Use Of MCNP With Voxel-Based Image Data For Internal Dosimetry Applications

The Monte Carlo Method: Versatility Unbounded
In A Dynamic Computing World
Chattanooga, TN, USA, April 17-21, 2005

M. G. Stabin\textsuperscript{1}, H. Yoriyaz\textsuperscript{2}, R. Li\textsuperscript{1}, T. E. Peterson\textsuperscript{1}, G. E. Holburn\textsuperscript{1}, M. A. Emmons\textsuperscript{1}, A. B. Brill\textsuperscript{1}

1. Vanderbilt University, Nashville, TN
2. Instituto de Pesquisas Energeticas e Nucleares, Sao Paulo, Brasil
Standard “MIRD” approach – organs are modeled in stylized geometries, for a standard individual.

Patient-specific, voxel-based approach.
## Radiation Dose Estimates for Y-90 labeled Zevalin

<table>
<thead>
<tr>
<th>ORGAN</th>
<th>Estimated Radiation Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mGy</td>
</tr>
<tr>
<td>Liver</td>
<td>4.8E+00</td>
</tr>
<tr>
<td>Lungs</td>
<td>2.0E+00</td>
</tr>
<tr>
<td>LLI Wall</td>
<td>4.8E+00</td>
</tr>
<tr>
<td>ULI Wall</td>
<td>3.6E+00</td>
</tr>
<tr>
<td>Red Marrow</td>
<td>1.3E+00</td>
</tr>
<tr>
<td>Spleen</td>
<td>9.4E+00</td>
</tr>
<tr>
<td>Testes</td>
<td>9.1E+00</td>
</tr>
<tr>
<td>Urinary Bladder Wall</td>
<td>9.0E-01</td>
</tr>
<tr>
<td>Other Organs</td>
<td>3.0E-01</td>
</tr>
</tbody>
</table>
Equation-based models of children and adults (Cristy/Eckerman, 1987)
Software Tools:
Nuclear Medicine Internal Dosimetry

CAMIRD $\rightarrow$ MIRDOSE $\rightarrow$ OLINDA

RADAR
Anatomic Data
MRI
CT-Scan

Activity Distribution
SPECT
PET

Region identification, file format conversions

Input Interface Software
SCMS

Energy Deposition
MCNP-4B
(MeV/Particle)

Output Interface Software
(DCFs)

Dose Distribution
Display Image Software
Region identification and organ number assignment (coregistered images)
Input Interface Software for Regional Dose Distribution in the Organ

- Each organ is divided into a certain number of regions, with each region consisting of a certain number of voxels (definable by the user).
- Average dose can be determined for each region instead of in individual voxels.
- Each organ may have a different number of regions, so that some organs may have more detailed dose distribution than others.
- As a result, regional dose distributions can be determined within a reasonable time.
Selected Results - Source = Liver, Photons

- **Lungs < Liver**: SAF (1/g) changes as energy (MeV) increases from 0.01 to 10.
  - ZUBAL:
  - Cristy/Eckerman
  - MIRD 5R

- **Kidneys < Liver**: SAF (1/g) changes as energy (MeV) increases from 0.01 to 10.
  - ZUBAL:
  - Cristy/Eckerman
  - MIRD 5R

- **Liver < Liver**: SAF (1/g) changes as energy (MeV) increases from 0.01 to 10.
  - ZUBAL:
  - Cristy/Eckerman
  - MIRD 5R

- **Pancreas < Liver**: SAF (1/g) changes as energy (MeV) increases from 0.01 to 10.
  - ZUBAL:
  - Cristy/Eckerman
  - MIRD 5R
Dose distribution in the liver, uniform source distribution, 1.0 MeV photons. Dose units are (mGy/MBq.s).
Regional dose distribution in a lesion region and surrounding tissues due to a hypothetical non-uniform activity distribution. Dose units are mGy/MBq.s.
3D Plot of organ doses, with dose contour maps
Introduction

• Rodent species are rapidly becoming the laboratory animal of choice for experimentation.

• As more therapy applications are being tested in animal models, calculating accurate dose estimates for the animals themselves becomes important, to explain and control potential radiation toxicity.

• We sought to develop realistic models of these animals in a form that would facilitate dose calculations.
Methods

• Transgenic mouse (27 g), Harlan Sprague Dawley rat (248 g).

• Images were acquired using the Imtek MicroCAT II scanner with the x-ray tube set at 80 kVp and 500 µA.

• A 600 msec exposure was used for each projection and 360 projections over 360° were acquired.
Methods

• Absorbed fractions for all identified organs were calculated at 12 discrete initial photon and electron energies.
  – Electrons – 0.1, 0.2, 0.4, 0.7, 1.0, 2.0 and 4.0 MeV.
  – Photons - 0.01, 0.015, 0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1, 1.5, 2, and 4 MeV.
• Electron and photon histories were run on a Sun workstation, with adequate numbers of histories to reduce uncertainties to 5-10%.
<table>
<thead>
<tr>
<th>Organ</th>
<th>Mouse</th>
<th>22 g mouse</th>
<th>Hui et al. 25 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lungs</td>
<td>0.135</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Heart</td>
<td>0.171</td>
<td>0.095</td>
<td>0.115</td>
</tr>
<tr>
<td>Liver</td>
<td>0.772</td>
<td>1.3</td>
<td>1.05</td>
</tr>
<tr>
<td>Kidney cortex</td>
<td>0.131</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidney medulla</td>
<td>0.202</td>
<td>0.34</td>
<td>0.265</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.295</td>
<td></td>
<td>0.175</td>
</tr>
<tr>
<td>Intestines</td>
<td>2.179</td>
<td>1.5</td>
<td>1.271</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.022</td>
<td>0.1</td>
<td>0.09</td>
</tr>
<tr>
<td>Testes</td>
<td>0.058</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bladder</td>
<td>0.012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Absorbed Fractions for organs in the mouse model, with comparison to values of Hui et al.

<table>
<thead>
<tr>
<th></th>
<th>Hui et al. (Y-90)</th>
<th>This study (1 MeV electrons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liver</td>
<td>Spleen</td>
</tr>
<tr>
<td>Liver</td>
<td>0.669</td>
<td>0.053</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Kidney</td>
<td>0.017</td>
<td>0.132</td>
</tr>
<tr>
<td>Lungs</td>
<td>0.06</td>
<td>0.291</td>
</tr>
<tr>
<td>Heart</td>
<td>0.007</td>
<td>0.142</td>
</tr>
</tbody>
</table>
Electron Source in Lungs (Mouse Model)

Energy (MeV)

SAF (1/g)

- LUNGS
- HEART
- LIVER
- STOMACH
- SPLEEN
- TESTES
- BLADDER
Electron Source in Heart (Mouse Model)

Energy (MeV) vs. SAF (1/g)

- LUNGS
- HEART
- LIVER
Photon Source in Liver (Mouse Model)
Photon Source in Lungs (Mouse Model)

![Graph showing SAF (1/g) vs. Energy (MeV) for different organs: LUNGS, HEART, LIVER, KID MEDULLA, KID CORTEX, STOMACH, INTESTINE, SPLEEN. The x-axis represents Energy (MeV) ranging from 0.01 to 10.00, and the y-axis represents SAF (1/g) ranging from 1.00E-04 to 1.00E+00. Different markers and colors are used to distinguish between organs.]
Conclusions

• Self-irradiation AFs were significantly less than 1.0 for many organs, at energies above 0.5 MeV, and significant amounts of cross-irradiation were observed for many organs for high energy electrons, such as those from Y-90 or Re-188.

• The absorbed fractions calculated in this study will be useful in determining the dose to mouse and rat organs for animals whose size is similar to those studied here.
Conclusions

• Other animal models can be studied using the methods described here, given acquisition of appropriate image data.

• Fused CT/PET or CT/SPECT image data, as with human subjects, could also be used for calculating doses to animal organs during pre-clinical investigations.

• The segmented, voxel-based models developed here could be used for external dose calculations as well.
Current Research Efforts

- NIH STTR grant, co-PIs Stabin and Xu:
  - Develop complete suite of voxel-based models to match standard phantoms in use for 20 years.
  - Adopt completed phantoms, as available, and applicable, from other researchers.
  - Fill in “family” of individuals of other ages and genders.
  - Contribute results to CCHP initiative.
  - Results to form the technical basis for OLINDA/EXM 2.0, to be released in 2007.
<table>
<thead>
<tr>
<th>Phantom (target body mass)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn (3.4 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>1-yr-old (9.8 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5-yr-old (19 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10-yr-old (32 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>15-yr-old (57 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Adult (70 kg)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3-month Pregnant Female (58 kg)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6-month Pregnant Female (62 kg)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9-month Pregnant Female (64 kg)</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Current Research Efforts

• Studies with Dr. Peter Kooij and Mark Konijnenberg on 3D dosimetry of Lu-177-DOTA-octreotate.

• Studies with Dr. Marta Cremonesi of the European Institute of Oncology to evaluate regional kidney dose in subjects experiencing renal toxicity when receiving Y-90 DOTATOC.

• Adapt existing 3D dose results to report BED as well as cumulative dose.