Bismuth Shielding: Helpful or Harmful

Cynthia H. McCollough, PhD, FAAPM, FACR
Director, CT Clinical Innovation Center
Professor of Radiologic Physics
Mayo Clinic, Rochester, MN
DISCLOSURES

Research Support:

<table>
<thead>
<tr>
<th>NIH</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB 007986</td>
<td>Society of Gastrointestinal Radiologists</td>
</tr>
<tr>
<td>EB 004898</td>
<td>Mayo Novel Methodology Development Award</td>
</tr>
<tr>
<td>DK 083007</td>
<td>Thrasher Foundation</td>
</tr>
<tr>
<td>DK 059933</td>
<td>Siemens Healthcare</td>
</tr>
<tr>
<td>DK 090728</td>
<td></td>
</tr>
<tr>
<td>AR 057902</td>
<td></td>
</tr>
<tr>
<td>RR 018898</td>
<td></td>
</tr>
</tbody>
</table>

Off Label Usage
None
Introduction

- Bismuth shielding has been used to reduce the dose from CT to superficial radiosensitive organs, such as the breast, lens of the eye, and thyroid.
- Concerns include an adverse effect on image quality and absorption of photons exiting the patient and on their way to the detector.
- Clinical studies did not control for noise level; primarily assessed whether “clinically acceptable”
Motivation

• To quantitatively assess the dose reduction and image quality in controlled experiments:
  – Standard clinical protocol
  – Bismuth shielding
  – Organ-based TCM
  – Globally decreasing the tube current to achieve the same dose reduction as bismuth shielding
Bismuth Eye Shielding
Scanning parameters

• Reference scan parameters were chosen from our standard spiral head scanning protocol
  – 120 kV, 1s rotation, 5 mm image thickness, 300 mm FOV

• Chose a reduced effective mAs [“Low-mAs”] to yield the same dose reduction to the eye as bismuth shield:

\[
\text{Low-mAs} = \text{Ref-mAs} \times \frac{\text{Bi}_\text{Dose}}{\text{Ref}_\text{Dose}}
\]

• Bi_Dose and Ref_Dose are the doses measured at the eye with and without bismuth shielding, respectively.
Current increased by 25%

Current reduced by 75% over angular range: of 120°

Duan et al, Dose Reduction to Anterior Surfaces With Organ-Based Tube-Current Modulation: Evaluation of Performance in a Phantom Study, AJR, 2011
# Eye scanning parameters

<table>
<thead>
<tr>
<th></th>
<th>Effective mAs</th>
<th>CTDIvol (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>250</td>
<td>38.18</td>
</tr>
<tr>
<td>Bi. Shielding</td>
<td>250</td>
<td>38.18</td>
</tr>
<tr>
<td>Organ-based TCM</td>
<td>250</td>
<td>37.57</td>
</tr>
<tr>
<td>Low-mAs</td>
<td>177</td>
<td>27.19</td>
</tr>
</tbody>
</table>
Dose reduction to the eye lens

Wang et al., *Bismuth Shielding, Organ-based Tube Current Modulation and Global Reduction of Tube Current for Dose Reduction to the Eye in Head CT*, Radiology, In Press
Reference | Bismuth shielding (one layer) | Organ-based TCM | Low-mAs

(ww/wl = 120/40)

Courtesy of Jia Wang
Image quality evaluation

Anterior
Central
Posterior
# Summary – Lens of Eye

<table>
<thead>
<tr>
<th></th>
<th>Bismuth</th>
<th>Organ-based TCM</th>
<th>Low mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose Reduction</strong></td>
<td>~ 26%</td>
<td>~ 30%</td>
<td>~ 30%</td>
</tr>
<tr>
<td><strong>Noise Increase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Central</td>
<td>~ 1HU</td>
<td>~ 1 HU</td>
<td>~ 1 HU</td>
</tr>
<tr>
<td>- Posterior</td>
<td>None</td>
<td>None</td>
<td>~ 1 HU</td>
</tr>
<tr>
<td><strong>CT Number Increase</strong></td>
<td>~ 1-3 HU</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Streak Artifacts</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Anterior vs. global dose reduction

- **Bismuth shielding**
  - reduces dose to **only the anterior surface** by \(\approx 26\%\)
  - total scanner output (CTDIvol) unchanged
- **Organ based tube current modulation**
  - reduces dose to anterior surface
  - increases dose to lateral and posterior surfaces
  - total scanner output (CTDIvol) unchanged
- **Globally reducing tube current**
  - reduces dose to **all surfaces** by \(\approx 30\%\)
  - total scanner output (CTDIvol) decreased \(\approx 30\%\)
Thorax phantoms

- Semi-anthropomorphic thorax phantoms
  (Cardio CT, QRM, Moehrendorf, Germany)

<table>
<thead>
<tr>
<th>Lateral (cm)</th>
<th>AP (cm)</th>
<th>Bismuth shields</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>11</td>
<td>Pediatric (2-ply)</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>Adult (4-ply)</td>
</tr>
<tr>
<td>35</td>
<td>25</td>
<td>Adult (4-ply)</td>
</tr>
<tr>
<td>40</td>
<td>30</td>
<td>Adult (4-ply)</td>
</tr>
</tbody>
</table>
Scanning Parameters

- Tube voltage:
  - 100kV for 15-cm phantom,
  - 120kV for three adult phantoms
- Collimation: 12 x 0.6 mm, Rotation time: 0.28s
- Automatic Exposure Control (CareDose4D, Siemens Healthcare, Forchheim, Germany)
- The bismuth shield was placed on the phantom after the topogram.
- CTDI\textsubscript{vol} was same for the reference scan as with bismuth or organ-based TCM
Globally Decreasing Tube Current

\[ m\text{As}_{\text{Low}} = m\text{As}_{\text{Ref}} \times \frac{\text{Dose}_{\text{Bismuth}}}{\text{Dose}_{\text{Reference}}} \]

Courtesy of Jia Wang
Organ-based tube current modulation

Current increased by 25%

Current reduced by 75%

Tube angle

X-ray tube
## Thorax scanning parameters

<table>
<thead>
<tr>
<th></th>
<th>15-cm</th>
<th></th>
<th>30-cm</th>
<th></th>
<th>35-cm</th>
<th></th>
<th>40-cm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eff.mAs</td>
<td>CTDI_{vol}</td>
<td>Eff.mAs</td>
<td>CTDI_{vol}</td>
<td>Eff.mAs</td>
<td>CTDI_{vol}</td>
<td>Eff.mAs</td>
<td>CTDI_{vol}</td>
</tr>
<tr>
<td>Reference</td>
<td>32</td>
<td>1.06</td>
<td>67</td>
<td>4.54</td>
<td>126</td>
<td>8.53</td>
<td>139</td>
<td>9.41</td>
</tr>
<tr>
<td>Bi Shielding</td>
<td>31</td>
<td>1.05</td>
<td>66</td>
<td>4.51</td>
<td>126</td>
<td>8.51</td>
<td>141</td>
<td>9.52</td>
</tr>
<tr>
<td>Organ-based TCM</td>
<td>32</td>
<td>1.08</td>
<td>66</td>
<td>4.45</td>
<td>128</td>
<td>8.62</td>
<td>139</td>
<td>9.41</td>
</tr>
<tr>
<td>Low-mAs</td>
<td>26</td>
<td>0.84</td>
<td>56</td>
<td>2.76</td>
<td>76</td>
<td>5.13</td>
<td>83</td>
<td>5.67</td>
</tr>
</tbody>
</table>
Dose measurement
Dose reduction to the anterior surface

Wang et al, Radiation Dose Reduction to the Breast in Thoracic CT: Comparison of Bismuth Shielding, Organ-based Tube Current Modulation and Use of a Globally Decreased Tube Current, Medical Physics, In Press
Image quality evaluation
## Summary - Thorax

<table>
<thead>
<tr>
<th></th>
<th>Bismuth</th>
<th>Organ-based TCM</th>
<th>Low mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose Reduction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Adult</td>
<td>~ 40%</td>
<td>~ 40%</td>
<td>~ 40%</td>
</tr>
<tr>
<td>-Pediatric</td>
<td>~ 20%</td>
<td>~ 12%</td>
<td>~ 20%</td>
</tr>
<tr>
<td><strong>Noise Increase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Adult</td>
<td>~ 2-4 HU</td>
<td>None</td>
<td>~ 2-5 HU</td>
</tr>
<tr>
<td>-Pediatric</td>
<td>~ 1 HU</td>
<td>None</td>
<td>~ 1 HU</td>
</tr>
<tr>
<td><strong>CT # Increase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Adult</td>
<td>~ 10-20 HU</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>-Pediatric</td>
<td>~ 2-6 HU</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Streak Artifacts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Adult</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>-Pediatric</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
**Anterior vs. global dose reduction**

- **Bismuth shielding**
  - reduces dose to *only the anterior surface* by $\approx 40\%$ (adults)/$20\%$ (ped)
  - total scanner output ($\text{CTDI}_{\text{vol}}$) unchanged
- **Organ based tube current modulation**
  - reduces dose to anterior surface
  - increases dose to lateral and posterior surfaces
  - total scanner output ($\text{CTDI}_{\text{vol}}$) unchanged
- **Globally reducing tube current**
  - reduces dose to *all surfaces* by $\approx 40\%$ (adults)/$20\%$ (ped)
  - total scanner output ($\text{CTDI}_{\text{vol}}$) decreased $\approx 40\%$/ $20\%$ (ped)
Bismuth Shielding Summary

**Useful**
- Reduces dose to anterior surface
- Limits effects on image quality to a specific range, vs. over the whole scan
- Patients feel protected
- Straightforward to use

**Disadvantages**
- Not efficient way to reduce dose
  - Only anterior dose reduction
  - Attenuates photons exiting patient
- Affects image quality
  - Decreases CT number accuracy
  - Increases noise and artifacts
  - Should not be used over liver
- Pitfalls with tube current modulation
  - Image quality is not as prescribed
- Placement/disinfection needed
Conclusions

- Alternative approaches to reduce anterior dose should be considered (e.g. those mentioned or z-specific mAs)
- Organ-based tube current modulation can achieve the same anterior dose reduction as bismuth shielding
  - No artifacts, CT Number unaffected, no noise increase
  - Moves “saved” does to posterior
- Globally lowering tube current can match anterior dose reduction by bismuth shielding, at same noise level
  - Medical Physicists should assist in determining appropriate scan parameters (e.g. Noise Index)
  - Adapt for different patient sizes (Noise Index technique chart)
Thank you!

CT Clinical Innovation Center

http://mayoresearch.mayo.edu/ctcic