Radiation Protection and Biology Review

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A.R.R.T.

• Radiation Protection
  – 40 questions (20% of exam)
    • Biological Aspects of Radiation (10)
    • Patient Protection (12)
    • Personnel Protection (9)
    • Radiation Exposure & Monitoring (9)

Objective

• To obtain optimum diagnostic information or therapeutic effects with minimum exposure of the patient.

Technologist’s Responsibility

• Recognize your duty to protect.
  – The patient
  – The public
  – Health professionals

• Utilize all mechanisms to reduce dose to the patient without compromising image quality.

First Triad of Radiation Protection

• Justification with net benefit
• Dose Limits
• Optimization (ALARA)

Second Triad of Radiation Protection

• aka “Cardinal Principles”
  • Time: Exposure is directly proportional to time.
  • Distance: Exposure is inversely proportional to the distance squared.
  • Shielding: Exposure is reduced by the placement of barriers between the source and the exposed individual.
Classification of Radiation

- Corpuscular
- Electromagnetic

Corpuscular Radiation

- aka Particulate
- Any subatomic particle in motion.
- Alpha, Beta, Neutrons, High Speed Electrons

Electromagnetic Radiation

- An electric and magnetic field, perpendicular to each other, but traveling through space in the same direction.
- X and Gamma radiation

Electromagnetic Radiation

- Energy (photon)/ No mass
- Travel at the speed of light
- Highly penetrating
- Ionizing (x and gamma)

Sources of Radiation Exposure

- Environmental (Background)
  - Cosmic
  - Terrestrial
  - Internal
- Artificial (Man-made)
  - Medical (Diagnostic and Therapeutic)
  - Nuclear Industry
  - Consumer Products
Sources of Radiation Exposure
1987

- Environmental Radiation: 295 mRem
- Artificial Radiation: 65 mRem
- Total: 360 mRem

* 198 mRem from Radon gas

Sources of Radiation Exposure
2009

- Environmental Radiation: 310 mRem
- Artificial Radiation: 310 mRem
- Total: 620 mRem

Interactions of Radiation with Matter

- Coherent Scattering
  - Unmodified, Classical, Thomson, Rayleigh
- Photoelectric Effect
  - True absorption
- Compton Effect
  - Modified Scattering
- Pair Production

Coherent Scattering

- Occurs at low energy levels (< 30 kVp)
- Photon- intermediate shell electron interaction
- Non-ionizing process
Photoelectric Effect

- Photon-inner shell electron interaction
- Probability depends on:
  - "Z" of absorber
  - Photon energy
  - Mass density of absorber

Compton Effect

- Photon-outer shell interaction
- Scattering with partial absorption
- Probability depends on:
  - Photon energy
  - Mass density

Pair Production

- Photon-nucleus interaction
- 1.022 MeV threshold
- Results in an annihilation reaction

Carlton & Adler, 2006

Radiation Quantities and Units

- Exposure (X): Roentgen (C/kg)
- Absorbed Dose (D): Rad (Gray)
- Equivalent Dose (EqD): Rem (Sievert)
- Effective Dose (EfD): Rem (Sievert)

Exposure

- Unit: Roentgen (C/kg)
- Measures ionizations produced in air
- Applicable to x and gamma radiation at energies < 3 MeV

Exposure

- 1 R = 2.58 x 10^-4 C/kg
- Used in the calibration of x-ray equipment

Carlton & Adler, 2006
Absorbed Dose

- Unit: Rad (Gray)
- Measures energy deposition in matter
- Applicable to all types of radiation

Equivalent Dose

- Unit: Rem (Sievert)
- Unit of biological effects
- \[ DE = D \times W_R \]
  (absorbed dose x radiation weighting factor)

Equivalent Dose

- Radiation Weighting (Quality) Factors
  - X-ray, Beta, Gamma: 1
  - Neutrons < 10 keV: 5
  - Neutrons > 100 keV – 2MeV: 20
  - Alpha particles: 20

Effective Dose

- Unit: Rem (Sievert)
- Unit of biological effects
- \[ DE = D \times W_R \times W_T \]
  \( D \): absorbed dose
  \( W_R \): radiation weighting factor
  \( W_T \): tissue weighting factor

Effective Dose Limits

NCRP Report # 116

- a.k.a. Dose Limits.
- Based on the lifetime risk of somatic or genetic injury.

Annual Occupational Exposure

- Effective Dose Limits
  (stochastic effects): 5 rem
  Cumulative Effective Dose (CED):
  1 rem x age (years)
- Effective Dose Limits
  (non-stochastic effects):
  - Lens of eye: 15 rem
  - All others: 50 rem
**Annual Educational and Training Exposure**

- Effective dose: 0.1 rem
- DE Limit (skin, hands, & feet): 5.0 rem
- DE Limit (lens of eye): 1.5 rem

**Embryo-fetus Exposure**

- Monthly Equivalent Dose Limit:
  - 0.05 rem/month
  - 0.50 rem/gestation

**Public Exposures**

- Continuous/ frequent exposure: 0.1 rem
- Infrequent exposure: 0.5 rem
- Tissues and organs:
  - Lens of eye: 1.5 rem
  - Localized skin, hands, and feet: 5.0 rem

**Dosimeters**

- Film Badge
- Pocket Dosimeters
- TLD
- OSL Dosimeters

**Film Badge**

Three parts:
- Lightweight plastic film holder
- Metal filters
- Film packet

**Structure**

- Deep (penetrating) or shallow (non-penetrating)
- Determines direction of radiation received
Advantages/Disadvantages

**Advantages**
- Constitutes a permanent, legal record of personnel exposure
- Economical
- Distinguish all types of low level radiation and their energies.

**Disadvantages**
- Temperature and humidity extremes cause fogging
- Radiation exposure cannot be determined on the day of occurrence.
- Has a limited range of sensitivity.

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Pocket Dosimeter

Structure

- Resembles a fountain pen
- Contains a thimble ionization chamber
- Two types
  - The self-reading type
  - The non-reading type

Function

- Contains two electrodes, one positive (the central electrode) and one negative (the outer electrode)
- The quantity of charge determines the position of the shadow along the scale

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Advantages/Disadvantages

**Advantages**
- Immediate readout for radiation workers
- Compact, easy to carry, and easy to use
- Accurate and sensitive, great for procedures that are relatively short in duration

**Disadvantages**
- Expensive
- If not read every day, could give an inaccurate reading
- Discharge if subjected to mechanical shock
- No permanent legal record of exposure

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Thermoluminescent dosimeter (TLD)
**Function**

- When irradiated, electrons in the LiF crystalline lattice structure absorb energy and are "Excited" to higher energy levels.
- When heated in the reading device, the electrons return to their original position and emit light.

**Advantages/Disadvantages**

- **Advantages**
  - The LiF crystals interact as human tissue does.
  - Read as low as 5 mR.
  - Not affected by temperature and humidity.
  - May be worn up to 3 months/Reusable.

- **Disadvantages**
  - Can be read only once.
  - Calibrated dosimeters must be prepared and read with each group of TLD's as they are processed.

**Optically Stimulated Luminescent Dosimeter (OSL)**

- A lightweight plastic holder.
- Aluminum oxide detector.

**Function**

- Radiation exposure is detected by the Aluminum oxide detector.
- The dosimeter is "read" using a laser.
- When laser light strikes the dosimeter, the sensing material becomes luminescent in proportion to the amount of radiation exposure received.
**Advantages/Disadvantages**

- **Advantages**
  - Read as low as 1 mR
  - Temperature and humidity changes do not affect the OSL
  - Can undergo reanalysis

- **Disadvantages**
  - No known disadvantages

**Patient Protection**

- Communication
- Exposure Factors
- Shielding
- Beam Restriction
- Filtration
- Image Receptor Speed
- Patient Positioning

**Exposure Factors**

- High kVp / low mAs techniques are best for patient protection.
- Choose a kVp level which is “optimum”.
- Optimum kVp gives adequate penetration, an acceptable level of contrast, and an acceptable level of scatter production.

**Shielding**

Shielding should be used if:

1. the reproductive organs are within or near the primary beam.
2. the objectives of the exam are not compromised.
3. the patient has reasonable reproductive potential.

**Types of Shields**

- Flat Contact Shields
- Shaped Contact Shields
- Shadow Shields

**Beam Restriction**

- Apertures
- Cones and cylinders
- Collimators
Beam Restriction

- Increased beam restriction results in:
  - Decreased patient dose
  - Improved image quality
  - Contrast

Filtration

- Reduces exposure to the patient’s skin and superficial body tissues.
- Absorbs low energy, long wavelength photons.
- Increases average beam energy

Filtration

- Two types:
  - inherent
  - added
- Total Filtration:
  - 2.5 mm Al (>70 kVp)
  - 1.5 mm Al (50-70 kVp)
  - 0.5 mm Al (< 50 kVp)

Image Receptor Speed

- High-speed image receptors require less exposure.
- The technologist should use the fastest possible image receptor consistent with diagnostic results.
- Increased speed decreases resolution.

Grids

- Grids are an image quality device
  - Absorb scatter radiation
  - Increase image contrast
- Increase patient dose
  - Higher grid ratio; higher patient dose

Fluoroscopy

- Pulsed progressive fluoro
  - Decreases dose
- Exposure factors
  - Low mA; high kVp
  - Decrease dose
- Fluoro Time
  - Increased time; increased dose
Patient Positioning

- PA vs AP
  - Scoliosis examinations
  - Skull examinations
  - Lumbar Spine examinations

Personnel Protection

- Sources of Exposure
- Cardinal Principles
  - Time
  - Distance
  - Shielding

Sources of Radiation Exposure

- Medical Diagnostic Exposure
  - Primary Beam
  - Secondary Beam
  - Leakage
  - Stray Radiation (leakage + scatter)

Protective Barriers

- Primary
  - 1/16th in. Pb. eq.
  - 7 feet high
- Secondary
  - 1/32nd in. Pb. eq.
  - Extend to ceiling

Equipment Recommendations

- NCRP Report # 102
  - Aprons/Thyroid Shields
    - 0.5 mm Pb equivalency
  - Gloves
    - 0.25 mm Pb equivalency
  - Glasses
    - 0.35 mm Pb equivalency

- NCRP Report # 102
  - Mobile Equipment
    - Exposure Cord:
      - 6 feet (180 cm).
    - Operators should wear leaded apron.
    - Operators should stand at a right angle to the scattering object.
**Equipment Recommendations**

**NCRP Report # 102**

- **Radiographic Units**
  - Tube Housing: < 100 mR/hr at 1 meter from source.
  - SID: +/- 2% of indicated SID.
  - Collimator: +/- 2% of SID.
  - Filtration: 2.5 mm Al (> 70 kVp).

- **Fluoroscopic Units**
  - Source-to Table-top Distance:
    - Should not be less than 15 inches (38 cm);
    - Shall not be less than 12 inches (30 cm).
  - Primary Protective Barrier: Must be interlocked with x-ray tube.
  - Exposure Switch: Dead-Man type.
  - Protective Drape: Minimum 0.25 mm lead equivalent.
  - Bucky Slot Cover: Minimum 0.25 mm lead equivalent.
  - Cumulative Timer: Produces an audible signal or interrupts beam at 5 minutes fluoro time.
  - Exposure Rate: Must not exceed 10 R/min.

**Biological Effects**

- Result from energy deposited into the biological system.
- Mechanisms of interaction:
  - Ionization (Photoelectric + Compton)
  - Excitation

**Somatic Effects**

- Effects occurring in the exposed individual.
Somatic Effects

- **Stochastic**
  - Mutational
  - Non-threshold
  - Example:
    - Cancer
- **Non-stochastic**
  - aka Deterministic
  - Cell killing
  - Threshold
  - Examples:
    - Burns
    - Epilation
    - Cataracts

Non-stochastic

- Linear, non-threshold dose response relationship
- Linear-quadratic, non-threshold dose response relationship
- Non-linear (sigmoidal), threshold dose response relationship

Genetic Effects

- Effects occurring in unborn generations.
- Linear, non-threshold dose response relationship

Genetically Significant Dose

- The average annual gonadal equivalent dose to members of the population who are of childbearing age
- Estimated at 20 mR

Doubling Dose

- The radiation dose that causes the number of spontaneously occurring mutations in a given population to double.

Long Term Effects

- Carcinogenesis
  - Radium watch dial painters
  - Uranium miners
  - Atomic bomb survivors
  - Thorotrast patients

- Cataractogenesis
- Life Span Shortening
- Embryological Effects

Genetic Effects

- Mutations
  - Typically recessive
  - Usually harmful
- Chromosome damage
  - Breaks
  - Gene rearrangement
Embryological Effects

- Pre-implantation
- Major organogenesis
- Fetal development

Factors Influencing Biological Effects

- Biological Factors
  - Related to the Organism
- Physical Factors
  - Related to the type and delivery of the radiation

Biological Factors

- Tissue Sensitivity
- Oxygen Effect
- Age
- Gender
- Temperature/ Metabolic Rate
- Stress Level
- Body Weight

Tissue Radiosensitivity

- Law of Bergonie and Tribondeau
  - Cells which are poorly differentiated and rapidly dividing are most radiosensitive.
  - Cells which are highly differentiated and slowly dividing are most radioresistant.

Radiosensitive Tissues

- Blood Cells (Lymphocytes)
- Epithelial Tissues
- Intestinal Crypt Cells
- Reproductive Cells
- Lens of the eye

Radioresistant Tissues

- Nervous Tissue
- Muscle Tissue
- Liver
Biological Factors
- Tissue Sensitivity
- Oxygen Effect (OER)
- Age
- Gender
- Temperature/ Metabolic Rate
- Stress Level
- Body Weight

Physical Factors
- LET: Linear Energy Transfer
  - Rate of energy deposition as radiation travels through matter
- RBE: Relative Biological Effectiveness
  - The relative effectiveness of a radiation in producing a given biological effect when compared to 250 keV x-rays

Physical Factors
- Time of dose delivery
  - Acute
  - Fractionation/ protraction
- Quantity of Radiation
- Quality of Radiation

Radiation Protection and Biology Review
- The End!