Limiting Radiation Exposure in Pediatric Imaging: Where We Are & Where We Are Headed

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Lecture Overview

• Brief overview of terms and concepts regarding radiation exposure in children.
• Currently accepted effective doses in commonly requested medical imaging exams.
• Strategies already implemented for reducing radiation dose with current technologies.
• How will newer technologies play a role in reducing exposure.
Effects of Radiation: Two Types

STOCHASTIC EFFECTS
- Probability of occurrence increases with dose, but...severity is independent of dose.
- Carcinogenesis.
- Cumulative over time.

DETERMINISTIC EFFECTS
- Occur reliably when a specific exposure level (or threshold) is reached acutely.
- Radiation burns.
- Radiation sickness.
How much is too much?

- All radiation exposure has potential to cause harm (“linear no threshold” concept).
  - There is no exact cut-off/threshold for damage.
  - Doses are cumulative over a lifetime.
- Generally accepted by medical and scientific communities.

Dose Describing Terms

• Absorbed Dose (D): the energy imparted to matter per unit mass; measured in J/kg or gray (Gr).

• Effective dose:
  – Allows for the fact that:
    • Some types of radiation more damaging than others
      – Gamma rays, X-ray photons
    • Some tissues more sensitive
      – Gonads, thyroid, lens, et al.
    • Radiation affects smaller people more
      – Effective doses highest in the very young, especially the fetus.
  • Measured in Sieverts (Sv); more practically, mSv.
## Annual Effective Dose: US Population

<table>
<thead>
<tr>
<th>Source of Radiation</th>
<th>mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Sources</td>
<td></td>
</tr>
<tr>
<td>• Cosmic sources</td>
<td>~0.5-0.6</td>
</tr>
<tr>
<td>• Inhaled (Radon)</td>
<td>~2.0</td>
</tr>
<tr>
<td>• Other</td>
<td>~0.4</td>
</tr>
<tr>
<td>Medical Procedures</td>
<td>~0.5-0.6</td>
</tr>
<tr>
<td><strong>TOTAL ANNUAL EFF. DOSE</strong></td>
<td>~3.0-3.5</td>
</tr>
</tbody>
</table>

*Source: Caffey’s Pediatric Diagnostic Imaging, Kuhn JP, et al; 2003*
Children are especially at risk

• The younger the patient, the greater the risk.
  – Fetus > Infant > Toddler > Adolescent...

• Depends on cell age and mitotic cycle.

• Effects can be obvious (malformation, growth restriction) or occur late (cognitive deficits, increased risk of cancer later in life).

• Even older children, 2-10x more sensitive than adults.

Oxford Study of Childhood Cancer (1958)

- Survey of children who had received radiation in the womb:
  - 1259 children.
  - Data reviewed again in 1997.
  - Conclusion: x-ray exposure lead to 40% increased of cancer of general over population.
  - Fetuses were mostly > 32 wks. at exposure.
    - Commonly radiating much younger children today.

International Commission on Radiological Protection (ICRP)
Publication 60 (1990)

• Survey of Japanese survivors of atomic bomb:
  – Overall pop. risk ~ 5%
  – Much higher in children exposed.
  – Higher in females:
    • ↑ breast/thyroid cancers.

So how much are we actually giving them?

<table>
<thead>
<tr>
<th>Area Imaged</th>
<th>Effective Dose (mSv)</th>
<th>CXR Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-view Chest X-ray (CXR)</td>
<td></td>
<td></td>
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<tr>
<td>3-view Ankle</td>
<td></td>
<td></td>
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<tr>
<td>2-view Abdomen (Supine/X-Table)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voiding Cystourethrogram (VCUG)³</td>
<td></td>
<td></td>
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<tr>
<td>Tc-99ᵐ Radionuclide Cystogram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tc-99ᵐ Bone Scan</td>
<td></td>
<td></td>
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<tr>
<td>Upper GI⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT Chest</td>
<td></td>
<td></td>
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<tr>
<td>CT Abdomen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tc-99ᵐ Hepatobiliary Scan (HIDA)</td>
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<td></td>
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</tbody>
</table>
Limiting dose in radiography (XR, Fluoro)

- Digital Radiography:
  - Decreased dose = poorer image quality (noise)
    - But okay, because of manipulations on PACS
  - No longer need repeated image because of over or under exposure.
Limiting dose in radiography (XR, Fluoro)

- EOS© Imaging System
- Only in a few children’s hospital in U.S.
- Significant reduction in dose due to use of a Chaprak chamber.
- Limited use due to cost, size; may see more applications in future.
5 yo with scoliosis

~90% reduction in dose
Limiting dose in radiography (XR, Fluoro)

- **Pulsed Fluoroscopy:**
  - Significant reduction in dose.
  - Can go as low as 1.0 FPS, depending on procedure.
  - Image capture rather than true exposure.

Limiting dose in CT

• Without question, largest dose of ionizing radiation of all imaging modalities.

• Best estimation, CT accounts for 15-20% of total exam numbers, but 65-75% of dose.

• Major advances in CT technology have taken place over the last several years, resulting in significant reduction in radiation exposure.
Advances in CT technology

• More detectors:
  – Toshiba Aquilon One...16 cm “volume” of 320 individual detectors, each 0.5 mm thick.

• Faster acquisition times...especially if performing a volume acquisition.
  – Can image entire area in one-half a gantry rotation, typically about 0.175 s.

• Improved postprocessing techniques allow for significant reduction in kVp and mA.
  – Huge reduction in dose, especially in kids.
For CT, a few new terms are needed...

- **CTDI_{vol} (mGy)**: an estimation of absorbed dose from a single CT study.
  - Generated by the scanner on every scan is performed.
  - Based upon measurements made from 32 cm and 16 cm phantoms.

- **DLP (mGy-cm)**: the product of the CTDI_{vol} and the total length of the patient that was scanned.
Effective Dose (E) = DLP × Tissue Coefficient Constant (k)

Teenager with abdominal pain

<table>
<thead>
<tr>
<th>Region of body</th>
<th>Effective dose per DLP (mSv mGy⁻¹ cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children⁶</td>
</tr>
<tr>
<td></td>
<td>0 years</td>
</tr>
<tr>
<td>Head</td>
<td>0.011</td>
</tr>
<tr>
<td>Neck</td>
<td>0.017</td>
</tr>
<tr>
<td>Chest</td>
<td>0.039</td>
</tr>
<tr>
<td>Abdomen/pelvis</td>
<td>0.049</td>
</tr>
</tbody>
</table>


232.00 mGy-cm × 0.015 mSv-mGy⁻¹-cm⁻¹ = ~3.5 mSv
Effective Dose ($E$)

Fell from a moving car

$$62.30 \text{ mGy-cm} \times 0.049 \text{ mSv-mGy}^{-1}\text{-cm}^{-1} = \approx 3.1 \text{ mSv}$$
14.10 mGy·cm x 0.039 mSv·mGy⁻¹·cm⁻¹ = ~0.55 mSv!!!
(about 25 CXR equivalents)
Effective Dose (E)
Effective Dose (E)

\[ \sim 3.0 - 4.4 \text{ mSv} \]
What about in the setting of trauma?

• LBUNKTHTMAY, TWENTYSIX: 8 yo female, MVA
  – CT HEAD: ~4.2 mSv
  – CT C-SPINE: ~0.8 mSv
  – CT Chest/Abdomen/Pelvis: ~2.5 mSv
  – Various X-rays (Chest, Pelvis, Lat. C-Spine, Tib/Fib)
    • Neglible; probably ~0.1-0.2 mSv

• Total Effective dose from “Trauma-gram”
  – Estimated at between 7-8 mSv.
• University of Vermont, June, 2012.
• Prospective study, 42 patients with abdominal pain:
  • 4-17 years (mean 11.5)
• All patients underwent ultrafast sequence MRI:
  • 3-plane T2 SSFSE and axial T2 SE with FS.
  • No oral or IV contrast.
  • No patient requiring sedation.
  • Avg. scan time: 5:40 (longest 8:45)
• 12 of 42 patients had acute appendicitis, surgically proven.
  • MRI: 100% sens., 99% spec., 100% NPV, 98% PPV.
7 yo female
13 yo male
5 yo female
Another, more recent publication from Brown University


- 60 patients enrolled, all underwent MRI after an inconclusive US.
- 10 of 60 MRI exams interpreted as positive; all compared with surgical results.
  - 100% sens., 96% spec., 100% NPV, 83% PPV
And, another recent paper, this one from Hershey, PA

- 208 children, ages 3 to 17 (mean 11.2).
- Diagnostic accuracy of MRI for detecting acute appendicitis:
  - 97.6% sens., 97.0% spec., 99.4% NPV, 88.9% PPV
- Time parameters:
  - Request to first sequence: 78.7 ± 52.5 min
  - Exam time: 14.2 ± 8.8 min
  - Report time: 57.4 ± 35.2 min
Take home point...

- MRI is a reliable imaging modality to evaluate for acute appendicitis in children.

However...

- Large scale studies from a multidisciplinary approach are still needed to examine its feasibility and utility.
Summary

• Radiation exposure from medical imaging is an important topic and efforts should be made to minimize such exposures (especially in children).
• Children are more susceptible to the affects of radiation than adults.
• Reviewed concept of effective dose and estimated effective doses from commonly ordered imaging exams.
Summary

• Reviewed currently available methods for reducing dose in radiography and fluoroscopy.
• CT is by far the leading contributor to radiation exposure to our patients.
• Current advances in CT technologies have led to a significant reduction in dose, though doses remain high.
• Increased utilization of MRI in evaluating children with abdominal pain will likely lead to greater acceptance and more indications.
References