Outline

- Challenges of pediatric IGRT
- IGRT practice patterns for adults and children
- COG survey of pediatric IGRT practice
- Estimated doses to children from IGRT procedures
- Should we worry about the effect of image guidance dose?
- Strategies of reducing image guidance doses
- Summary

Challenges of pediatric RT and image guidance

Radiation sensitive structures adjacent to tumor and shorter distance in between than adults

- Lens
- Optic chiasm
- Brainstem
- Cochlea
- Ovary
- Testis

Variation in body size requiring different imaging protocol settings
Previously reported IGRT practice patterns

Adults
- Australia and New Zealand 2008 (Rybovic et al., J Med Imaging Radiat Oncol, 52(2):183-190)
- ASTRO member survey 2016 (NabaviSadegh et al., IROBP, 54(4):850-857)

Children
- Portal imaging practice of COG institutions 2008 (Olich et al., IROBP, 67(2):594-600)
- Canadian pediatric imaging practice 2014 (Rodgerson, Radiography, 20(3):183-188)

Adult IGRT practice patterns

ASTRO survey 2016

Volumetric imaging was common (60-77%) for all sites except breast.
Daily IGRT was preferred for H&N, lung, prostate, esophagus, pelvis. Weekly IGRT was popular for brain and breast.

Pediatric IGRT practice patterns

International pediatric research consortium survey 2014 (7 institutions)

IGRT was consistently employed in nearly all CNS cases but varied across facilities in abdominal and pelvic cases.
In contrast to adults, daily IGRT was performed more than weekly for CNS tumors.
Only 57% of photon institutions used specialized lower-dose pediatric protocols.
COG survey – design and response

Survey conducted in late 2017

39 clinical questions designed for pediatric radiation oncologists (COG members)
23 technical questions for medical physicists

Responses from 105 radiation oncologists and 63 medical physicists

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COG survey – recommended pediatric IGRT method

![Graph showing recommended IGRT methods for different tumor types](image)

- 2D techniques (kV or MV) dominant for AP/PA (Wilms) and parallel-opposed FF (whole brain)
COG survey – recommended image guidance frequency

![Image showing recommended image guidance frequency](image)

COG survey – selected results of technical questions

Q: Are anatomic site-specific IGRT protocols used routinely for children?

- 0 – 10
- 10 – 20
- 20 – 30
- 30 – 40
- 40 – 50
- 50 – 60

Q: Does your institution modify kV/mAs setting from vendor's adult IGRT protocols for children?

- Vendor does not allow.
- No need to reduce.
- No. Will reduce if guidelines available.

Q: What measures are employed to reduce image guidance doses to pediatric patients (check all that apply)?

- None
- Supplement with non-ionizing methods
- Upgrade IGRT hardware and software
- Age- and size-specific protocols
- Image less frequently
- Use collimation
- Use kV instead of MV
- Lower mAs/kVp

COG IGRT survey – Opinions

![Image showing opinions](image)
COG IGRT survey – Opinions

COG IGRT survey – Opinions

Estimated organ doses from IGRT procedures

Organ dose from CBCT depends on protocol setting (kVp, mA, # projections, gantry start-stop-angles), hardware, collimation (scan length), and child body habitus.

High quality head protocol

<table>
<thead>
<tr>
<th>OAR</th>
<th>40 kVp</th>
<th>60 kVp</th>
<th>80 kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>18</td>
<td>12</td>
<td>51</td>
</tr>
<tr>
<td>Eyes</td>
<td>9</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>Lens</td>
<td>11</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Optic nerves</td>
<td>9</td>
<td>17</td>
<td>27</td>
</tr>
</tbody>
</table>

High quality, standard, low-dose head protocols

<table>
<thead>
<tr>
<th>OAR</th>
<th>40 kVp</th>
<th>60 kVp</th>
<th>80 kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>7.4</td>
<td>3.2</td>
<td>1.5</td>
</tr>
<tr>
<td>R/L eye</td>
<td>1.8/1.4</td>
<td>0.4/0.2</td>
<td>0.2/0.2</td>
</tr>
<tr>
<td>Skin</td>
<td>8.9</td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>10.1</td>
<td>2.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

The choice of kVp affects organ doses.

Newer versions CBCT reduced organ doses from 0.5 to 6 mGy ranges.
Estimated organ doses from IGRT procedures

<table>
<thead>
<tr>
<th>Default pelvic protocol</th>
<th>Default pelvic protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Varian OBI, 125kV, 80mA, 13ms, half fan bowtie filter)</td>
<td>(Varian OBI v1.4, 125kVp, 80mA, 13ms, half fan bowtie filter)</td>
</tr>
<tr>
<td>5 y/o boy</td>
<td>5 y/o girl</td>
</tr>
<tr>
<td><strong>OAR</strong></td>
<td><strong>mGy</strong></td>
</tr>
<tr>
<td>All kidneys</td>
<td>22/23</td>
</tr>
<tr>
<td>Bladder</td>
<td>32</td>
</tr>
<tr>
<td>Prostate</td>
<td>26</td>
</tr>
<tr>
<td>Rectum</td>
<td>29</td>
</tr>
</tbody>
</table>
| Pelvic organ doses are in the cGy range if default adult pelvis protocol was used for a 5 y/o. Total dose could add up to 1 Gy if such protocol was used daily.

Should we worry about the effect of IGRT doses?

- Although much lower than target dose, IGRT doses could be equal to or greater than peripheral doses from therapeutic beams (especially for scanning protons)
- Level of clinical evidence?
  - Increased risk of leukemia and brain cancer in children receiving diagnostic CT
    - Excess relative risk of 0.04 and 0.03 per mGy for leukemia and brain cancer from UK and Australian studies (Pearce et al. Cancer 2012, Matthews et al. BMJ 2013)
    - Excess relative risk of 0.86 per 100 mGy for brain cancer from Dutch study (Meulepas et al. JNCI 2019)
  - However, the French study (Journy et al. BJC 2015, J Radiol Prot 2016) showed no significant risk if cancer predisposing factors were adjusted.
  - epi-CT study (9 European national cohorts) is ongoing.

- Should we worry about the effect of IGRT doses?
  - Level of clinical evidence?
    - Higher incidence of second cancers in in-field tissues receiving medium-to-high doses
    - Peaked at the area surrounding the PTV (Diallo et al. IJROBP 2009)
  - Some normal tissues may have no or very low thresholds (e.g., thyroid, ovaries, testis, bone marrow).
    - Adding IGRT doses to doses from therapeutic beams may increase the risk of normal tissue toxicity.
    - PENTEC group will provide pediatric organ-specific tolerance guidelines.
Recommendations on reducing imaging dose

- Recommendations from AAPM TG 180, ACR-AAPM and ACR-ASTRO technical standard, literature publications
- COG recommendations will be available later this year.
- Balance of clinical task performance and imaging dose reduction (don't overkill)
- Some strategies are presented here:

  - Create dedicated protocols for younger children
  - Use adult low dose protocols for children (e.g., adult low dose head for pediatric head, adult H&N for pediatric body)
  - Choose imaging settings for specific tasks (marker, bony anatomy, soft-tissue detectability)
  - Use collimation to reduce the imaged length/volume to block sensitive OARs
  - Smaller field-of-view when appropriate (e.g., partial view of body may be sufficient for registration)
  - Choose appropriate kVp and mA (tissue scatter, radiation)
  - Reduce the chance of repeated imaging due to difficulty in adjusting patient position
  - Avoid organ at risk by using partial arc CBCT (gantry rotation start-stop angles)
  - Smaller image guidance equipment
  - Proper calibration, improving imaging technology
  - Training of image equipment operators
  - Consistent patient setup and immobilization
  - Supplement with non-ionizing radiation techniques (e.g., surface imaging, optical imaging)

Summary

- What we found in the COG survey
  - Most radiation oncologists recommended daily image guidance
  - Volumetric image guidance not as prevalent as in adults
  - 40% indicated scan setting (kVp/MA) not adjusted for children because of lack of guidelines

- What can you do in the mean time as a physicist?
  - Review CBCT practice for children in your institution
  - Know your IGRT doses
  - Don't use adult protocols without modifications for young children and infants
  - Consult with your diagnostic imaging physicist colleague
  - Discuss with physicians and apply strategies easy to implement first

- Opportunities
  - Practice guidelines and research (e.g., beyond dose reduction)
  - Work to facilitate creation of site-specific pediatric protocols
  - Join COG physics committee to contribute

Acknowledgment

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