CT Radiation Safety in Adults:
Where are we now? What can be done?

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Canadian Association of Radiologists Annual General Meeting
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No conflicts of Interest to declare
Objectives

- Identify the health risks from radiation doses in diagnostic CT helping radiologists ...
  - Optimize protocols
  - Intelligently discuss radiation concerns with patients or referring physicians
- Highlight some features of the “Image Wisely” program
- Review some basics of CT dose optimization
CT Radiation Dose
In the News
2 ½ year old male, neck CT following fall

- Technologist repeated sans 151 times for > 1 hour
  - If neck CT 3 mSv - total 453 mSv

- Article also included patients with hair loss after brain perfusion scans

Over 400 patients identified with hair loss following CT brain perfusion scans

400 patients at eight hospitals, received doses up to 13x higher than usual


FDA investigating blames lack of dose controls, inadequate technologist training, and desire for better quality pictures

Lawyers now involved

UCSF study showing triple rate of use of CT between 1996 and 2011

“although the test can have great benefit, it can also have the potential to cause real and significant risk”, including cancer
“given that modern patients and doctors want to be as informed as possible. Its not going to be easy countering the expectation for more and more testing”

“However, experts warn that it’s high time we step back and make sure every scan is justifiable and can provide a justifiable health benefit”

http://healthland.time.com/2012/06/13/too-many-scans-use-of-ct-scans-triples-study-finds/
2010 Manitoba study by Elbakri and Kirkpatrick
Manitoba doses 3-25% higher than BC and SK for chest and abdomen
Wide variation in dose between sites

Emphasized importance of newest technologies
Encourages patients to act as advocates
A joint campaign of:

- Radiologists (ACR, RSNA)
- Physicists (AAPM)
- Technologists (ASRT)

Goals:

- Address concerns about the increasing public radiation exposure from medical imaging
- Lower radiation used in medically necessary imaging studies
- Eliminating medically unnecessary procedures

www.imagewisely.org
Pledge for Imaging Professionals

Yes, I want to image wisely.

I wish to optimize the use of radiation in imaging patients and thereby pledge:

1. To put my patients' safety, health, and welfare first by optimizing imaging examinations to use only the radiation necessary to produce diagnostic-quality images;
2. To convey the principles of the Image Wisely program to the imaging team in order to ensure that my facility optimizes its use of radiation when imaging patients;
3. To communicate optimal patient imaging strategies to referring physicians, and to be available for consultation;
4. To routinely review imaging protocols to ensure that the least radiation necessary to acquire a diagnostic-quality image is used for each examination.
Image Wisely
For Imaging Professionals

- Includes radiologists, technologists, nuclear medicine & medical physicists
- Manufacturer and model specific CT protocols for dose optimization
- Info on ionizing radiation in medicine
- Ways to limit dose:
  - US or MRI alternatives to CT
  - Appropriateness criteria
  - Pregnant patient
Image Wisely
For Referring Practitioners

- The risks of ionizing radiation
- What to tell patients
- Appropriateness and alternative tests
- Special considerations
  - Pediatrics & Pregnancy
  - Patients requiring repeated imaging

www.imagewisely.org
Image Wisely
For Patients

- Links to other sites
- Encourages patients to discuss radiation concerns with doctors
- Medical Imaging History Cards
- List of common exams with dose levels and relative risk

Before undergoing any X-ray exam or treatment procedure, remember to ask your doctor:
- Why do I need this exam?
- How will having this exam improve my health care?
- Are there alternatives that do not use radiation and which are equally as good?

Remember:
- Be sure to tell the doctor or technologist if you are, or might be, pregnant before having an exam.
- Don’t insist on an imaging exam if the doctor explains there is no need for it.
- And, don’t refuse an imaging exam if there’s a clear need for it and the clinical benefit outweighs the small radiation risk.

www.imagewisely.org
Low Level Radiation Risk?

- There is risk from a single scan because of no threshold models\(^{(1)}\)
- Risks are higher in children

Demographic Studies

- Atomic bomb survivors with mean 40 mSv dose (range 5-150 mSv) show ‘significant increase risk of malignancy’ (1, 3)

- Radiation workers in nuclear industry with mean dose 19.4 mSv (range 5-150 mSv) show ‘significant association between dose & development of cancer’ (2, 3)

Extrapolation of BEIR VII data

Excess cancer risk and mortality per 1000 patients receiving 10 mSv

39 yo male = 0.06% cancer incidence

5 yo female = 0.32% cancer incidence

Cumulative CTs

- Patients often require >1 scan at visit or multiple visits
- From imaging history of >30,000 patients receiving CT in 2007\(^{(1)}\)
- Percentage of patients with multiple CT’s\(^{(1)}\)
  - 33% > 5 CTs
  - 5% > 22 CTs
  - 1% > 38 CTs
  - Max > 130 CTs

Cumulative Dose

- Percentage of patients above certain dose levels\(^1\)
  - 30% > 50 mSv
  - 15% > 100 mSv
  - 1% > 399 mSv

Population risk from CT

- Based on USA CT use in 2006\(^{(1)}\):
  - 1.5-2\% of cancers attributable to CT

- Canadian based on 1991-1996\(^{(3)}\):
  - 1.1\% of cancers attributable to CT

- Based on 2012 Canadian statistics:
  - Potentially 1,320 fatal malignancies induced by CT/ year
  - (5\% risk/ Sv, 4.4 million CTs & 6 mSv mean dose per scan)

Difficulty With Models

- There is no transference of risk
  - If one person has 15 CT scans they will not share this risk with the rest of the population
  - CT scans in terminally ill will not increase population risk of malignancy
- Ignores benefits of CT
  - Detection and staging of malignancy to enable treatment
  - Imaging of acute injury/disease
CT Dose Knowledge

- Is there risk of cancer from a single CT?
- What is dose of abdo-pelvis CT scan vs. chest x-ray?
## CT Dose Knowledge: Increased Risk of Malignancy?

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Country</th>
<th>% confirm Increased risk cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Jacob</td>
<td>England</td>
<td>12.5%</td>
</tr>
<tr>
<td>2004</td>
<td>Lee (ER only)</td>
<td>USA</td>
<td>9%(MD) 47% (RAD)</td>
</tr>
<tr>
<td>2005</td>
<td>Rassin</td>
<td>Israel</td>
<td>70%</td>
</tr>
<tr>
<td>2007</td>
<td>Rice</td>
<td>USA</td>
<td>53%</td>
</tr>
<tr>
<td>2008</td>
<td>Gumas</td>
<td>Turkey</td>
<td>52%</td>
</tr>
<tr>
<td>2008</td>
<td>Soye</td>
<td>England</td>
<td>19%</td>
</tr>
<tr>
<td>2011</td>
<td>Irving</td>
<td>Sask</td>
<td>74%M D 97%RAD</td>
</tr>
</tbody>
</table>

### CT Dose Knowledge: Dose Levels in CXR equivalents

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Country</th>
<th>% correct CXR equivalent</th>
<th>% underestimate CXR equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Renston</td>
<td>USA</td>
<td>93%</td>
<td>93%</td>
</tr>
<tr>
<td>1997</td>
<td>Quinn</td>
<td>England</td>
<td>9%</td>
<td>60%</td>
</tr>
<tr>
<td>2004</td>
<td>Lee (ER only)</td>
<td>USA</td>
<td>22%</td>
<td>74%</td>
</tr>
<tr>
<td>2004</td>
<td>Jacob</td>
<td>England</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Rassin</td>
<td>Israel</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Heyer</td>
<td>Germany</td>
<td>89%</td>
<td>12%</td>
</tr>
<tr>
<td>2006</td>
<td>Thomas</td>
<td>Canada</td>
<td>1-13%</td>
<td>99-87%</td>
</tr>
<tr>
<td>2007</td>
<td>Aeslanoglu</td>
<td>Turkey</td>
<td>2-8%</td>
<td>83%</td>
</tr>
<tr>
<td>2007</td>
<td>Rice</td>
<td>USA</td>
<td>19%</td>
<td>76%</td>
</tr>
<tr>
<td>2008</td>
<td>Gumas</td>
<td>Turkey</td>
<td>17%</td>
<td>73%</td>
</tr>
<tr>
<td>2008</td>
<td>Shiralkar</td>
<td>England</td>
<td>6%</td>
<td>97%</td>
</tr>
<tr>
<td>2011</td>
<td>Irving</td>
<td>Sask</td>
<td>18%</td>
<td>52%</td>
</tr>
</tbody>
</table>

Dose Audits
Dose Audits

- A review of current practice, not optimal practice\textsuperscript{(1,2)}
- Important to let institutions know of local doses\textsuperscript{(1,2)}
- Compare with reference levels helps maintain doses\textsuperscript{(1)}
- Variation is both good and bad\textsuperscript{(2,3)}
  - Tailor exams to patient sizes/needs
  - Variation between sites can indicate equipment/protocol problems

2. Dumaine et al Changing Radiation Dose from Diagnostic CT in Saskatchewan. CARJ (2012) 63(3) 183-91
How to Do a Dose Audit

- Standard patient vs. actual cases
- Older systems did not archive CTDI/DLP
  - Needed technologists to complete forms
- If CTDI/DLP archived on PACS:
  - Manual review
  - Automated review
- Third party software solutions:
  - e.g. eXposure by Radimetrics/Bayer
    - Individual study and patient history dose tracking
    - Also aggregate data by physician, technologist, protocol etc

1. Leswick DA et al Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-781
2. Jaron Chong
3. Radimetrics.com
SK Dose Surveys: 2006 & 2008

- **2006:**
  - 1,734 patients, 12 of the 13 provincial scanners

- **2008:**
  - 3,358 patients, all 13 scanners

- No new installs/upgrades between the studies

1. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78
## 2006 SK Dose Survey\(^{(1)}\)

<table>
<thead>
<tr>
<th></th>
<th>Avg. SK Dose mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>2.7 ± 1.6</td>
</tr>
<tr>
<td>Chest</td>
<td>11.3 ± 8.9</td>
</tr>
<tr>
<td>Abdomen &amp; Pelvis</td>
<td>15.5 ± 10.0</td>
</tr>
<tr>
<td><strong>Theoretical Trauma Patient:</strong> Total for head, chest, abdomen &amp; pelvis</td>
<td><strong>29.5</strong></td>
</tr>
</tbody>
</table>

- Significant variability between sites
- Wide variability in individual patient doses

1. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78*
2. 0.05 mSv PA CXR ED in Mayo et al. Radiation exposure at chest ct: A statement of the Fleishner Society. Radiology. 2003; 228: 15-21 & our RUH review
2006 Variability Between Sites
CT Chest Doses by Scanner

1. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2): 71-78
2006 vs. 2008

- Did mean doses change?
- Did variability of doses change
  - Between sites
  - Between patients

2. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78
# Dose (mSv) 2008 vs. 2006
Overall MDR Single Phase Only

<table>
<thead>
<tr>
<th></th>
<th>2008(^{(1)})</th>
<th>2006(^{(2)})</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>3.2 ± 1.2</td>
<td>2.7 ± 1.5</td>
<td>+19% ((p&lt;0.001))</td>
</tr>
<tr>
<td>Chest</td>
<td>9.5 ± 3.9</td>
<td>13.7 ± 9.7</td>
<td>-31% ((p&lt;0.001))</td>
</tr>
<tr>
<td>Abdo &amp; Pelvis</td>
<td>13.9 ± 6.0</td>
<td>16.8 ± 10.6</td>
<td>-17% ((p&lt;.001))</td>
</tr>
</tbody>
</table>

**Significantly lower** | **No difference** | **Significantly Higher**

2. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78
Change in Variability Mean Doses for Chest CT – 2008 vs. 2006

2006 vs. 2008 Chest Doses Histograms

1. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78
2. Leswick DA, Syed NS, Dumaine CS, Lim H, Fladeland DA. Radiation Dose from Diagnostic CT in Saskatchewan. CARJ. 2009; 60(2):71-78
CTDI, DLP, ED, and SSDE

- **CTDI_{(vol)}**: CT Dose Index
  - Measurement of radiation exposure in a cylindrical phantom

- **DLP**: Dose Length Product
  - CTDI_{(vol)} adjusted for scan length

- **ED**: Effective Dose
  - Conversion factor accounts for tissue radiosensitivity
  - Developed in an idealized phantom
  - Best used for dose to a population of patients

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Size Specific Dose Estimate (SSDE)

- Accounts for different patient geometry to give more accurate estimate of dose at the centre of a phantom & patient
- Cannot estimate effective dose because does not account for organ dose
- Apply conversion factor based on patient geometry to CTDI to produce SSDE (mGy)

2. www.imagewisely.
SSDE

- Patient size strong correlation with \( \text{CTDI}_{\text{vol}} \)
- SSDE eliminated size correlation
- Variation seen because of different patient density & protocols

Dose Reduction Techniques

- ATCM
- ASIR
- Minimizing Overlapping Coverage
- Shielding
Automatic Tube Current Modulation
Adjust mA to size, geometry and density of the body part being scanned to provide diagnostic images with lower dose \(^{(1)}\)

Evaluating the effectiveness of ATCM systems is difficult:

- performance varies significantly with radiologist and technologist technique choice

Previous study showed dose reduction ranges for ATCM systems as follows:¹

- chest 14-20%
- abdomen 18-38%
- abdomen-pelvis 26-32%

ASIR

Adaptive Statistical Iterative Reconstruction

- Modified method for reconstructing data from traditional filtered back projection\(^{(1)}\)
- Lower image noise, so equivalent IQ obtained with lower dose\(^{(1)}\)
- Same spatial and low contrast resolution
  - Slightly ‘waxy’ look may take time getting used to\(^{(1)}\)
- How much ASIR to use:
  - 30-50% at many centers\(^{(1)}\)

   Accessed April 24, 2013
ASIR - Effect on Dose

- Chest CT study – 30% ASIR\(^{(1)}\)
  - Lower objective image noise than FBP
  - 28% decrease ED

- Abdo CT Study – 40% ASIR\(^{(2)}\)
  - Lower objective image noise than FPB
  - 25% lower dose

- Trauma Pan Scans\(^{(3)}\)
  - ASIR: 20-40% Ch-AP   30% Brain/C-Sp
  - ↓ dose:  14% Ch-AP   20% Brain/C-Sp
  - No difference in objective IQ

Overlapping Dose

- When doing combined neck, chest, abdo-pelvis scans often have regions of overlap

Overlapping Dose

- **2010 QA project on Pan-scans**
- **Neck-Chest Overlap**
  - 25% of chest coverage 1.8 ± 0.8 mSv
- **Chest-Abdo Pelvis Overlap**
  - 41% of chest coverage 2.6 ± 1.3 mSv
- **Overall**
  - 66% of chest coverage
  - 4.4 mSv (20% of total dose received)

Overlapping Dose

- 20% of radiation given was to overlapping areas\(^{(1)}\)
- Compares with 17% in literature\(^{(2,3)}\)

3. Ptak et al. Radiation dose is reduced with a single-pass whole body MDR CT trauma protocol compared with a conventional segmental method: initial experience. Radiology 2003;229(902-905)
2 main types of shielding for CT:

- ‘In-Plane’
  - Superficial shields that partly attenuate the CT beam placed over radiosensitive tissues
  - Eg. Bismuth breast shields during chest CT

- ‘Out-of-Plane’/scatter shielding
  - Shield body parts not exposed to the primary beam
  - Eg. Shielding abdo/pelvis during chest CT
In-Plane shields

- In-plane bismuth shields can:
  - Reduce dose to eyes: 49%\(^{(1)}\)
  - Reduce dose to thyroid: 42% to 74%\(^{(1-3)}\)
  - Reduce dose to breast: 26% to 52%\(^{(1,2,4-6)}\)

- When combined with ATCM:
  - Must place after scout scan\(^{(3,6)}\)

- Never use with AEC

- Minimize local image noise using a spacer\(^{(2)}\)

In-Plane Shields
Controversy

- **Wasting photons** \(^{(1-3)}\)
  - Attenuates some photons already passed through the patient

- **Image noise**
  - If willing to tolerate noise from shields, adjust noise for whole image
  - Image noise reduces reliability of HU \(^{(2)}\)

- Can’t use with AEC systems \(^{(2-3)}\)

Out of Plane (Scatter) Shielding

- Shields outside scan range to absorb scatter radiation
Scatter Shielding
Pregnant CTPE exams

- **8DR scanner** (100 kVp to diaphragm)\(^1\)
  - Shields ↓ fetal dose by 50\(^\%\)\(^1\)
    - (0.17 to 0.08 mGy)

- **64DR scanner** (100 kVp, 30% ASIR, ATCM, ASC)\(^2\)
  - Shields ↓ fetal dose by 69\(^\%\)\(^2\)
    - (0.13 to 0.004 mGy)

2. Chatterson et al. “Shields Up! Fetal Shielding combined with state of the art CT dose erduction strategies during maternal chest CT” CAR Annual Meeting 2012
Is CT Evil?

Definitely not

Non-invasive clinical information invaluable for diagnosis and patient management

Radiation penalty must be managed

Dr. Evil

I used to use Windows, but it was designed by freakin’ idiots.

Now I use Linux allowing me to control the “lasers” on my “death star” with ease.

I’m Dr. Evil, and I’m aspiring to take over the world.

Jareeedo.com
Although there is risk this must be balanced against potential clinical value.

“Risk of not performing the examination (e.g. delayed or inaccurate diagnosis or treatment) must exceed the potential risk associated with the examination”\(^{(1)}\)

Justification of Scans

For symptomatic patients, the risk of disease is variable based on symptoms.

- Guidelines (e.g. ACR Appropriateness Criteria & CAR imaging guidelines) can help direct to best exam type\(^{(1)}\)

For asymptomatic patients the risk of disease is lower

- Justification can be based on potential morbidity of a disease, a pre-clinical phase where screening can help and morbidity from other potential screening tests\(^{(1)}\)

What Do We Do Now?

- **Monitor Dose**
  - Perform dose audits
  - If site is above average, revisit equipment or protocols

- **Education**
  - Educate patients, ordering MDs & radiologists about CT’s dark side
  - Radiologists *must* act as consultants

- **Decrease # of CT scans**
  - Decrease unnecessary scans
  - Use US and MRI

- **Minimize dose from each scan performed**

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CT use increasing, and doses can result in harm

Knowledge limited, so radiologists should act as consultants

www.ImageWisely.org has resources that can help

Benefit to knowing local doses

Optimizing protocols helps control dose
Thank you for your time

David.Leswick@saskatoonhealthregion.ca
References study by showing that children with 2-3 CT scans had 3x risk brain cancer and 5-10 CT scans had 10x risk leukemia\(^{(2)}\). Scans between 1985-2002

Pearce “We need to make sure that everyone knows that yes, we’ve shown a significant increased risk of cancer, but the absolute risk is small”


Parents should ask:

- “is there an alternative to CT scans that can answer the medical question?”
- “does the facility adjusts doses of radiation for children?”

CT Scans in Childhood Can Triple the Risk of Cancer

Having multiple CT scans in childhood may triple the risk of certain cancers, according to a new study.

In the first study of its kind, researchers from the U.S., U.K. and Canada worked for nearly 20 years, tracking cancer rates among children who had had CT scans during their first 15 years of life and comparing them to children who did not have the same exposure to radiation from the scans.

Researchers found that children who had had two to three CT scans in childhood had triple the risk of later developing brain tumors, and children who had had five to 10 scans also had three times the risk of

Frush “doses today are lower, approximately 50% lower than at time of study”

Balance risk with potential benefit as the scans are done for clinical reasons