Pediatric Imaging in Nuclear Medicine

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Disclosure

I am PI of a subproject for the following grant based at Johns Hopkins University

Dose Reduction in Pediatric Molecular Imaging
2 R01 EB013558-05A1
(G. Sgouros, PI)

James G. Kereiakes
Most national and international bodies (ICRP, NCRP) have based their low dose (<100 mSv) risk estimates on linear extrapolation of the higher dose data. This report states that there is a significant trend in this range, consistent with that observed for the full dose range.


SNMMI Dose Optimization Statement

Radiation dose for all nuclear medicine and molecular imaging procedures should be optimized so that the patient receives the smallest possible amount of radiopharmaceutical that will provide the appropriate diagnostic information. However, if an appropriate procedure—one that can provide the physician with clinical information essential to the patient’s treatment—is not performed when necessary due to fear of radiation, it can be detrimental to the patient. The right test with the right dose should be given to the right patient at the right time. When nuclear medicine and molecular imaging procedures are performed correctly on appropriate patients, the benefits of the procedure very far outweigh the potential risks.

Dose Optimization and Standardization

Although controversies and disagreements may exist regarding the nature and magnitude of health effects associated with ionizing radiation at dose levels associated with diagnostic imaging and nuclear medicine (Siegel et al. JNM 2017;58:1-6 and 865-868), it remains prudent to determine the most appropriate administered activity for the pediatric patient.

It is unlikely that the most appropriate administered activity for a 5-year-old child is the same as that for a 40-year-old adult.
**Lifetime Attributable Risk**

10 mGy in 1,000,000 exposed persons

(Based on BEIR VII Phase 2, 2006)

**MIRD Equation**

\[ D_T = \sum_s \tilde{A}_s \left( \sum_i \Delta_i \varphi_i / m_T \right) \]

Where

- \( D_T \) is radiation dose to target organ in Gy
- \( \tilde{A}_s \) is the time-integrated activity in source organ in MBq-h
- \( \Delta_i \) is mean energy per nuclear transformation in g-Gy/MBq-h
- \( \varphi_i \) is the fraction of energy emitted from the source organ that is absorbed by the target organ
- \( m_T \) is mass of the target organ in g

\( \Sigma \) indicates summed over all source organs
\( \sum \) indicates summed over all emitted radiations

This allows the calculation of radiation dose to individual target organs.

**Medical Internal Radiation Dosimetry Committee of the SNMMI**
Effective Dose

- Equivalent to absorbed dose given to whole body resulting in the same biological effect.
- Sum of organ doses weighted by its radiation sensitivity.

$$ED = \sum H_T \times W_T$$

- $H_T$ is dose to organ, $T$, and $W_T$ is its radiosensitivity weight.
- Since $W_T$ is based on population averages, ED does **NOT** apply to individual patients, particularly children.

### MIRD Equation

<table>
<thead>
<tr>
<th>Tissue or Organ</th>
<th>ICRP 183</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spleen</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.06</td>
</tr>
<tr>
<td>Kidney</td>
<td>0.09</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.04</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Brain</td>
<td>0.03</td>
</tr>
<tr>
<td>Bone surface</td>
<td>0.01</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.01</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>0.01</td>
</tr>
<tr>
<td>Respiratory tract</td>
<td>0.12</td>
</tr>
<tr>
<td>Total</td>
<td>1.08</td>
</tr>
</tbody>
</table>

- Two 10 YO girls: same weight, different body types
- ED varied by 44%
- Used BEIR VII models to assign age- and sex-specific risk factors
- Simulated DMSA studies with lesion at different admin act levels and utilized channelize Hotelling observer models and ROC to assess image quality

- Image risk index (RI) based on BEIR VII for dose optimization
- Family of phantoms
- Weight-based admin activity of $^{99m}$Tc DMSA
- Affect of body habitus on RI
- Body habitus (var upto 18%)
- Dependence of RI on kidney size for $^{99m}$Tc DMSA


Developed a pharmacokinetic (PK) mode for FDG in peds using compartmental models and data for literature and BCH

Factors Affecting Dose in NM, SPECT and PET

- Injected activity
  - Total counts and imaging time
- NM/SPECT
  - Choice of camera (Detector material/thickness, # of detectors)
  - Choice of collimator (Hi Sens, Gen Purpose, Hi Res, Pinhole)
  - Image processing and reconstruction
- PET
  - Crystal material and thickness
  - Axial field of view
  - Image processing and reconstruction
Use of OSEM-3D Reconstruction
In SPECT

Sheehy et al. Radiol 2009; 251:511-516
Stansfield et al. Radiol 2010; 257:793-801

Patient Effective Dose (mSv)

<table>
<thead>
<tr>
<th>Summary</th>
<th>1 Year</th>
<th>5 Year</th>
<th>10 Year</th>
<th>15 Year</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>9.7</td>
<td>19.8</td>
<td>33.2</td>
<td>56.8</td>
<td>70</td>
</tr>
<tr>
<td>Tc-MDP (20 mCi*)</td>
<td>2.8</td>
<td>2.9</td>
<td>3.9</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Tc-ECD (20 mCi*)</td>
<td>4.1</td>
<td>4.6</td>
<td>5.3</td>
<td>5.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Tc-MAG3 (10 mCi*)</td>
<td>1.2</td>
<td>1.3</td>
<td>2.2</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>FDG (10 mCi*)</td>
<td>5.2</td>
<td>5.9</td>
<td>6.6</td>
<td>7.3</td>
<td>7.4</td>
</tr>
</tbody>
</table>

*max admin activ

Variability in Administered Doses in Pediatrics

- In 2007, surveyed 13 dedicated pediatric hospitals in North America.*
- In 2011, the North American Guidelines for Administered Activities in Children and Adolescents was published.@
- In 2012, Image Gently and SNM launch the Go to the Guidelines campaign
- In 2013, a follow-up survey of the same 13 pediatric institutions was performed.#

2007 Survey of Administered Activity in Children at Dedicated Pediatric Institutions

- Surveyed 15 dedicated pediatric hospitals in North America (13 responded)
- Requested information on 16 studies commonly performed in pediatric NM
  - Administered dose per kg
  - Maximum administered dose
  - Minimum administered dose


Variability in Administered Doses in Pediatrics

- Consider the ratio of maximum over minimum reported values as a parameter of variability referred to as the dose range factor
- For Admin dose/kg and Maximum dose the range factor varied, on average, by a factor of 3, and by as much as a factor of 10
- Minimum dose range factor varied, on average, by a factor of 10 and as much as a factor of 20


www.snmmi.org/pedactivitytool
2013 Follow-Up Survey of Dedicated Pediatric Institutions

- Surveyed the same 13 pediatric institutions
- Requested information on the same 16 procedures
- Dose parameters reduced or same in all cases.
- Range factor reduced in dose/kg and min dose but raised in max dose due to dose reduction (some stayed the same while some lowered).
- All familiar with Image Gently and North American Guidelines. 10/13 modified their administered activities based on North American Guidelines


Pediatric NM in Clinical Practice
Survey of US General Hospitals

- Most children imaged at general hospitals so we sought to characterize practice and familiarity with Guidelines
- 121/194 hospitals (62%) responded. 80% perform pediatric NM studies. Essentially all scaled administered activity in smaller patients (90% by weight).
- Of 5 procedures (MDP, DMSA, MAG3, HIDA, FDG) considered, the median of the surveyed group was consistent with the North American Guidelines in all cases of dose/kg and Min Dose except for MAG3.
- 83% familiar with Image Gently, 58% familiar with North American Guidelines, 55% modified their administered activities based on North American Guidelines


### Pediatric NM in Clinical Practice (General Hospitals)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Respondents</th>
<th>Value Based on Guideline (MBq)</th>
<th>Percentage of Respondents Using Guideline +/- 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>F; MDP</td>
<td>90 25 18</td>
<td>110.0</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>F; MAG3</td>
<td>42 27 12</td>
<td>111.0</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>F; DMSA</td>
<td>37 23 12</td>
<td>37.0</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>F; HIDA</td>
<td>27 15 10</td>
<td>37.0</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>F; FDG</td>
<td>20 14 5</td>
<td>111.0-155.4</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>G; MDP</td>
<td>50 26 18</td>
<td>277.5</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>G; MAG3</td>
<td>43 27 12</td>
<td>166.5</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>G; DMSA</td>
<td>37 23 12</td>
<td>55.5</td>
<td>Familiarity with 2010 Guidelines: Total Yes No</td>
</tr>
<tr>
<td>G; HIDA</td>
<td>27 15 10</td>
<td>55.5</td>
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CT Dose in the Context of Hybrid Imaging

- In helical CT as in hybrid imaging, the radiation dose varies as tube voltage ($\alpha kVp^2$), linearly with tube current-time product (mAs) and inversely with pitch. Also, beam collimation, patient size and region of patient
- For attenuation correction (AC), the kVp and mAs can be reduced almost as low as possible.
- For diagnostic (Dx), might want to limit high dose to region of clinical interest.
- For anatomical correlation (non-Dx), the mAs can be reduced significantly.

Effective Dose from CT of PET/CT

- Six anthropomorphic tissue equivalent phantoms (CIRS, Model 007TE) were utilized. The head, thorax and abdomen phantoms of medium-sized adults and 15-, 10-, 5- and 1-year-old children were scanned on a Siemens mCT 40 PET/CT scanner according to our Dx (CARE Dose 4D Quality Reference mAs (QRM) = 150,) and AC (QRM = 35) protocols.
- $CTD_{vol}$ (mGy) was recorded for each acquisition. DLP (mGy·cm) was calculated for both Dx and AC scans by multiplying $CTD_{vol}$ by a nominal scan length (cm) from Deak et al. (Radiol. 2010;257:158-66) for each region (abdomen, thorax, head) and age.
- Effective dose (ED) was calculated for the Dx and AC series using DLP conversion factors for ICRP 103 ED organ radiosensitivity weights.
Effective Dose from CT of Siemens mCT PET/CT

Visual representation of the different scenario protocols for imaging a 10 year old child:

- **Scenario 1:** Whole body Dx + Whole body AC
- **Scenario 2:** Whole body Dx only
- **Scenario 3:** Whole body AC
- **Scenario 4:** Abdomen Dx + Whole body AC
- **Scenario 5:** Abdomen Dx + Head and Chest AC

Effective Dose from CT of PET/CT

Effective Dose from CT for 10 YO

- 1.0
- 0.8
- 0.7
- 0.6
- 0.5
Thanks!
Questions?