Confining radiation dose for dual energy stereoscopic x-ray imaging

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Outline

• Introduction
  – Dual energy stereoscopic imaging for SBRT
  – Why confine dose?

• Dose measurement methods
  – AAPM - TG61

• Results
  – Dose measurement
  – Dual energy imaging of a phantom

• Conclusion
Stereotactic body radiation therapy (SBRT)

Precise delivery of highly conformal hypo-fractionation (extra-cranial)

- Early stage lung cancer
- Extra-cranial metastasis (lung, spine)

Accuracy: Fundamental requirement
(high doses, limited fractions)

⇒ Image guidance
**Image guidance**

**CBCT:**
- Volumetric
- Slow
- Tx interruption

**Stereoscopic (ExacTrac):**
- 3D info from 2 x 2D
- Fast acquisition, processing
- Finer resolution
- Low dose
- Tissue overlap
Tissue overlap problem

- see bone/tumor in ref images
- cannot see in stereoscopic

Lung: Bone overlap
Spine: Soft tissue overlap

Remove “anatomical noise”? 
soft - tissue - only - image
bone - only - image
Dual energy imaging

Different material → different attenuation (energy dependent)

- Take 2 images:
  - **HE**: High Energy \( (\rho) \)
  - **LE**: Low Energy \( (\rho, Z) \)

- Weighed subtraction:
  
  \[
  \ln(HE) - \omega_t \ln(LE) = \text{soft - tissue - only}
  \]
  
  \[
  - \ln(HE) + \omega_b \ln(LE) = \text{bone - only}
  \]

Bushberg (2012) 3rd ed
Dual energy: Material identification

Airport security

HE: High Energy ($\rho$)
LE: Low Energy ($\rho, Z$)
Dual energy: Chest radiography

Conventional Clinical Single Energy (SE)

soft – tissue – only

Dual Energy (DE)

bone – only

Dual energy: Why confine dose?

\[ \text{Dose}_{\text{LE}} + \text{Dose}_{\text{HE}} = \text{Dose}_{\text{DE}} \]

\( \Rightarrow \) dose accumulation

Dose_{\text{DE}} \leq \text{Dose}_{\text{SE}}
Objective

1. To measure dose for stereoscopic imaging and

2. To confine dose for dual energy (DE) such that dose is $\leq$ than that of clinical single energy (SE) imaging.
Methods: Dose measurement (TG61)

surface dose

\[ D_{w,z=0} = A \cdot B_w \cdot \left[ \frac{\bar{\mu}_{en}}{\rho} \right]_\text{air}^w \]

backscatter factor

air kerma

RaySafe detector

mass energy-absorption coefficient

HVL measured using the RaySafe detector

kVp = [60, ...80, 120...140]
Tin filter [0, 0.7] mm

mAs varied such that \( \text{dose}_{DE} \leq \text{dose}_{SE} \)

Dose_{DE} = Dose_{LE} (30\%) + Dose_{HE} (70\%)
Methods: Physical phantom experiment

Implemented a sphere tumor model in the lung of a Rando phantom
Acquired SE & DE images
Calculate DE images in Matlab

Bowman (2017) Med Phys
Results: Air kerma

⇒ Can calculate patient dose of any given imaging protocol
Results: Patient dose – Clinical single energy

Dose 0.52 mGy

X-ray Generator Energy Presets

<table>
<thead>
<tr>
<th>Preset Name</th>
<th>kV</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen (High)</td>
<td>145</td>
<td>25.00</td>
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<tr>
<td>Abdomen (Low)</td>
<td>100</td>
<td>16.00</td>
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<tr>
<td>Abdomen (Medium)</td>
<td>120</td>
<td>20.00</td>
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<tr>
<td>Cranial (High)</td>
<td>100</td>
<td>12.50</td>
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<tr>
<td>Cranial (Low)</td>
<td>80</td>
<td>6.30</td>
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<tr>
<td>Cranial (Medium)</td>
<td>80</td>
<td>6.30</td>
</tr>
<tr>
<td>Head and Neck (High)</td>
<td>100</td>
<td>10.00</td>
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<tr>
<td>Head and Neck (Low)</td>
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<td>6.30</td>
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<tr>
<td>Pelvis (High)</td>
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<tr>
<td>Pelvis (Low)</td>
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<td>Pelvis (Medium)</td>
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<td>Shoulder (High)</td>
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<tr>
<td>Thorax (Medium)</td>
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<td>25.00</td>
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<tr>
<td>TympanTracking</td>
<td>140</td>
<td>0.63</td>
</tr>
<tr>
<td>BL Correction Images (Tube 1)</td>
<td>60</td>
<td>0.63</td>
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</tbody>
</table>
Results: Patient dose – Rando phantom

<table>
<thead>
<tr>
<th>mAs</th>
<th>Single energy</th>
<th>Dual-energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>120 (kVp), 0 mm Sn (clinical)</td>
<td>140,60 (kVp), 0 mm Sn</td>
</tr>
<tr>
<td>40 (LE)</td>
<td>140,60 (kVp), 0 mm Sn</td>
<td>140,60 (kVp), 0.2 mm Sn</td>
</tr>
<tr>
<td>12 (HE)</td>
<td>140,60 (kVp), 0 mm Sn</td>
<td>140,60 (kVp), 0.2 mm Sn</td>
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<tr>
<td>347 (LE)</td>
<td>140,60 (kVp), 0.2 mm Sn</td>
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</tr>
<tr>
<td>40 (HE)</td>
<td>140,60 (kVp), 0.2 mm Sn</td>
<td></td>
</tr>
</tbody>
</table>

| Dose [mGy] | 0.52 | 0.52 | 0.52 |

Bowman (2017) Med Phys
Conclusion

- Patient dose was measured and fully characterized for both clinical SE and DE imaging as a function of tube mAs, kVp, and tin filtration.

- DE imaging parameters were optimized and mAs values varied such that DE imaging dose is confined to the clinical single dose of 0.52 mGy.
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• Angela Henry
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[BrainLAB logo]
[Nova Scotia Health Authority logo]