Radiation dose reduction in Interventional Radiology

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Radiation dose reduction in Radiology

- Radiation risk in relation to medical imaging has been a growing concern in recent years.

- Radiation dose delivery and reduction will be discussed, with special emphasis on interventional procedures.

- Potential avenues for reduction will be discussed.
Concerns about radiation exposure from medical imaging

- National Council on Radiation Protection and Measurements (NCRP): the U.S. population’s total exposure to ionizing radiation has nearly doubled over the past two decades. Per capita exposure to ionizing radiation from all sources was 3.6 mSv. By 2006, that figure had risen to 6.25 mSv.

- In the early 1980’s, medical imaging accounted for 15% of the U.S. population’s per capita exposure to ionizing radiation from all sources (0.54 mSv of 3.6 mSv). In 2006, medical imaging accounted for 48% of the per capita exposure (3 mSv of 6.25 mSv), with CT, nuclear medicine, and interventional fluoroscopy accounting for 24%, 12%, and 7%, respectively.

- NCRP estimates that 80 million CT scans, 20 million nuclear medicine procedures, and 21 million interventional fluoroscopy procedures were performed in the U.S. in 2015, and the authors predict that these figures will continue to grow.

Radiation risk and Interventional Radiology

- International Commission on Radiological Protection (ICRP)
- National Council on Radiation Protection and Measurements (NCRP)
- Professional societies

- Importance of estimating skin dose during and after fluoroscopically guided interventions

- Prediction of probability and severity of deterministic skin effects to recognize patients who require follow-up for detection of possible skin injuries.

- A skin dose > 15 Gy is a sentinel event (Joint Commission).

- Important to be able to estimate peak skin dose (PSD)—the greatest absorbed skin dose at any point on the patient’s skin—during and after procedures


Issues related to medical decision making

- Concerns that physicians may lack important information that could inform their decisions in ordering medical imaging exams that use radiation.

- Ordering physicians may not have access to patients’ medical imaging or radiation dose history.

- Ordering physicians may lack or be unaware of recommended criteria to guide their decisions about whether or not a particular imaging procedure is medically efficacious.
Deterministic Effects of ionizing radiation

Occur only once a threshold dose has been exceeded

References

Food and Drug Administration: [http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115359.htm](http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115359.htm)
Radiation injury

Peruvian patient who inadvertently placed a 26-Ci (0.962-TBq) irridiun-192 (192 Ir) source in his back pocket for 6.5 hours. 3 days and 10 days postexposure. He sought medical advice and was told he probably had been bitten by an insect. In the meantime, his wife sat on the patient's pants (her case appears on the next page) while breastfeeding the couple's 1½-year-old child. The source was recovered several hours later by nuclear regulatory authorities, and the patient was transported to Lima for treatment. This patient had a drastic reduction in lymphocyte count by day 3, and a 4-by-4-cm lesion appeared on day 4. Then he suffered a massive ulceration and necrosis with infection, and his right leg was amputated. Grade II and III CRI was also evident on his hands, left leg, and perineum, but he survived and returned to his family.

http://www.bt.cdc.gov/radiation/criphysicianfactsheet.asp
# Types of radiation injury

<table>
<thead>
<tr>
<th>Phase</th>
<th>Symptom</th>
<th>Whole-body absorbed dose (Gy)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1–2 Gy</td>
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<tr>
<td><strong>Immediate</strong></td>
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<tr>
<td></td>
<td><strong>Nausea and vomiting</strong></td>
<td>5–50%</td>
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<tr>
<td></td>
<td><strong>Time of onset</strong></td>
<td>2–6 h</td>
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<tr>
<td></td>
<td><strong>Duration</strong></td>
<td>&lt; 24 h</td>
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<tr>
<td></td>
<td><strong>Diarrhea</strong></td>
<td>None</td>
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<tr>
<td></td>
<td><strong>Time of onset</strong></td>
<td>—</td>
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<tr>
<td></td>
<td><strong>Headache</strong></td>
<td>Slight</td>
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<td></td>
<td><strong>Time of onset</strong></td>
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<tr>
<td></td>
<td><strong>Fever</strong></td>
<td>None</td>
</tr>
<tr>
<td></td>
<td><strong>Time of onset</strong></td>
<td>—</td>
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<tr>
<td></td>
<td><strong>CNS function</strong></td>
<td>No impairment</td>
</tr>
<tr>
<td><strong>Latent period</strong></td>
<td></td>
<td>28–31 days</td>
</tr>
<tr>
<td><strong>Illness</strong></td>
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<td></td>
<td>Mild to moderate</td>
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<td></td>
<td><strong>Leukopenia</strong></td>
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<tr>
<td></td>
<td><strong>Fatigue</strong></td>
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<tr>
<td></td>
<td><strong>Weakness</strong></td>
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<tr>
<td></td>
<td><strong>Severe leukopenia</strong></td>
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<tr>
<td></td>
<td><strong>Purpura</strong></td>
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<tr>
<td></td>
<td><strong>Hemorrhage</strong></td>
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<tr>
<td></td>
<td><strong>Infections</strong></td>
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<tr>
<td></td>
<td><strong>Epilation</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td><strong>High fever</strong></td>
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<tr>
<td></td>
<td><strong>Diarrhea</strong></td>
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</tr>
<tr>
<td></td>
<td><strong>Vomiting</strong></td>
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<tr>
<td></td>
<td><strong>Dizziness and disorientation</strong></td>
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<tr>
<td></td>
<td><strong>Hypotension</strong></td>
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<tr>
<td></td>
<td><strong>Electrolyte disturbance</strong></td>
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<tr>
<td></td>
<td><strong>Shock</strong></td>
<td></td>
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<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Without care</strong></td>
<td>0–5%</td>
</tr>
<tr>
<td></td>
<td><strong>With care</strong></td>
<td>0–5%</td>
</tr>
<tr>
<td></td>
<td><strong>Death</strong></td>
<td>6–8 weeks</td>
</tr>
</tbody>
</table>

Stochastic Effects of ionizing radiation

Develop years after low levels of exposure

References


Radiation-induced fibrosis

Greatest sources of radiation exposure to U.S. citizens

- The average effective dose from **background radiation** is about **3 mSv**/year.
- 0.02 mSv is the average adult effective dose from a posteroanterior chest x-ray.
- 2 mSv is the average adult effective dose from a CT exam of the head.
- 8 mSv is the average adult effective dose from a CT exam of the abdomen.
- 16 mSv is the average adult effective dose from a CT coronary angiography exam.
- 0.2 mSv is the average adult effective dose from a lung ventilation exam using 99mTc-DTPA.
- 41 mSv is the average adult effective dose from a cardiac stress-rest test using thallium 201 chloride.
- 5 mSv is the average adult effective dose from a head and/or neck angiography exam.
- 70 mSv is the average adult effective dose from a transjugular intrahepatic portosystemic shunt placement.

http://www.ncrponline.org/Publications/Press_Releases/160press.html
General exposure to radiation

- Medical Procedures - 36%
- Cosmic (Space) - 5%
- Terrestrial (Soil) - 3%
- Internal - 5%
- Radon and Thoron - 37%
- Consumer Products - 2%
- Nuclear Medicine - 12%
How is dose measured?

- CT dose index (CTD\text{Ivol}) in milligrays: measure of the intensity of radiation directed at a patient by the CT scanner. CTD\text{Ivol} calculations are based on scanning of an acrylic phantom with a cross-sectional diameter of 32 cm.
- Dose-length product (DLP) in mGy-cms is the product of the CTD\text{Ivol} and scan length and represents the integrated dose over the length of exposure.
- CT effective dose is measured in millisieverts. By converting DLP values from milligray-centimeters to mSv, one can obtain an approximate whole-body dose from partial body exposures, a measure that allows comparisons with the approximate whole-body radiation dose from other CT examinations as well as with the background radiation dose.
- DLP values are easily converted to mSv by using conversion factors specific to the anatomic region imaged.
- Conversion factors listed by the American Association of Physicists in Medicine for the chest, abdomen, and pelvis are 0.014, 0.015, and 0.015 mSv/(mGy·cm).
- Conversion factors are periodically updated, so care should be taken to apply the most recent ones.


## Radiation Doses from Various Types of Medical Imaging Procedures

<table>
<thead>
<tr>
<th>Type of Procedure</th>
<th>Average Adult Effective Dose (mSv)</th>
<th>Estimated Dose Equivalent (No. of Chest X-rays)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental X-ray</td>
<td>0.005-0.01</td>
<td>0.25-0.5</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.4</td>
<td>20</td>
</tr>
<tr>
<td>CT</td>
<td>2-16</td>
<td>100-800</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>0.2-41</td>
<td>10-2050</td>
</tr>
<tr>
<td>Interventional Fluoroscopy</td>
<td>5-70</td>
<td>250-3500</td>
</tr>
</tbody>
</table>
Dose reduction

High radiation doses
- Skin injury to patient
- Hair loss
- Cataract/lens opacification in patients
- Fibrosis
- Cancer

Dose reduction measures
- Equipment
- Quality management
- Operator training
- Occupational radiation protection

Multiple exposures to CTA/CTP

53 yo man, 4 CT/CTA/CTP, 2 DSA within 15 days for aneurysmal SAH

Imanishi et al., Eur Rad 2005;15:46
Dose reduction

Dose reduction measures

- Equipment
- Quality management
- Operator training
- Occupational radiation protection

Dose reduction - Equipment

• Digital imaging allows a wide range of dose values to obtain the desired/required level of quality imaging

• Fluoroscopy dose should be optimized: pulse fluoroscopy

• Collimation

• Filters

• ALARA
Dose reduction

Dose reduction measures

- Equipment
- Quality management
- Operator training
- Occupational radiation protection

Dose reduction – Quality management

• Diagnostic Reference Level DRL : “common examinations” done in standard way
• For fluoroscopically-guided interventions, difficulty in finding standards
  - Variations in procedure types/duration/complexity
  - Variations in patient anatomy and pathology
• Consensus that DRLs can be assessed and used in IR
• Parameters should be defined: fluoroscopy time, number of images, KAP and CK at IRP
• Identification of unacceptable practices
• Optimization process
• Complexity of procedures:
• How to manage high skin doses in non-optimized/multiple procedures?


### DRL for Interventional Radiology

<table>
<thead>
<tr>
<th>Type of examination</th>
<th>Fluoroscopy time (min)</th>
<th>Number of images</th>
<th>KAP (Gy cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transjugular intrahepatic portosystemic shunt creation</td>
<td>60</td>
<td>300</td>
<td>525</td>
</tr>
<tr>
<td>Biliary drainage</td>
<td>30</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Nephrostomy for obstruction</td>
<td>15</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>Nephrostomy for stone access</td>
<td>25</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>Pulmonary angiography</td>
<td>10</td>
<td>215</td>
<td>110</td>
</tr>
<tr>
<td>Inferior vena cava filter placement</td>
<td>4</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Renal or visceral angioplasty without stent</td>
<td>20</td>
<td>210</td>
<td>200</td>
</tr>
<tr>
<td>Renal or visceral angioplasty with stent</td>
<td>30</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Iliac angioplasty without stent</td>
<td>20</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>Iliac angioplasty with stent</td>
<td>25</td>
<td>350</td>
<td>300</td>
</tr>
<tr>
<td>Bronchial artery embolisation</td>
<td>50</td>
<td>450</td>
<td>240</td>
</tr>
<tr>
<td>Hepatic chemoembolisation</td>
<td>25</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>Uterine fibroid embolisation</td>
<td>36</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Other tumor embolisation</td>
<td>35</td>
<td>325</td>
<td>390</td>
</tr>
<tr>
<td>Gastrointestinal hemorrhage localization and treatment</td>
<td>35</td>
<td>425</td>
<td>520</td>
</tr>
<tr>
<td>Embolisation in the head for AVM</td>
<td>135</td>
<td>1,500</td>
<td>550</td>
</tr>
<tr>
<td>Embolisation in the head for aneurysm</td>
<td>90</td>
<td>1,350</td>
<td>360</td>
</tr>
<tr>
<td>Embolisation in the head for tumor</td>
<td>200</td>
<td>1,700</td>
<td>550</td>
</tr>
<tr>
<td>Vertebroplasty</td>
<td>21</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Pelvic artery embolisation for trauma or tumor</td>
<td>35</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td>Embolisation in the spine for AVM or tumor</td>
<td>130</td>
<td>1,500</td>
<td>950</td>
</tr>
</tbody>
</table>

Dose reduction – Quality management

- **Complexity** of procedures
- Acquire database and compare with other facilities
- Automatic trigger for analysis for procedures that deliver high doses and low doses

- NCRP 168 defines *high dose procedure* as one when >5% of cases result in CK >3Gy or KAP >300 Gycm2

- **Trigger level** = dose level aimed at alerting IR physician on skin dose which can be comparable to threshold on tissue effects
  - TL may be expressed on modern equipment as PSD (peak skin dose)
  - Clinical follow-up recommended for patients exceeding TL

- If repeated excessive doses -> procedure protocol/operator behavior
Dose reduction measures

- Equipment
- Quality management
- **Operator training**
- Occupational radiation protection

Dose reduction - Operator

Operator behavior = 3 interventional cardiologists work in same hospital with same equipment performing similar mix of procedures
Average KAP for fluoro and cine modes

![Graph showing average fluoroscopy time & KAP per IC procedure](image.png)
Dose reduction

Dose reduction measures

- Equipment
- Quality management
- Operator training
- Occupational radiation protection

Dose reduction - Occupational

• Dose tracking tools
• IEC, DICOM and IHE developed standards
• Registration, distribution

• Occupational radiation protection

• Is exposure to staff known?
• Poor standards at this time despite >50 years of experience

• Use of dosimeters highly variable from surveys: wearing, position of dosimeters,
• Over apron-> estimates eye exposure
• Probably large numbers of IR MD have annual eye doses > 20 mSv/y
• Use of eye shields, dosimeter position, X-ray protection
Conclusion

• Radiation exposure during interventional procedures is a problem

• Equipment optimization

• Quality Control

• Need to improve staff monitoring

• Training/monitoring of procedural patterns

• Dosimetry

• Reduce staff exposure: training theoretical and practical

• 2013 IAEA formal recognition of E&T in RP required by new BSS -> diplomas and qualifications