Biologic Effects of Diagnostic Imaging Modalities

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Biologic Effects
Biological Interactions

Radiation
Ultrasound
MRI
Biological Effects of X-rays

- Mutagenic
- Teratogenic
- Life shortening
- Lethal
- Carcinogenic
ELECTROMAGNETIC SPECTRUM

MRI | Radar | X-Rays

Visible | Infra-Red

A-M Broadcast | Television | F-M Broadcast

Ultra Violet | Cosmic Ray Photons

Photon Energy (eV)

10 10 10 10 10 10 10 10 10 10
Mechanism of Biological Effects of X-rays

• Photon
  • Bundle of energy
  • Photons with > 15 ev of energy can ionize an atom

• Ionization
  • Ejection of one or more orbital e\textsuperscript{-} by a photon
  • Creates ion pair: dislodged e\textsuperscript{-} and ionized atom
  • Ions are unstable and give rise to free radicals
Free Radical Production

\[
\begin{align*}
\text{H}_2\text{O} & \rightarrow \text{H}_2\text{O}^+ + e^- \rightarrow \text{OH}^- + \text{H}^+ \\
\text{OH}^- + \text{H}^+ & \rightarrow \text{H}_2\text{O} \\
\text{H} + \text{H} & \rightarrow \text{H}_2
\end{align*}
\]

or

\[
\begin{align*}
\text{OH}^- + \text{OH}^- & \rightarrow \text{H}_2\text{O}_2
\end{align*}
\]

\(\text{H}^+ = \text{free hydrogen Radical}\)

\(\text{OH}^- = \text{free hydroxy radical}\)

\(\text{H}_2\text{O}_2 = \text{hydrogen peroxide}\)
Free Radicals

- Atom or group of atoms with an orbit containing a single unpaired e⁻
- Produced by ionization or excitation
- Extra e⁻ can be transferred from molecule to molecule → Free Radical.
- Free Radicals create critical changes in organic molecules → RADIATION DAMAGE → affect cell structure and function
Risk – Benefit Ratio

• Evaluate value of the risk to radiation exposure to see if it is outweighed by the benefit that the patient, or society receives as a result of the exposure

• For example, small risk of future cancer as a result of radiation therapy, large current benefit if treatment causes cure or remission of a fatal disease
Risk – Benefit Ratio

- Diagnostic imaging involves relatively low levels of exposure
- Diagnostic information exceeds the risk of injury to the patient
Lowest Exposures Possible

- Fewest exposures necessary
- Modern equipment
- Only request necessary procedures
Image Gently Campaign

- **www.imagegently.org**
- Action group to reduce radiation exposure especially to children
- Resources including brochures and table for parents record keeping
US Per Capita Effective Medical Radiation Dose

- Recent literature
- Frequency of exams increased 10 fold from 1950
- Exposure increase 6 fold from 1980
- Increase from 0.5 mSv 1980 to 3.0 mSv 2006
- Majority of exposure increase related to CT scanning
  - Radiology November 2009 Vol. 253 No. 2 pp 520 - 531
X-Ray

- Standard imaging relatively low exposures
- Fluoroscopy – moderate to high exposures
- CT Scanning – moderate to high exposures
Radiation measurements and equivalents

- Effective dose = mSv
- Risk equivalence 1 mSv
  - Smoking 75 cigarettes
  - 1 glass wine/ day 6months
  - 125 miles by motorcycle
  - 2500 miles by car
  - Rock climbing 75 minutes
  - Canoeing 5 hours
Risk Estimates

- CT exam with effective dose of 10 mSv
- 1 chance in 2000 of causing fatal cancer
- 1 chance in 5 normal incidence of fatal cancer
- Risk increases as more individuals are scanned
## FDA Dose comparisons

<table>
<thead>
<tr>
<th>Type of examination</th>
<th>Dose (mSv)</th>
<th>Number of Chest X-rays (PA film) for Equivalent Effective Dose²</th>
<th>Equivalent days exposure to natural background exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x ray (PA film)</td>
<td>0.02</td>
<td>1</td>
<td>2.4 days</td>
</tr>
<tr>
<td>Skull x ray</td>
<td>0.07</td>
<td>4</td>
<td>8.5 days</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>1.3</td>
<td>65</td>
<td>158 days</td>
</tr>
<tr>
<td>I.V. urogram</td>
<td>2.5</td>
<td>125</td>
<td>304 days</td>
</tr>
<tr>
<td>Upper G.I. exam</td>
<td>3</td>
<td>150</td>
<td>1.0 year</td>
</tr>
<tr>
<td>Barium enema</td>
<td>7</td>
<td>350</td>
<td>2.3 years</td>
</tr>
<tr>
<td>CT head</td>
<td>2</td>
<td>100</td>
<td>243 days</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>10</td>
<td>500</td>
<td>3.3 years</td>
</tr>
</tbody>
</table>
Everyday Life Comparison

- Flight from LA – Boston 0.05 mSv
- Flight from NY – Tokyo 0.20 mSv
- 1 Year Denver 1.88 mSv
- Chest 0.04 mSv
- Abdomen 1.5 mSv
- L- Spine  2.4 mSv
- IVU 4.6 mSv
- Abdomen CT 7.2 mSv
- Brain CT 1.8 mSv
Radionuclides

• Commonly used agents
  • Technetium- 99m
    • Short half life, relatively low exposures
  • I-123
    • Short half life, relatively low exposures
  • I-131 (radio-iodine)
    • Longer half life, could be higher exposures
  • Thallium- 201
    • Longer half life, could be higher exposures
Radionuclides

- Consideration regarding bio-effects of radionuclides
  - Concentration in organs
    - Knowledge of target organ
    - Organ of excretion
  - Half-life of radionuclides
    - Decay half life
      - Natural decay of the isotope to stable non radioactive state
    - Physiologic half life
      - Length of time that the isotope remains in the body
Common Procedures

• Tc99m Bone scan  3.6 mSv
• Tc99m Lung scan 1.0 mSv
• I123 thyroid scan 4.4 mSv
Ultrasound Risks

- Relatively risk free at diagnostic levels
- May have induction of ‘micro-bubbles’ in the tissues
- Some tissue heating may take place – (applications of ultrasound for cancer therapy)
- Importance of using the lowest power level available for the imaging task at hand
- Especially important when imaging embryos and fetuses
Ultrasound Risks

• Some concerns raised in 2004 at the BioMed conference as to safety of lower frequencies of US

• Current and future application of the principles of tissue heating.

• Using MRI localization – treatment of solid tumors – currently fibroids, possibly breast and other cancers
MRI Risks

- Relatively non invasive
- Strong magnetic fields
  - Possible flashing sensation in eyes or sensation elsewhere
  - Caution with ferromagnetic materials
  - Risk to patients from unexpected projectiles
  - Increased problem with 3-Tesla and higher magnets
MRI Risks

- Varied radio-frequency exposure
  - Controlled level of exposure
  - Caution with metal objects/ wires
  - Generated currents leading to thermal injury
  - Limited deposition of energy SAR (Specific Absorption Rate) prescribed by FDA – related to field strength and radio frequency energy
  - Equipment lock out if SAR is exceeded
MRI Risks

- Some sensation from field / RF is possible
  - Stimulation of nerves / muscles
  - Increased issue at higher field strengths and increased RF levels
- Significant problems not seen at diagnostic MRI levels
MRI Risks

- Rare entity related to Gadolinium contrast administration
- Appears confined to patients in renal failure on dialysis
- Nephrogenic systemic fibrosis and nephrogenic fibrosing dermopathy
- Avoid Gd contrast in these patients