RADIATION SAFETY AND BIOLOGICAL RISK IN INTERVENTIONAL RADIOLOGY

Vascular & Interventional Education Days - 2018
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In the beginning....

Experimenters circa 1890s
In the beginning....

Advertisement for General Electric, early 1900s
In the beginning....

Thoracic fluoroscopy circa 1909
In the beginning....

Battlefield fluoroscopy during operation in WWI
In the beginning....

Pediatric X-Ray, 1942
In the beginning....

Thoracic fluoroscopy circa 1940
In the beginning....

National Chiropractors Convention, Chicago, 1956
In the beginning....

Fluoroscopic shoe fitting, 1920-1970
In the beginning....

...we knew a lot less than we do now!
In the beginning....

Experimenters circa 1890s

If photons were mosquitos, everyone would be a radiation safety master!
And as a result of that?

Hands of Radiologist
- 33 years old in first picture
- 40 years old in fourth
- Died shortly after last picture

What’s the point?
“X-rays are indispensible in medicine and must be applied with a great deal of respect for their potential hazards.”
And as a result of that?

- **The Frank Balling Case (IL, 1897)**
  - 09/02/1895 – Frank Balling thrown from his buggy and broke his ankle
  - Continued pain/stiffness for over a year
  - 09/19/1896 – referred for a new type of examination → X-ray photography
    - 3 exposures: 35-40 minutes each, with tube 5-6” from skin surface
    - Developed erythema, followed by blistering & ulceration
  - 11/28/1896 – amputation of foot
  - 08/27/1897 – amputation of leg

First successful litigation for x-ray burn

*Retired a $10,000-aire, which was a millionaire in today's terms…*
What’s YOUR point, Tom?

For safe use, fluoroscopy requires training!

- Proper machine operation
- Patient positioning
- X-ray tube positioning
- Image Quality vs. Radiation Dose
  - HIGHEST Quality
  - LOWEST Dose
- Scattered radiation
- Personnel positioning in room
- Shielding
Safe Use: Patient vs. Staff

- Lower patient exposures = Lower staff exposure
- Risk vs. Benefit for Interventional Patients
  - Risks are generally skin effects (deterministic)
  - Cross a threshold \(\rightarrow\) risk becomes reality (or Risk > Benefit if you cross a line)
  - Proper Radiation Safety practices IMMENSELY decreases chance of crossing the threshold for effects (or Benefit > Risk if you “Step Gently”)
    - Effects are still possible in some cases
    - Larger patients, longer/more complex procedures, etc.
    - BUT…these are minimized with good safety practices
- Good practice \(\rightarrow\) lower exposures all around!
Aside: Radiobiological Effects

- **Stochastic (statistical) Effects**
  - Radiation-induced cancer.
  - Probability of occurrence increases with dose.
  - Severity does not increase with dose.
  - No dose threshold for this type of effect.

- **Deterministic Effects**
  - Skin effects (erythema, epilation, etc) & cataracts.
  - A dose threshold exists for this type of effect.
  - Severity increases with dose.
  - *Fluoroscopy normally concerned with these.*
What’s wrong with these pictures?

What’s the point?

“X-rays are indispensable in medicine and must be applied with a great deal of respect for their potential hazards.”

~20Gy from Coronary Angiography

~18Gy from 3 separate AVM Embolizations (17 months after procedure)
What’s wrong with these pictures?

120 minutes. Coronary Angiography

6 weeks later

16 weeks later

18 months later

What’s the point?

“X-rays are indispensable in medicine and must be applied with a great deal of respect for their potential hazards.”
What’s wrong with these pictures?

Other than seeing bone???

What type of procedure was performed? What bad practice resulted in this injury?
What’s wrong with these pictures?

Arm is in the beam!!!

What does this do to the image?

What does the x-ray tube do?
Radiation-Induced Injuries

No sensation during procedure!
- Threshold dose 2Gy
- Latent period between procedure and effects
- Need to know about high exposures

Table 3. Potential Effects in skin from fluorooscopy. (Adapted from Ref. 38 and revised according to information provided in private communication with J. W. Hopewell, 1999.)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Single-dose threshold (Gy)</th>
<th>Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early transient erythema</td>
<td>2</td>
<td>~2–24 h</td>
</tr>
<tr>
<td>Main Erythema</td>
<td>6</td>
<td>~10 d</td>
</tr>
<tr>
<td>Temporary epilation</td>
<td>3</td>
<td>~3 wk</td>
</tr>
<tr>
<td>Permanent epilation</td>
<td>7</td>
<td>~3 wk</td>
</tr>
<tr>
<td>Dry desquamation</td>
<td>14</td>
<td>~4 wk</td>
</tr>
<tr>
<td>Moist desquamation</td>
<td>18</td>
<td>~4 wk</td>
</tr>
<tr>
<td>Secondary ulceration</td>
<td>24</td>
<td>&gt;6 wk</td>
</tr>
<tr>
<td>Late erythema</td>
<td>15</td>
<td>8–10 wk</td>
</tr>
<tr>
<td>Ischemic dermal necrosis</td>
<td>18</td>
<td>&gt;10 wk</td>
</tr>
<tr>
<td>Dermal atrophy (1st phase)</td>
<td>10</td>
<td>&gt;12 wk</td>
</tr>
<tr>
<td>Dermal atrophy (2nd phase)</td>
<td>10</td>
<td>&gt;1 y</td>
</tr>
<tr>
<td>Induration (invasive fibrosis)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Telangiectasia</td>
<td>10</td>
<td>&gt;1 y</td>
</tr>
<tr>
<td>Dermal necrosis (late phase)</td>
<td>&gt;12?</td>
<td>&gt;1 y</td>
</tr>
<tr>
<td>Skin cancer</td>
<td>None known</td>
<td>&gt;5 y</td>
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10 Pearls: Radiation protection of patients in fluoroscopy

1. Maximize distance between the X ray tube and the patient to the extent possible

2. Minimize distance between the patient and the image receptor

3. Minimize fluoroscopy time
   - Keep records of fluoroscopy time and DAP/KAP (if available) for every patient

4. Use pulsed fluoroscopy with the lowest frame rate possible to obtain images of acceptable quality

5. Avoid exposing the same area of the skin in different projections
   - Vary the beam entrance port by rotating the tube around the patient

6. Larger patients or thicker body parts trigger an increase in entrance surface dose (ESD)

7. Oblique projections also increase ESD
   - Be aware that increased ESD increases the probability of skin injury

8. Avoid the use of magnification
   - Decreasing the field of view by a factor of two increases dose rate by a factor of four

9. Minimize number of frames and cine runs to clinically acceptable level
   - Avoid using the acquisition mode for fluoroscopy
   - Documentation should be performed with last image hold whenever possible and not with cine images

10. Use collimation
    - Collimate the X ray beam to the area of interest

Dose Rates and Dose

- Fluoro Dose Rates → Patient Dose → Staff Dose
  - Greatest where x-rays enter patient (skin)
  - Vary from <10 mGy/min to >500 mGy/min
    - 30 min procedure (low): 300 mGy
    - 30 min procedure (high): 15000 mGy = 15 Gy
  - We need to minimize the doses

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Control Your Dose

Continuous vs. Pulsed Fluoroscopy

A. Continuous fluoroscopy

Blurred appearance of motion with continuous x-ray production because exposure time lasts the full 1/30th of a second for each image interval.

Images: [Diagram showing continuous x-ray production and blurred images]

Continuous stream of x-rays produces blurred images in each frame.

B. Pulsed fluoroscopy, no dose reduction

Sharp appearance of motion because each of 30 images per second is captured in a pulse.

B. Pulsed fluoroscopy, dose reduction at 7.5 pulses per second

Pulsed fluoroscopy at 7.5 images per second with only 25% the dose of that in Fig. 19A or 19B.

Images: [Diagram showing pulsed x-ray production and sharp images]

Things to consider:
1. How much do I need to see?
2. How “true” do I need to see?
3. Last Image Hold!
4. The more you give, the more you get.
Patient Safety vs. Staff Safety

- Lower patient exposures = Lower staff exposure
- Risk vs. Benefit for Interventional Patients
  - Risks are generally skin effects (deterministic)
  - Cross a threshold → risk becomes reality (or Risk > Benefit if you cross a line)
  - Proper Radiation Safety practices IMMENSELY decreases chance of crossing the threshold for effects (or Benefit > Risk if you “Step Gently”)
    - Effects are still possible in some cases
    - Larger patients, longer/more complex procedures, etc.
- Risks from Occupational Exposures
  - Risks are cataracts (deterministic) and increased cancer incidence (stochastic)
  - Both associated with repeated chronic exposure to radiation
  - Proper Radiation Safety practices IMMENSELY decreases chance of crossing the threshold for cataracts, or probability for cancer incidence
What’s wrong with these pictures?

What’s the point?

“X-rays are indispensable in medicine and must be applied with a great deal of respect for their potential hazards.”

Or as Spiderman would say, “With great power comes great responsibility.”

Lens injuries induced by occupational exposure in non-optimized interventional radiology laboratories.

http://bjr.birjournals.org/content/71/847/728.full.pdf+html
Radiation Induced Cataracts?

ICRP issues statement lowering threshold for eye lens

There have been a number of reports in recent years indicating prevalence of opacities in the eyes of staff exposed to radiation levels below the thresholds as established by the ICRP (ICRP Publication 60 of 1990 and ICRP Publication 103 of 2007). The values for detectable lens opacities are: 5 Sv for protracted and 0.5-2.0 Sv for brief exposure. The 2007 ICRP report stated “However, new data on the radiosensitivity of the eye with regard to visual impairment are expected”, and concluded “Because of the uncertainty concerning this risk, there should be particular emphasis on optimization in situations of exposure of the eyes”.

The Commission has now reviewed recent epidemiological evidence and has issued a statement after its meeting on 21st April 2011.

According to this statement, the threshold in absorbed dose for the lens of the eye is now considered to be 0.5 Gy.

Further, for occupational exposure in planned exposure situations the Commission now recommends an equivalent dose limit for the lens of the eye of 20 mSv in a year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv.

The Commission continues to recommend that optimisation of protection be applied in all exposure situations and for all categories of exposure. With the recent evidence, the Commission further emphasises that protection should be optimised not only for whole body exposures, but also for exposures to specific tissues, particularly the lens of the eye, and to the heart and the cerebrovascular system.
Cancer?

- Biological Exposure to Ionizing Radiation, Report VII, Phase 2
- Used data from Japanese atomic bomb survivors
- Created the Linear-No-Threshold (LNT) model

**LNT says:**
*There is no safe radiation dose. Any amount of radiation may initiate cancer.*
“Boy I’m lucky I never had one of these done! I was always skeptical of this procedure. It was my intuition that told me don’t go there!” …USA Today
Cancer Risks from Radiation Exposure

- Used data from Japanese atomic bomb survivors
- Critics of BEIR VII say:
  - Doses too high (shouldn’t extrapolate to low doses used in imaging)
  - Committee ignored at least four other data sets that showed lower cancer incidence
  - Ignored any repair mechanism for radiation-induced DNA damage
What is the truth?

“One photon is all it takes…”

“A little radiation is good for you…”

• Attributing these risks to individual patients is inappropriate.
• Attributing these risks to large populations leads to sensationalized results.
• The numbers that BEIR VII predicted have not panned out.

Current and ongoing research is increasingly leaning toward a slightly nonlinear risk under 100mGy – nearly all imaging exams result in doses well under 50mGy.
IAEA Staff Safety


10 Pearls: Radiation protection of staff in fluoroscopy

Reducing patient dose always results in staff dose reduction

1. Use protective devices!
   - Advisable skirt type lead apron to distribute weight
   - Lead glass eyewear with side protection
   - 0.25 mm lead equivalence but with overlap on front to make it 0.5 mm on the front and 0.25 mm on the back (Provides >90% protection)
   - Thyroid protection

2. Make good use of time-distance-shielding (TDS) principle
   - Minimize time
   - Maximize distance as much as clinically possible
   - Use shielding

3. Use ceiling suspended screens, lateral shields and table curtains
   - They provide more than 90% protection from scattered radiation in fluoroscopy
   - Mobile floor shielding is advisable when using cine acquisition

4. Keep hands outside the primary beam unless totally unavoidable
   - Hands inside the central area of the primary beam will increase exposure factors (kV, mA) and doses to patient and staff

5. Only 1-5% of radiation falling on the patient’s body exits the other side
   - Stand on the side of the transmitted beam (i.e., by the detector), which contains only 1-5% of the incident radiation and its respective scatter

6. Keep X ray tube under the patient table and not over it
   - Undercoush systems provide better protection from scattered dose

7. Use personal dosimetry
   - Use at least two dosimeters
     - One inside the apron at chest level
     - One outside the apron at neck or eye level
   - Personal dosimeter behind the lead apron at chest level
   - Additional finger ring dosimeter for procedures requiring hands close to primary beam
   - Real time dosimetry systems are useful

8. Update your knowledge about radiation protection

9. Address your concerns about radiation protection to radiation protection specialists (medical physicists)

10. REMEMBER!
   - Quality control testing of fluoroscopy equipment enables safe and stable performance
   - Know your equipment! Using the equipment’s features appropriately will help reduce doses to patients and staff
   - Use injector devices
Conclusions?

- Lower patient exposures = Lower staff exposure

- Risk vs. Benefit for Interventional Patients
  - Risks are generally skin effects (deterministic)
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Always ALARA!!!
Always Practice ALARA

- What does this mean for YOU?
  1. Follow “pearls” for patient and staff safety
  2. Wear quality, comfortable leaded glasses
  3. Don’t be overly worried about cancer risk
  4. Whatever you do, don’t fall out of your buggy…
THE END!