This module can begin wherever you wish, depending on the audience or objectives. The module is composed of eight sections.
Medical Radiation and Children

Sections

1. History
2. Basic dosimetry
3. Biology of radiation effects
4. Unique issues with radiation in children
5. Optimization of risk/benefit ratio
6. Use appropriate techniques
7. Joint efforts with healthcare providers
“[The radiologist] must be exposed to the special techniques required to handle infants and children, and must have experience in their use.”

Bertram R. Girdany, MD  Am J Roentgenol Radium Ther Nucl Med 1971; 112:202
I. History

• Early years
• Nobel Prize
• Memorial to martyrs of radiology
Radiology - the fastest translational research

• Dec 28th 1895 Roentgen submits manuscript to Physical Medical Society of Wurzburg: printed and distributed in 3 days

• Jan 9, 1896: Vienna Press

• January 23rd appeared in *Nature*, in England

• Jan 23rd, 1896, presented paper to Physical Medical Society of Wurzburg

• By mid 1896, in practice, including fluoroscopy
Radiology…tremendous benefits, but also risks
Side Effects

Started reporting within 3 months of discovery
Public Spectacle: Side Effects

- Fluoroscopy in Bloomingdales
- Deep sunburn
- Hair loss
- Bloodshot eyes, vision impaired
- Transient
2. Basic dosimetry

• Dose units
• Measures of dose
• Conversions
Table 3. Radiation Measurements

1. Units

<table>
<thead>
<tr>
<th>Radioactivity</th>
<th>Absorbed Dose</th>
<th>Dose Equivalent</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common units</td>
<td>curie (Ci)</td>
<td>rad</td>
<td>rem</td>
</tr>
<tr>
<td>New units</td>
<td>becquerel/Bq)</td>
<td>gray (Gy)</td>
<td>sievert (Sv)</td>
</tr>
</tbody>
</table>

2. Conversion Equivalents

- 1 millicurie (mCi) = 37 megabecquerels (MBq)*
- 100 rad = 1 Gy
- 1 rad = 1 cGy
- 100 rem = 1 Sv
- 1 rem = 10 mSv

3. Background radiation dose is approximately 1 millirad/day

*To convert mBq to mSv, use conversion table

1 mrad = millirad=1/1000 of a rad

*rem = rad x radiation factor; weighting for gamma and x-ray this factor is 1

rem = rad x 1
Many different measures of dose in medical imaging: e.g.

- Exit dose
- Dose (or KERMA) area product (DAP/KAP)
- Entrance skin dose
- Organ dose
- Dose equivalent
- Effective dose
- Dose computed from a phantom (e.g. CTDI)
Radiation Dose: measures for risk assessment

• Absorbed Dose (Gray – Gy)
  – For an individual tissue or organ
  – Difficult to measure; not practical

• Effective Dose Equivalent (Sievert – Sv)
  – Nonuniform exposure to organ or region
  – Expression of risk equivalent to whole body exposure

Not “Scanner” Dose Units (mGy)
  – CTDI$_{vol}$ and DLP: phantom determination
  – Not helpful in assigning risk without conversion!!
CTDI – CT Dose Index

- On scanner consoles
- Based on phantom (16 or 32 cm diameter)
- Only represents the dose to the phantom based on CT parameters selected
- Does not indicate dose to the child in the CT scanner
- Conversions of CTDI to effective dose are only rough estimations for children
  - e.g. no age based chest modifications
<table>
<thead>
<tr>
<th>Conversion</th>
<th>Unit</th>
<th>Equivalent Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gy</td>
<td></td>
<td>100 rads</td>
</tr>
<tr>
<td>1 cGy</td>
<td></td>
<td>1 rad</td>
</tr>
<tr>
<td>1 Sv</td>
<td></td>
<td>100 rads</td>
</tr>
<tr>
<td>10 mSv</td>
<td></td>
<td>1 rad</td>
</tr>
</tbody>
</table>
Effective Dose

• It is a radiation dose quantity
• It is a computation based on:
  Organ dose and radiosensitivity
  Weighting factors
• It is not a risk number

Huda, W Pediatric Radiology 2002: 32; 272-279
3. Biology of radiation effects
Learned from the Past:
Biological Effects of Radiation

- Deterministic effects
- Stochastic effects
There are Two Types of Bio Effects

Dose dependent:
- severity depends on dose
- there is a threshold
- burns, hair loss

This is a **deterministic** effect
<table>
<thead>
<tr>
<th>Injury</th>
<th>Approximate Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Skin</strong></td>
<td></td>
</tr>
<tr>
<td>1. Transient erythema</td>
<td>200 rad (2 Gy)</td>
</tr>
<tr>
<td>2. Dry desquamation</td>
<td>1000 rad (10 Gy)</td>
</tr>
<tr>
<td>3. Most desquamation</td>
<td>1500 rad (15 Gy)</td>
</tr>
<tr>
<td>4. Temporary epilation</td>
<td>200 rad (2 Gy)</td>
</tr>
<tr>
<td>5. Permanent epilation</td>
<td>700 rad (7 Gy)</td>
</tr>
<tr>
<td><strong>B. Eyes</strong></td>
<td></td>
</tr>
<tr>
<td>Cataracts (acute)</td>
<td>&gt;200 rad (&gt;2.0 Gy)</td>
</tr>
<tr>
<td><strong>C. Late effects on tissue</strong></td>
<td></td>
</tr>
</tbody>
</table>

Deterministic Effects
There are Two Types of Bio Effects

Non dose dependent:

– severity is independent of dose
– risk of event occurring is dependent on dose
– there is “no threshold”
– cancer, genetic mutations

This is a stochastic effect
Biological effects of radiation damage to DNA

- Reactions are rapid
- Induction of cancer takes many years
- The damage to DNA may lead to genomic instability
Genomic Instability

“Persistent enhancement in the rate of which genetic change arises in the descents …..”

Little
4. Unique issues with radiation in children

• Plain film history
  – Scoliosis

• Therapy
  – Tinea capitis
  – Thymus

• Low dose effect and cancer
  – Atomic bomb survivors
  – Brenner
Table 3. Breast cancer mortality and diagnostic X-rays for scoliosis (*ERR* excess relative risk; from [4])

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,822 Exposed; 644 nonexposed</td>
</tr>
<tr>
<td>Mean age at exposure, 10.6 years</td>
</tr>
<tr>
<td>Mean dose, 0.11 Gy</td>
</tr>
<tr>
<td>70 Observed cancers; 35.7 expected</td>
</tr>
<tr>
<td>ERR at 1 Sv = 5.4 (95% CI = 1.2–14)</td>
</tr>
<tr>
<td>Results similar to A-bomb survivors</td>
</tr>
</tbody>
</table>
Table 5. Childhood leukemia (*ALL*) risks and diagnostic X-ray exams (from [6])

Population-based, Quebec 1980–1993
491 ALL cases (0–9 years); 491 controls
Mostly bone X-rays

<table>
<thead>
<tr>
<th>Exams</th>
<th>OR(^a)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.00</td>
<td>–</td>
</tr>
<tr>
<td>1</td>
<td>1.08</td>
<td>0.7–1.6</td>
</tr>
<tr>
<td>2+</td>
<td>1.78</td>
<td>1.2–2.6</td>
</tr>
</tbody>
</table>

\(^a\) Excludes X-rays 3 months before diagnosis
### Table 7. Thyroid cancer after childhood radiotherapy

<table>
<thead>
<tr>
<th>Study</th>
<th>Mean dose (Gy)</th>
<th>ERR/Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlarged thymus</td>
<td>1.4</td>
<td>9.1 (3.6–29)</td>
</tr>
<tr>
<td>Michael Reese tonsils</td>
<td>0.6</td>
<td>2.5 (0.6–26)</td>
</tr>
<tr>
<td>Israeli <em>tinea capitis</em></td>
<td>0.1</td>
<td>32 (14–57)</td>
</tr>
<tr>
<td>Childhood cancer</td>
<td>12</td>
<td>1.1 (0.4–29)</td>
</tr>
<tr>
<td>A-bomb survivors (&lt; 15 years)</td>
<td>0.3</td>
<td>4.7 (1.7–16)</td>
</tr>
</tbody>
</table>
... 96 minutes of x rays
Alice Stewart, 95; Linked X-Rays to Diseases

By CARMEL MCCOUBREY

Dr. Alice M. Stewart, an epidemiologist who first demonstrated the link between X-rays of pregnant women and disease in their children, a finding that changed medical practice, died on June 23 in Oxford, England. A resident of the countryside outside Oxford, she was 95.

Dr. Stewart, who became one of the most authoritative critics of the safety of the American nuclear weapons program and a leading proponent of the idea that no level of exposure to radiation is safe, came to prominence in 1956 for her report on prenatal X-rays.

It was an increasingly common practice in the 1950’s to X-ray the abdomens of pregnant women to determine the position of their babies, said Dr. Gayle Greene of Scripps College in Claremont, Calif., who wrote “The Woman Who Knew Too

A critic’s warning about radiation drew outrage, until it was found to be true.

ependent researchers in 1990 and surrendered its monopoly on government financing of radiation research.

More recently, Dr. Stewart devoted her time to arguing that data on Hiroshima survivors, the main source for standards on the safe levels of radiation exposure, was deeply flawed and underestimated radiation’s harmful effects.

She was born Alice Mary Naish Sheffield, England. Her mother Lucy Wellburn Naish was one of...
Alice Stewart’s fetuses are today’s premature infants who we may irradiate several times each day.
Table 3. Relative risk of different types of childhood cancer following irradiation *in utero*, OSCC data for deaths during 1953–1967 (after Bithell and Stewart [12])

<table>
<thead>
<tr>
<th>Type of cancer</th>
<th>No. of deaths</th>
<th>Associated with <em>in utero</em></th>
<th>Relative risk</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lymphatic leukaemia</td>
<td>2007</td>
<td>290</td>
<td>1.54</td>
<td>(1.34, 1.78)</td>
</tr>
<tr>
<td>Myeloid leukaemia</td>
<td>866</td>
<td>120</td>
<td>1.47</td>
<td>(1.20, 1.81)</td>
</tr>
<tr>
<td>Other and undefined leukaemia</td>
<td>1179</td>
<td>159</td>
<td>1.43</td>
<td>(1.19, 1.71)</td>
</tr>
<tr>
<td>Lymphoma</td>
<td>719</td>
<td>92</td>
<td>1.35</td>
<td>(1.07, 1.69)</td>
</tr>
<tr>
<td>Wilm’s tumour</td>
<td>590</td>
<td>87</td>
<td>1.59</td>
<td>(1.25, 2.01)</td>
</tr>
<tr>
<td>Central nervous system</td>
<td>1332</td>
<td>179</td>
<td>1.42</td>
<td>(1.20, 1.69)</td>
</tr>
<tr>
<td>Neuroblastoma</td>
<td>720</td>
<td>99</td>
<td>1.46</td>
<td>(1.17, 1.83)</td>
</tr>
<tr>
<td>Bone</td>
<td>244</td>
<td>26</td>
<td>1.11</td>
<td>(0.74, 1.66)</td>
</tr>
<tr>
<td>Other</td>
<td>856</td>
<td>129</td>
<td>1.63</td>
<td>(1.33, 1.98)</td>
</tr>
<tr>
<td>All leukaemias</td>
<td>4052</td>
<td>569</td>
<td>1.49</td>
<td>(1.33, 1.67)</td>
</tr>
<tr>
<td>All solid tumours</td>
<td>4461</td>
<td>612</td>
<td>1.45</td>
<td>(1.30, 1.62)</td>
</tr>
<tr>
<td>All cancers</td>
<td>8513</td>
<td>1181</td>
<td>1.47</td>
<td>(1.34, 1.62)</td>
</tr>
</tbody>
</table>
Pierce and Preston (2000)

- 50,000 survivors (1988-1994)
- Risk of cancer at low dose
  - 50-150 mSv
- Excess cancer *deaths*
What is Low-level Radiation?

< 100 mSv
Typical Radiation Doses (mSv)

- Average annual technician dose: 3.2 mSv
- Natural background: 3.5 mSv
- Dental x-rays: 0.09 mSv
- BE (marrow): 8.75 mSv
- CXR (marrow): 0.01 mSv
- Mammogram (breast): 0.5 - 7.0 mSv
- Airline passenger: 0.03 mSv
- Flight crew / attendants: 1.6 mSv
- CT: < 1.0 – 30 mSv
**Typical Medical Radiation Doses: 5 year-old (mSv)**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose (mSv)</th>
<th>CXR Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-view ankle</td>
<td>0.0015</td>
<td>1/14&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-view chest</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>Tc-99m radionuclide gastric emptying</td>
<td>0.06</td>
<td>3</td>
</tr>
<tr>
<td>Tc-99m radionuclide cystogram</td>
<td>0.18</td>
<td>9</td>
</tr>
<tr>
<td>Tc-99m radionuclide bone scan</td>
<td>6.2</td>
<td>310</td>
</tr>
<tr>
<td>FDG PET</td>
<td>15.3</td>
<td>765</td>
</tr>
<tr>
<td>Fluoroscopic cystogram</td>
<td>&lt;.33</td>
<td>16</td>
</tr>
<tr>
<td>Chest CT</td>
<td>up to 3</td>
<td>150</td>
</tr>
<tr>
<td>Abdomen CT</td>
<td>up to 5</td>
<td>250</td>
</tr>
</tbody>
</table>
One PET CT in a 5 yr old...

- 23.3 mSv
- 1165 chest x rays, or.....
- 7.5 years of background radiation
From the Editor's Notebook

Taking Care of Children: Check Out the Parameters Used for Helical CT

S

ory to say, but kids can get overlooked. In most cases, I am sure this is not intentional. Maybe it is more fiscally neglected, "out of sight, out of mind." Nevertheless, oversight does occur, some of which are unfortunate.

I am writing in the midst of our presidential campaign. I am therefore compelled to quickly add that these overights, in our case, are not of a political nature, policies not kept—or worse—promises made with no intention of keeping them. During elections, kids are pawns in the game. When granting for votes, politicians promise children health care and education because it sounds good to their parents and other voters. But those promises are often hollow. Once the election is over, these same politicians, knowing they can get away with this charade because children can't vote, find all manner of excuses for not fulfilling.

But, as it turns out, we, as radiologists, should watch what we say; those in glass houses should not throw stones. It has come to light that in one way, at least, we radiologists may be as guilty as others when it comes to not watching out for children.

In this issue Brenner et al. [1] report on their assessment of the potential risks of cancer arising as a result of the increased use of CT in the pediatric population. They point out that the use of CT has significantly increased in children for both clinical and research reasons. But they warn that this increased usage carries with it a potential for increased exposure to radiation. And further, the excess exposure and consequent increase in radiation dose risk is an increased risk of cancer in the population.

The reason for the excess radiation dose is the common practice of using the same X-ray exposure factors for CT examinations of children as those used for adults. A report by Paterson et al. [2], also in this issue, tends to support this concern. However, such exposure factors are greater than those necessary to perform a satisfactory CT examination in children. In fact, a perfectly satisfactory examination of a child can be obtained with approximately half the exposure necessary for an adult examination. The reduction in exposure needed for children is achieved with the lowest possible radiation dose. This does not require any significant changes in hardware, if indeed it...

Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

OBJECTIVE. Our objective was to determine whether adjustments related to patient age are made in the scanning parameters that are determinants of radiation dose for CT examinations of children.

Helical CT of the Body: Are Settings Adjusted for Pediatric Patients?

Minimizing Radiation Dose for Pediatric Body Applications of Single-Detector Helical CT: Strategies at a Large Children's Hospital

T

here has been much recent debate concerning the rising number of irradiations for which helical CT is used and the radiation dose to which children are exposed. Increasing numbers of publications suggest more widespread use of CT as the primary imaging technique in multiple clinical scenarios: the child with abdominal pain, suspected appendicitis, or suspected small bowel obstruction. A major disadvantage of this increased use of CT is the radiation exposure. Radiation dose is particularly important in children because of the relatively increased lifetime cancer risks of children compared with that of adults (5-7). Recent publications have focused on the fact that the radiation dose associated with helical CT is greater than the dose associated with most other imaging procedures (1-3), CT, which accounts for approximately 4% of the medical radiographic examinations, contributes 40% of the lifetime cancer risk. The dose associated with helical CT is greater than the risk of the radiation dose, technical factors should be adjusted to minimize the radiation dose. This adjustment is the responsibility of the radiologist supervising the examination. Little attention has been given to the technical parameters that can be adjusted to reduce the radiation dose associated with CT. In this perspective, we review the adaptations made to our helical CT protocols with the intention of reducing the radiation dose to pediatric patients. We hope that by calling attention to the issue of reducing radiation exposure in the pediatric population, these adaptations will be implemented for helical CT in pediatric and general imaging departments. Two parameters that can be adjusted easily and that have a profound effect on radiation dose are tube current and pitch.

Tube Current (mA)

In conventional radiography, the need to maximally image the patient while keeping radiation exposure within regulatory limits is balanced by the fact that higher tube currents can result in lower noise on CT images. Powerful image reconstruction algorithms allow for noise reduction through iterative reconstruction techniques, however, these algorithms are not employed in clinical practice. CT images are typically reconstructed using a single filter, which results in a low noise CT image with moderate spatial resolution. In this type of reconstruction, the dose associated with helical CT is greater than the risk of the radiation dose, technical factors should be adjusted to minimize the radiation dose. This adjustment is the responsibility of the radiologist supervising the examination. Little attention has been given to the technical parameters that can be adjusted to reduce the radiation dose associated with CT. In this perspective, we review the adaptations made to our helical CT protocols with the intention of reducing the radiation dose to pediatric patients. We hope that by calling attention to the issue of reducing radiation exposure in the pediatric population, these adaptations will be implemented for helical CT in pediatric and general imaging departments. Two parameters that can be adjusted easily and that have a profound effect on radiation dose are tube current and pitch.
Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

OBJECTIVE. In light of the rapidly increasing frequency of pediatric CT examinations, the purpose of our study was to assess the lifetime cancer mortality risks attributable to radiation from pediatric CT.

MATERIALS AND METHODS. Organ doses as a function of age-at-diagnosis were estimated for common CT examinations, and estimated attributable lifetime cancer mortality risks (per unit dose) for different organ sites were applied. Standard models that assume a linear extrapolation of risks from intermediate to low doses were applied. On the basis of current standard practice, the same exposures (milliampere-seconds) were assumed, independent of age.
RESULTS. The larger doses and increased lifetime radiation risks in children produce a sharp increase, relative to adults, in estimated risk from CT. Estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT in a 1-year-old are 0.18% (abdominal) and 0.07% (head)—an order of magnitude higher than for adults—although those figures still represent a small increase in cancer mortality over the natural background rate. In the United States, of approximately 600,000 abdominal and head CT examinations annually performed in children under the age of 15 years, a rough estimate is that 500 of these individuals might ultimately die from cancer attributable to the CT radiation.

CONCLUSION. The best available risk estimates suggest that pediatric CT will result in significantly increased lifetime radiation risk over adult CT, both because of the increased dose per milliampere-second, and the increased lifetime risk per unit dose. Lower milliampere-second settings can be used for children without significant loss of information. Although the risk–benefit balance is still strongly tilted toward benefit, because the frequency of pediatric CT examinations is rapidly increasing, estimates that quantitative lifetime radiation risks for children undergoing CT are not negligible may stimulate more active reduction of CT exposure settings in pediatric patients.
Fatal Cancer Risk

- Estimated
- Debated
- May be zero
- May be, in children, 1 in 500 - 1,000 risk* from a single CT

* Risk is of fatal cancer!!
Low-level Harmful? Support:

- NCRP
- ICRP
- BEIR
- NCI
- FDA
- Various radiology societies
Above doses of 50-100 mSv (protracted exposure) or 10-50 mSv (acute exposure), direct epidemiologic evidence from human populations demonstrate the exposure to ionizing radiation increases the risk of some cancer.
Conclusions from BEIR VII (2005) include:

“...the risk of cancer proceeds in a linear fashion at lower doses without a threshold and ... the smallest dose has the potential to cause a small increase risk to humans.”
“It should be noted, however, that the inability to detect increased [cancer] risks at very low doses does not mean that those increases do not exist.”
CT doses can overlap doses from the A-bomb!
<table>
<thead>
<tr>
<th>Diagnostic Procedure</th>
<th>Typical Effective Dose (mSv)$^1$</th>
<th>Number of Chest X rays (PA film) for Equivalent Effective Dose$^2$</th>
<th>Time Period for Equivalent Effective Dose from Natural Background Radiation$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x ray (PA film)</td>
<td>0.02</td>
<td>1</td>
<td>2.4 days</td>
</tr>
<tr>
<td>Skull x ray</td>
<td>0.07</td>
<td>4</td>
<td>8.5 days</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>1.3</td>
<td>65</td>
<td>158 days</td>
</tr>
<tr>
<td>I.V. urogram</td>
<td>2.5</td>
<td>125</td>
<td>304 days</td>
</tr>
<tr>
<td>Upper G.I. exam</td>
<td>3.0</td>
<td>150</td>
<td>1.0 year</td>
</tr>
<tr>
<td>Barium enema</td>
<td>7.0</td>
<td>350</td>
<td>2.3 years</td>
</tr>
<tr>
<td>CT head</td>
<td>2.0</td>
<td>100</td>
<td>243 days</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>10.0</td>
<td>500</td>
<td>3.3 years</td>
</tr>
</tbody>
</table>

1. Effective dose in millisieverts (mSv).

2. Based on the assumption of an average "effective dose" from chest x ray (PA film) of 0.02 mSv.

3. Based on the assumption of an average "effective dose" from natural background radiation of 3 mSv per year in the United States.
Sensitivity of children to radiation

Digital $\rightarrow$ uncoupling of final product and dose

Radiation sensitivity $\uparrow$ inversely with age
Radiation Risks in Children: No Debate

- Tissues are more radiosensitive
- Longer lifetime to manifest radiation-induced injury (cancer, cataracts)
- Each exam (therefore dose) is cumulative
Effective Dose Equivalent (EDE)

Equal exposure:
Child EDE > adult EDE
Table 7
Dose Summary for CT Examinations (at 120 kVp)

<table>
<thead>
<tr>
<th>Patient Age (y)</th>
<th>Radius (mm)*</th>
<th>Mean Section Dose (mGy)</th>
<th>Milliampere Second Setting</th>
<th>Energy Imparted to the Phantom (ml)</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>52.5</td>
<td>41.3</td>
<td>300</td>
<td>32.2</td>
<td>6.0</td>
</tr>
<tr>
<td>1</td>
<td>71.4</td>
<td>39.2</td>
<td>340</td>
<td>75.2</td>
<td>4.9</td>
</tr>
<tr>
<td>5</td>
<td>83.9</td>
<td>38.8</td>
<td>380</td>
<td>120.0</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>87.3</td>
<td>39.5</td>
<td>400</td>
<td>142.0</td>
<td>2.8</td>
</tr>
<tr>
<td>15</td>
<td>91.9</td>
<td>37.8</td>
<td>400</td>
<td>150.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Adult</td>
<td>94.3</td>
<td>36.8</td>
<td>400</td>
<td>165.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Head Examinations

| Newborn        | 57.6         | 19.7                     | 150                        | 14.4                              | 5.3                 |
| 1              | 75.7         | 16.6                     | 150                        | 32.8                              | 4.2                 |
| 5              | 92.9         | 15.0                     | 160                        | 56.7                              | 3.7                 |
| 10             | 108.0        | 14.4                     | 180                        | 95.6                              | 3.7                 |
| 15             | 132.0        | 12.5                     | 200                        | 158.0                             | 3.6                 |
| Adult          | 143.0        | 11.2                     | 200                        | 172.0                             | 3.1                 |

Abdomen Examinations

* Computed with Equation (4).
Children at least 2x more sensitive (2-10x)
6. Optimization of benefit/risk ratio

- Appropriate to do exam
- Appropriate timing of exam
- Appropriate modality
- Get clinician/radiologist together
- Technologist
• Small individual risk
• Bigger public health problem
• CT valuable in diagnostic imaging
<table>
<thead>
<tr>
<th>Activity</th>
<th>Risk of Death (per million/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being a person age 55 years (all causes)</td>
<td>10,000</td>
</tr>
<tr>
<td>Smoking a pack of cigarettes daily (all causes)</td>
<td>3,500</td>
</tr>
<tr>
<td>Rock climbing for 2 h (accident)</td>
<td>500</td>
</tr>
<tr>
<td>Canoeing for 20 h (accident)</td>
<td>200</td>
</tr>
<tr>
<td>Motorcycling for 1,000 miles (accident)</td>
<td>200</td>
</tr>
<tr>
<td>Traveling 1,500 miles by car (accident)</td>
<td>40</td>
</tr>
<tr>
<td>Being a pedestrian (accident)</td>
<td>40</td>
</tr>
<tr>
<td>Working 1 week as a firefighter (accident)</td>
<td>15</td>
</tr>
<tr>
<td>Working 1 week in agriculture (accident)</td>
<td>10</td>
</tr>
<tr>
<td>Fishing (drowning)</td>
<td>10</td>
</tr>
<tr>
<td>Eating (choking on aspirated food)</td>
<td>8</td>
</tr>
<tr>
<td>Skiing for 10 h (accident)</td>
<td>8</td>
</tr>
<tr>
<td>Working 1 month in a typical factory (accident)</td>
<td>5</td>
</tr>
<tr>
<td>Traveling 5,000 miles by air (accident)</td>
<td>5</td>
</tr>
<tr>
<td>Having a chest radiograph (radiation-induced cancer)</td>
<td>1</td>
</tr>
<tr>
<td>Visiting Denver for 2 months (cancer from cosmic rays)</td>
<td>1</td>
</tr>
<tr>
<td>Living in the vicinity of a nuclear power plant (radiation-induced cancer)</td>
<td>&lt; 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk</th>
<th>Risk of Death/Person/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influenza</td>
<td>1 in 5000</td>
</tr>
<tr>
<td>Leukemia</td>
<td>1 in 12,500</td>
</tr>
<tr>
<td>Struck by an automobile (United Kingdom)</td>
<td>1 in 16,600</td>
</tr>
<tr>
<td>Struck by an automobile (United States)</td>
<td>1 in 20,000</td>
</tr>
<tr>
<td>Floods (United States)</td>
<td>1 in 455,000</td>
</tr>
<tr>
<td>Tornadoes (Midwest United States)</td>
<td>1 in 455,000</td>
</tr>
<tr>
<td>Earthquakes (California)</td>
<td>1 in 588,000</td>
</tr>
<tr>
<td>Bites of venomous creatures (United Kingdom)</td>
<td>1 in 5 million</td>
</tr>
<tr>
<td>Lightning (United Kingdom)</td>
<td>1 in 10 million</td>
</tr>
<tr>
<td>Falling aircraft (United States)</td>
<td>1 in 10 million</td>
</tr>
<tr>
<td>Release from nuclear power plant</td>
<td></td>
</tr>
<tr>
<td>At six boundary (United States)</td>
<td>1 in 10 million</td>
</tr>
<tr>
<td>At one kilometer (United Kingdom)</td>
<td>1 in 10 million</td>
</tr>
<tr>
<td>Flooding of dike (the Netherlands)</td>
<td>1 in 10 million</td>
</tr>
<tr>
<td>Explosion, pressure vehicle (United States)</td>
<td>1 in 20 million</td>
</tr>
<tr>
<td>Falling aircraft (United Kingdom)</td>
<td>1 in 50 million</td>
</tr>
<tr>
<td>Meteorite</td>
<td>1 in 100 billion</td>
</tr>
</tbody>
</table>

References for Unnecessary High CT Doses

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• AJR 2004 183:809-816 (chest)
• AJR 2003 181:939-944 (sinus)
• AJR 2002 179:461-465 (chest)
• AJR 2002 179:1101-1106 (abdomen)
• AJR 2002 179:1107-1113 (abdomen)
• Pediatric Radiology 1999 29:770-775 (brain)
How Do We Respond?

- Pediatricians’ responsibility:
  - Be sure the test is necessary
  - Use the least invasive modality which gives a high certainty of success
  - Discuss case with radiologist when unsure
How Do We Respond?

• **Pediatricians’ responsibility:**
  - Understand radiation doses of modalities
  - Order on medical indications not parental/legal pressure
  - Discuss options with radiologist
  - Consider information for parents
Table 2. Radiation Dose by Imaging Test*

<table>
<thead>
<tr>
<th>Exam</th>
<th>mrad or mrem</th>
<th>Site Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest - 2 views</td>
<td>10-20</td>
<td>entrance (skin)</td>
</tr>
<tr>
<td>Abdominal – 2 views</td>
<td>50-100</td>
<td>entrance (skin)</td>
</tr>
<tr>
<td>Fluoroscopy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nonpulsed</td>
<td>300-500/min</td>
<td>entrance (skin)</td>
</tr>
<tr>
<td>pulsed</td>
<td>100-150/min</td>
<td>entrance (skin)</td>
</tr>
<tr>
<td>Computed tomography(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>head</td>
<td>6000 (2000-3000)</td>
<td>middiameter of phantom of 16 cm</td>
</tr>
<tr>
<td>abdomen</td>
<td>3000 (1000)</td>
<td>middiameter of phantom of 32 cm</td>
</tr>
</tbody>
</table>

Nuclear medicine\(^2\)
(\(^{99m}\)TcMAG3-renal)

- 120 mrem                              effective dose

Positron emission tomography\(^2\)
(Brain FDG)

- 185 mrem                              effective dose
  whole body

*Background radiation is approximately 1 mrad/day (300 mrad/year)

\(^1\)Scan explained as CT dose index (CTDI). First dose is with adult factors, second in () are examination adjusted for children.

\(^2\)This is expressed as effective dose. These are rough guidelines for dose given to a 5-year-old with normal renal function. From ICRP publication 80.

\(^{99m}\)TcMAG3 = \(^{99m}\)technetium mercaptoacetyl triglycine
FDG=(F-18) fluoro-2-deoxyglucose
How Do We Respond?

- Radiologists’ responsibility
  - Understand radiation doses
  - Review requests for higher dose studies
  - Discuss with clinicians
  - Use appropriate technical factors
Awareness of Radiation Dose and Possible Risks

PURPOSE: To determine the awareness level concerning radiation dose and possible risks associated with computed tomographic (CT) scans among patients, emergency department (ED) physicians, and radiologists.

MATERIALS AND METHODS: Adult patients seen in the ED of a U.S. academic medical center during a 2-week period with mild to moderate abdominopelvic or flank pain and who underwent CT were surveyed after acquisition of the CT scan. Patients were asked whether or not they were informed about the risks, benefits, and radiation dose of the CT scan and if they believed that the increased their lifetime cancer risk. Patients were also asked to estimate the radiation dose for the CT scan compared with that for one chest radiograph. ED physicians who requested CT scan and radiologists who reviewed the CT scans were surveyed with similar questions and an additional question regarding the number of years in practice. The \( \chi^2 \) test of independence was used to compare the three respondent groups regarding perceived increased cancer risk from one abdominopelvic CT scan.

RESULTS: Seventy percent (70% of 579) of patients reported that they were told about risks and benefits of their CT scan, while 22% (10 of 45) of ED physicians reported that they had provided such information. Forty-seven percent (47% of 579) of radiologists believed that there was increased cancer risk, whereas only 9% (four of 45) of ED physicians and 3% (two of 76) of patients believed that there was increased risk (\( \chi^2 = 41.45, p < .001 \)). All patients and most ED physicians and radiologists were unable to accurately estimate the dose for one CT scan compared with that for one chest radiograph.

CONCLUSION: Patients are not given information about the risks, benefits, and radiation dose for a CT scan. Patients, ED physicians, and radiologists alike are unable to provide accurate estimates of CT doses regardless of their experience level.

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TABLE 3
Dose Estimates for One CT Scan versus One Chest Radiograph

<table>
<thead>
<tr>
<th>Respondent Group</th>
<th>CT ≤ CR</th>
<th>CT &gt; CR</th>
<th>CT ≥ 10 × CR</th>
<th>CT = 100–250 × CR*</th>
<th>CT ≥ 500 × CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n = 67)</td>
<td>19 (28)</td>
<td>43 (64)</td>
<td>5 (7)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>ED Physicians (n = 45)</td>
<td>3 (7)</td>
<td>20 (44)</td>
<td>10 (22)</td>
<td>10 (22)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Radiologists (n = 39)</td>
<td>2 (5)</td>
<td>22 (56)</td>
<td>6 (15)</td>
<td>5 (13)</td>
<td>4 (10)</td>
</tr>
</tbody>
</table>

Note.—Data are the number of respondents. Numbers in parentheses are percentages. \( \chi^2 \) test result, 67.04; \( P < .001 \). CR = chest radiograph.
* Accurate range.
X-ray dose training: are we exposed to enough?

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Keywords
Radiation dosage; Medical education

AIM: To study knowledge of radiation exposure among doctors of various grades and specialties in a large district general hospital.

METHODS: A multiple-choice format questionnaire with a total of 11 questions was distributed amongst doctors at Derriford Hospital, Plymouth, UK. Doctors of various grades and specialties completed 240 questionnaires which tested knowledge of terrestrial and medical radiation exposure.

RESULTS: With a pass mark of only 45% and a generous marking scheme, only 66 (27.5%) doctors passed. Only 15.4-25.8% of doctors knew the doses relative to a chest radiograph of various more complex procedures involving ionizing radiation and only 12.5% of doctors were aware of the one in 2000 risk of induction of fatal carcinoma from CT of the abdomen. Only 56.7% of practitioners who, under Ionizing Radiation (Medical Exposures) Regulations 2000, have responsibility for justifying procedures, passed the test. The proportion of practitioners correctly identifying the relative dose of a test to a chest radiograph varied from 30 to 56.7%, depending on the exam type. Only 20% in this group were aware of the risk of inducing a fatal cancer from a CT of the abdomen.

CONCLUSION: The study demonstrated an urgent need to improve knowledge of radiation exposure amongst doctors in clinical practice.
Figure 3  Results of questions on relative doses of various examinations among whole group of doctors.
6. Use appropriate techniques

- Radiography
- Fluoroscopy
- CT
Digital Radiography

• Do we know what the dose is?
• Use appropriate radiographic technique
  - Coning
  - Rotation
  - Centering
  - Shielding
  - mA and kVp
Fluoroscopy

- Digital
- Pulsed
- Last film save
- Think with your foot off the pedal
- Appropriate fluoro times for each exam
CT

• Judicious use of CT

• Adjust scan parameters
  - scan indication
  - scan region/organ system
  - adjust individual parameters
  - simplify scanning
<table>
<thead>
<tr>
<th>Weight</th>
<th>mA (Chest)</th>
<th>mA (Abdomen or Pelvis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lbs</td>
<td>Kg</td>
<td></td>
</tr>
<tr>
<td>10–19</td>
<td>4.5–8.9</td>
<td>40</td>
</tr>
<tr>
<td>20–39</td>
<td>9.0–17.9</td>
<td>50</td>
</tr>
<tr>
<td>40–59</td>
<td>18.0–26.9</td>
<td>60</td>
</tr>
<tr>
<td>60–79</td>
<td>27.0–35.9</td>
<td>70</td>
</tr>
<tr>
<td>80–99</td>
<td>36.0–45.0</td>
<td>80</td>
</tr>
<tr>
<td>100–150</td>
<td>45.1–70.0</td>
<td>100–120</td>
</tr>
<tr>
<td>&gt;150</td>
<td>&gt;70</td>
<td>&gt;140</td>
</tr>
</tbody>
</table>

Donnelly et al. AJR. 176;303

Suggested Tube Current (mA) by Weight of Pediatric Patients for Single-Detector Helical CT
Do the Proper CT Exam

- Phases of the study
- Distance scanned
- Detector collimation in MDCT
- Parameters of the exam
Radiologist - Parameters

• mAs
  – Linear to dose

• kVp
  – Non linear to dose
    20% ↓ kV = 30-40% ↓ dose

• MDCT > radiation
“Lower” Dose Pediatric MDCT

- Large abnormalities, or...
- High contrast regions
  - Lungs
  - Bones
  - CTA
15 mAs
CT Dose Reduction

• Bone studies: lower mA
  – Initially 100 mA : 1.3 cGy
  – Lowered... 40 mA : 0.5 cGy
  – Currently 20 mA : 0.25 cGy
8. Joint efforts with healthcare providers

How do we help with private/adult practice?
• Train residents to be aware/concerned about radiation
• Get the techs to be invested in best practice
• Continue to monitor your own department

Consider:
• Call referring physicians when outside CT has wrong parameters for a child
• Follow this call with a letter giving the correct protocol
Ask questions

1. How much radiation do we receive each day?
2. How much radiation does a neonate/child get from a single view chest X-ray, abdominal film, CT head, CT abdomen?
3. What is the metric for absorbed dose, protection or reconstructed phantom?
4. Why is dose important?
Conclusion

We are part of the way there

• We Need to be Proactive
  Involve Non-Imagers
  Control Our Departments
  Engage Our Community
Some additional material for the module
The ALARA* Concept in Pediatric CT

*As Low As Reasonably Achievable
**Introduction**

Interventional fluoroscopy uses ionizing radiation to guide small instruments such as catheters through blood vessels or other pathways in the body. Interventional fluoroscopy represents a tremendous advantage over invasive surgical procedures, because it requires only a very small incision, substantially reduces the risk of infection and allows for shorter recovery time compared to surgical procedures. These interventions are used by a rapidly expanding number of health care providers in a wide range of medical specialties. However, many of these specialists have little training in radiation science or protection measures.

The growing use and increasing complexity of these procedures have been accompanied by public health concerns resulting from the increasing radiation exposure to both patients and health care personnel. The rise in reported serious skin injuries and the expected increase in late effects such as lens injuries and cataracts, and possibly cancer, make clear the need for information on radiation risks and on strategies to control radiation exposures to patients and health care providers. This guide discusses the value of these interventions, the associated radiation risk and the importance of optimizing radiation dose.

**Increasing use and complexity of interventional fluoroscopy**

In 2002, an estimated 657,000 percutaneous transluminal coronary angioplasty (PTCA) procedures were performed in adults in the United States. In addition, the rate of coronary artery stent insertion doubled from 157 to 318 per 100,000 adults, aged 45-64, from 1996 to 2000 (CDC 2004). At the same time, the complexity of interventional fluoroscopy has been increasing rapidly. This is due to the development of new devices and procedures, such as endo grafts for the treatment of abdominal aortic aneurysms, the development of vertebroplasty, kyphoplasty and uterine artery embolization, and increasing use of fluoroscopic guidance during complex endoscopic biliary and upper urinary tract procedures. As the complexity of these procedures has increased, the dose to patients and health care personnel has increased as well.
There is No Radiation When You Don’t Do the Exam
We are not alone…

- Pediatricians
- Radiology Residents
- Pediatric Cardiologists
- NCI/NIH Study

200,000 Children who had CT in England
Neonatal Imaging

• Most important place to start
• Emphasize US and MR
• Decreased number of plain films
• Alice Stewart’s fetuses are today’s premature infants
Suggested Readings

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