Justification, Optimization and Communication in Pediatric CT Imaging: Recent Improvements and Persistent Challenges

Designated Emphasis in Nuclear Sciences – 2016 Seminar

Jerrold Bushberg Ph.D., DABMP, FAAPM
Clinical Professor Radiology & Radiation Oncology
U.C. Davis, School of Medicine
Senior Vice-President NCRP
Why Should You Care?

- CT is a common exam: You’re a radiation professional and people look to you for *answers on all things radiation*.
- You might be interested in the **benefits of CT in kids** & the fundamental **principles that govern its safe use**
- Your might want to know what **resources** are available for people that have questions about **CT radiation and patient safety**
- You, or someone you care about, might have a child that is scheduled for a CT and you might want to know **what are the right questions to ask**.
- You might be curious about the ways to **reduce the dose** from CT exams
- **Grant fund** are available and have been awarded to work on the question of CT dose optimization and biological effects
Reasons For Using CT in Children

CT has many advantages:
- **Rapid and noninvasive evaluation of solid organ and vascular injury**: e.g., following trauma where time is the enemy—minutes count
- **Short sedation times**: avoiding complications of prolonged anesthesia
- **Airway evaluation**: e.g., Virtual Bronchoscopy with 3D reconstruction
- **Surgical planning**: e.g., treat congenital abnormalities like bronchopulmonary sequestration to show the surgeon where the artery is coming off the descending aorta & potential complications.
- **Evaluate the effectiveness of chemotherapy in pediatric cancer patient**
- **Many others….”
Its not often that we get a chance to image the cancer and its etiology at the same time.

**Annual Average per capita Effective Dose**

- **Total 1980’s:** 3.6 mSv
  - Background (83%): 3.1 mSv
  - Medical (15%): 0.53 mSv
- **Total 2006:** 6.2 mSv
  - Background (50%): 3.1 mSv
  - Medical (48%): 3.0 mSv
  - Occupational / industrial (0.3 %)
  - Consumer (2 %)
Which Imaging Modalities Increased?

• Computed Tomography (49%)
• Nuclear Medicine – myocardial perfusion studies (26%)
• Interventional fluoroscopy (14%)
• All other radiography and fluoroscopy. 11%

~3.0 mSv/yr
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Procedures (millions)</th>
<th>%</th>
<th>Collective Effective Dose (person Sv)</th>
<th>%</th>
<th>E_{US} (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed Tomography</td>
<td>67</td>
<td>17</td>
<td>440,000</td>
<td>49</td>
<td>1.5</td>
</tr>
<tr>
<td>+ Nuclear Medicine</td>
<td>18</td>
<td>5</td>
<td>231,000</td>
<td>26</td>
<td>0.8</td>
</tr>
<tr>
<td>Interventional</td>
<td>17</td>
<td>4</td>
<td>128,000</td>
<td>14</td>
<td>0.4</td>
</tr>
<tr>
<td>Conventional Radiography &amp; Fluoroscopy</td>
<td>292</td>
<td>74%</td>
<td>99,000</td>
<td>11%</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>426</strong></td>
<td><strong>100</strong></td>
<td><strong>898,000</strong></td>
<td><strong>100</strong></td>
<td><strong>~3</strong></td>
</tr>
</tbody>
</table>
WHY THE INCREASE?

Unparalleled Diagnostic Capability

Defensive Medicine

Tens of Millions of Dollars for satisfied Medical Malpractice Clients

Self-Referral
The biggest problems were in the smallest patients.

CT scans in *children* are often performed using "adult" techniques resulting in higher radiation dose.
Image Gently™

Campaign launched in January 2008 by the Alliance for Radiation Safety in Pediatric Imaging, founded by:

- Society for Pediatric Radiology (SPR)
- American College of Radiology (ACR)
- American Society of Radiologic technologists (ASRT)
- American Association of Physicists in Medicine (AAPM).

Its goal is to reduce radiation dose used in pediatric computed tomography (CT) and other exams.

- Now has grown to include 80 participant organizations/agencies.
- It has become an international movement.
- Over 1 Million medical imaging professionals have pledged to follow its principles.
The Alliance urges providers who perform imaging exams on children to:

- Significantly reduce, or “child-size,” the amount of radiation used
- Not over-scan:
  - Scan only when necessary
  - Scan only the indicated region
  - Scan once; multi-phase scanning (pre- and post-contrast, delayed exams) is rarely helpful
- Compare patient dose to Reference Levels
- Be a team player:
  - Involve medical physicists to monitor pediatric CT techniques - Involve technologists to optimize scanning
Image Gently Web Site

The Alliance for Radiation Safety in Pediatric Imaging

Resources for PARENTS

Take the Image Gently pledge!

One size does not fit all...so when we image, let's image gently!

www.imagegently.org
Let's image gently when we care for kids! The image gently Campaign is an initiative of the Alliance for Radiation Safety in Pediatric Imaging. The campaign goal is to change practice by increasing awareness of the opportunities to lower radiation dose in the imaging of children.

RESOURCES

- Image Gently Practice Quality Improvement Module in Computed Tomography (CT) Scans in Children
- Alternatives to CT
- ASRT White Paper - Computed Tomography in the 21st century: Changing Practice for Medical Imaging and Radiation Therapy Professionals
- RadiologyQuality.com - This site provides ABR-certified practice quality improvement projects to fulfill Maintenance of Certification Part IV requirements.
- From the Pediatric Emergency Physician community: ALARA: is there a cause for alarm? Reducing radiation
Dose Management Using Angular and Longitudinal TCM

Angular Modulation
mA during 1 rotation
Tube Angle

Longitudinal (z) Modulation
Average mA per rotation

Dose Modulation and Reduction

Longitudinal (z) and Angular Modulation
mA
Scan Distance (z)
Dose Alert Levels

- **Dose Alert Levels** require specific action by the operator to begin scanning.
- **Dose Alert Levels** are typically much higher than Notification (e.g., CT Cerebral angiography).
- Triggering a **Dose Alert** requires that the operator confirm the protocol and settings are correct by entering in his or her name. Optionally, sites may require that the operator provide a brief explanation in the provided field.
NCRP Report 172 Available

The NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States is now available. This Report represents an important continuation of NCRP reports on radiation safety and health protection in medicine and lays the foundation for the development and application of DRLs and achievable doses for diagnostic x-ray examinations. Please click here to...
### “Size Specific” CT Protocols

#### Abdomen

<table>
<thead>
<tr>
<th>Thickness (cm)</th>
<th>Approx Age</th>
<th>kVp</th>
<th>mA</th>
<th>Time</th>
<th>Pitch Abdomen</th>
<th>Pitch Thorax</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>newborn</td>
<td>120</td>
<td>200</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1 yr</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>5 yr</td>
<td>120</td>
<td>200</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>10 yr</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>15 yr</td>
<td>120</td>
<td>200</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>small adult</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>med adult</td>
<td>120</td>
<td>200</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>large adult</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Baseline:**
- kVp = 120
- mA = 200
- Time = 0.5 sec
- Pitch Abdomen = 1
- Pitch Thorax = 1

**mAs Reduction Factor (RF):**
- Estimated mAs = BL x RF (fill in)

#### Head

<table>
<thead>
<tr>
<th>Thickness (cm)</th>
<th>Approx Age</th>
<th>kVp</th>
<th>mA</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>newborn</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
</tr>
<tr>
<td>16</td>
<td>2 yr</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
</tr>
<tr>
<td>17</td>
<td>6 yr</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
</tr>
<tr>
<td>19</td>
<td>med adult</td>
<td>140</td>
<td>400</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Baseline:**
- kVp = 140
- mA = 400
- Time = 0.5 sec
### 2014 UPDATE OF THE NORTH AMERICAN CONSENSUS GUIDELINES FOR PEDIATRIC ADMINISTERED RADIOPHARMACEUTICAL ACTIVITIES

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>Administered Activity (μCi/g)</th>
<th>Minimum Administered Activity (μCi/mL)</th>
<th>Maximum Administered Activity (μCi/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>99mTc-MAG</strong></td>
<td>5.5 μCi/g</td>
<td>27 μCi/mL</td>
<td>70 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-MDP</strong></td>
<td>9.3 μCi/g</td>
<td>57 μCi/mL</td>
<td>130 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-DPD</strong></td>
<td>(A) 7.5 μCi/g</td>
<td>37 μCi/mL</td>
<td>100 μCi/mL</td>
</tr>
<tr>
<td></td>
<td>(B) 5.9 μCi/g</td>
<td>27 μCi/mL</td>
<td>70 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-DCE</strong></td>
<td>3.7 μCi/g</td>
<td>14 μCi/mL</td>
<td>40 μCi/mL</td>
</tr>
<tr>
<td></td>
<td>(B) 2.0 μCi/g</td>
<td>6 μCi/mL</td>
<td>16 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-DMSA</strong></td>
<td>(A) 1.0 μCi/g</td>
<td>6 μCi/mL</td>
<td>16 μCi/mL</td>
</tr>
<tr>
<td></td>
<td>(B) 0.7 μCi/g</td>
<td>4 μCi/mL</td>
<td>10 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-MAA</strong></td>
<td>(A, C) 7.5 μCi/g</td>
<td>37 μCi/mL</td>
<td>100 μCi/mL</td>
</tr>
<tr>
<td></td>
<td>(D) 5.5 μCi/g</td>
<td>22 μCi/mL</td>
<td>50 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-RSA</strong></td>
<td>(A, B, C) 1.5 μCi/g</td>
<td>6 μCi/mL</td>
<td>16 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-RISA</strong></td>
<td>(A) 1.5 μCi/g</td>
<td>6 μCi/mL</td>
<td>16 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-MMAA</strong></td>
<td>(A) 1.5 μCi/g</td>
<td>6 μCi/mL</td>
<td>16 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-pertechnetate</strong></td>
<td>(A) 0.05 μCi/g</td>
<td>0.2 μCi/mL</td>
<td>0.5 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-dirodine</strong></td>
<td>(A) 0.05 μCi/g</td>
<td>0.2 μCi/mL</td>
<td>0.5 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-sodium</strong></td>
<td>(A) 0.05 μCi/g</td>
<td>0.2 μCi/mL</td>
<td>0.5 μCi/mL</td>
</tr>
<tr>
<td><strong>99mTc-pinephrine</strong></td>
<td>(A) 0.05 μCi/g</td>
<td>0.2 μCi/mL</td>
<td>0.5 μCi/mL</td>
</tr>
</tbody>
</table>

For patients who weigh more than 70 kg, it is recommended that the maximum administered activity should not exceed the product of the patient’s weight (kg) and the recommended weight-based administered activity, if applicable. The maximum administered activity for (99mTc) radiopharmaceuticals is a medium energy range for 99mTc.

*Indicated procedures may use lower administered activities if the equipment or software permits them to do so. Higher administered activities may be required in selected patients. No recommendation is given for 99mTc sestamibi. Intravenous 99mTc sestamibi should be used very infrequently and only in low doses.

The use of the scanner should be considered for smaller patients. Administration activity may vary depending on patient mass and time available on the PET scanner.

**Nuclear Medicine Radiopharmaceuticals**

Follow the new North American Guidelines for Pediatric Nuclear Medicine for high quality images at low radiation dose.
Step Lightly: Practice of ALARA in Pediatric Interventional Radiology
Ideal World

- Clinical Success with Least Amount of Radiation (Resident & Faculty)
- Use of Consensus guidelines
- IR Dose Quality Assurance Program
  - Identify unusually High Dose Studies
  - Patient follow up for tissue reactions
  - What could have or should have been done to lower dose.
Today’s Reality

- Patient Dose: w/Resident > Faculty)
- Many Complicated IR procedures require high quality images & long fluoroscopy time
- There are NO consensus guidelines.
  - Practices vary from institution to institution, and even within an institution.
- There are NO IR Dose Quality Assurance Programs
  - Just Published NCRP: Recommendations (SC 4-1 Commentary)
Where Can We Start?

- Train -Train -Train
  - Imaging Parameters: image quality vs dose.

- Develop & Utilize Consensus guidelines.

- Implement QA Programs
Department of Radiology

Our physicians, nurse-practitioners, technologists and nurses are trained in special techniques appropriate to the pediatric patients and use tools and imaging equipment created or modified for children. Because some pediatric interventional procedures rely on x-ray technology, we have adapted our equipment and protocols to keep radiation exposure as low as reasonably achievable (the ALARA standard) during your child's procedure.

Our expertise
**ACR Appropriateness Criteria**

<table>
<thead>
<tr>
<th>Relative Radiation Level</th>
<th>Effective dose range</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Minimal</td>
<td>Less than 0.1 mSv</td>
</tr>
<tr>
<td>Low</td>
<td>0.1 – 1.0 mSv</td>
</tr>
<tr>
<td>Medium</td>
<td>1.0 – 10 mSv</td>
</tr>
<tr>
<td>High</td>
<td>10 – 100 mSv</td>
</tr>
</tbody>
</table>

* Adapted from ACR Appropriateness Criteria, Radiation Dose Assessment Introduction 2008*
# ACR Appropriateness Criteria

## Table 11: Acute Abdominal Pain and Fever in a Pregnant Patient

Patient presenting with fever, non-localized abdominal pain and no recent operation

<table>
<thead>
<tr>
<th>Exam</th>
<th>Rating</th>
<th>RRL scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>US abdomen</td>
<td>8</td>
<td>None</td>
</tr>
<tr>
<td>MRI abdomen and pelvis w/o contrast</td>
<td>7</td>
<td>None</td>
</tr>
<tr>
<td>MRI abdomen and pelvis w/contrast</td>
<td>7</td>
<td>None</td>
</tr>
<tr>
<td>CT abdomen and pelvis w/contrast**</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>CT abdomen and pelvis w/o contrast</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>X-ray abdomen</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>X-ray upper GI series with small bowel</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>X-ray colon contrast enema</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Nuclear Imaging Ga-67 of abdomen</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Nuclear Imaging Tc99m WBC abdomen and pelvis</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Interventional arteriography visceral</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

*adapted from ACR Appropriateness Criteria® October 2008

** only after all exams that do not use ionizing radiation have been used or ruled out as possible.
Pediatric C-Spine CT

- Patient Immobilized
- Scan Time (few sec)
- Absorbed Dose ~30 mGy
- Effective Dose <1 mSv
Accident at Mad River Hospital

- 2 yo male fell from bed with neck pain the following morning

- Plain x-rays and then a CT scan of neck ordered by ED

- CT table did not index (move)

- Technologist manually acquired 151 slices of same area over a period of ~1 hour

Absorbed Dose
- Skin ~7.3 Gy
- Lens of eye ~1.5 Gy
CT Over Exposure to a young patient
Mad River Hospital

- At ~2 hours after CT developed a erythema line around his head at the scan location

- Dose estimates from reconstruction ~ 7.5 Gy to skin
The risks of NOT performing an exam include missing a diagnosis and initiating treatment too late to improve the medical outcome. The potential to improve patient’s life expectancy due to early diagnosis and treatment must be considered in comparison to the magnitude of the cancer risk & its latency compared to the age of the patient and other comorbidities.
In the United States, increasingly, we and many other experts believe that an important culprit may be our own medical practices: We are silently irradiating ourselves to death.

Neither doctors nor patients want to return to the days before CT scans. But we need to find ways to use them without killing people in the process.
After a pelvic CT scan of a pregnant patient in the ED to evaluate trauma following an MVA, she is seen by her PCP. Which statement delivers the most appropriate response to her question about the risk to the fetus?

A. “The study that you had two weeks ago has perhaps doubled the risk that your child will develop cancer before age 19. ” [0.6% vs 0.3%]

B. “The CT was an important exam that allowed the Drs to rapidly evaluate and treat your injuries which otherwise could have placed your health and the health of your baby at risk. The risk of adverse outcome is very small and the likelihood of normal development is still nearly the same as it is for any child. ” [96.7% vs 96.4%]
NEW WHO RESOURCE...COMING SOON
COMMUNICATING RADIATION RISKS IN PEDIATRIC IMAGING TO SUPPORT RISK-BENEFIT DIALOGUE
COMMUNICATION TOOL FOR HEALTH CARE PROVIDERS

Team Leader: Dr. Maria del Rosario Perez (WHO)

1: INTRODUCTION TO RADIATION AND OVERVIEW OF TRENDS IN MEDICAL IMAGING
2: RADIATION DOSES AND RISKS IN PEDIATRIC PROCEDURES
3: APPROPRIATE USE OF RADIATION IN PEDIATRIC IMAGING
4: PROMOTING A RADIATION SAFETY CULTURE TO IMPROVE PRACTICE
5: PRACTICAL TIPS FOR BENEFIT-RISK DISCUSSION
6: ETHICAL CONSIDERATIONS
7: CREATING A DIALOGUE IN THE MEDICAL COMMUNITY

- APPENDIX A- TALKING ABOUT RADIATION: GLOSSARY OF TERMS
- APPENDIX B - REFERENCES
- APPENDIX C - RESOURCES TO LEARN MORE
CT is an indispensable diagnostic tool that has saved countless lives and improves health outcomes for millions of people a year.

While the cancer risk following a single CT is low, multiple CTs are a concern.

– thus medical benefit should be clear and the dose ALADA (As Low As Diagnostically Acceptable)

Meanwhile, it would seem **prudent to assume** that the low doses of radiation received during a CT scan may produce a small additional risk of cancer, and **clinical practice should be guided by this assumption.**
Our Responsibility

- Communicate what we know as clearly and responsibly as possible
- Adhere the principles of optimization & justification
- Continue to improve upon our knowledge of effects at low dose