KARNATAKA RADIOLOGY EDUCATION PROGRAM

POSITRON EMISSION TOMOGRAPHY

Modern non-invasive imaging technique for quantification of radioactivity in vivo.

PET imaging utilises radionuclides that decay via positron emission, which then collides with an electron. The resulting annihilation produces two 511 KeV photons which are detected by PET scanner to create an image

Unlike CT or MRI, which show structural details, PET captures metabolic and biochemical processes, making it invaluable in oncology, neurology, and cardiology.

FORMATION OF PET IMAGES

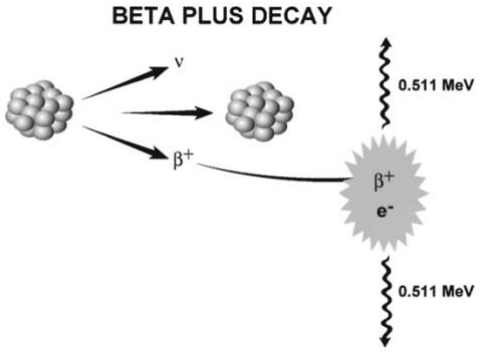
1. **Tracer administration – most commonly used tracer: 18F-FDG**

Isotopes in PET

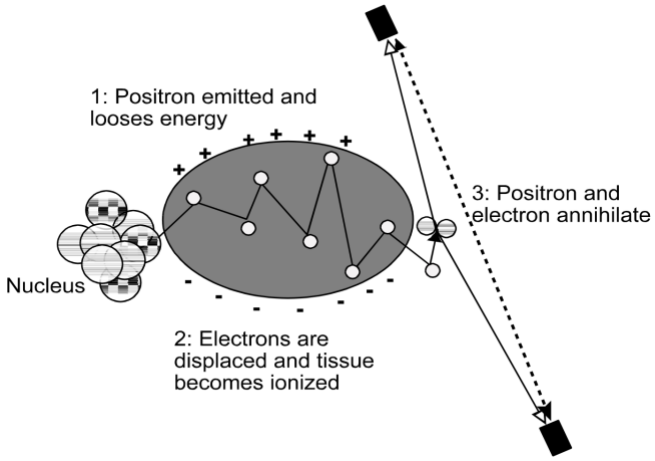
Common Isotopes:

- **11C**: Half-life 20.4 min, used for various applications.
- **13N**: Half-life 10 min, cardiac blood flow.
- **18F**: Half-life 110 min, glucose metabolism (FDG tracer).

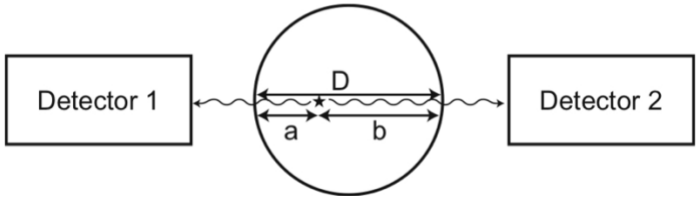
2. **Radioactive decay by positron emission**
   A proton rich radionuclide converts a proton into neutron, positron and a neutrino
   This emitted proton travels short distance before interacting with an electron



3. **Annihilation of positron and electron and Production of 2 gamma ray**
   The positron and electron annihilate, releasing two gamma photons of 511keV energy each, emitted in opposite direction.

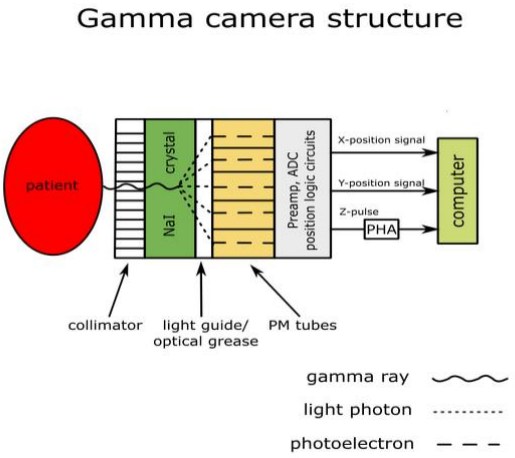


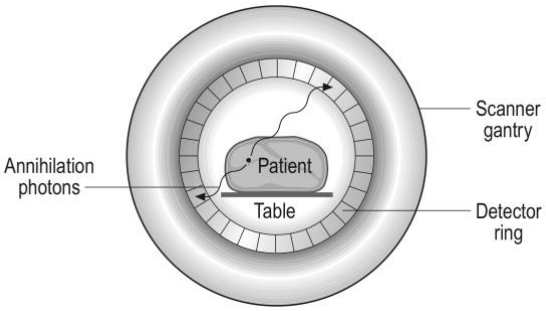
4. **Coincidence detection of gamma rays along Line of response**
   PETscanners detect the pair of photons that reach the detectors simultaneously



5. **Scintillation and photomultiplication**
6. **Data acquisition and image reconstruction**

INSTRUMENTS:





Detector Configuration:
• Arrays of detectors are arranged to form complete or partial cylinder around the patient.
• Multi-ring systems for whole-body imaging.

Scintillation Detectors:
• Scintillators convert gamma photons into visible light.
• Materials used:
• LSO (Lutetium Oxyorthosilicate): High light output and fast decay time.
• BGO (Bismuth Germanate): High density but slower decay time.
• GSO (Gadolinium Oxyorthosilicate): Good compromise for sensitivity and speed.

Photodetectors:
• Photomultiplier Tubes (PMTs): Traditional detectors converting light into an electrical signal.
• Digital PET: Uses Silicon Photomultipliers (SiPMs) for improved resolution, sensitivity, and timing accuracy.

Time-of-Flight (TOF) PET:
• Measures the slight difference in arrival times of the annihilation photons.
• Improves image resolution and signal-to-noise ratio by better localizing the origin of photons.

Field of View (FOV):

• Axial FOV: Length of the scanner; extended FOV increases sensitivity for whole-body imaging.

• 3D Mode: All photons are collected without collimation, improving sensitivity.

DATA ACQUISITION:

Acquisition Modes:

- **2D Mode**: Uses lead or tungsten septa between detector rings to reduce scatter and random coincidences.

Lower sensitivity but higher contrast for brain or cardiac imaging.

- **3D Mode**: Removes septa, allowing detection of photons from all directions.

Increases sensitivity significantly but requires robust scatter and random corrections.

List Mode vs. Sinogram:

- **List Mode**: Records each event with its position, time, and energy.
- **Sinogram**: Stores event counts in a matrix format based on angular and radial positions.

Used in traditional PET reconstruction.

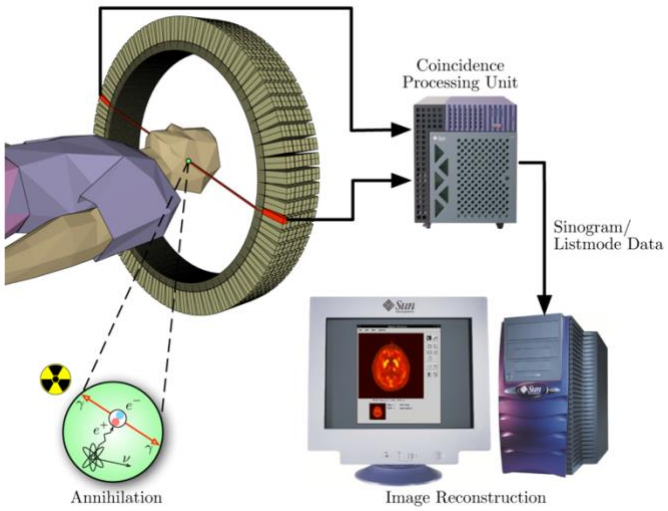
Coincidence Timing:

PET systems operate with a **coincidence timing window** (typically 4–12 ns) to detect annihilation photons arriving simultaneously.

Coincident events are classified into:

- **True coincidences**: Both photons originate from the same annihilation event.
- **Scatter coincidences**: One or both photons undergo Compton scattering.
- **Random coincidences**: Two unrelated photons are detected within the timing window.

IMAGE RECONSTRUCTION:



1. Reconstruction Algorithms:

- Filtered Back Projection (FBP):
- Quick and computationally efficient.
- Prone to streak artifacts in low-count studies.
- Iterative Reconstruction:
- Corrects for noise and scatter.
- Algorithms like OSEM (Ordered Subset Expectation Maximization) refine the image through multiple iterations.

2. Corrections for Imaging Artifacts:

Attenuation Correction: Uses a CT scan (in PET/CT) or transmission source to account for photon absorption in tissue.

Scatter Correction: Removes scattered photons using energy windows or Monte Carlo simulations.

Random Correction: Subtracts random coincidences using delayed coincidence timing.

3. Quantitative Measures:

Standardized Uptake Value (SUV) = (Tissue activity concentration) / (Injected dose/body weight).

- Indicates metabolic activity relative to a standardized dose.

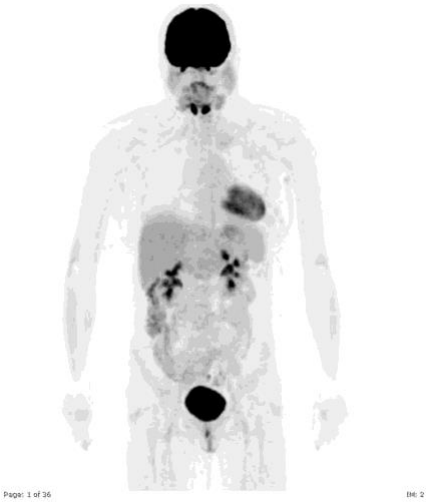
FACTORS AFFECTING QUALITY OF IMAGE

1. **Physical -** Spatial resolution, sensitivity, scatter, noise, attenuation.
2. **Technical -** TOF technology, reconstruction algorithms, detector material, photodetectors.
3. **Biological -** Radiotracer uptake, motion artifacts, patient body size, physiological uptake.
4. **Procedural -** Radiotracer dose, acquisition time, patient preparation.
5. **Environmental -** Scanner calibration, electrical noise, temperature control.

HYBRID PET:

PET images have high sensitivity for functional and metabolic activity but poor spatial resolution.
Hence hybrid imaging systems are acquired by combining PET with CT/MRI

PET-CT – combines PET with CT where sequential acquisition of CT followed by PET imaging is done in same session- Provides high resolution images with short acquisition time
PET-MRI – Unlike PET-CT, PET-MRI dats is acquired simultaneously - Provides better soft tissue contrast with low radiation dose



Challenges in Hybrid PET Imaging

PET/CT Challenges

High radiation dose from the CT component.

Limited soft tissue contrast.

PET/MRI Challenges

Longer imaging times.

High cost and limited availability.

Complex attenuation correction due to lack of direct tissue density measurements.

CLINICAL APPLICATIONS:

Oncology:

• Tumor detection, staging, and monitoring therapy response.

• FDG-PET for high-glucose-uptake tumors (e.g., lung cancer, lymphoma).

Neurology:

• Diagnosing and monitoring neurodegenerative diseases (e.g., Alzheimer's, Parkinson's).

• Epilepsy localization for surgical planning.

Cardiology:

• Viability assessment (e.g., FDG for myocardial metabolism).

• Perfusion studies with tracers like 13N-ammonia.

Infection and Inflammation:

• Identifying sites of infection or inflammation using tracers like FDG.

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