Limited Scope X-Ray Technician Course

Module 3: Radiobiology

Presented by

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OLYMPIC HEALTH PHYSICS

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Outline

- Biology
  - Cell Structure, DNA, Cell Cycle
- Radiometric Quantities
  - Dose, Dose Equivalent
- Radiation Interactions with Cell
  - Radiobiology
- Types of Radiation Effects
  - Stochastic vs Non Stochastic
- Radiation Risk
  - LNT and associated problems
- Pregnancy & Radiation

The New York Times

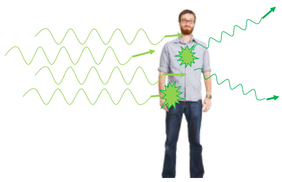
THE OPINION PAGES | OP-ED CONTRIBUTORS

We Are Giving Ourselves Cancer

By RITA F. REDBERG and REBECCA SMITH-BINDMAN JAN. 30, 2014

Objective

Provide you with an understanding of what happens when radiation interacts with biological tissue.



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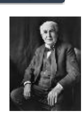
History of Radiation Biology



Don't talk to me about X-rays, I'm afraid of them.
-Thomas A. Edison

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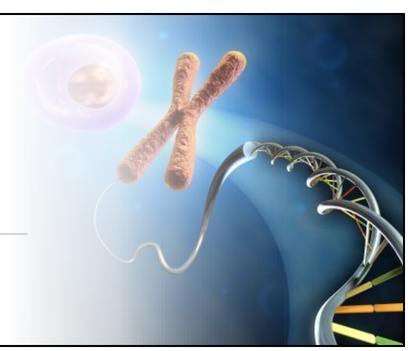
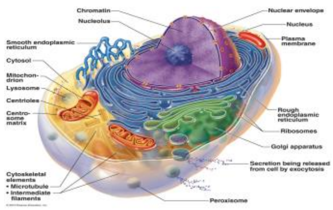


Biology Overview

Human Cell



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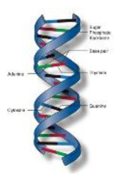
DNA

- Deoxyribonucleic Acid
  - Carries all genetic information used for growth, development, function, and reproduction
  - It's really important stuff!
- Base Pairs
  - Adenine – Thymine
  - Guanine – Cytosine
- Codons
  - Amino Acids
  - Proteins



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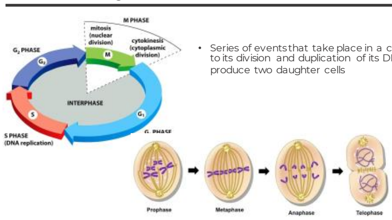
The Cell Cycle



- Series of events that take place in a cell leading to its division and duplication of its DNA to produce two daughter cells

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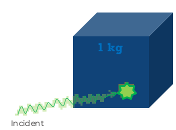
Radiation Physics Reminders

What Is Radiation Dose?

- Dose is defined as the energy deposited per unit mass
  - 1 J/kg = 1 Gray
  - Absorbed Dose
- Measured in units of
  - Gray or Rad
  - 100 rad = 1 Gy



1.6×10^{-19} Joules = 1 eV

Dose Equivalent

- Absorbed dose multiplied by weighting factors

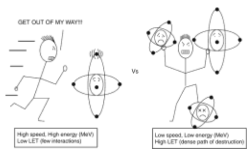
$$Absorbed\,Dose(Gy) \times W_T \times W_R = Dose\,Equivalent$$

- Measured in units of
  - Sieverts or Rem
  - 100 rem = 1 Sievert (Sv)
- Weighting Factors account for
  - Radiation Type (W_R)
  - Tissue Type (W_T)

Radiation Weighting Factors (W_R)

- Each type of radiation has it's own W_R
- W_R is based on amount of damage radiation can do along a given path

Radiation Type	Weighting Factor (W_R)
Alpha Particles	20
Slow Neutrons	5
Beta Particles	1
X-Rays	1
Gamma Rays	1



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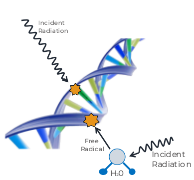
Radiation + Biology = Radiobiology

How Does Radiation Cause Damage?

- Direct Damage vs Indirect Damage
  - Single Strand Break
  - Double Strand Break



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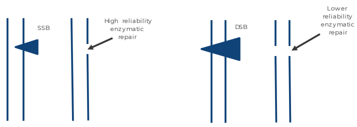
DNA Strand Breaks



If the breaks are not at the same position, they can be more easily repaired:

5'-C-G-A- -C-C-G-A-3' → 5'-C-G-A-T-C-C-G-A-3'
3'-G-C-T-A- -G-C-A-5' → 3'-G-C-T-A-G-G-C-A-5'

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The Role of Double Strand Breaks

- Double Strand Breaks are most problematic as they are largely unrepairable
- The Good News
  - Double strand breaks are more likely to be produced by High LET radiation such as alpha particles
  - X-Rays are more likely to produce single strand breaks, which are more easily repaired
- DNA breaks are not unusual
  - ~10,000 DNA breaks per day per cell
  - We're really good at repairing DNA breaks

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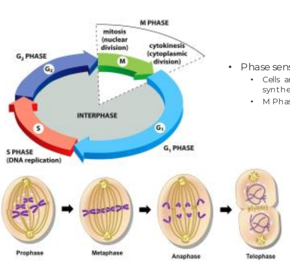

- Phase sensitivity
  - Cells are more radioresistant when synthesizing DNA
  - M Phase is most radiosensitive

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Radiation As A Carcinogen

- What is a Tumor?
  - Mass of undifferentiated tissue growing amidst differentiated tissue
- What is Cancer?
  - Growth of one or more malignant tumors
- 3 Stage Model of Cancer Formation
  - Initiator – mutational event
  - Promoter – functional change
  - Progression – tumor invasion
- Radiation is a weak carcinogen because it acts only as an initiator.

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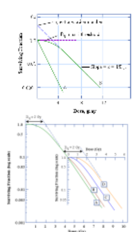
But It's More Complicated

- Elkind & Sutton (1959)
- Damage is dependent on
  - Type of Radiation
    - High LET vs. Low LET
    - Relative Biological Effectiveness
  - Dose Rate (DDREF)
  - Tissue Type
- Repair is dependent on
  - DNA Repair Enzymes
    - Some mechanisms are more error prone than others



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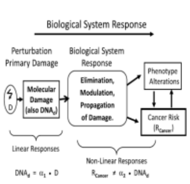
Other Considerations



- Bystander Effects
  - Unirradiated cells exhibit irradiated effects
- Adaptive Reponses at low doses
  - Repair mechanisms are "primed" to handle radiation insults
- Multiple Causation
  - Effects of multiple potentiators

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Types of Radiation Effects

Deterministic Effects (non-probabilistic)	Non-Deterministic Effects (probabilistic)
• A threshold dose exists • Erythema • Epilation • Dermal Necrosis • Radiation Dose is proportional to damage	• A threshold does (might) not exist - LNT • Most common non-deterministic effect is cancer • Non-Deterministic effects have a latency period • Radiation Dose is not proportional to damage

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- Repeated radiation exposure scans is not like chopping down a tree, where each axe blow weakens the tree until it finally topples with the last blow – that is a deterministic effect!

- A non-deterministic effect (i.e. cancer) is more akin to dodging a bullet. If the bullet misses, there is no harm done.

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Acute Radiation Effects

Radiation Effect	Threshold to Produce (rad)	Amount of Fluoroscopy to produce at 5 R/min	Amount of Cine to produce at 30 R/min	Time to Effect
Transient Erythema	200	0.7 hours	0.1 hours	24 hours
Epilation	300	1 hour	0.2 hours	3 weeks
Main Erythema	600	2 hours	0.3 hours	10 days
Dermal Necrosis	1800	6 hours	1 hour	>10 weeks

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Acute Radiation Effects In Action

6 – 8 weeks

On March 29, 1990, a 40-year-old male underwent coronary angiography, coronary angioplasty and a second angiography procedure (due to complications) followed by a coronary artery by-pass graft. Total fluoroscopy time estimated to be >120 minutes. The injury was described as "turning red about one month after the procedure and peeling a week later."

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Acute Radiation Effects In Action

16 – 21 weeks

At 16 – 21 weeks post procedure, the radiation induced injury appears to be healing.

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Acute Radiation Effects In Action

18 – 21 months

In fact, only the superficial dermal layers were able to heal while the deep dermal layers went untreated.

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Acute Radiation Effects In Action

18 – 21 months

Post skin grafting

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Acute Radiation Effects In Action

Example of an injury to the arm of a patient. The patient was draped for the procedure and the physicians did not realize that she had moved her arm so that it was resting on the port of the X-Ray tube during the procedure

Wagner LK, Archer BR. Minimizing Risks from Fluoroscopic X Rays 4th edition. The Woodlands, Texas Partners in Radiation Management, 2004.

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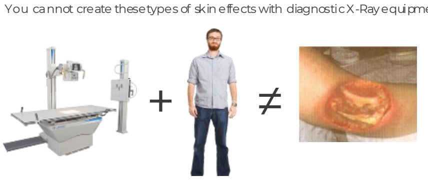
Note

You cannot create these types of skin effects with diagnostic X-Ray equipment



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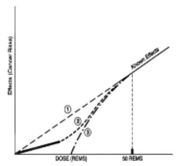
Linear No Threshold

- LNT states there is no known threshold and that any exposure to radiation will lead to an increase in risk, however small.



Biological Effects of Ionizing Radiation (BEIR) VII Report (2006)

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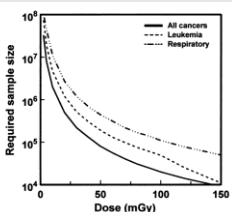
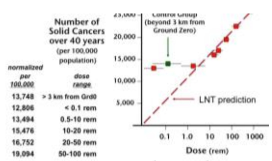
It's All In The Noise

The real issue with LNT is that we cannot see above the "statistical noise"





Putting Radiation Risk Into Perspective

	Male	Female
Risk of Developing Cancer	42.05%	37.58
Risk of Dying from Cancer	22.62%	19.13%

- Let's assume a LNT model
- For every 10 mSv (1000 mrem) increase in dose, there is a 0.1% cancer incidence increase

Dose above Bkgd	Chance of NOT getting cancer from radiation
0 mrem (mSv)	100% (Normal background radiation exposure)
100 mrem (1 mSv)	99.99% (Public dose limit)
500 mrem (5 mSv)	99.95%
1000 mrem (10 mSv)	99.90% (Abdominal CT scan)
5000 mrem (50 mSv)	99.5% (Radiation worker dose limit)
10000 mrem (100 mSv)	99.0%

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Consider the Following

- There is a small probabilistic risk that you will be involved in a car accident on your commute to work.

Would it make sense to add up all of the risk from previous commutes to determine your risk of commuting today? The number of previous commutes is irrelevant to your commute today.

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Other Issues with LNT

- Often does not consider benefit
- A "one size fits all" model
  - Cancer formation is a highly complex process
  - Does not account for variability in type of radiation insult or variability in biological systems
- Misapplication of ALARA to individuals and medical exposures

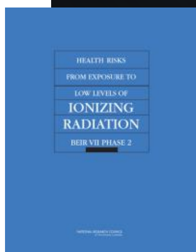
ALARA

- As Low As Reasonably Achievable
- Circa 1940's via Herman Muller
  - Experiments with Fruit Flies
  - Lowest dose with measurable response was 275,000 mrem
  - Data fit linear curve from 275,000 mrem to 10,000,000 mrem
- ALARA was never meant to be applied to patient exposures
  - It is a regulatory concept for occupationally exposed workers – 10 CFR 20.1101

Herman Muller

What Do The Experts Say?

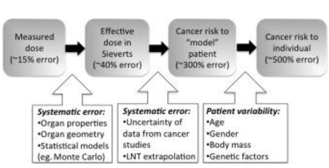
- BEIR VII, Phase 2
  - "At doses less than 40 times the average yearly background exposure – 100 mSv (10,000 mrem), statistical limitations make it difficult to evaluate cancer risk in humans"
  - BEIR VII supports, LNT but also states:
    - "The committee finds the linear no-threshold model to be a computationally convenient starting point..."



What Do The Experts Say?

- AAPM Position Statement
  - Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be nonexistent. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures.

Risk Get's Complicated



- Converting to effective dose and assessing risk is difficult at best
  - Based on estimates, assumptions, and models
  - High degree of variance

Radiation Doses from Medical Procedures

- Single Exposure Radiographs
  - All are <1 mSv

Procedure	Dose
Chest (PA)	0.02 mSv (2 mrem)
IVP (6 films)	2.5 mSv (250 mrem)
Barium Swallow (24 images, 106 sec fluoroscopy)	1.5 mSv (150 mrem)
CT Head	2 mSv (200 mrem)
CT Abdomen	10 mSv (1000 mrem)
Mammogram	0.13 mSv (13 mrem)
Nuclear Medicine Bone Scan	4.2 mSv (420 mrem)

NOTE: All procedures would be considered "low dose" (<100 mSv) according to BEIR VII and are below the threshold of known effects of LNT.

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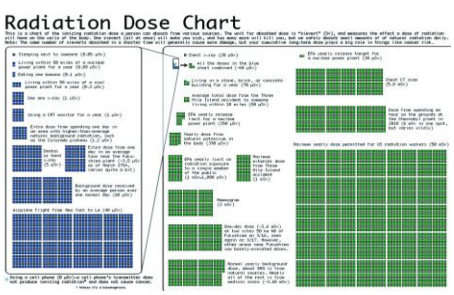

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Pregnancy and Radiation

- Radiation Induced Malformations
  - Threshold of 100 – 200 mGy
  - Fetal doses of 100 mGy are not reached even with 20 diagnostic X-Rays
- Pre-conception radiation has never been shown to increase risk of cancer or malformations in children
- Prenatal doses from most properly performed diagnostic procedures present no measurably increased risk of prenatal death or malformation.

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Final Thoughts

- Radiogenic risk can be a concern for both patients and staff
- A basic understanding of radiation biology can be beneficial in protecting patients and staff as well as serving as a model for alleviating potential concerns

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