Chapter 4: Single Photon Emission Computed Tomography (SPECT)
Contents

Emission Tomography (ET) for Nuclear Medicine Applications
• Introduction and basic principle of Emission Tomography
• Early developments
• Generation of radio-nuclides for ET.
• Detector technologies for ET
• System design considerations

Other Related Imaging Applications
• Coded aperture imaging
• Compton Imaging
Traditional Definition of Nuclear Medicine

NUCLEAR MEDICINE SHOWS PHYSIOLOGY

Whereas

RADIOLOGY SHOWS ANATOMY
Traditional Definition of Nuclear Medicine

NUCLEAR MEDICINE

PHYSIOLOGY

DIAGNOSIS

THERAPY

NON-IMAGING

IMAGING

SPECT

PET

Emission Tomography (ET)
What is Emission Tomography?

- A branch of medical imaging that encompasses two main modalities – single photon emission computed tomography (SPECT) and positron emission tomography (PET)
- It uses radioactive materials to image properties of body’s physiology, such as glucose metabolism, blood flow, receptor concentrations.
- ET is categorized as **functional imaging** techniques to distinguish it from methods such as X-ray CT that principally depict the body architectural structure (anatomy).
The Tracer Principle

What is the tracer principle?

• Appropriately chosen radioactive compounds participate in an organism’s physiological processes in the same way as non-radioactive materials.

• These compounds can be detected through the detecting of their radiation signatures, such as gamma rays.

Two major attributes

• Because one can detect even minute quantities of radioactive material, the tracer principle can be used to measure molecular concentrations with a tremendous sensitivity.

• Tracer measurements are noninvasive – the concentration of tracer is deduced from the number of gamma rays detected.
Emission Tomography

- Drug is labeled with radioisotopes that emit gamma rays.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem).

Drug Distributes in Body
Single Photon Emission Computed Tomography (SPECT)

Siemens Symbia SPECT/CT

Philips Precedence SPECT/CT
Single Photon Emission Computed Tomography (SPECT)

Collimator in front of the detector to select gamma rays from certain directions only…

Rotated around the object for collecting multiple projections…

Collimator  Pinhole

Coded Aperture  Compton
Single Photon Emission Computed Tomography (SPECT)

\[ I = I_0 e^{-\mu_1 \Delta x} e^{-\mu_2 \Delta x} \cdots e^{-r} = I_0 e^{-(\mu_1 + \mu_2 + \cdots + \mu_n) \Delta x} \]

\[ P = -\ln \left( \frac{I}{I_0} \right) = \int_{-\infty}^{\infty} \mu(x) dx \]

\[
\begin{array}{cccc}
A & B & \rightarrow 7 \\
C & D & \rightarrow 7 \\
 & 9 & \rightarrow 6 \\
 & 8 & \rightarrow 5 \\
\end{array}
\begin{array}{cccc}
A + B = 7 \\
A + C = 6 \\
A + D = 5 \\
B + C = 9 \\
B + D = 8 \\
C + D = 7 \\
\end{array}
\begin{array}{cc}
2 & 5 \\
4 & 3 \\
\end{array}
Single Photon Emission Computed Tomography (SPECT)

Endocrine tumor visualized with a commercial SPECT system.

Application of SPECT for Small Animal Studies

- Imaging of dopamine transporter in mouse brain.
- In vivo tracking of radiolabeled T cells in mouse brain.
“Small animal SPECT and its place in the matrix of molecular imaging technologies”

Early Developments

Radionuclides for diagnostic purpose

1935 Hevesy: radiophosphorous for metabolic studies in rats

1949 Cassen: rectilinear scanner consisting of a calcium tungstate crystal coupled to a photomultiplier tube for I-131 uptake in thyroid with ¼" resolution

1957 Anger: stationary area detector.

scintillation camera (Anger or gamma camera) consisting of a large-area sodium iodide crystal coupled to an array of PM tubes
Early Development

Radionuclides for diagnostic purpose – cont.

Early 1960s Kuhl & Edwards: idea of transverse section tomography (cf. X-ray CT), unsatisfactory results because of without the aid of computers & reconstruction algorithms

1977 Keyes & Jaszczak: SPECT (Single-photon emission computed tomography), improved image contrast compared to stationary cameras

1970s: PET (positron emission tomography), large number of scintillation detectors surrounding the patient, unique capability to study metabolic function in humans.
Desired Properties of Nuclides Used in ET

Provide useful clinical information while exposing patients to minimal radiation

• Half life approximately equal to the duration of the investigation
• No particulate radiation
• Emit gamma ray of energy high enough to travel through tissue and low enough for efficient detection by gamma camera
• Low enough mass to avoid affecting the biochemistry of the patient
Radionuclides are Produced in a Nuclear Reactor or a Cyclotron

Reactor - target bombarded with neutrons
Cyclotron - target bombarded with charged particles

• Diagnosis uses radionuclides from both
• Therapy radionuclides produced in a nuclear reactor
• PET radionuclides produced in a cyclotron
## Radionuclides in Biology & Medicine

<table>
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<th>$T_{1/2}$</th>
<th>R/A</th>
<th>Nuclide</th>
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<td>R</td>
<td>$^{67}$Ga</td>
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<td>A</td>
<td>$^{68}$Ga</td>
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<td>$^{82}$Rb</td>
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<td>110m</td>
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<td>$^{99m}$Tc</td>
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$R = \text{Reactor, } A = \text{Accelerator, } G = \text{Generator}$
Tc-99m for Nuclear Medicine

The Basic Aspects:

- $^{99m}\text{Tc}$ (IT,$\gamma$) $^{99}\text{Tc}$ - 6 hr half life (from $^{99}\text{Mo}$)
- Reactor produced ($^{235}\text{U} + ^1\text{n} \rightarrow ^{137}\text{Cs} + ^{99}\text{Mo}$)
- $\gamma$ emission at 140 keV - ideal
- 6 hr half life - ideal
- Readily available from a Generator
- 90% of all nuclear medicine studies use $^{99m}\text{Tc}$
Tc-99m Generator

The Basic Principle:

• Based on the concept of Ion Exchange Column
• The Mo-99 is absorbed on alumina column in binding sites in the form of \((\text{NH}_4)_2 \, ^{99}\text{MoO}_4\) (ammonium molybdate).
• The \(^{99}\text{Mo}\) in this compound exist in the form of molybdate ion \(^{99}\text{MoO}_4^{2-}\) in an ionic state of -2 unit of charge.
• When \(^{99}\text{Mo}\) decays, its transformed into \(^{99m}\text{TcO}_4^-\) in form of the ion \(^{99m}\text{TcO}_4^-\).
• Since \(^{99}\text{MoO}_4^{2-}\) has 2 unit of charge per ion, it can be attached firmly to two binding sites.
• \(^{99m}\text{TcO}_4^-\) has only one unit of charge per ion, it is only weakly bounded.
• Elution with isotonic saline solution would break the binding between \(^{99m}\text{TcO}_4^-\) and the alumina column and wash out the \(^{99m}\text{TcO}_4^-\), whilst leaving the \(^{99}\text{MoO}_4^{2-}\) in the reactor.
FIGURE 6 Schematic drawing of a $^{99}$Mo-$^{99m}$Tc generator. (Adapted from Rollo, 1977.)