Ionizing Radiation
a revolution in medical science

- 1895 - Wilhelm Röntgen discovered x-rays
- 1902 – skin cancer linked to radiation
- 1972 – invention of CT by Godfrey Hounsfield and Allan Cormack

Brenner DJ; Hall EJ
New England Journal of Medicine
Working Party Goals

• **Summarize** the evidence and arguments regarding whether medical radiation does cause cancer, and at what threshold of radiation dose such a risk (if real) occurs

• **Inform** gastroenterologists about dosages of radiation associated with commonly ordered diagnostic tests and therapeutic procedures in gastroenterology

• **Educate** gastroenterologists about opportunities to limit or avoid radiation exposure that is either unnecessary, or for which non-radiating alternative studies can be considered
**GRADE system**

"Strong" - benefit of the intervention or treatment clearly outweighs any risk

"Conditional" - uncertainty exists about the risk-benefit ratio

<table>
<thead>
<tr>
<th>Rating of Quality of Evidence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Quality</td>
<td>Further investigation is unlikely to change our confidence in the estimate of effect</td>
</tr>
<tr>
<td>Moderate Quality</td>
<td>Further investigation is likely to impact our confidence in the estimate of effect and may change the estimate</td>
</tr>
<tr>
<td>Low Quality</td>
<td>Further investigation is likely to impact our confidence in the estimate of effect and is likely to change the estimate</td>
</tr>
<tr>
<td>Very Low Quality</td>
<td>Estimate of effect is uncertain</td>
</tr>
</tbody>
</table>

**Definitions**

- **Ionizing radiation**: radiation with enough energy to produce ionization in substances through which it passes
- **Absorbed dose**: amount of energy deposited in a substance
  - Expressed as J/kg or gray (Gy)
- **Equivalent dose**: Absorbed quantity of radiation weighted according to radiation and tissue type
  - Expressed as sievert (Sv) or millisievert (mSv)
- **Effective dose**: equivalent dose multiplied by a factor related to the risk for all exposed tissues or organs
  - Expressed as sievert (Sv) or millisievert (mSv)
Definitions

• **Low dose exposure**: ≤ 100 mSv
• **Deterministic effects**: predictable, usually limited by thresholds; become worse with increasing exposure
  – Ex: cataracts, infertility, skin or hair changes
• **Stochastic effects**: probability of occurrence related to the absorbed dose, but severity is independent of the absorbed dose
  – Ex: genetic abnormalities or cancer

Radiation Dose

• **Exposure**: Coulomb per kilogram (C/kg), roentgen (R)
• **Dose**: Gray (Gy), rad
• **Equivalent dose**: Sievert (Sv), rem
• **Effective dose**: Sv, rem
• 1 Sv = 1000 mSv = 100 rem

- Average annual natural background dose: 3 mSv
- Natural background radiation can vary by about 10 mSv/year at different U.S. locations
- Average annual background dose Denver: 12 mSv
Relative Radiation Exposures

Comparative radiation dose for different imaging modalities

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Average effective dose (mSv)</th>
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<tbody>
<tr>
<td>Higher Altitudes</td>
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</tr>
<tr>
<td>CT-colonography</td>
<td>5-8</td>
</tr>
</tbody>
</table>

Mettler et al. Radiology 2008;248:254-263
www.radiologyinfo.org
### Radiation Dose - ERCP

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Mean effective dose (mSv)</th>
<th>Equivalent number of PA chest radiographs (each 0.02 mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCP (diagnostic) [HA]</td>
<td>3.9</td>
<td>195</td>
</tr>
<tr>
<td>Percutaneous transhepatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cholangiography (PTC) [HA]</td>
<td>8.1</td>
<td>405</td>
</tr>
<tr>
<td>Bile duct drainage [HA]</td>
<td>9.9</td>
<td>495</td>
</tr>
<tr>
<td>Bile duct stenting [HA]</td>
<td>14</td>
<td>700</td>
</tr>
<tr>
<td>ERCP (therapeutic) [OL]</td>
<td>20</td>
<td>1000</td>
</tr>
</tbody>
</table>


### What are the common radiation associated cancers?

- **Thyroid gland** and **bone marrow**
- **Leukemia**
- **Skin Cancer**
- **Lung cancer, breast cancer, stomach cancer**

- Factors affecting radiation induced cancer development
  - Age at exposure - children more sensitive to effects of ionizing radiation than adults.
  - Synergy with genetic predisposition to cancer development
  - Immune incompetence – (Crohn’s and immune modulating drugs?)
Radiation Risk

A complex function of dose, age, sex, exposure, time

- Models to predict risk
  - Linear No Threshold
  - Threshold model
  - Hormesis model
- Higher risk for younger age of exposure 1,2
- Rates of cancer death fall dramatically after 35 years of age 2
- Excess relative risk (ERR per Gy) decreases by about 17% per 3 decade increase in age at exposure
- Excess absolute risk (EAR per Gy) increases despite decrease in ERR 3


### Radiation Risk

<table>
<thead>
<tr>
<th>study</th>
<th>weighted organ doses</th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preston 2007</td>
<td>40% of population &lt; 5mGy, 3% &gt; 1 Gy</td>
<td>• Solid cancer risk shows linear dose response</td>
</tr>
<tr>
<td>Preston 1994</td>
<td></td>
<td>• Dose response for solid cancer significantly increased at low doses (&lt;0.15Gy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Risk higher for exposure at early ages</td>
</tr>
<tr>
<td>Ron 2003</td>
<td>1-15 Gy</td>
<td>• ERR per Gy consistent with findings from atomic bomb survivors</td>
</tr>
<tr>
<td>Boice 2006</td>
<td>2 to &gt; 200Gy</td>
<td>• Risks by anatomic site and age at exposure similar to atomic bomb survivors</td>
</tr>
<tr>
<td>Cardis 2005</td>
<td>0 to &gt; 500 mSv, mean lifetime dose from 15 to 25 mSv</td>
<td>• Significantly inc ERR per Sv for all cancers other than leukemia</td>
</tr>
<tr>
<td>Cardis 2007</td>
<td></td>
<td>• Significantly inc ERR per Sv for all leukemia except CLL</td>
</tr>
<tr>
<td>Muirhead 2006</td>
<td></td>
<td></td>
</tr>
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Adapted from Linet et al. CA CANCER J CLIN 2012;62:75-100
Risks of Low Dose Radiation
abdominal/pelvis CT scan

Risk of cancer at 5 mSv 0.04%
Risk of cancer at 10 mSv 0.08%
Risk of dying from cancer at 5 mSv 0.02%
Risk of dying from cancer at 10 mSv 0.04%

Risk of perforation at colonoscopy 0.1-0.2%
Risk of dying due to colonoscopy 0.01-0.02%

The risk of dying from colonoscopy is a known occurrence and immediate risk. The risk of dying from CT is not proven, theoretical and is a worst case risk after a delay of many years.

Latency Period Varies

GI disease specific groups

- IBD
  - Crohn’s disease
  - Ulcerative colitis
  - Indeterminate colitis
- Organic GI disorders
- Functional GI disorders
• 2590 patients
• Study period: January 1999-January 2009 (10 year study period).
• Diagnostic imaging was performed on 57% of the patients.
• Plain radiography was the most commonly performed imaging exam
• Stable use of Plain radiography, ultrasound and barium studies over study period.
• Increased use of CT

What GI Imaging modalities are used in Gastroenterology?

Comparison of radiation exposure between IBD & other GI disorders

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>N</th>
<th>Annual CED* (mSv/year)</th>
<th>Total CED* (mSv)</th>
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<tr>
<td>All patients</td>
<td>250</td>
<td>3.6</td>
<td>10.5</td>
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<tr>
<td>Organic disorder</td>
<td>101</td>
<td>3.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Functional disorder</td>
<td>629</td>
<td>3.1</td>
<td>5.6</td>
</tr>
<tr>
<td>IBD</td>
<td>957</td>
<td>4.9</td>
<td>20.5</td>
</tr>
<tr>
<td>Crohn’s Disease</td>
<td>445</td>
<td>7.6</td>
<td>30.1</td>
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<tr>
<td>Ulcerative Colitis</td>
<td>453</td>
<td>2.5</td>
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<tr>
<td>Indeterminate colitis</td>
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* CED: cumulative effective dose
IBD: radiation exposure in Crohn’s Disease & Ulcerative Colitis

- Patients with CD exposed to higher ionizing radiation than patients with UC
- CD patients receive 2.46 x more effective dose compared to UC patients over 9-year follow up
- Over 15-year period
  - Mean cumulative effective dose received in CD increased from 7.9 to 25.1 mSv
  - Proportion of radiation from CT increased from 46.7% to 85%


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<td>Three phase liver CT</td>
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Tanner RJ et al. Radiation exposure of the UK population from medical and dental x-ray examinations: publication W4. United Kingdom National Radiation Protection Board 2002
Mettler et al. Radiology 2008;248:254-263
www.radiologyinfo.org
IBD: sensitivity & specificity of diagnostic modalities

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<th>Test</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
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<tr>
<td>WCE</td>
<td>83</td>
<td>53</td>
</tr>
<tr>
<td>Ileocolonoscopy</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>CTE</td>
<td>82</td>
<td>89</td>
</tr>
<tr>
<td>SBFT</td>
<td>65</td>
<td>94</td>
</tr>
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- MRE & CTE equally accurate to assess disease localization, activity & bowel wall thickening in CD
- MRE may be superior to CTE in detecting intestinal strictures (P=0.04) & ileal wall enhancement (p=0.02)

Fiorino et al. Inflamm Bowel Dis 2011;17:1073-1080

Comparison of radiation exposure between functional bowel disorders & other GI disorders

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* CED: cumulative effective dose
How to Reduce Radiation Exposure

• Justification
• Perform the procedure at the lowest possible radiation dose
• Choose an alternative test that result in less exposure to ionizing radiation, when feasible.

Advances in CT Technology

• Automatic Exposure Control
  – Automatic Tube Current Modulation
• Patient Dose Tracking
• Noise Reduction
  – Noise reduction filters
• Iterative Reconstruction Algorithms
  – Combined with low dose CT
Radiation Dose Tracking

• Computer workstation inserted between modality and PACS - Radiation Dose Database

• Patient information:
  - Dose information included in patient report
  - Instantaneous patient lifetime CED estimation

• Radiology Department Quality Assurance in Radiation Protection:
  - Monitor mean doses per radiographer, Modality (e.g. CT), radiologist, and compare to international standards.

Iterative Reconstruction

• Iterative Reconstruction (IR) became available in 2007

• IR techniques - Mathematical algorithms employed for reconstruction of 2D and 3D Images
Iterative reconstruction techniques remove noise and make images more diagnostically acceptable.

Reduces risk of missed diagnosis on noisy low dose images.

Poor TV Signal

Following noise removal

Low dose CT

Post noise removal

Low dose Crohn’s disease:

70% dose reduction

Working Party Recommendations

Patient Groups

• Pediatric patients and those with inflammatory bowel disease are at increased risk for radiation exposure. Radiation dose in these patients should be minimized and alternative imaging modalities always considered. (Strong recommendation, low quality of evidence)

• For elective small bowel imaging in patients with Crohn's disease under the age of 40, MR enterography should be considered as an alternative to CT enterography and barium small bowel studies (Strong recommendation, low quality of evidence)

• Evidence-based guidelines for the use of imaging in patients with inflammatory bowel disease and functional bowel disorders should be developed (Strong recommendation, low quality of evidence)

Working Party Recommendations

Abdominal-Pelvis CT Imaging

• The choice of imaging modality must have established diagnostic or therapeutic indications (Strong recommendation, low quality of evidence)

• Patient dose recording, auditing and tracking are highly recommended (Strong recommendation, low quality of evidence)

• Where available, computer-prompted entry criteria related to indications for an imaging modality should be utilized to more appropriately select patients for CT (Conditional recommendation, low quality of evidence)

• Individualized protocols should be employed for each patient undergoing CT (Strong recommendation, low quality of evidence)

• CT image acquisition parameters should be optimized and, where available, automatic exposure control and iterative reconstruction should be used (Strong recommendation, low quality of evidence)
Working Party Recommendations

Fluoroscopy

• Gastroenterologists and staff must wear appropriate protection (eyewear, thyroid and body shielding) during fluoroscopy (Strong recommendation, low quality of evidence)

• During fluoroscopy, the physician should use an efficient method for dose management
  – The x-ray tube should be kept as far away from the patient as possible and the image receptor as close as possible (Strong recommendation, low quality of evidence)
  
  – Pulsed fluoroscopy should be utilized with the lowest frame rate possible to achieve acceptable image quality (Strong recommendation, low quality of evidence)

Working Party Recommendations

Fluoroscopy

– Multiple exposures of the same area from different projections should be avoided (Strong recommendation, low quality of evidence)

– Use of magnification should be minimized (Strong recommendation, low quality of evidence) The number of frames and the use of cine mode should be minimized (Strong recommendation, low quality of evidence)

– The X-ray beam should be collimated to the area of interest (Strong recommendation, low quality of evidence)

– There should be appropriate shielding of patients (Strong recommendation, low quality of evidence)
Working Party Recommendations

Fluoroscopy

• Gastroenterologists should record the time and dose of fluoroscopy as part of their documentation of a fluoroscopic session (Strong recommendation, low quality of evidence)

• Fluoroscopy equipment must meet standards of IEC, and testing of fluoroscopy equipment should be performed after each repair and yearly servicing, or according to the time interval as recommended by the manufacturer (Strong recommendation, low quality of evidence)

• Hospitals should set up credentialing programs for those who use fluoroscopy (Strong recommendation, low quality of evidence)

Working Party Recommendations

Education

• The IAEA “10 pearls! Radiation protection of staff in fluoroscopy” poster should be mounted in the imaging area of the GI endoscopy suite for staff and patient education (Strong recommendation, low quality of evidence)

• Tracking and reporting of cumulative effective dosage to physician and staff should be performed (Strong recommendation, low quality of evidence)

• Radiation education should begin in medical school and be integrated into residency and gastroenterology sub-specialty training (Strong recommendation, low quality of evidence)

• CME should be offered to gastroenterologists to increase awareness of typical GI imaging radiation doses and risks (Strong recommendation, low quality of evidence)