Radiation Safety in the Catheterization Lab

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Disclosures

None
Ionizing radiation can directly/indirectly damage DNA.

Health effects vary widely:
- Type of radiation
- Total radiation dose
- Dose rate

<table>
<thead>
<tr>
<th>Time Unit</th>
<th>Effects</th>
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</thead>
<tbody>
<tr>
<td>SECONDS</td>
<td>Biochemical effects</td>
</tr>
<tr>
<td>HOURS</td>
<td>Cell division</td>
</tr>
<tr>
<td>DAYS</td>
<td>CNS and GI effects</td>
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<tr>
<td>YEARS</td>
<td>Cancer</td>
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<tr>
<td>GENERATIONS</td>
<td>Genetic effects</td>
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</tbody>
</table>
Radiation Safety

- The more frequently cells divide (mitotic rate) the more sensitive they are to radiation injury.
- The more specialized (degree of differentiation) the cells are, the less sensitive they are to radiation injury.
- At low doses, radiation effects are a statistical probability.
- In all cases the effects of radiation will be delayed.
Radiation Safety: Biological Effects

- **Stochastic Injury**
  - Cell is modified (not lost) and reproduces
  - Single cell injury
  - Probability $\propto$ dose
    - Severity not related to dose
  - Does not have a threshold
  - Cancer

- **Deterministic Injury**
  - Number of cells lost in an organ/tissue resulting in loss of tissue function $\rightarrow$ Injury to multiple cells
  - Has a threshold. Dose dependent.
    - Severity related to dose
  - Cataracts, skin erythema/necrosis

  Deterministic, dermis, dose dependent
Radiation Safety: Terminology

- Quantities measured in sieverts represent stochastic risk
  - A biological effect/impact
  - Measure of the health effect of low levels of radiation
  - Used to represent the risk of the effect
  - Not used for high dose rates of radiation (which are typically related to deterministic effects)
  - $1 \text{ Sv} = 1 \text{ J/kg} = 1 \text{Gy}$

- Quantities measured in gray are typically those that relate to deterministic risk
  - A physical quantity
  - $1 \text{ Gy} = 1 \text{ J/kg} = 1 \text{ Sv}$

$1 \text{ gray (Gy)} = 100 \text{ rem} = 1 \text{ Sv}$
Radiation Safety: Terminology

Fluoroscopic time: duration fluoro is used
- Does NOT include cine acquisition
- Alone, is not a useful descriptor of patient dose

Air Kerma (sum of kinetic energy released per unit mass)
- Sum of energy of charged particles liberated by ionizing radiation in a unit mass of air (J/kg = Gy)
- Measures ionization in air not tissue

Chambers et al. CCI 2011; 77(4): 546-56
Total Air Kerma at the interventional reference point ($K_{a,r}, \text{Gy}$)
- Used to monitor thresholds/patient dose
- Cumulative procedural dose of x-ray energy (delivered to air) at the reference point (usually along central x-ray beam)
- Required since 2006 on interventional x-ray systems
- Associated with deterministic effects (skin effects)
- Not a true peak skin dose

Chambers et al. CCI 2011; 77(4): 546-56
Radiation Safety: Terminology

Air Kerma area-product ($P_{ka}$, Gy-cm$^2$)

- Previously the dose area product
  - Absorbed dose (air kerma in mGy or Gy) x exposed area in cm$^2$
  - Displayed on most current screens
  - Used to monitor patient dose and possible risk of inducing cancer

Chambers et al. CCI 2011; 77(4): 546-56
Radiation Safety: Terminology

Effective dose (mSv)
- Calculated value
- Marker of stochastic risk
- Takes 3 factors into account:
  - Absorbed dose to all organs (total body vs organ specific; weighted for tissue)
  - Relative harm level
  - Sensitives of each organ
- Used to assess potential for long term effects from procedure
- Not intended to apply to a specific patient
Radiation Safety: Terminology

Peak Skin Dose (PSD, Gy)
- Max dose received at any area of skin
- Derived not measured (Ka and x-ray geometry → physicist)
- Determines deterministic effects of exposure (probability and severity increase as PSD increases)
- Dependent on dose rate and duration x-ray beam directed toward area
- **Calculated by physicist**
Radiation Safety: Terminology

Radiation Safety: Biological Effects

- **0-2 Gy**
  - < 2 weeks: None
  - 2-8 weeks: None
  - 6-52 weeks: None
  - Permanent: None

- **2-5 Gy**
  - < 2 weeks: Transient erythema
  - 2-8 weeks: Epilation
  - 6-52 weeks: Recovery from hair loss
  - Permanent: None expected

- **5-10 Gy**
  - < 2 weeks: Transient erythema
  - 2-8 weeks: Persistent erythema/epilation
  - 6-52 weeks: Prolonged erythema and permanent partial epilation/full recovery
  - Permanent: Full recovery to dermal atrophy/induration

- **10-15 Gy**
  - < 2 weeks: Transient erythema
  - 2-8 weeks: Erythema, epilation, dry/moist desquamation
  - 6-52 weeks: Prolonged erythema, permanent epilation
  - Permanent: Telangiectasia, dermal atrophy/induration

- **15 Gy**
  - < 2 weeks: Transient erythema, very high dose → moist desquamation, edema/ulceration
  - 2-8 weeks: Erythema, epilation
  - 6-52 weeks: Dermal atrophy with secondary ulceration/induration; high dose → dermal necrosis/surgery
  - Permanent: Late skin breakdown

The Joint Commission has identified a peak skin dose > 15 Gy as a sentinel event (cumulative over 6-12 months)

Chambers et al. CCI 2011; 77(4): 546-56
Balter et al. Radiology 2010; 254: 326-41
Radiation Safety: Dose estimates

- < 100 mSv considered low dose
  - Annual background radiation: 3.1 mSv
  - Chest x-ray: 0.1 mSv
  - Whole body CT scan: 10 mSv
    - Cardiac CT 16 mSv
    - Chest CT 7 mSv

- Adult catheterization:
  - Diagnostic coronary 9.1 mSv
  - PCI 17 mSv

- Pediatric cardiac catheterization:
  - Diagnostic/straight forward interventions: < 5 mSv
  - Most < 20 mSv

Radiation Safety

ALARA

As low as reasonably achievable

- Basically keep the dose as low as possible
- Assume no safe dose (linear no threshold model)
Radiation Safety: monitoring

- Personal dosimeter
  - Required nationally by law
  - 2 locations:
    - Collar → outside protective garment
      - May overestimate some areas
    - Waist → below protective garment

Ann ICRP 2000; 85: 25-43
Radiation Safety: Recommended maximum dose

RADIATION WORKER
- Whole body dose
  - < 50 mSv/yr (NCRP)
  - 100 mSv/5 yrs (ICRP)
- Extremities (hands) < 500 mSv/yr (both)
- Lens of eye < 150 mSv/yr (both)
- Fetus (after declaration of pregnancy)
  - < 0.5 mSv/mo (5 mSv/term) (NCRP)
  - 1 mSv/term (ICRP)

GENERAL POPULATION
- Avg of 1 mSV/yr of effective dose
Radiation Safety.
How to reduce exposure

- TIME
- DISTANCE
- SHIELDING
- EDUCATION
Radiation Safety.
How to reduce exposure: time

- Focused study
- Plan
- Avoid unnecessary angiograms
- If an angiogram is redundant, don’t do it
  - Fluoroscopy is ~95% of the time, and ~40% radiation
  - Cine ~5% time and 60% radiation
Radiation Safety.
How to reduce exposure: time

- Plan the angiograms and views
  - review prior angiograms, CT, MRI
- Use lowest acceptable frame rate
- Image quality and radiation dose are tightly coupled
  - Reduction of one results in reduction of the other
- Do not use fluoroscopy to make changes to patient/table position or collimators/shields
- If your eye is not on the screen, step off
Radiation Safety.
How to reduce exposure: distance

- Goal is to decrease exposure to scatter
- Physician radiation exposure is changed by camera projection
  - Steep angulation of x-ray beam increases radiation dose and scatter
- Collimation decreases scatter
- Increased BMI \(\rightarrow\) increased dose and subsequently increased scatter
Radiation Safety. How to reduce exposure

- Take a step back during cine
  - Double the distance from the patient and reduce exposure by a factor of 4
- Copper filters decrease primary beam exposure
  → skin dose

- Remove anti-scatter grids when catheterizing small children
  - Air gap technique
  - Can reduce dose without compromising image quality
Radiation Safety. Where is exposure?

- Scattered radiation main source of exposure for operator and staff
- Most scatter originates from beam entrance
- Intensity of scatter radiation decreases with increasing distance from the patient

Heidbuchel et al; Europace 2014; 16(7) 946-64
Radiation Safety.
How to reduce exposure

- **Time.**
- **Distance**
- **Shielding**
  - Remote shielding, should use it
  - Wear lead protective aprons
  - Hang aprons appropriately (avoid cracks)
- **Education**
  - Institutional radiation safety programs
  - Dosimeter badge
  - SCAI Pediatric QIT
Radiation Safety.
How to reduce exposure

Precautions to minimize exposure to patient and operator
- Minimize cine
- Avoid steep angles
- Minimize magnification
- Minimize frame rate
- Collimate
- Keep detector close to patient
- Monitor real time doses

Minimize exposure to operator
- Use protective garments
- Maintain garments appropriately
- Maximize distance of operator from x-ray source and patient
- Utilize shielding (above and below table)
- Keep body parts out of field of view

Minimize exposure to patient
- Keep table height as high as comfortable
- Vary imaging beam angle
- Keep non-target body parts out of beam
- Keep body parts out of field of view
Radiation Safety: Post-procedure issues

- Record both $K_{a,r}$ and $P_{ka}$ for each case
- For $K_{a,r} > 5$ Gy should document in chart and counsel patient regarding possible skin changes
- $K_{a,r} > 10$ Gy ($P_{ka} > 1000$ Gy-cm$^2$) $\rightarrow$ notify physicist to calculate PSD
  - Follow up pt in 2-4 weeks for skin exam
- PSD > 15 Gy notify hospital risk mgmt within 24hrs
  - Must be reported to regulatory agency
Radiation Safety

Children are potentially at greater risk of stochastic effects:

- Tissues more sensitive to radiation than adults
- Younger at time of radiation, longer period of time for malignancies to develop
- Many receive high doses over a lifetime (previously untracked)
  - CT scans, CXRs, Catheterizations….
Radiation Dose Benchmarks During Cardiac Catheterization for Congenital Heart Disease in the United States

7 sites participating in C3PO
Fluoroscopy alone not adequate; correlated poorly with DAP ($P_{ka}$) and $K_{a,r}$
75th Percentile for adult diagnostic cath 1180 mGy; PCI 3120 mGy (95th 4050 mGy)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Total No.</th>
<th>Total Air Kerma, mGy</th>
<th>Dose Area Product, Gy·cm²</th>
<th>Total Fluoroscopy Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Median</td>
<td>75th Percentile</td>
<td>n</td>
</tr>
<tr>
<td>PDA</td>
<td>548</td>
<td>362</td>
<td>109</td>
<td>175</td>
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<tr>
<td>ASD</td>
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<td>532</td>
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<tr>
<td>PS</td>
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<tr>
<td>AS</td>
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<td>215</td>
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<tr>
<td>CoA</td>
<td>452</td>
<td>360</td>
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<td>940</td>
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<tr>
<td>TPV</td>
<td>223</td>
<td>200</td>
<td>2,286</td>
<td>3,424</td>
</tr>
</tbody>
</table>

AS = aortic stenosis; ASD = atrial septal defect; CoA = coarctation of aorta; PDA = patent ductus arteriosus; PS = pulmonary stenosis; TPV = transcatheter pulmonary valve placement.
Radiation Safety

Tracking and recommendations specific for pediatrics in the works:

- Quality Metrics Working Group of ACC
  - Radiation dose metric for procedures
- IMPACT

Lifetime risk unknown

- Longer life expectancy → stochastic risk?
- Gamma-H2AX used as biomarker
  - Formed when double stranded DNA breaks
  - 1:1 ratio to DSBs

Radiation Safety

Focus on radiation reduction:

- Flat panel detectors
- Digital image acquisition
- Stored fluoroscopy
- Pediatric dosing
- Increased awareness