Reducing Radiation
A Vascular Surgeons Guide

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Disclosures:
Radiation Safety

Radiation Physics

Ionizing: Gamma Rays, X-Rays, InfraRed, Radio
Non-ionizing

Ionization of an Atom

Nucleus

Electron
Background ("Environmental") Radiation

Natural (Avg does 310 mrem/yr)
- Cosmic radiation
  - sun and stars
- Radon gases
  - soil and rock

Man Made (Avg does 310 mrem/yr)
- Non-Medical amount of biological damage
  - Industrial, occupational, consumer sources
- Medical
  - Largest component "Man Made Sources"
Radiation Daily

- 29 mrem radiation dose from smoking a pack of cigarettes

- 1,300 mrem radiation dose single full-body (CT) scan
  - 1.5 mi: from Hiroshima atomic explosion to receive an equivalent dose

- 70 million CT scans performed /yr with 10% increase annually
  - 0.08% increase in risk of death from cancer after a full-body CT scan
  - 3.75% increase risk CA death if you receive a full-body CT scan yearly at age 25
  - 7 % patients informed of the risks of their CT scans

Sources: American College of Radiology, David J. Brenner/Columbia University Medical Center, U.S. Food and Drug Administration, David C. Levin/Thomas Jefferson University Hospital, National Institutes of Health, Nuclear Energy Institute, Yale University School of Medicine
Two systems:
- Older used in U.S. Regulatory language Curie, Rad and Rem
- Standardized International Units: Becquerel, Gray and Sievert

**RAD**: Radiation Absorbed Dose
- a unit describing the amount of energy deposited per unit mass from radiation in any type of medium.

SI Unit: \(100 \text{ rads} = 1 \text{ Gray}\)

**REM**: Roentgen Equivalent Man
- a unit used for measuring human dose equivalent.

SI Unit: \(100 \text{ rem} = 1 \text{ Sievert}\)
**KERMA**

- **Kinetic Energy Released in Matter**
- A measure of energy delivered (dose)
- **Air Kerma** = kerma measured in air (low scatter environment)
  - Also abbreviated as KAP, DAP
  - \((\text{Dose}) \times (\text{Area})\) of irradiated field (Gy·cm\(^2\))
  - Total energy delivered to patient:
    - Good indicator of stochastic risk
    - Poor descriptor of skin dose

\[ \text{Radiation Dose} = \text{Field} \]
1906: Law of Bergonie’ and Tribondeau
• Rapidly dividing cells and less differentiated cells are more sensitive to radiation

**Target Theory:** regions of cells that are more sensitive to radiation

**Indirect Effect:** free radical generation → DNA damage

**Direct Effect:** direct injury to DNA helix
Absorbed Dose

- Dose absorbed by target tissue
  - amount of energy absorbed per kg tissue
- Proportional to Biological Radiation Damage
- Measured Gray (\textbf{Gy}) or Rad
  - $1 \text{ Gy} = 100 \text{ Rad}$
  - $1 \text{ Gy} = 1 \text{ Joule/Kg}$
  - $100 \text{ Rad} = 1 \text{ Joule/Kg}$

Effective Dose

- Amount of biological damage
  - takes into account tissue sensitivity to radiation
- Used to equate dose to risk
- Reflects whole body dose
- Measured in Sieverts (Sv) or Rem
  - $1 \text{ Sv} = 100 \text{ Rem}$
  - $1 \text{ mSv} = 100 \text{ mRem}$
  - $1 \text{ SV} = 1 \text{ Joule/Kg}$
  - $100 \text{ Rem} = 1 \text{ Joule/Kg}$
Tissue Radiosensitivity

Highly Radiosensitive:
- Lymphoid Tissue
- Embryonic Tissue
- Gonads
- Bone Marrow
- Gastrointestinal Epithelium

Moderately Radiosensitive:
- Vascular Endothelium
- Lung
- Kidney
- Liver
- Skin
- Lens of Eye

Least Radiosensitive:
- Bone
- Cartilage
- Muscle
- Connective Tissue
- Nervous Tissue
Fluoroscopic Time:
- major monitor until 2006.
- Least useful

Total Air Kerma at the Interventional Reference Point ($K_{a,r}$, Gy)
- x-ray energy delivered to air 15cm from for patient dose burden for deterministic skin effects.

Air Kerma Area Product ($P_{KA}$, Gycm$^2$)
- product of air kerma and x-ray field area
- estimates potential stochastic effects (radiation induced cancer).

Peak Skin Dose (PSD, Gy)
- is the maximum dose received by any local area of patient skin.
- No current method to measure PSD, can be estimated if air kerma and x-ray geometry are known.
- Joint Commission Sentinel event, >15 Gy.
Deterministic Effects
- Large number of cells are damaged
- Threshold Dose $\rightarrow$ Certainty of Effect
- Severity is proportional to Dose
  - hair loss
  - skin damage
  - cataracts
  - congenital abnormalities

Stochastic Effects
- Probability damage proportional to Dose
- Linear non-threshold Dose
- Severity independent of Dose
  - Cancer
  - Birth defects
  - Genetic effects
Human Responses to Ionization Radiation

### Early Effects

<table>
<thead>
<tr>
<th>Acute Radiation Syndrome</th>
<th>Hematologic Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrointestinal syndrome</td>
<td></td>
</tr>
<tr>
<td>Central nervous system</td>
<td></td>
</tr>
<tr>
<td>Local Tissue Damage</td>
<td>Skin</td>
</tr>
<tr>
<td></td>
<td>Gonads</td>
</tr>
<tr>
<td></td>
<td>Extremities</td>
</tr>
<tr>
<td>Hematologic Depression</td>
<td></td>
</tr>
<tr>
<td>Cytogenic Damage</td>
<td></td>
</tr>
</tbody>
</table>

### Late Effects

<table>
<thead>
<tr>
<th>Acute Radiation Syndrome</th>
<th>Hematologic Syndrome</th>
</tr>
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<tbody>
<tr>
<td>Gastrointestinal syndrome</td>
<td></td>
</tr>
<tr>
<td>Central nervous system</td>
<td></td>
</tr>
<tr>
<td>Other Malignant Disease</td>
<td>Bone cancer</td>
</tr>
<tr>
<td></td>
<td>Lung cancer</td>
</tr>
<tr>
<td></td>
<td>Breast cancer</td>
</tr>
<tr>
<td>Leukemia</td>
<td></td>
</tr>
<tr>
<td>Genetic Significant Dose</td>
<td></td>
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<tr>
<td>Lifespan Shortening</td>
<td></td>
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</tbody>
</table>

Most radiation effects will **NOT** be seen during hospitalization; Injury expression: Days – Years

It is highly likely that their occurrence is under-reported
### Tissue Reaction Radiation Dose

<table>
<thead>
<tr>
<th>Skin Dose</th>
<th>2-8 wks</th>
<th>6-52 wks</th>
<th>&gt;40 wks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2 Gy</td>
<td>no observable effects expected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-5 Gy</td>
<td>transient erythema</td>
<td>epilation</td>
<td>recovery</td>
</tr>
<tr>
<td>5-10 Gy</td>
<td>transient erythema</td>
<td>erythema</td>
<td>recovery</td>
</tr>
<tr>
<td>10-15 Gy</td>
<td>transient erythema</td>
<td>dry/moist</td>
<td>permanent</td>
</tr>
<tr>
<td></td>
<td>erythema</td>
<td>desquamation</td>
<td>epilation</td>
</tr>
<tr>
<td>&gt;15 Gy</td>
<td>acute ulcer</td>
<td>moist desquamation</td>
<td>dermal surgery</td>
</tr>
</tbody>
</table>
Impact of “Medical” Radiation for Physicians

- 6% of physicians limit their case load
- 10% of physicians have taken medical leave of absence
  - increased risk of cancer
    - left side brain cancer
    - leukemia
    - breast and skin cancer

70% of MY cases involve diagnostic or endovascular intervention

How About Yours?
Radiation Training: Student, Residency, Fellowship, and Practice

What I Was Told:
- Patients were more at-risk than providers
- Higher doses of radiation: increased risk CA

What TheyForgot to Say:
- Risk of chronic exposure to low-level radiation
- Strong dose-response relationship between:
  - Radiation exposure
  - Years worked
  - Prevalence of stochastic effects

➢ Rudimentary vascular surgery radiation training
➢ Vascular team members (RN & Surgical Techs) were being trained by me
As Low As Reasonably Achievable

Principles

- Reduce **TIME** of your exposure
- Increase **DISTANCE** from the source
- Make use of available **SHIELDING**
Time: Reducing Radiation

- Decrease time spent in radiation field
- Fluoroscopy only when viewing monitor
- Use pulsed fluoroscopy when possible
- Use last image hold: Last frame displayed w/beam off
- Set procedural time limits
Intensity of Radiation is inversely proportional to the distance from the source. Double the distance from the source of radiation - reduce dose by a factor of 4.

\[ \frac{l_2}{l_1} = \left( \frac{d_1}{d_2} \right)^2 \]

General rule: 3 meters (≈10 ft) from the source of radiation - dose is insignificant.
## Shielding: Reducing Radiation Penetration

### Protective Barriers
- lead glass / acrylic for windows
- lead sheets (doors, walls)
- concrete / brick walls
- minimize x-rays beam at windows / doors
- find best location during x-ray exposure
- lead drape fluoroscopy tower / table
  - additional 90% protection
  - remaining 10% from lead aprons

### Personal Shielding
- lead aprons
  - at least 3 - 5mm Pb
  - can provide up to 90% shielding
- thyroid
- eye shielding
- glasses
- plexiglass shield
- lead gloves
As Low As Reasonably Achievable

- correct exposure factors
- correct radiographic technique
- appropriate radiation protection
- appropriate viewing techniques
- appropriate radiographic positions for examination
- minimize repeat examinations
- continuing education
Radiation Scatter

- Principal source of exposure to patient and staff
- Produced when beam enters the patient.
- The amount depends on:
  - Compton interactions within the patient (scattering of photon due to an electron)
  - Directly related to the primary dose
- Constitutes noise as beam interacts
  - Noise reduces image quality
- Increases with field size
- Increases with intensity of X-ray beam
**Tube-Housing Leak**

**Secondary Scatter**

**Primary Scatter**

**Transmitted Radiation**

**Stray Radiation “Scatter”**

**Radiation Dispersion Terminology**

**Radiation Safety**
Radiation Dispersion

- Intense Primary Beam
- Weak Scatter Region
- Strong Backscatter Region

X-ray tube

Image Intensifier

Primary Beam Radiation Levels:
- 0.1 R / min
- 3 R / min
- 11 R / min
- 25 R / min

Radiation Safety

Attenuation
Fluoroscopic Geometry: Ray Spacing

To Close

Increased ray spacing to and from x-ray tube

To Far

Increased Entrance Dose

Optimum

X-ray tube farther entrance dose is more uniform
Overhead Intensifier provides for less backscatter to the face
Fluoroscopic Geometry: Backscatter

Primary Beam closer to therefore more intense radiation scattered to the surgeon.

more **Attenuation** through the soft tissue less radiation scattered to the surgeon.
Radiation Safety

**Radiation Backscatter**

- **Optimum**
  - Far from Radiation Source
  - Dose Attenuates
  - Some Pass Over Radiation

- **Poor**
  - Close to Rad Source
  - Pass Over Radiation
  - Pass Through Radiation
Radiation Monitoring

Rational Monitors:
- Control Room
- Procedure Room
- Personnel

Dosimetry (Instruments of Measure)
- Body: Badge:
- Extremity: Ring
- Internal Contamination: urinalysis, thyroid bioassay

Badge readings are reviewed regularly by the RSO
- Institutional investigation levels are set below regulatory limits
- Personnel are notified regularly and badge readings are posted
Hospital Radiation Safety

Medical Physicist / Radiation Safety Officer
- Generally independent Contractor
- Inspect and calibrate all fluoroscopy
- Inspect and monitor protective equipment
- Review and Record dose information
- Implements and monitors radiation protocols

Site Assistant Radiation Safety Officer
- Hospital / Facility employee
- Inspect / work with fluoroscopy
- Inspect protective equipment
- Obtain Record dose information
- Organize / participate staff meetings

State Department of Health
- Reviews Reports from independent RSO
- Provides safety information to the public
- Investigates facility / provider public complaints

Medical Chief of Staff

5 Gy

15 Gy

Board of Medicine
Recommended Lead 0.5mm thick

Equivalent Types
- Lead composite
  - Lead + another metal
  - (25 % lighter)
- Non-lead
  (bismuth, tin, tungsten, barium, aluminum)

- 50% market share
- 70% product has poor performance
- 10 times the exposure

“Light Lead”

0.5” thick
Double Layer Front
Top and Bottom
1” thick

0.25” thick
Double layer front

All lead
4040 Grams
“Heavy”

Non-lead
2130 Grams
“Feels Light”
Radiation Safety

Software Upgrades

- Increasing the thickness of x-ray beam spectral filters for acquisition imaging
- Reducing detector dose rate in acquisition imaging
- Setting default fluoroscopy dose rate mode from normal to low with other various combination changes
- Reducing the frame rate from 15FPS to 7.5 FPS
- Programmed x-ray parameters for voltage, current spectral filter, time, and patient size
Quality Assurance and Control

Upgrades
- Installation of ECO™ Dose software
- Addition of 58-in monitor with digital zoom

DoseAware real-time provider dose monitoring

Existing safeguards
- Ceiling-mounted and rolling lead shield
- Table-mounted lead skirt
- Standard lead apron with collar

○ 61% decrease ($p > 0.001$) in mean patient DAP

○ 57% decrease mean monthly surgeon/patient dose PRE and POST ECOS™
  - PRE Upgrade: 930 mRem/month
  - POST Upgrade: 400 mRem/month

Recall: occupational dose limit = 5,000 mRem / year

### Complex Endovascular Aorta Cases
(Branch TEVAR/FEVAR/Snorkel)

<table>
<thead>
<tr>
<th>Outcome, mean (±SD)</th>
<th>PRE Upgrade</th>
<th>POST Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose Area Product, mGy*cm²</td>
<td>1.41E6 (5.7E5)</td>
<td>5.55E5 (2.6E5)</td>
</tr>
<tr>
<td>Fluoroscopy time, min</td>
<td>64.6 (23)</td>
<td>56.7 (23)</td>
</tr>
<tr>
<td>Total contrast volume, mL</td>
<td>90.1 (33)</td>
<td>106.2 (66)</td>
</tr>
<tr>
<td>Operative time, min</td>
<td>169.3 (39)</td>
<td>171.1 (48)</td>
</tr>
</tbody>
</table>
Future Protection
Protective ALARA Measures

**Patient**
- Increase Table Height
- Vary Beam Angle
- Keep Extremities Out of Beam

**Operator**
- Optimize Shielding
- Protective Gear
- Increase Distance From Source
- Keep Body Out of Beam

Limit Radiation Use
Limit Cine Use
Decrease Frame Rate
Real Time Dose Monitoring
Image Intensifier Close to Patient
Use Software Magnification
Minimize Steep Angles
Collimate
Working With “Medical” Radiation

- Develop, Build, and Maintain Safe Work Space
- Train Surgical Staff
- Maintain ALARA Principles
- Plan to Purchase Software Upgrades
- QA Your Work Environment
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