Radiation Quantification

- Absorbed Dose – Described in units of gray (Gy) or radian (rad).

- Radiation Exposure – Roentgen (R). Also measured in Coulomb/kg.

- Dose Equivalent – Radiation equivalent of man (rem). Also measured in Sievert (Sv).

1 R = 2.5 x 10^{-4} C/kg	1 Gy = 100 rad	100 rem = 1 Sv
1R = 1 rad = 1 rem		

Annual Limits of Exposure

- Skin rate of absorption = 2 – 5 rad/min
- MPD – Maximum permissible dose. Healthcare workers should not receive greater than 10% of the MPD[1].
- Annual Occupational Effective Dose Limit – 5,000 mrem/yr
- Cumulative Lifetime Effective Dose Limit – 1,000 mrem X age

Body area	MPD
Whole Body	5 rem
Pregnant Woman	0.5 rem
Lens of Eye	15 rem
Extremities	50 rem
Thyroid	50 rem

Minimizing Radiation Exposure

- ALARA – "as low as reasonably achievable"

- Collimation – Option on C-arm that reduces x-ray field. Two options: Linear (leaf) and circumferential (iris) collimation. This process during imaging is often referred to as "conning in".

- Inverse Square Law – doubling the distance from the x-ray source will reduce the dose by a factor of four. Tripling the distance will reduce the dose by a factor of nine.

- Shielding – lead apron minimum thickness of 0.25mm. Most aprons are 0.5mm in thickness. Aprons and eyewear decrease exposure by 40%. Eyewear is recommended if x-ray collar badges accumulate greater than 4 rem/month. Eyewear of 0.5mm protect the eyes 4 times more than regular glasses[3]. Pregnant women should wear wraparound aprons with a thickness of 1mm.

- Scatter Radiation – is greatest when standing on the same side as the x-ray tube. Therefore, it would be better to stand on the side of the image intensifier during lateral fluoroscopy. Radiation scatter during anterior-posterior (AP) image acquisition will be greatest below the procedure table.

Steps to Limit Exposure[2]
Apply the Inverse Square Law
Limit the field of view directly over the area of interest. Use collimation when possible
Use Pulsed Mode – creates fewer frames per second
Use intermittent fluoroscopy rather than live imaging
Keep image intensifier closer to the patient and the x-ray tube further away
Utilize the c-arms default automatic brightness control option: adjusts kV while keeping mA low
Avoid high-level fluoroscopy (HLF) imaging as this increases x-ray current (mA)
Ensure proper shielding and regular inspection of shielding material
When the C-arm is in the lateral position the operator should not stand directly behind the x-ray tube
Inverting the C-arm with the x-ray tube above the table increases exposure to radiation and should be avoided

- Radiation exposure is cumulative
- Current is expressed as milliamps (mA)
- Energy is expressed as kilovolts (kVp)
- Single image fluoroscopy typically utilizes high kVp and low mA[4]

- Parallax Error – also described as pincushion distortion, is an optical distortion during c-arm imaging resulting in sides of the image being magnified more the central aspect of the image. Parallax error can be avoided by keeping the target destination perpendicular and in the center of the x-ray beam.

- Vignetting – an optical distortion that results in darkening at the image edges.

References

1. National Council on Radiation Protection and Measurements (NCRP). Report 116. Limitation of Exposure to Ionizing Radiation. Bethseda, MD. 1993
2. Wang LH, McKenzie-Brown AM, Hord AH. *Handbook of C-Arm Fluoroscopy-Guided Spinal Injections*. Boca Raton: CRC/Taylor & Francis; 2006.
3. Radiation Safety for Anesthesia Providers - aana.com. https://www.aana.com/docs/default-source/aana-journal-web-documents-1/jcourse2_0611_p257-2674c8137731dff6ddbb37cff0000940c19.pdf?sfvrsn=a47e5ab1_6. Accessed June 27, 2019
4. Benzon HT. *Practical Management of Pain*. Philadelphia, PA: Elsevier/Saunders; 2014

