AN INTRODUCTION TO NUCLEAR MEDICINE
WITH RESPECT TO THYROID DISORDERS

By: B. Shafiei MD
Nuclear Physician
Taleghani Medical Center
Radioactive:

An element with *Unstable Nucleus (Excess Energy)*, can achieve to stable status by *Radiation* ($\alpha, \beta, \gamma$)
when it is used in medical studies, named:

RADIOPHARMACEUTICAL
Radiation can be:

- As a particle: $\alpha$ & $\beta$
- or as a photon: $\gamma$
Particles (\(\alpha, \beta\)) have mass, and can carry high energy in a short length. Therefore, radiopharmaceuticals with \(\beta\) decay are used in therapy.
Photon ($\gamma$) has no mass, and can carry low energy in a long distance. Therefore, radiopharmaceuticals with $\gamma$ decay are used in imaging.
Radiopharmaceuticals were supplied and administered in different forms:

Pure Element or Ion:
\[ ^{127}\text{Xe}, ^{99m}\text{TcO}_4^- \text{ (Pertechnetate)}, \text{Na}^{131}\text{I} \]

Complex Molecule or Radiotracer:
\[ ^{131}\text{I-MIBG}, ^{99m}\text{Tc-MIBI}, ^{18}\text{F-FDG} \]
Relative Penetrating Power

Alpha particle:
easily stopped
least penetrating

Beta particle:
very much smaller
more penetrating

Gamma ray and X-ray:
pure energy with no mass
most penetrating

○ neutral atom or molecule
● ion
## Physical Properties of $^{99m}$Tc:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Life</td>
<td>6 hours</td>
</tr>
<tr>
<td>Principal $\gamma$ Energies</td>
<td>140 keV</td>
</tr>
</tbody>
</table>
Biological Properties of Technetium:

- Accumulated normally in:
  choroid plexus
  salivary glands
  thyroid gland
  stomach
  kidneys & bladder
  active mammary glands

- Discharge from:
  saliva
  urine
  stool
  milk
Technetium is trapped by thyroid gland, but not organified
Physical Properties of $^{123}$I:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Life</td>
<td>13.2 hours</td>
</tr>
<tr>
<td>Principal $\gamma$ Energy</td>
<td>159 keV</td>
</tr>
</tbody>
</table>
Physical Properties of $^{124}$I:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Life</td>
<td>4.18 days</td>
</tr>
<tr>
<td>Principal $\beta^+$ Energy</td>
<td>511 keV</td>
</tr>
<tr>
<td>Property</td>
<td>Value</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Half Life</td>
<td>8.04 days</td>
</tr>
<tr>
<td>Principal $\gamma$ Energies</td>
<td>80 keV</td>
</tr>
<tr>
<td></td>
<td>284</td>
</tr>
<tr>
<td></td>
<td>364</td>
</tr>
<tr>
<td></td>
<td>637</td>
</tr>
<tr>
<td>Principal $\beta$ $E_{max}$</td>
<td>610 keV</td>
</tr>
<tr>
<td>Average Range</td>
<td>0.2-1 mm</td>
</tr>
</tbody>
</table>
Biological Properties of Iodine:

- Accumulated normally in:
  - choroid plexus
  - salivary glands
  - thyroid gland
  - stomach
  - kidneys & bladder
  - active mammary glands

- Discharge from:
  - saliva
  - sweat
  - urine
  - stool
  - milk
Iodine is trapped and organified by thyroid gland, and storage in this gland
## Dosimetry:

<table>
<thead>
<tr>
<th></th>
<th>$^{99m}$Tc-Pertechnetate</th>
<th>$^{123}$I</th>
<th>$^{131}$I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(rad/5mCi, cGy/185MBq)</td>
<td>(rad/200µCi, cGy/7.5MBq)</td>
<td>(rad/50µCi, cGy/1.85MBq)</td>
</tr>
<tr>
<td><strong>Thyroid</strong></td>
<td>0.6</td>
<td>1.5 to 2.6*</td>
<td>39 to 65*</td>
</tr>
<tr>
<td><strong>Bladder Wall</strong></td>
<td>0.43</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Red Marrow</strong></td>
<td>0.1</td>
<td>0.06</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Testis</strong></td>
<td>0.05</td>
<td>0.027</td>
<td>0.006</td>
</tr>
<tr>
<td><strong>Ovaries</strong></td>
<td>0.15</td>
<td>0.072</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Fetus</strong></td>
<td>0.2</td>
<td>0.175</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Body</strong></td>
<td>0.07</td>
<td>0.009</td>
<td>0.035</td>
</tr>
</tbody>
</table>

*according to 15% to 25% RAIU
Units of Radiation:

Radiation source

Radiation beam

Absorber

RADIATION EXPOSURE

Coulomb per kilogram (SI unit)
Roentgen (traditional unit)

RADIOACTIVITY

Becquerel (Bq) as SI unit
Curie (Ci) as traditional unit

1 mCi is equal to 37 MBq

ABSORBED DOSE

Gray (Gy) as SI unit
rad (rad) as traditional unit

1 Gy is equal to 100 rad
Equivalent Dose:

There are other quantities derived from the gray and the rad which express the *biological effects* of such absorbed radiation energy when the absorber is living matter.

- **Sievert (Sv)** as SI unit
- **Rontgen equivalent man (rem)** as traditional unit

10 mSv is equal to 1 rem
### Dosimetry:

<table>
<thead>
<tr>
<th></th>
<th>$^{99m}$Tc-Pertechnetate (rad/1mCi, cGy/37MBq)</th>
<th>$^{123}$I (rad/1mCi, cGy/37MBq)</th>
<th>$^{131}$I (rad/1mCi, cGy/37MBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thyroid</strong></td>
<td>0.12</td>
<td>7.5 to 13*</td>
<td>780 to 1300*</td>
</tr>
<tr>
<td><strong>Bladder Wall</strong></td>
<td>0.08</td>
<td>0.35</td>
<td>3</td>
</tr>
<tr>
<td><strong>Red Marrow</strong></td>
<td>0.02</td>
<td>0.3</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Testis</strong></td>
<td>0.01</td>
<td>0.135</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Ovaries</strong></td>
<td>0.03</td>
<td>0.36</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Fetus</strong></td>
<td>0.04</td>
<td>0.875</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total Body</strong></td>
<td>0.012</td>
<td>0.045</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*according to 15% to 25% RAIU
Radiation: Overview

Biological injury:
- Ionization of atoms within the cell
- Ionization breaks molecular bonds
- Cell damage occurs when critical cell structures are affected, directly or indirectly
Mechanisms of Damage Direct Effects

- The radiation may directly affect an important molecule, like DNA or a cell membrane component.

- The general scheme is:

  \[ A + \text{energy} \xrightarrow{\dagger} A^+ + e^- , \text{where A is a molecule which is critical to the proper functioning or production of the cell} \]
Mechanisms of Damage Indirect Effects

- The radiation may result in the production of a free radical
- Free radicals are chemically very reactive with other molecules
- The result of the interaction of the free radical with other molecules causes the actual damage
Radionuclides do not damage the cells in a moment, but in a period of time.

The time of complete damage depends on the amount of radiation exposure.
Radioactive usage in Thyroid disorders:

- *Imaging* of thyroid gland, or extra thyroidal functioning tissue
- *Uptake ratio* of thyroid gland
- *Treatment* of hyperthyroidism and well differentiated carcinoma
Thyroid Uptake or Iodine Uptake:

is a *quantitative method* that measures *affinity* of thyroid gland to iodide and its *metabolism*
- In uptake measurement

$^{123,131}$Iodine (NaI), (Trapping, Organification, Storage)

2-4 hours & 24 hours measurements
HYPERTURNOVER

HYPERTHYROIDISM (hyper functioning thyroid tissue)

NORMAL RANGE

ENZYME DEFICIENCY

LOW UPTAKE

HOURS AFTER ADMINISTRATION
Uptake ratio of thyroid gland is depended to iodine pool, medication, TSH stimulation and thyroid metabolic state
Indications of Thyroid Uptake:

- Assessment of Hyperthyroidism Due to:
  - Sub-acute Thyroiditis
  - Factitious Hyperthyroidism
  - Hyperfunctioning aberrant thyroid tissue
  - Postpartum Thyroiditis

- Calculation of ablated dose of radioiodine

- Assessment of thyroid remnant after thyroidectomy

- Making decision in treatment of Jod-Basedow phenomenon and Sub-acute Thyroiditis
How Request?

Nuclear Medicine Department

Please,

Thyroid Uptakes after 2 hours and 24 hours
How to obtain a functional imaging?
1. The patient is injected with Radiopharmaceutical.
2. Radiopharmaceutical is absorbed by an organ.
Imaging or quantitative process

7. The processing board takes signal and sends it to the computer monitor where the image is displayed.
Imaging is strongly depended to uptake amount of thyroid tissue
Isotopes which Used in Imaging:

\[ ^{99m}\text{Technetium (TcO}_4^\text{-}), \text{(Trapping):} \]

- Thyroid study
- Thyroglossal duct route

\[ ^{131,123}\text{Iodine (NaI), (Trapping, Organification, Storage)} \]

SPECIFIC FOR THYROID TISSUE

- Retro-sternal thyroid tissue
- Ovary thyroid tissue
- Metastasis
Indications of Thyroid Scan:

- Studying of Function of Thyroidal Nodule (Particularly in Hyperthyroid Status).
  Performed by $^{99m}$Tc or $^{123}$I

- Evaluation of Function of Follicular Neoplasia
  Performed by $^{123}$I

- Proving Retrosternal Goiter.
  Performed by $^{123,131}$I

- Proving Aberrant Thyroid Tissue in Thyroglossal duct.
  Performed by $^{99m}$Tc

- Proving Aberrant Thyroid Tissue in Ovary.
  Performed by $^{123,131}$I

- Whole Body Scan, for Detection of Metastases, Related to Well-Differentiated Thyroidal Cancer.
  Performed by $^{131}$I
How Request?

Nuclear Medicine Department

Please, Thyroid Scan by $^{99m}$Tc
How Request?

Nuclear Medicine Department

Please, Whole body $^{131}$Iodine Scan
Normal Thyroid

Diffuse Goiter
Normal Thyroid
Cold Nodules of Right Lobe
Hot Nodule
Toxic Multinodular Goiter

24 hr RAIU: 53 %
Graves’ Disease with Prominent Pyramidal lobe
Very Low Thyroid Uptake

- Sub-acute Thyroiditis
- Thyrotoxicosis factitia
- High Iodine Pool
- Antithyroid Drug
- Hypothyroidism
Functioning Retrosternal Goiter
Thyroid Tissue in Thyroglossal Duct
Metastatic Lesions to Cervical Lymph Nodes and Both Lungs
Diffuse Metastatic Lesions

Anterior

Posterior
March 2006
HTg: >1000 ng/ml

March 2008
HTg: 91 ng/ml