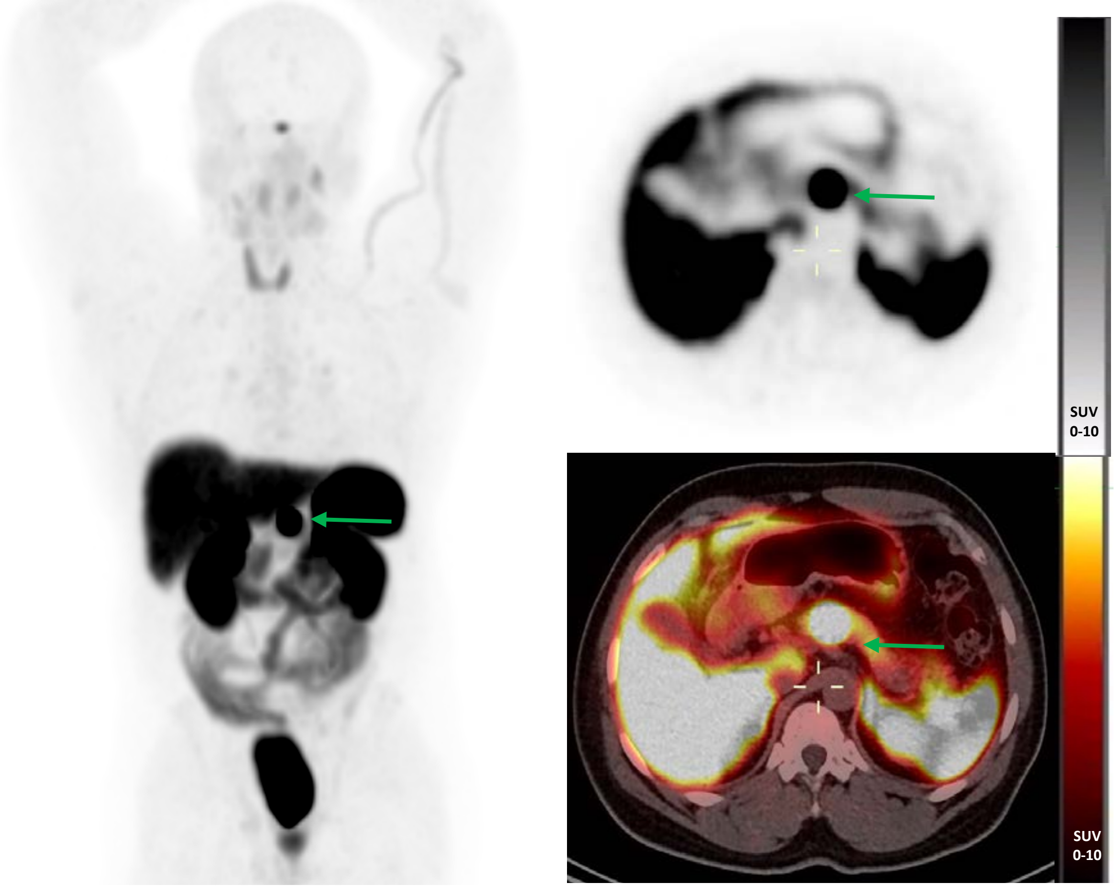


Figure 54. [^{68}Ga]Ga- DOTATATE PET Scan

Chapter Outline

DOTATATE PET Scan

Usefulness of the test compared with other imaging modalities:

Multiple studies have shown [^{68}Ga]Ga- DOTATATE PET/CT to be more accurate than conventional imaging, including octreotide SPECT/CT and contrast material–enhanced CT, in the diagnosis of low- and intermediate-grade NETs.

Most NETs have low uptake on [^{18}F]FDG PET/CT scan. It is used in the staging or restaging (including pre-operative assessments) of selected patients with poorly differentiated high-grade NETs.

Take-Home Messages

- Nuclear Medicine is specialty allowing functional assessment beyond anatomical information provided by other imaging modalities.
- A radiopharmaceutical combines a radionuclide and pharmaceutical, enabling targeting of different organs and physiological processes.
- Three major imaging modalities used in nuclear medicine are planar, SPECT and PET.
- SPECT and PET imaging can be combined with CT/MRI for attenuation correction and anatomical localization.
- Techentium-99m is the most commonly used radiopharmaceutical in planar and SPECT imaging.
- Fluorine-18 FDG is the most commonly used radiopharmaceutical in PET imaging.

Chapter Outline

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Chapter Outline

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Chapter Outline

Test Your Knowledge

1. What type of radiation is used in Planar and SPECT imaging?

a) Alpha radiation

b) X-ray

c) Ultraviolet

d) Gamma radiation

Test Your Knowledge

1. What type of radiation is used in Planar and SPECT imaging?

a) Alpha radiation

b) X-ray

c) Ultraviolet

✓ Gamma radiation

Planar and SPECT imaging uses gamma radiation. Alpha radiation is used in radiotherapy and certain radionuclide therapies. X-ray is used for conventional radiology imaging techniques including plain film radiography, fluoroscopy and computed tomography. Ultraviolet has no role in imaging studies.

Chapter Outline

Test Your Knowledge

2. What is the half-life of Technetium-99m?

a) 110 minutes

b) 6 hours

c) 68 minutes

d) 8 days

Test Your Knowledge

2. What is the half-life of Technetium-99m?

a) 110 minutes

✓ 6 hours

c) 68 minutes

d) 8 days

The half-life of Technetium-99m is 6 hours. This makes for a good radiopharmaceutical because it is long enough to be able to transport but not too long that the patient is radioactive for an extended period of time.

Chapter Outline

Test Your Knowledge

3. Technetium-99m is used in the assessment of bone metastasis. Which of the following cancers is [^{99m}Tc]Tc- HDP used in the assessment of bone metastasis?

a) Prostate

b) Lung

c) Renal

d) Thyroid

Test Your Knowledge

3. Technetium-99m is used in the assessment of bone metastasis. Which of the following cancers is [^{99m}Tc]Tc- HDP used in the assessment of bone metastasis?

✓ Prostate

✓ Lung

c) Renal

d) Thyroid

[^{99m}Tc]Tc- HDP is useful for osteoblastic metastasis such as prostate and breast (can be mixed). Lytic/osteoclastic bone metastases are not evident compared and may even appear as photopenic regions.

Test Your Knowledge

4. 36 years old female patient presents with clinical and biochemical symptoms of hyperthyroidism. As part of the investigation, she had a [^{99m}Tc]Tc-pertechnetate thyroid scan (see Figure 52 below). What diagnosis is demonstrated in the study?

a) Graves' disease

b) Toxic multinodular goitre

c) Autonomous toxic nodule

d) Subacute thyroiditis

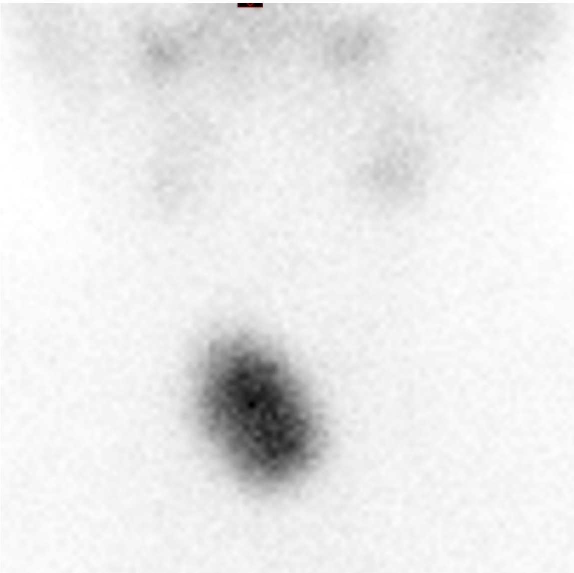


Figure 56. [^{99m}Tc]Tc Thyroid scan

Test Your Knowledge

4. 36 years old female patient presents with clinical and biochemical symptoms of hyperthyroidism. As part of the investigation, she had a [^{99m}Tc]Tc-pertechnetate thyroid scan (see Figure 52 below). What diagnosis is demonstrated in the study?

a) Graves' disease

b) Toxic multinodular goitre

✓ Autonomous toxic nodule

d) Subacute thyroiditis

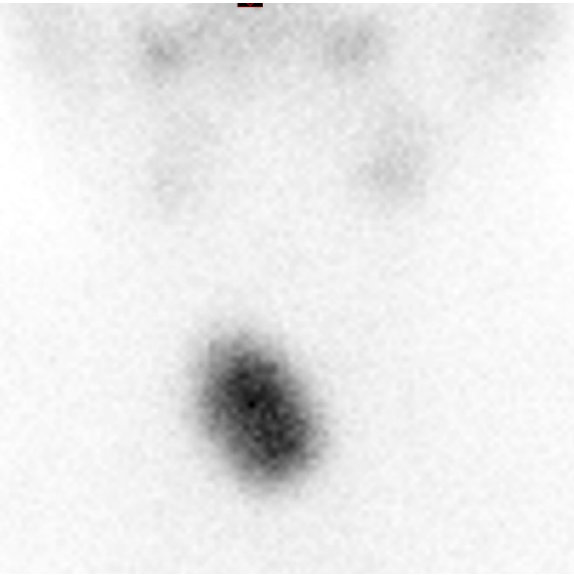


Figure 56. [^{99m}Tc]Tc Thyroid scan

There is a rounded, focal tracer activity centred on the mid right lobe of the thyroid. Appearances in keeping with autonomous nodule in the right lobe of the thyroid.

Chapter Outline

Test Your Knowledge

5. Which of the following is an indication for renal DMSA?

a) Assessment of renal scarring

b) Calculation of e-GFR

c) Identify renal obstruction

d) Corticomedullary differentiation

Test Your Knowledge

5. Which of the following is an indication for renal DMSA?

✓ Assessment of renal scarring

b) Calculation of e-GFR

c) Identify renal obstruction

d) Corticomedullary differentiation

DMSA scans allow detection of focal renal parenchymal abnormalities including assessment of renal scarring. [^{99m}Tc]Tc- DTPA is used for eGFR calculation. MAG3 renogram plays crucial role in confirming renal obstruction alongside other imaging modalities such as US and CT. US, CT, and MRI demonstrate the anatomy including corticomedullary differentiation of the kidneys.

Chapter Outline

Test Your Knowledge

6. Radiation dose to maternal breast tissue is greater for CTPA compared to V/Q scan.

Is the above statement TRUE/FALSE?

Chapter Outline

Test Your Knowledge

6. Radiation dose to maternal breast tissue is greater for CTPA compared to V/Q scan.

The above statement is TRUE.

Typically, radiation dose to maternal breast tissue is greater for CTPA compared to V/Q scan; doses to foetus are equivalent.

Test Your Knowledge

7. Figure 53 demonstrates a left pheochromocytoma. What nuclear medicine study do these images represent?

a) [^{68}Ga]Ga- PSMA

b) [^{18}F]FDG

c) [^{123}I]I- MIBG

d) [^{99m}Tc]Tc- pertechnetate

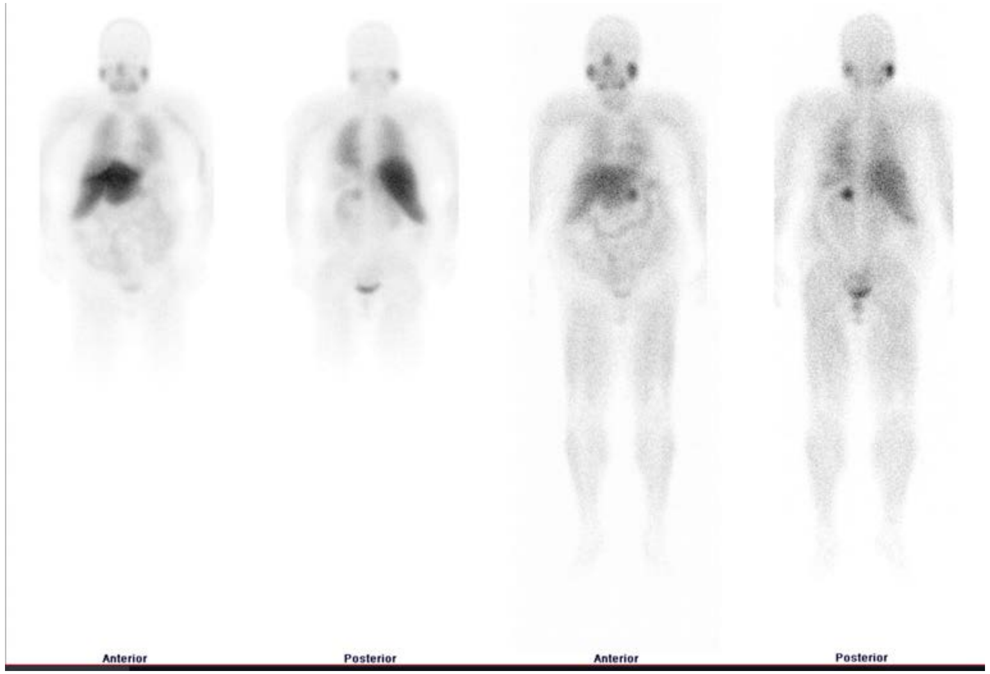


Figure 57. NM Study

Test Your Knowledge

7. Figure 53 demonstrates a left pheochromocytoma. What nuclear medicine study do these images represent?

a) [^{68}Ga]Ga- PSMA

b) [^{18}F]FDG

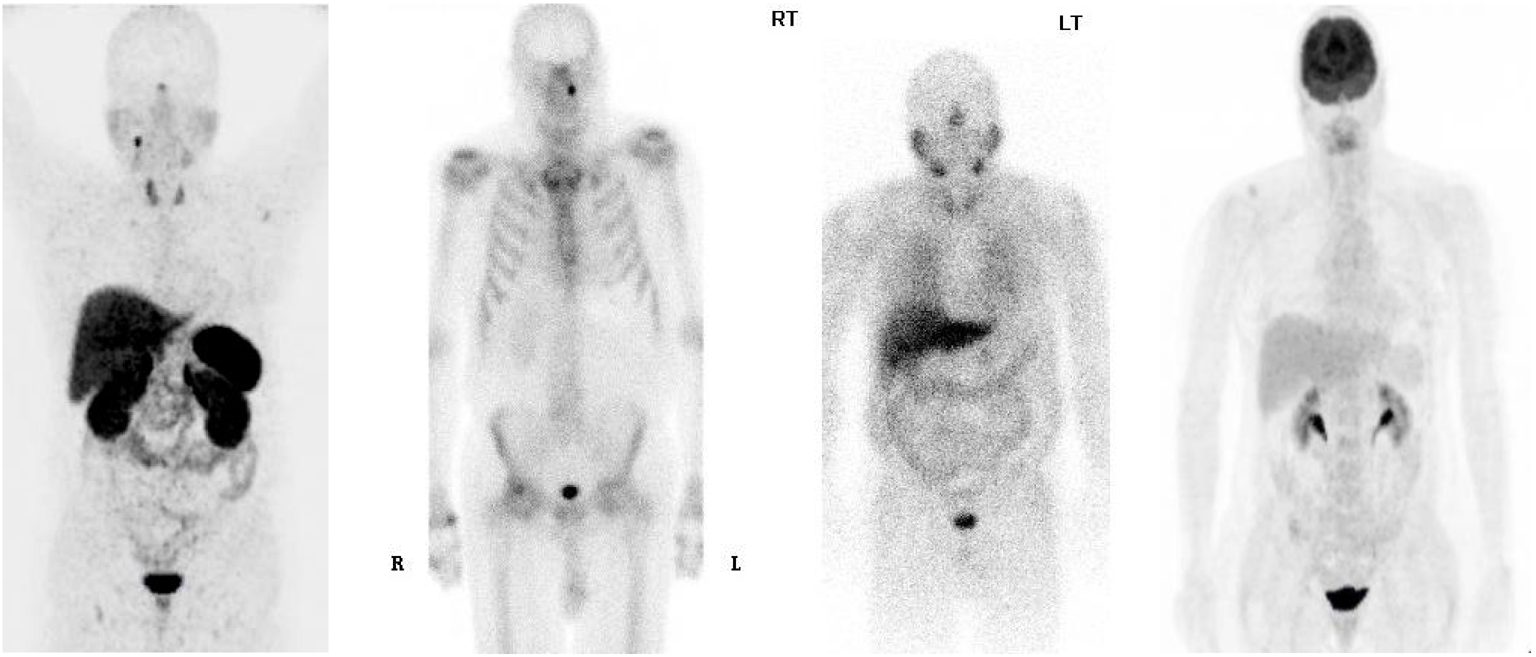
✓ [^{123}I]I- MIBG

d) [^{99m}Tc]Tc- pertechnetate

Figure 53 corresponds to images from [^{123}I]I- MIBG study. [^{68}Ga]Ga- PSMA is used for metastatic prostate cancer assessment. [^{18}F]FDG widely used in oncology, neuroradiology and cardiology. [^{99m}Tc]Tc- pertechnetate is used for thyroid scans.

Test Your Knowledge

8. Which of the images represents an FDG PET study?



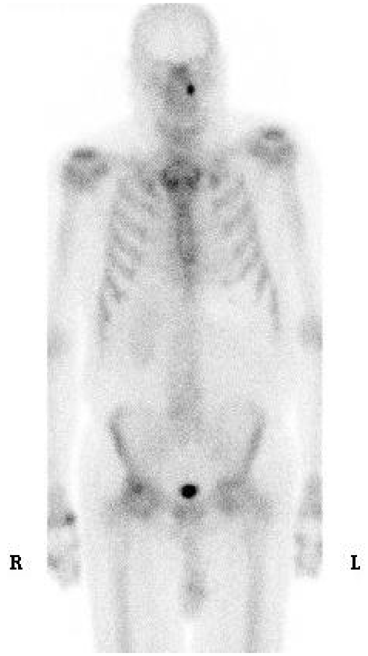
A B C D

Chapter Outline

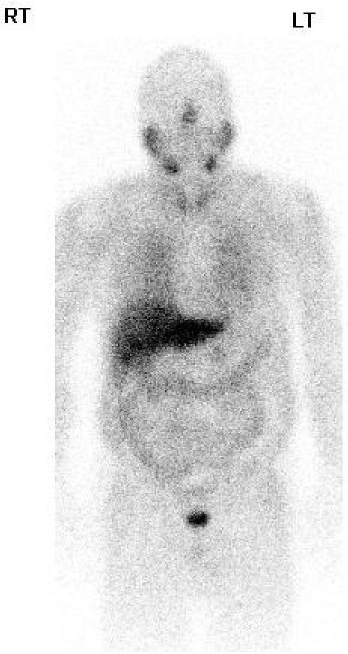
Test Your Knowledge

8. Which of the images represents an FDG PET study?

A. [^{68}Ga]Ga – DOTATATE PET scan



B. [^{99m}Tc]Tc –HDP whole body bone scan



C. [^{123}I]I –MIBG scan

D. [^{18}F]FDG–PET scan

Chapter Outline

Test Your Knowledge

9. Which radionuclide is PSMA labelled for the detection of metastatic disease in prostate cancer

a) Gallium-68

b) Rubidium- 82

c) Iodine-123

d) Technetium-99m

Test Your Knowledge

9. Which radionuclide is PSMA labelled for the detection of metastatic disease in prostate cancer

✓ Gallium-68

b) Rubidium- 82

c) Iodine-123

d) Technetium-99m

Rubidium-82 is used in myocardial perfusion imaging. Iodine-123 is the commonly used in thyroid imaging. Technetium-99m is the most widely used radionuclide in planar and SPECT imaging.

Chapter Outline

Test Your Knowledge

10. Which of the following organs demonstrate normal physiological update in DOTATATE PET imaging?

a) Brain

b) Heart

c) Spleen

d) Pancreas

Chapter Outline

Test Your Knowledge

10. Which of the following organs demonstrate normal physiological update in DOTATATE PET imaging?

a) Brain

b) Heart

✓ Spleen

d) Pancreas

Normal physiological uptake in DOTATATE PET scan is related to specific receptor binding and nonspecific tissue handling of the peptide. Spleen demonstrates highest intensity physiologic uptake due to SSTR expression. Other organs with normal physiological uptake include kidneys, pituitary, thyroid, adrenal glands, liver, salivary glands and GI tract.