Quantitative planar imaging

Michael Ljungberg, PhD
Medical Radiation Physics
Lund University, Lund, Sweden

MIRD CE Session
Accuracy and Precision in Internal Dose Assessments: Radioactivity Quantification
2008 SNM Meeting
New Orleans, June 14-18, 2008
Introduction

• Activity Quantitation with a scintillation camera is the method of choice for dosimetry.

• Scintillation camera imaging with a parallel hole collimator needs to include corrections for
  – Photon attenuation in the patient
  – Scatter Contribution
  – Resolution problems

• However, Planar Quantification with a scintillation camera is a 2D method (no depth information) making many of the correction methods approximative.
Topics that needs to be adressed...

• Photon attenuation
  – Decrease in counts due to photon interactions in the patient
  – Making the sensitivity (cps/MBq) **spatially variant** within the FOV

• Scatter Contribution
  – Additional unwanted counts acquired due to the limited energy resolution of the camera.
  – Making the sensitivity (cps/MBq) **spatially variant** within the FOV and **reduce the image contrast**.

• Collimator Resolution
  – Limits the spatial resolution of the system (~1cm)

  Partial Volume Effects
Topics that needs to be addressed...

- Background Activity
  - Circulating activity in blood and plasma

- Overlapping Activities
  - Activities in organs or tissues that cover all or parts of the target organ

For Dosimetry

- Organ Mass Determination
  - Difference in Organ Masses relative to Standard Man/Female

- Absorbed Dose Conversion Factors
  (MIRD II session: *Anatomic Models and Radionuclide S Values*)
Geometrical-Mean Method

- Based on data acquisition in opposite views

\[ C_A = C_0 e^{-\mu d} \]
\[ C_P = C_0 e^{-\mu (T-d)} \]

- Geometric-mean eliminates 'd'

\[ \sqrt{C_A \cdot C_P} = \sqrt{C_0 e^{-\mu d} \cdot C_0 e^{-\mu (T-d)}} = \sqrt{C_0^2 \cdot e^{-\mu T}} = C_0 \cdot e^{-\mu T/2} \]

- Activity calculated from

\[ A = \frac{\sqrt{C_A \cdot C_P} \cdot e^{\mu T/2}}{K} \]

K=system sensitivity (cps/MBq)
Source-Depth Correction

- Geometric-mean only valid for a point source

- Flemming derived a correction based on a source with length x in an uniform media

- Still only valid for one source

\[
A = \frac{\sqrt{C_A \cdot C_P} \cdot e^{\mu T/2}}{K \cdot \sinh(\mu \cdot x / 2)}
\]
Photon attenuation

- Attenuation a function of photon energy, density and tissue composition.
- Attenuation varies along the projection through the patient.

**Approximation**: Assume an uniform attenuation (linear attenuation)

**Better**: Measure the attenuation by a transmission study with and without a patient

\[
\frac{N_{\text{Patient}}}{N_{\text{Blank}}} = e^{-\mu T} \quad \left( \text{or } e^{-\int_0^T \mu(x) \, dx} \text{ if nonhomogeneous} \right)
\]
Transmission – External Flood Source

- $^{57}$Co Flood source
  - Broad-beam
  - Difficulties with energy scaling due to scatter contamination in transmission data
  - Poor Signal-to-Noise ratio and spatial resolution.
  - Long acquisition time (15-20min)
Transmission on SPECT/CT systems

• X-ray Scout
  – Fast (2 min)
  – Low Image Noise
  – High Spatial Resolution (<3 mm)

• Potential problems
  – Energy Scaling due to X-ray Spectra
  – Fraction material in FOV affect the transformation to attenuation values.
The Scatter Problem

True imparted energy

Measured energy

Scatter in the energy window cannot be separated from primary!
Effective Attenuation Coefficient

- Account for scatter by reduce the magnitude of the attenuation correction by using a lower attenuation coefficient.

- Method do not remove the scatter!

- Empirical and require calibration against a known activity for a given organ.

- Generally not correct since scatter depends on source distribution.
Scatter Correction

Triple Energy Window Method

- Based on acquisition in two adjacent energy windows.
- Scatter estimate is obtained by average taking into account differences in energy window size $W$.

$$S_{Peak} \approx \left[ \frac{C_{Low}}{W_{Low}} + \frac{C_{High}}{W_{High}} \right] \cdot \frac{W_{Peak}}{2}$$

(Ogawa, IEEE TMI, 1991)
**Scatter Correction**

*Triple Energy Window Method*

Energy window
Width = 4 keV

Primary + Scatter

TEW Scatter

Scatter
Scatter Correction
Triple Energy Window Method

- Narrow energy windows means high noise level
- Approximation of a straight line not accurate

Energy window Width = 2 keV

Primary + Scatter
Scatter
TEW Scatter

99Tcm - energy imparted as measured from the scintillation light
• Image affected by system resolution PSF (due to collimator, scatter and
collimator penetration).

\[
\text{Image} = \text{Object} \otimes \text{PSF} = \mathcal{F}(\text{Object}) \mathcal{F}(\text{PSF})
\]

\[
\text{Object} = \mathcal{F}^{-1} \left[ \mathcal{F}(\text{Object}) \mathcal{F}(\text{PSF}) \mathcal{F}^{-1} \left( \frac{1}{\mathcal{F}(\text{PSF})} \right) \right]
\]

• If PSF can be accurately described by a function H – then an inverse filter
\( T=1/H \) can be applied to the measured data.

\[
\frac{1}{\mathcal{F}(\text{PSF})} \approx T_{u,v}(K) = \frac{1}{H(u,v)} \mathcal{F}^{-1} \left( \frac{|H(u,v)|^2}{|H(u,v)|^2 + K} \right)
\]

• \( K \) = compromise between spatial resolution and image noise
Image Restoration

Wiener Filter

- No Additional Energy Windows

- Needs a MC code to generate scatter kernels

- Can include scatter, collimator blur, septum penetration and backscatter components.

- Spatially invariant - select a representative depth.

- Makes it easier to define ROI because of sharper images

Example of a $^{131}$I scatter correction
Biokinetics

Intensity [counts] vs. Time [h]

SNM MIRD – Medical Internal Radiation Dose

Lund University

Slides are not to be reproduced without permission of author.
Whole-Body Registration

- Image registration aims to minimize errors in patient positioning between time-points
- Useful when using one transmission scan or one set of ROIs
- One stationary image (transmission scan)
Whole-Body Registration

• Image registration aims to minimize errors in patient positioning between time-points

• Useful when using one transmission scan or one set of ROIs

• One stationary image (transmission scan)

Sjögreen K et al. J Nucl Med 2001; 42(10):1563-1570
Background and Organ Overlap

Corrections for background activity and organ overlap essential
Organ overlap correction

- Based on patient thickness in the ROI projection line, and
- Pre-calculated, organ-background-volume-fraction.

\[
\text{Calculate:} \\
\begin{align*}
\text{I. } & \text{MBq/pixel for non-overlapped segment } \times N_{\text{PIX}} \\
\text{II. } & A_{\text{OL}} - N_{\text{PIX}} \times \text{MBq/pixel of overlapping organ} \\
\text{III. } & A_{\text{OL}} \text{ as it is (uncorrected)}
\end{align*}
\]

The smallest of I-III is selected.
Region –of-Interest Definition

- Previous correction for overlap approximative

- Even if drawing ROI from a good resolution image – depth still unknown.

- Draw 3D ROIS from a registered CT image may account for this drawback
The QPlanar Method

- 2D planar images and 3D ROIs
- Model-based projector
- ML algorithm for ideal noise properties

\[ p_i = \sum_{r=0}^{7} A_r c_{ir} \]

\[ A_{r+1}^n = A_r^n \frac{1}{\sum_i c_{ir} p_i} \sum_j c_{ij} A_j^n \]
Residence Time

Planar Processing

Anterior

Posterior

Planar

Curve Fitting

Residence Time

<table>
<thead>
<tr>
<th>Hour</th>
<th>Anterior</th>
<th>Posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>144</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{A_{\text{organ}}(t)}{A_0}
\]
Hybrid 2D/3D organ quantification

Shape from WB studies

Activity at one time point from SPECT/CT

Accuracy and Precision?

- Cplanar
  - Geometric-Mean
  - TEW method
  - Background

- Qplanar
  - 3D Organ ROI manually defined
  - Create activity projections by forward projection

- QSPECT
  - OSEM
  - Nonhomogeneous attenuation
  - Scatter (ESSE)
  - Collimator Response

- Comparisons
  - Phantom experiments
  - NCAT Monte Carlo simulations
Accuracy and Precision?  

Phantom experiment

<table>
<thead>
<tr>
<th>Method/organs</th>
<th>Heart (%)</th>
<th>Lungs (%)</th>
<th>Liver (%)</th>
<th>Large sphere (%)</th>
<th>Small sphere (%)</th>
<th>Whole body (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPlanar</td>
<td>-3.21</td>
<td>-17.22</td>
<td>-2.51</td>
<td>-7.02</td>
<td>-28.95</td>
<td>0.00</td>
</tr>
<tr>
<td>QSPECT</td>
<td>-0.59</td>
<td>4.26</td>
<td>2.15</td>
<td>-5.05</td>
<td>-3.06</td>
<td>0.80</td>
</tr>
<tr>
<td>QPlanar</td>
<td>0.90</td>
<td>7.61</td>
<td>3.22</td>
<td>-1.16</td>
<td>-0.59</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Slides are not to be reproduced without permission of author.
NCAT Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Method\organs</th>
<th>Heart (%)</th>
<th>Lungs (%)</th>
<th>Liver (%)</th>
<th>Kidneys (%)</th>
<th>Spleen (%)</th>
<th>Marrow (%)</th>
<th>Blood vessels (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPlanar (realistic)</td>
<td>14.76 ± 0.53</td>
<td>9.40 ± 0.29</td>
<td>−8.35 ± 0.27</td>
<td>13.90 ± 2.08</td>
<td>45.59 ± 1.72</td>
<td>−47.62 ± 0.65</td>
<td>5.77 ± 0.32</td>
</tr>
<tr>
<td>QSPECT</td>
<td>−0.46 ± 0.68</td>
<td>−1.84 ± 0.94</td>
<td>−1.34 ± 0.35</td>
<td>−5.42 ± 1.54</td>
<td>−0.39 ± 1.20</td>
<td>2.14 ± 0.74</td>
<td>1.36 ± 0.84</td>
</tr>
<tr>
<td>QPlanar</td>
<td>−1.76 ± 0.31</td>
<td>13.36 ± 0.34</td>
<td>−0.20 ± 0.16</td>
<td>−4.03 ± 0.86</td>
<td>−1.39 ± 0.71</td>
<td>3.35 ± 0.52</td>
<td>1.59 ± 0.81</td>
</tr>
</tbody>
</table>
Concluding remarks

- Planar Imaging a 2D method.
- Geometric-Mean method reduce source depth dependence but does not eliminate it for realistic source distributions
- Transmission with X-scout or projected registered CT preferred
- Overlap and background correction very important
- Errors in position may mimic the accuracy for small ROI when using a single set of ROI
- QSPECT method by He et al promising but drawback with time-consuming ROI definitions. An accurate projector algorithm is also required
- If multiple SPECT/CT studies not realistic then hybrid Planar/QSPECT may improve the accuracy
Thank you for your attention