Radiation Safety Update

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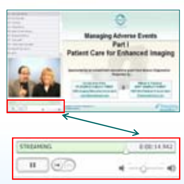
Outline

- Public perception (the media, gossip, the facts)
- Radiation safety basics
- Units of measure / conversions
- Exposure effects
- Dose response curves
- CT dose & dose calculation
- Factors affecting dose
- Dose reduction for patients
- Occupational dose



Navigation Information, for this video lecture

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Objectives

Upon completion of this course, the learner should:

- Recognize the public perception of radiation safety.
- Describe the basics of radiation safety.
- Identify the units of measure of radiation safety.
- Describe dose response curves.
- Identify CT dose descriptors.
- Demonstrate methods for reducing dose.
- Recognize occupational dose.

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Radiation Safety Update – Perception

- Public perception of radiation safety
- Risk comparison
- Radiation dose

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Where does the public get their perception?


Science

Radiation Overdoses from CT Perfusion Brain Scans Spark FDA Investigation

Print E-mail del.icio.us listen now

CT perfusion imaging devices are giving patients severe radiation poisoning

When you go in for a medical imaging procedure, you're typically made to understand that there's some risk involved. Even mild procedures like chest X-Rays expose you to small doses of radiation that minutely increase your cancer risk. More advanced procedures can come with larger risks.

One such procedure is the CT perfusion scan, which involves injecting an iodine tracer into the bloodstream and taking X-Rays for up to a minute of blood flow in the brain. The procedure is commonly used to

Alabama schoolteacher Becky Coudert had one of the scans and then experienced symptoms of radiation sickness -- hair loss, memory loss. She's

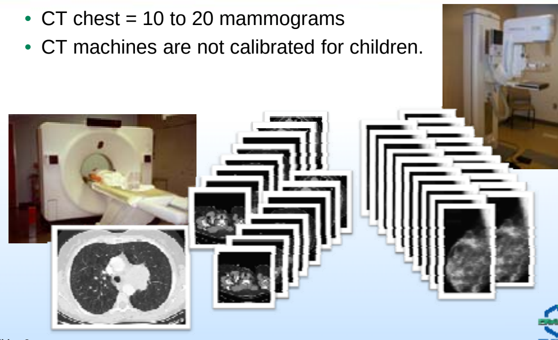
Slide - 6 http://www.dailytech.com/Radiation+Overdoses+from+CT+Perfusion+Brain+Scans+Spark+FDA+Investigation/article

Public Perception – From USA Today 1/22/01

- 1.6 million CT head & abdomen
- 1,500 will die from radiation induced cancer
- Doses are greater than those at three mile island

Public Perception – From USA Today 1/22/01

- CT chest = 10 to 20 mammograms
- CT machines are not calibrated for children.



Risk Comparison – Death Rate from Cancer

- Statistically … death rate for cancer is 20%.
- 10,000 = 2,000 die from cancer.
- We can estimate that 2,000 may die “mathematically” from cancer.
- We can’t say out of 2,000 who will really die from cancer.

Risk Comparison – Bio-effects Committee Risk of Death

- 10,000 and expose them to 1 rem
- Using the Biological Effects committee’s risk of death from 1 rem is 0.08%
- Linear threshold model
- 8 additional deaths
- 2008 people will die from cancer

Risk Comparison – With Exposure of 1 rem

- There is a risk that 8 additional people will die in a group of 10,000 if they all received 1 rem instantaneously.
- Risk can be looked at many different ways.
  - Number of days lost
  - 1 in a million chances of dying

Risk Comparison – Health / Environment vs. Radiation Exposure

- Overweight 15 % = 2 years
- Alcohol = 1 year
- All accidents = 207 days
- All natural hazards = 7 days
- 300 mrem/year = 15 days
- 1 rem/year = 51 days

1 in a Million

- Smoking 1.4 cigarettes (lung cancer)
- Spending 2 days in LA (pollution)
- Driving 40 miles (accident)
- Canoeing for 6 minutes
- Receiving 10 mrem of radiation (cancer)

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Psychology Model – Control

Control vs. no control

- Less fear of risk

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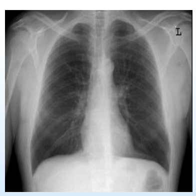
Psychology Model – Immediate vs. Chronic

More afraid of risk

- Accident vs. lung cancer

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Psychology Model – Natural vs. Man-Made

More afraid of risk

- Cell phone / electrical wires vs. sunshine


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Risk vs. Benefit – Medications & Side Effects

- All medications have side effects, including contrast agents.
- The administration of medications (and contrast agents) is a risk/benefit decision.
- All risk/benefit decisions are made by the physician.

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Imposed vs. Voluntary

- Voluntary recommendations
- Imposed restrictions

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Trust vs. Distrust

- Technologists informing
- Risk policies
- Credentials
- Certifications
- Accreditations

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Comparisons

Try to avoid "inappropriate" comparisons like …

The radiation from your CT scan is…
Like spending 3 hours in the sun !!!

The reality is…

- Airplane (altitude @ 39,000 feet) = 0.500 mrem/hr
- Coast to coast = 5 mrem … for a round trip flight
- Chest x-ray = 8-16 mrem
- Your body = 39 mrem/year

www.physics.isu.edu/radinf/risk.htm

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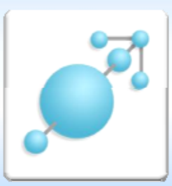
Radiant Reflection…



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Radiant Reflection…

Statistically, the death rate for cancer is:

a. 10%
b. 20%
c. 35%
d. 50%

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Radiant Reflection…

Statistically, the death rate for cancer is:

a. 10%
b. 20%
c. 35%
d. 50%

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 9 on the table of contents.
Remember, you are NOW on slide 23. Click slide 23 to continue with this lecture.

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Radiant Reflection…

The general public is typically more 'afraid' of ____________ than ______________ radiation.

a. Natural / man-made
b. Man-made / natural
c. Chronic / man-made
d. Controlled / man-made

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Radiant Reflection…

The general public is typically more ‘afraid’ of ____________ than ______________ radiation.

a. Natural / man-made
b. Man-made / natural
c. Chronic / man-made
d. Controlled / man-made

If you had difficulty answering this “Radiant Reflection” question correctly, or if you would like to re-review this concept: Click back to slide 14, 15, 16 on the table of contents. *Remember*, you are NOW on slide 25. Click slide 25 to continue with this lecture.

Radiation Safety Update – Measurements

- Exposure measurements
- Short term & long term effects
- Radiation characteristics

Radiation Quantities & Units of Measurement

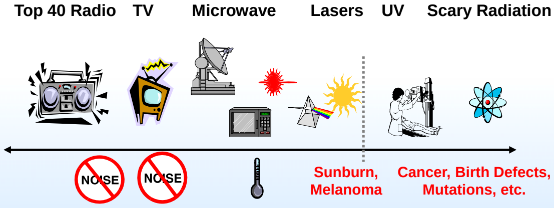
Quantity	Traditional Unit	SI Unit
Exposure in air	roentgen (R)	C/kg
Absorbed dose	rad	gray (Gy)
Dose equivalent	rem	sievert (Sv)
Radioactivity	curie (Ci)	becquerel (Bq)

Radiation Safety Basics

- Short-term health effects
- Long-term health effects
- Limits on exposure
- Radiation protection

Officials Warn People to Stay Indoors Within 30-Kilometer Radius

Electromagnetic Spectrum



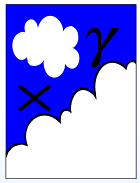
Characteristics of X-rays

- Invisible
- Highly penetrating
- Electrically neutral
- Poly-energetic
  - In the past
  - Today homogeneous for CT (filtered)
- Give off heat as they pass through matter
- Travel in straight lines at the speed of light

- Cause certain materials to fluoresce
- Cannot be focused by a lens
- Cause ionization
- Affects photographic film
- Produces scatter radiation
- Causes biologic changes

Radiation Measurement Units – Roentgen (R)

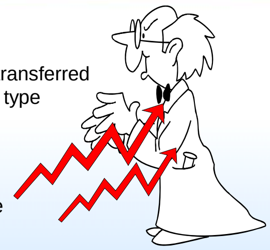
- REM
  - Units used in the United States (US)
- SI unit = c/kg
  - Scientific International Units
  - Used other than in the US
- Exposure in air only
- Measured in STP
  - Standard Temperature & Pressure
- Measures electrons liberated by ionization
- Measures X-ray and gamma and their interactions with air
- One R is the photon exposure that produces, under STP, a total positive or negative ion charge of 2.58×10^{-4} coulombs per kg of dry air.



Measurement in air

Radiation Absorbed Dose (rad)

- SI unit = Gray (Gy)
- Energy deposited in matter
- Amount of radiant ENERGY transferred to an irradiated object by any type of ionizing radiation
- 1 rad = 100 ergs/gram
- Unit of kerma
- Absorbed dose is responsible for biological damage in tissues exposed

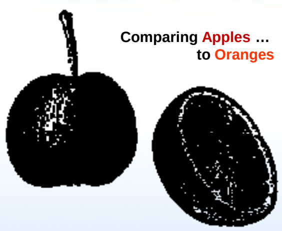

Measurement of Absorption Energy Deposited

Radiation Equivalent *in* Man (rem)

- SI unit = Seivert (Sv)
- Unit of dose <u>equivalent</u>
- Accounts for differences in biologic effectiveness of different radiations
- Quality factors (QF)
- Interrelationship of units:

  rem = rads X QF

Comparing Apples … to Oranges



Monitored Dose Equivalency Allows for the Comparison of Apples to Oranges

Quality Factors

- Factors assigned to different radiations to compare their ability to produce biological damage
- rad X QF = rem
- Higher the QF, the more biological damage for a given dose (higher **Relative Biological Effectiveness (RBE)**)
- Higher **Linear Energy Transfer (LET)** radiations have a higher QF
  - Alpha (α)= 20
  - Fast neutrons = 20
  - Thermal neutrons = 5
  - Beta (β) = 1
  - Gamma (γ) = 1
  - X-ray = 1

Equivalent Dose

- A quantity that attempts to take into account the variation in biological harm produced by different types of radiation.
- Used to report doses (rem or Sv)
- Enables the calculation of effective dose equivalent

Effective Dose Equivalent

- Dose that takes into account the dose for all types of ionizing radiation to organs or tissues in the human body
- Utilizes the overall harm done to different tissues or organs using the weighting factor to determine the risk of radiation induced cancer and genetic effects
  - Looks at how sensitive the tissue or organ is as well as how much of what type radiation it received

<u>**Weighting Factors:**</u>

<u>**0.01**</u>
Bone Surface
Skin

<u>**0.05**</u>
Bladder
Breast
Liver
Esophagus
Thyroid

<u>**0.12**</u>
Bone Marrow
Stomach

<u>**0.20**</u>
Gonads

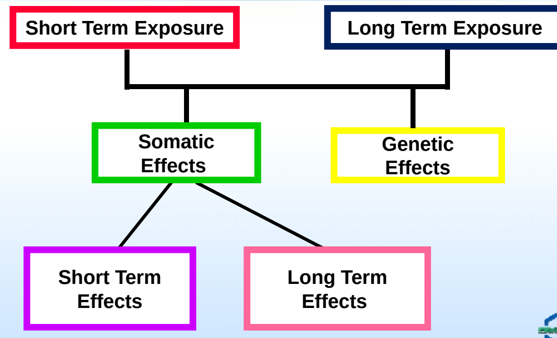
Radiation Unit Conversions

- rad to mrad
  - # rad x 1000 = mrad
- mrad to rad
  - # mrad/1000 = rad
- rem to mrem
  - # rem x 1000 = mrem
- mrem to rem
  - # mrem/1000 = rem

- rad to Gray
  - # rad/100 = Gray
- Gray to rad
  - # Gray x 100 = rad
- rem to Seivert
  - # rem/100 = Seivert
- Seivert to rem
  - # Seivert x 100 = rem

United States uses rad & rem…
Seivert & Gray the rest of the globe.

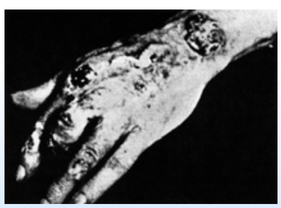
Exposure Effects



Stochastic Effects

Probability of an effect (not the severity) is a function of radiation dose.

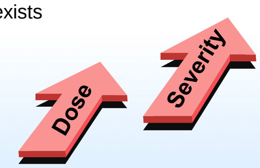
- No threshold
- Examples:
  - Cancers
  - Leukemia
  - Genetic effects



Exposed to large quantities of radiation (acute **radiation sickness**)

Non-Stochastic Effects

- Effects for which the **severity** of the effect in affected individuals varies with the absorbed dose
- Increases in severity with increasing absorbed dose
- Usually a threshold dose exists
- **Deterministic effect**
- Examples
  - Erythema
  - Desquamation
  - Cataracts



Short Term Effects

- Quantity of radiation to which a person is exposed.
- Ability of ionizing radiation to cause ionization of human tissue.
- Amount of body area exposed.
- Which body parts are exposed.
- measurements have been made from persons exposed to the atomic bomb and/or the Chernobyl accident

Atomic Bomb

Chernobyl Reactor

Early or Acute Effects

- Erythema
- Inflammation
- Decrease in blood cell production
- Epilation
- Desquamation
- Temporary or permanent sterility

What was she thinking? Was she thinking?

The New York Times
"Radiation Overdoses Point Up Dangers of CT Scans"
Written by: WALT BOGDANICH
Published: October 15, 2009
http://www.nytimes.com/2009

Reproductive Effects

Male
- Depressed sperm count
  - 100 rads or less (1 Gy)
- Temporary sterility
  - Less than 200 rads (2 Gy)
- Permanent sterility
  - 500 rads or more (5-6 Gy)

Female
- Variable depending on stage
- Type of ova:
  - Immature – very radio-sensitive
  - Mature – little radio-sensitivity
- Genetic impact must not be forgotten!

Long Term Somatic Effects

- Take place in the individual exposed
- Cannot be passed on to future generations
- Can occur many months or years after recovery from a large dose of radiation

OR

- They may occur from small doses that did not result in any short term effects.
- Increased *probability* of developing certain diseases

Types of Long Term Somatic Effects

- **Carcinogenesis**
  - Radium dial painters
  - Radiation therapy for enlarged thymus in infants
  - Early medical radiation workers
  - Uranium miners
  - Radiation therapy for ankylosing spondylitis
  - Chernobyl survivors
  - Hiroshima/Nagasaki A-Bomb survivors
- **Cataractogenesis**
- **Non-specific life span shortening**
  - **Used to be thought that exposure would make you get a disease that you might be predisposed to … NO MORE.**

Genetic Effects

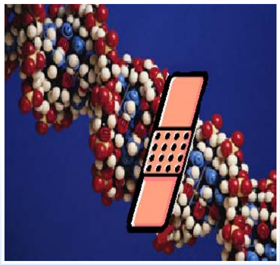
- Biological effects on generations not yet born, as a result of changes in the genetic materials of germ cells.
- Causes:
  - Spontaneous mutations
  - Mutations induced by a mutagen
    - Ionizing radiation
    - Chemicals
    - Viruses
- Most radiation-induced mutations are recessive

How does this occur? DNA Attack!

- Ionization / radiation
- Radiation / free radicals

DNA Attack!

- Repair mechanisms
  - Fix DNA damage
- May be overwhelmed
  - At high doses
  - Or high dose rates



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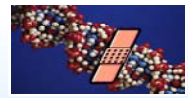
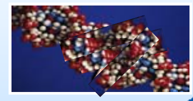
What happens to the cell?

- Nothing – DNA damage repaired in time, or is insignificant.
- DNA damage is significant and the cell dies … body can replace.
- DNA modification results in a heritable mutation, or cancer.





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Fractionation

- Fractionation is a division of the total dose of radiation into small doses administered at intervals.
- A radiation dose which is divided into smaller doses over time does less damage than if it is delivered all at once.

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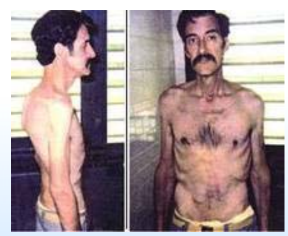
Late Effects

- Cancer
- Cataracts
- Genetic effects



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Cancer from Exposure to Radiation

- Patients treated with large radiation doses for diseases other than cancer had unusual incidence of leukemia (pre-war).
- Atomic bomb survivors also had unexpected excess cancer rates (1970's).
- Cancer effects studied continuously since 1945, National Academy of Sciences reports.

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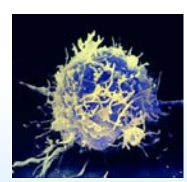
Relative Tissue Radiosensitivity

Most Sensitive

- Lymphocytes
- Immature germ cells
- Immature blood cells
- Skin
- Small intestine
- Muscle
- Adult nerve cells

Least Sensitive



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Radiosensitivity

Sensitive	Less Sensitive
Children	Adults
Epithelial Cells	Nerve Cells
Stem Cells	
Cancer Cells	

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Low Dose Effects

- For planning purposes, we assume that there is some risk, even at very low doses.

“ALARA”

As **L**ow **A**s **R**easonably **A**chievable

- Every reasonable effort is made to control radiation exposure.

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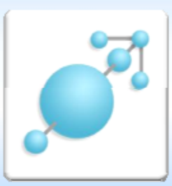
Radiant Reflection…



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Radiant Reflection…

Absorbed dose of radiation is measured in units of:

a. Roentgen (R)
b. Rad
c. Rem
d. Curie (Ci)

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Radiant Reflection…

Absorbed dose of radiation is measured in units of:

a. Roentgen (R)
b. Rad
c. Rem
d. Curie (Ci)

If you had difficulty answering this “Radiant Reflection” question correctly, or if you would like to re-review this concept: Click back to slide 27 on the table of contents.
Remember, you are NOW on slide 59. Click slide 59 to continue with this lecture.

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Radiant Reflection…

The Acronym ALARA stands for:

a. As Low as Reasonably Achievable
b. As Low As Roentgen Allows
c. A Loud Assignment Rem Activity
d. Acronym Listing As Radiation Activates

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Radiant Reflection…

The Acronym ALARA stands for:

a. **As Low as Reasonably Achievable**
b. As Low As Roentgen Allows
c. A Loud Assignment Rem Activity
d. Acronym Listing As Radiation Activates

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Remember, you are NOW on slide 61. Click slide 61 to continue with this lecture.

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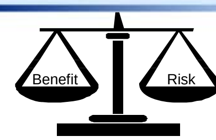
ALARA

- **A**s
- **L**ow
- **A**s
- **R**easonably
- **A**chievable



Benefit vs. Risk

Keep benefit high by providing optimal images.

Keep risk low by practicing good radiation protection.

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ALARA continued…

- Based on the assumption that radiation can cause harm, and any exposure should be kept as low as possible.
- Concept similar to standard precautions
- Provide radiation protection because a harmful effect MAY occur.

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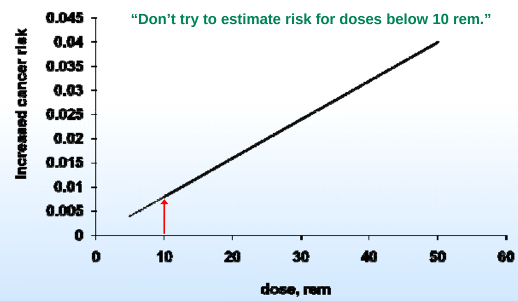
Low Dose Effects



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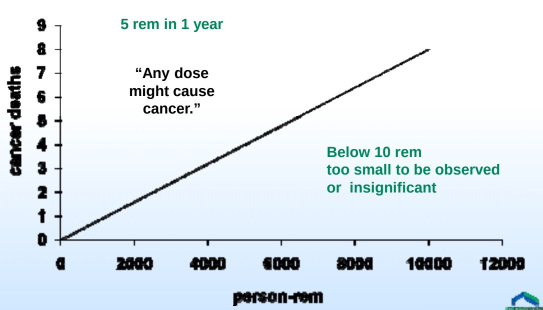
Linear Hypothesis



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Low Dose effects

- There is no useful bomb survivor data at low doses.
- There is no statistically significant cancer risk from doses less than 10 rem for exposed workers.
- Below 10 rem too small to be observed or insignificant
- People living in naturally high radiation background areas are not at increased risk for cancer.
  - Stochastic vs. non-stochastic effects
  - Somatic vs. genetic effects

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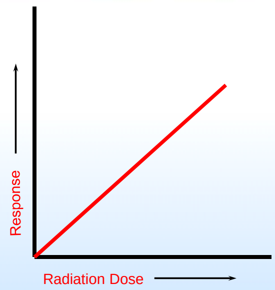
Linear, Non-threshold Dose Response Curve

- NO THRESHOLD FOR RESPONSE
- NO level of radiation exposure is absolutely safe.
- Used for genetic effects, stochastic effects and some somatic effects (cancer, leukemia).



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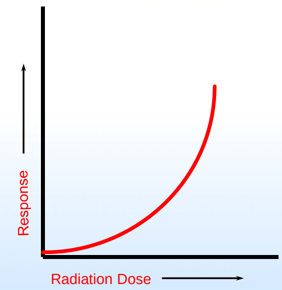
Non-Linear, Non-Threshold Dose Response Curve
Linear-Quadratic Dose Response Curve

- Includes elements of both linear and sigmoid dose response curves.
- Adverse health effects increase very slowly at low exposures, increasing more sharply for greater exposures.
- Assumes a proportional increase of risk at low levels, but not as high as suggested by pure linear dose response curve.



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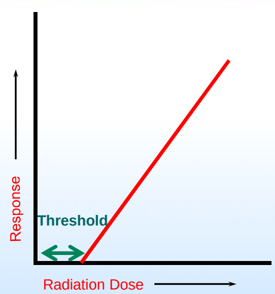
Linear, Threshold Dose Response Curve

- There is a dose at which no response will be seen.
- Correct for many short term somatic effects.
- Erythema, epilation, sterility



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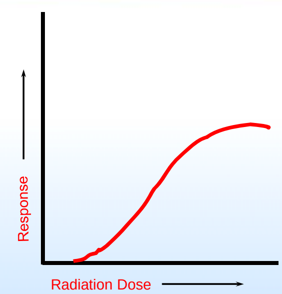
Sigmoid Dose Response Curve Threshold
(Nonlinear, Threshold)

- There is a threshold below which a response is not seen.
- This dose-response curve best fits short term somatic effects such as erythema.
- Would also be a good fit for cataracts.
- Not correct for genetic effects.



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Genetically Significant Dose (GSD)

- Potential genetic impact of the gonadal dose received by exposed individuals or children in future generations
- Rad per person?

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Radiation Safety Update
CT Dose Descriptors

Dose descriptors

- Computed Tomography Dose Index (CTDI)
- Multiple Scan Average Dose (MSAD)
- Isodose curves
- Dose Length Product (DLP)

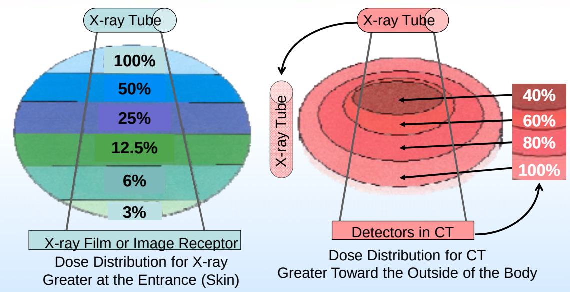
Slide - 72

Average Doses from Routine Studies

X-ray Exam	Kvp / mAs	ESE (mrad)	Gonad Dose (mrad)
Skull	76 / 50	200	Less than 1
Chest	110 / 3	10	Less than 1
C Spine	70 / 40	150	Less than 1
L Spine	72 / 60	300	225
Abdomen	74 / 50	400	125
Pelvis	70/ 50	150	150
Extremity	60/ 5	50	Less than 1

CT Exam	Kvp / mAs	ESE (mrad)	Gonad Dose (mrad)
CT Skull	125 / 300	3000	50
CT Pelvis	124 / 400	4000	3000

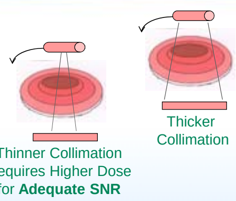
Dose Distribution – Radiography vs. CT



Artwork by Jeannette Harris

Factors Affecting Dose in CT

- Scanner type / beam geometry
  - SSCT scanners (conventional)
  - Spiral/helical volume scanners
- Collimation
  - Smaller collimation field…
  - Increase exposure factors to maintain SNR
- Pitch
- Patient position & scanned tissue volume
- Patient characteristics
- Length of area scanned

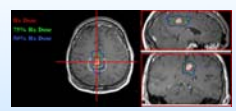


Radiation Dose Descriptors

CTDI
- **Computed Tomography Dose Index**
- Dose descriptor used in the Federal Performance Standard for CT scanners

MSAD
- **Multiple Scan Average Dose**
- The average dose at the center of a series of scans

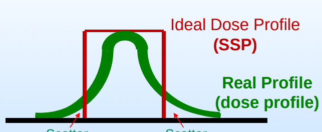
Isodose Curves



DLP
- **Dose Length Product**
- Includes MSAD, thickness and # of slices

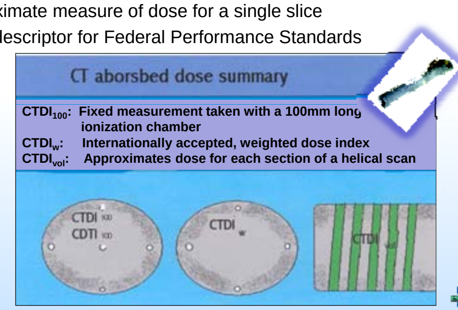
Single Slice Radiation Profile

- Slice sensitivity profile (SSP)
  - Describes reconstructed CT slice
- Dose profile
  - Actual 'slice' of tissue exposed is greater than width of the SSP
    - Must be taken into account when calculating dose



Computed Tomography Dose Index (CTDI)

- *Most commonly used dose descriptor*
- Approximate measure of dose for a single slice
- Dose descriptor for Federal Performance Standards



CTDI

Represents the dose to a location (e.g., depth) in a scanned volume from a complete series of slices.

- $CTDI_w$ approximates dose along the X and Z axes of the conventional, axial scan
- $CTDI_{vol}$ is based on $CTDI_w$ but takes into account the pitch of the helical scan

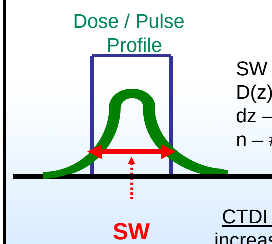
$$CTDI_{vol} = \frac{CTDI_w}{pitch}$$

As pitch increases, dose decreases.

Dose NOT consider total length of scan.

CTDI Formula Made Easy

$$CTDI = \frac{1}{n\text{-}SW} \int D(z)\,dz$$

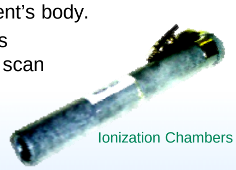


SW – slice width or thickness (in mm)
D(z) – dose distribution
dz – dimension along patient's axis
n – # of active arrays

<u>CTDI can be increased by:</u>
increasing radiation intensity
opening collimators at x-ray tube.

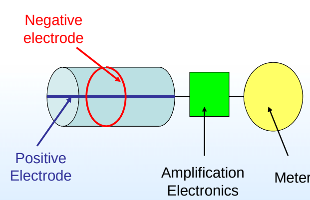
CTDI Measurement

- Measured by inserting an ionization chamber (dosimeter) into a phantom that mimics a patient's body.
- The CTDI phantom measurements are converted to an actual patient scan dose estimate.
  - Ionization chamber inserted into phantom measures Roentgen, which is then converted into cGy (centiGray).

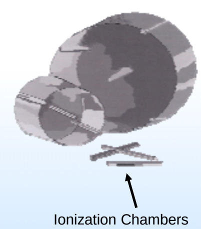


Equipment for Measuring Dose

<u>Ionization Chamber</u>



<u>CTDI Phantoms</u>



Artwork by Jeannette Harris

What Doesn't CTDI Do?

- CTDI is useful for both single slice scanners and spiral/helical scanners,

  but…
- A CTDI measurement does not tell us about the total radiation delivered to a patient because the total radiation delivered is proportional to the volume of tissue scanned.

Multiple Scan Average Dose (MSAD)

- The average dose at the center of a series of scans
- Directly proportional to scan time
- Increases with increasing kVp
  - Compared to average kVp of 120
  - @ 0.2 - 0.4 times less at 80 kVp
  - @1.2 - 1.4 times more at 140 kVp
- Increases slightly with decreasing slice thickness

Artwork by Jeannette Harris

Multiple Scan Average Dose (MSAD)

- Calculates average cumulative dose to each slice within the center of a multiple slice scan
- MSAD dose higher than single slice dose due to scatter contribution
- Beginning and end slices slightly lower dose due to lack of dose on the outer side
- Account for slice spacing [bed index – distance the bed (or table) travels during a CT acquisition] for conventional scanning
  - Overlapping slices increase dose, larger BI decreases dose
  - If slice thickness = BI, then CTDI = MSAD

Slide - 85

Multiple Scan Average Dose (MSAD)

- Need CTDI to calculate MSAD
- MSAD slightly overestimates radiation dose

$$\text{MSAD} = \text{CTDI}\ \frac{(\text{SW})}{(\text{BI})}$$

SSCT (conventional)

SW = slice width in mm
BI = bed index or slice spacing in mm

$$\text{MSAD} = \frac{\text{CTDI}}{\text{pitch}}$$

MSCT

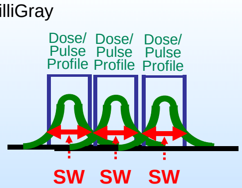
Pitch = $\frac{\textbf{table travel per rotation}}{\text{collimation}}$

As BI or Pitch increases – MSAD will decrease

Slide - 86

Estimation of MSAD

- Similar at iso-center and near surface for head scans
- Significantly less at iso-center than near surface for body scans
  - Typical MSADs for head scans: 40 - 60 mGy
  - Typical MSADs for body scans: 10 - 40 mGy
  - mGy = milliGray



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Dose Length Product (DLP)

DLP is a more realistic value for telling us about the total radiation for the area scanned.

DLP *(SSCT)* = MSAD x slice thickness (mm) x number of slices

DLP *(MSCT)* = $\mathbf{CTDI_{vol}}$ **x scan length**

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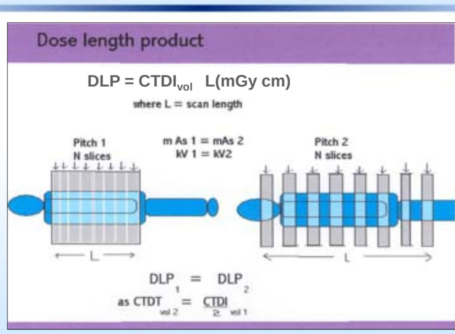
Dose Length Product (DLP)



Artwork by Jeannette Harris

Slide - 89

Scanner to Scanner

Is the dose the same?

- Recent assessments show wide variations.
- CTDI variations can vary from very small to fairly large, depending on body part and scanner configuration.

Xoran (Mini CT)

Philips (CT)

GE (PET CT)

Slide - 90

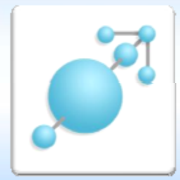
Dose Comparison

Dose Efficiency Index (DEI)

- Evaluating dose as a function of image quality
- Comparing scanners by comparing low contrast resolution performance and including CTDI measurements
- Specialized software

Slide - 91

Radiant Reflection…



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Radiant Reflection…

The unit of measure of CT dose, that is the average dose at the center of a series of scans is known as the:

a. CTDI – CT Dose Index
b. MSAD – Multiple Scan Average Dose
c. Isodose Curve
d. DLP - Dose Length Product

Slide - 93

Radiant Reflection…

The unit of measure of CT dose, that is the average dose at the center of a series of scans is known as the:

a. CTDI – CT Dose Index
b. MSAD – Multiple Scan Average Dose
c. Isodose Curve
d. DLP - Dose Length Product

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 84 – 85 on the table of contents.
Remember, you are NOW on slide 94. Click slide 94 to continue with this lecture.

Slide - 94

Radiant Reflection…

With respect to CTDI measurements, all CT scanners are created equally:

a. True
b. False

Slide - 95

Radiant Reflection…

With respect to CTDI measurements, all CT scanners are created equally:

a. True
b. False

CTDI variations can vary from very small to fairly large, depending on body part and scanner configuration.

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 90 on the table of contents.
Remember, you are NOW on slide 96. Click slide 96 to continue with this lecture.

Slide - 96

Radiation Safety Update –
Technique vs. Dose in CT

- Benefits of CT
- Risk vs. benefit
- Technique vs. dose
- Dose reduction
- Risk vs. benefit
- Technique & dose

Slide - 97

Low Contrast Resolution

- Critical component of CT image quality
- Ability of the scanner to show small differences or changes in tissue density
- Low contrast resolution is affected by the noise level which is greatly impacted by mAs, kVp, slice thickness, patient size, and particular algorithm used for the exam.
  - Many of the above affect radiation dose

Axial CT of the Chest
Displayed with Lung Windows

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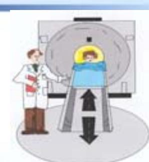
Technical Parameters

- Need sufficient penetration of the region of interest (ROI)
- Need adequate density
- Need adequate contrast between tissues
- Need adequate signal to noise ratio (SNR)
- Sufficient anatomy must be included.
- Techniques should be appropriate for the protocol/procedure, pathology and patient age.



Artwork by Jeannette Harris

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Effective Doses in Adults

Exam	Effective Dose (mrem)	Effective Dose (mSv)
Skull Series	5	.06
Chest	5	.06
L Spine	100	1.0
Pelvis	160	1.0 – 2.0
CT Head	200	1.8 – 2.0
CT Chest	700	6.0 – 7.0
CT Abdomen	900	9.0
CT Pelvis	900	9.0

mrem = milli-Rem   mSv = milli-Sievert

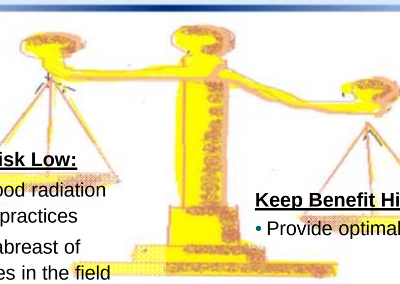
Slide - 100

CT on the Hot Seat!

- Are all these exams necessary?
- Can parameters be changed to reduce patient dose?
- Is multiphase scanning necessary for the indication of the procedure?
- What about kids?

Slide - 101

Risk vs. Benefit



Keep Risk Low:
- Use good radiation safety practices
- Keep abreast of changes in the field

Keep Benefit High:
- Provide optimal images

***Remember that the benefit should always *outweigh* the risk !**

Artwork by Jeannette Harris

Slide - 102

CT Dose Reduction

Decrease mAs		Decrease Dose
Decrease kVp		Decrease Dose
Decrease Volume Scanned		Decrease Dose
Decrease Slice Thickness (collimation)	Increase mAs (to decrease noise)	Increase Dose
Decrease Pitch		Increase Dose
Decrease Pixel/Voxel Size (increase detail)	Increase mAs (to decrease noise)	Increase Dose

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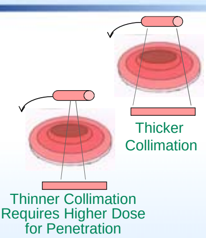
Factors Affecting Dose in CT

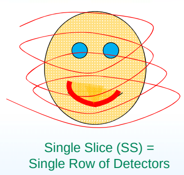
- Scanner type / beam geometry
  - Single slice scanners
  - Spiral/helical volume scanners
- Smaller collimation field:
  - Increase exposure factors to maintain SNR
- Pitch
- Patient position & scanned tissue volume
- Patient characteristics

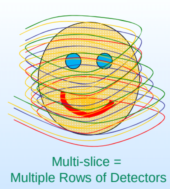


Slide - 104

Dose Comparison – SS Spiral vs Multislice

- Detector Technology
  - Single slice
  - Multi-slice
- X-ray Spectrum
  - mA
  - kVp
- Tube filtration
- Multiphase scans





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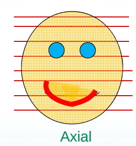
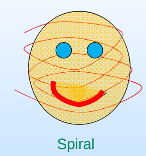
Dose Comparison – Axial vs Spiral

Spiral / Helical vs. Conventional

- Tube currents are set to lower values than in conventional CT.
- Need for retake single scans is largely eliminated in spiral/helical CT.
- No need to perform overlapping scans.
- Pitch values >1 can be used to reduce radiation dose.
- Gapless scanning
- Motion artifacts reduced





Slide - 106

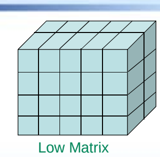
Reducing Radiation Dose

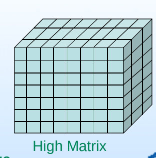
- General methods for practicing ALARA:
  - Reduce multiphase scanning
  - Optimize protocol for each patient
    - mA
    - kVp
    - Slice thickness
    - Pitch
  - Scan indicated region only
  - Shielding
  - Automatic Tube Current Modulation (ATCM)
  - *Image Gently*™ campaign for pediatrics

Slide - 107

Pixels and Voxels

- Decrease pixel / voxel size for the field of view (FOV)
  - Increase resolution
  - Increase patient dose, since technique is increased to optimize penetration
- Common image matrix sizes:
  - 256 x 256
  - 512 x 512
  - 1024 x 1024



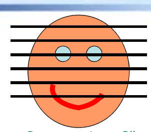


Matrix = Number of pixels to make up the image

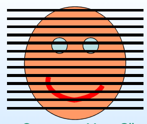
Slide - 108

Collimation & Slice Thickness

Single Slice CT (SSCT):
- Collimation
  - Pre-patient collimator defines slice thickness (ST) in z-axis
  - Greater collimation = thinner slice thickness
  - Dose typically increased to preserve SNR
- Slice Thickness
  - Thin slice thickness requires increased number of slices with less interslice gap to preserve coverage
  - ST greater than image spacing = overlapping scans



Less Coverage, Less Slices, Thicker Slices, Less Dose

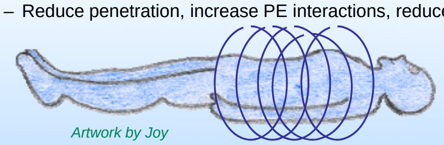


More Coverage, More Slices, Thinner Slices, More Dose

Slide - 109

Key Factors Directly Affecting Dose

Probably the most important parameters:
- mAs
  - Increase mAs, increased dose, increase signal
- Pitch
  - Increase pitch, reduce dose, decrease spatial resolution
- Length of scanned area
  - Increased scan area, increased dose
- kVp
  - Reduce penetration, increase PE interactions, reduce dose



Artwork by Joy

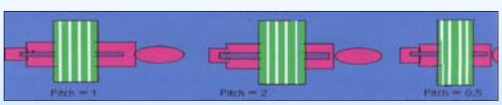
Slide - 110

Pitch

<u>Single Slice:</u> ratio of distance (L) the tabletop travels for 1 complete rotation of the x-ray tube to the x-ray beam collimation (related to the bandwidth (BW)).

<u>Spiral/Helical:</u> the distance (in mm) that the CT table moves during 1 revolution of the x-ray tube.

Pitch Ratio = distance tube travels <u>during 360^0 revolution</u> slice thickness or beam collimation



HINT:
Dose is always inversely proportional to pitch. If pitch is increased, dose is reduced.

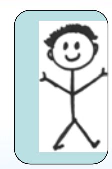
Artwork by Jeannette Harris

Slide - 111

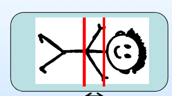
Length and Position

- Patient position
- Length of area scanned

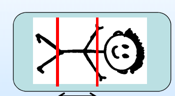
Patient Centered



Patient Off-center



Small Area of Coverage



Larger Area of Coverage

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Automated Tube Current Modulation (ATCM)

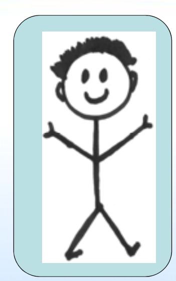
- Main goal of ATCM is to reduce dose, while maintaining image quality
  - Single tube current (mA setting) is not appropriate for an entire scan series
  - Modifies the tube current in the:
    - Z axis (longitudinal modulation) – or –
    - X and Z axes (angular modulation)

Artwork by Jeannette Harris

Slide - 113

Limitations of ATCM

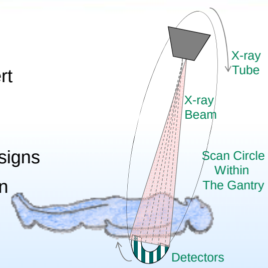
- ATCM only refines the mAs selected; settings include:
  - Selected mAs
  - Maximum "ceiling"
  - Minimum "floor"
- ATCM is not always effective with the very small patient.
- Optimal centering of the patient is important for the effectiveness of ATCM.



Slide - 114

Improved Use of the X-Ray Beam

- MDCT- Multi-Detector CT
  - Multiple detectors
  - Designed to capture & convert photons into CT images
- An issue with MDCT
  - Limitations: With detector designs
  - Results: Poor signal detection
- MDCT Improvements
  - New detector designs
  - Designed to capture & convert photons that are being missed due to the beam geometry & detector configuration.

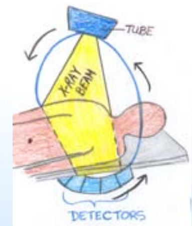


Detector Technology

- Type of detector
  - Solid-state
  - Gas-ionization chambers

Solid State Detector
Efficiency: 90% - 99%

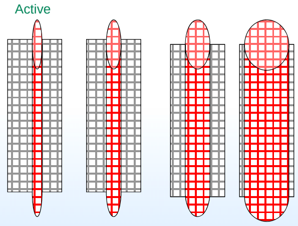
Xenon Detector
Efficiency: 50% - 60%



Detector Efficiency

Efficiency = ability of the detector to:
- Capture
- Absorb
- Convert

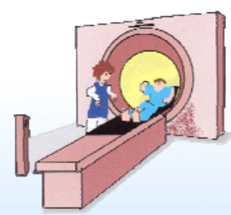
photons to electrical signals.



Total Signal = Capture X Absorption X Conversion Efficiency

Detector Stability, Response Time, & Dynamic Range

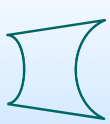
- Stability:
  Steadiness of the detectors; if not stable, signals not useful
- Response Time:
  Speed of detector
  (should be microseconds)
- Dynamic Range:
  The ratio of the largest to smallest signal that can be discriminated or detected



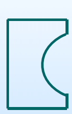
Artwork by Jeannette Harris

CT Filtration

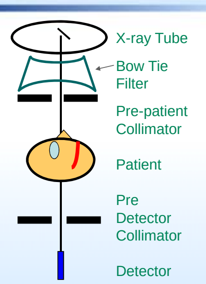
Filters
- Shape the beam
- Harden the beam
- Makes beam more uniform or homogeneous



Bowtie Filter



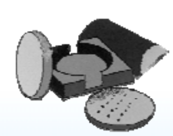
Alternate Type Filter



Configuration Of Components During CT Image Acquisition

Improved Filters

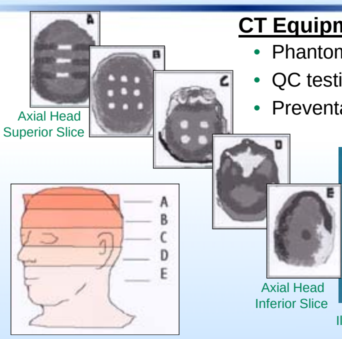
- Special noise reduction filters are available
- Processes raw data in segments, and then recombines the processed data
- Has good potential for pediatric dose reduction
- Noise reduction results in improved CT image quality
  - Improved quality = less repeats
  - Better SNR, that can be traded for better resolution



Spatial Resolution Phantom

Artwork by Jeannette Harris

CT Quality Control



Axial Head Superior Slice

Axial Head Inferior Slice

CT Equipment for QC

- Phantom imaging
- QC testing
- Preventative maintenance (PM)

Localizes Axial Slice Locations

Illustration of Head Phantom for CT

Artwork by Jeannette Harris

Slide - 121

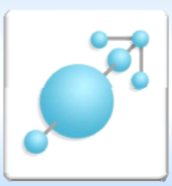
For example… Reducing Dose

- Increase the pitch to 1.5 or 2.0 when it will not compromise spatial resolution and the integrity of the study…
  - From a 1.0 to 1.5 pitch: results in a 25-33% reduction in dose.
  - From a 1.0 to 2.0 pitch: results in about a 50% reduction in dose.
- Tube current can be reduced 33% - 75% in many cases.
  - ATCM
  - mAs is the BEST method for reducing dose for CT & X-ray.
- kVp can be reduced.
- Bypass scout images of brain exams.
- Use a gantry angle of 20 degrees to the orbitomeatal line.
  - Reduces eye dose

Our pediatric patients are somebody's kids!

Slide - 122

Radiant Reflection…



Slide - 123

Radiant Reflection…

Low contrast resolution is affected by the noise level, which is greatly impacted by mAs, kVp, slice thickness, patient size and particular algorithm used for the exam.

a. True
b. False

Slide - 124

Radiant Reflection…

Low contrast resolution is affected by the noise level, which is greatly impacted by mAs, kVp, slice thickness, patient size and particular algorithm used for the exam.

a. <u>True</u>
b. False

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 98 on the table of contents.
Remember, you are NOW on slide 125. Click slide 125 to continue with this lecture.

Slide - 125

Radiant Reflection…

Detector efficiency is the ability of the detector to perform all of the following EXCEPT:

a. Capture
b. Absorb
c. Convert photons to electrical signals
d. Transmit x-ray beams

Slide - 126

Radiant Reflection…

Detector efficiency is the ability of the detector to perform all of the following EXCEPT:

a. Capture
b. Absorb
c. Convert photons to electrical signals
d. Transmit x-ray beams

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 117 on the table of contents.
Remember, you are NOW on slide 127. Click slide 127 to continue with this lecture.

Radiation Safety Update
Image Quality vs. Dose in CT

- CT image quality & dose
- Final tips for reducing dose
- Pediatric imaging
- Occupational exposure

CT Image Quality & Dose

- CT image quality is described in terms of…
  - Contrast
  - Spatial resolution
  - Image noise
  - Artifacts
- A strength of CT is … low contrast
  - Limited primarily by noise and is therefore closely associated with radiation dose
  - The higher the dose contributing to the image, the less apparent is image noise and the easier it is to perceive low-contrast structures.

CT exams are the highest dose exams in radiology.
It is critical to pay special attention to methods of dose reduction.
It is important to balance dose to image quality.

Controlling Radiation Exposure

- CT accounts for the greatest dose of all diagnostic medical examinations.
  - Up to 30 mSv
  - 10x background radiation exposure
- Some of which can, and should, be controlled.


Pediatric Patients

Therefore, we as technologists need to take an active role in minimizing CT dose, particularly in pediatric patients.

10 Ways to Reduce Unnecessary Patient Dose

1. Avoid… Unnecessary exams (or repeats)
2. Improve… Communication (with the patient, the doctor)
3. Practice… Beam limitation (technique optimization)
4. Improve… Positioning (compression, immobilization)
5. Optimize… Technique selection (improve quality)
6. Practice… Shielding (when possible)
7. Update… Image receptors (as needed)
8. Implement… Optimum grid type (as appropriate)
9. Employ… Filtration (when possible)
10. Know… Your system capabilities! (Always!)

Risk vs. Benefit for CT in Pediatrics

- Fast and accurate imaging reduces the need for sedation
- High quality images
- Non-invasive in most cases
- Risk is quite small to the individual when compared to the benefits derived **HOWEVER…**
  - The cells of children are far more rapidly dividing than those of adults.
  - Increased sensitivity to radiation exposure
  - Children have a longer life expectancy than an irradiated adult.
  - Increased risk of developing a cancer

"Risks of Radiation Induced Cancer"
Pediatric CT

A research study, conducted by Brenner, Elliston, Hall & Berdon

- Looked at the risk of radiation-induced fatal cancer from CT examinations of children.
- Study results suggested there is a significant increased lifetime radiation risk compared to the adult.

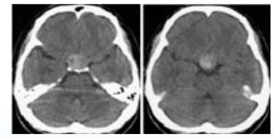
Slide - 133

Avoid Additional Scans

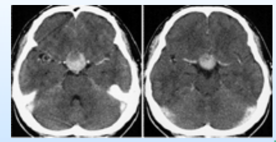
WHY?

- Most common reason is scans "with and without contrast".
- Are both necessary?
- Consider time interval between scans.
- Avoid repeats – do it right the first time!

Without Contrast



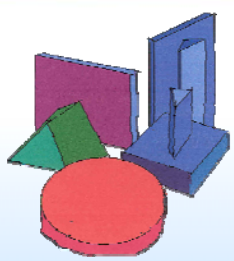
With Contrast



Slide - 134

Immobilization

- Reduce voluntary motion
  - Reduce poor quality scans
  - Reduce repeat scans
  - Repeats increase dose
- Things to use
  - Tape
  - Restraints
  - Sponge wedges & blocks
  - Sheets & pillows
  - Anything radiolucent



Sponge wedges & blocks

Artwork by Jeannette Harris

Slide - 135

Pediatric Immobilization Precautions

- Preserve circulation to extremities
- Airway obstruction
- Do not restrict respiration
- Secure patient from falling
- Avoid abrasion or tearing of skin
- Avoid excessive flexion or extension of neck

Handle with care!

Slide - 136

Patient Shielding in CT

- To shield or not to shield???
- Patients who should be shielded
  - All children
  - Patients who have a likelihood of reproducing (child bearing age)
  - Shield only when it will not interfere with the anatomy imaged – region of interest (ROI)
  - Shield front and back of patient
- Don't forget about shielding for somatic effects, when possible.
  - Breast, thyroid, lens of the eye
- Shield anyone who remains in the scan room

Slide - 137

Over-exposure is NEVER Acceptable!

- Unnecessary excessive dose often goes unrecognized.
- Quality of the CT exam is not typically compromised by factors such as increased tube current.
- No designated radiologic personnel to oversee imaging parameters and protocols relative to dose.

Adult Over-exposure

"Radiation Overdose from CT Perfusion Brain Scans Spark FDA Investigation"
Written by: James Mick
Published: December 17, 2009

http://www.dailytech.com/Radiation+Overdoses+from+CT+Perfusion+Brain+Scans+Spark+FDA+Investigation/article

Pediatric Over-exposure

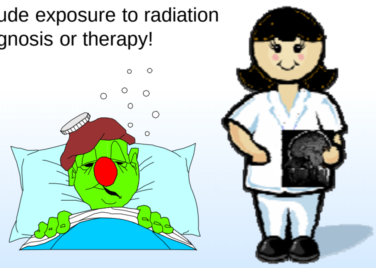
The New York Times
"Radiation Overdoses Point Up Dangers of CT Scans"
Written by: WALT BOGDANICH
Published: October 15, 2009

http://www.nytimes.com/2009

Slide - 138

Occupational Exposure

- For the healthcare worker
- Does NOT include exposure to radiation for medical diagnosis or therapy!



Slide - 139

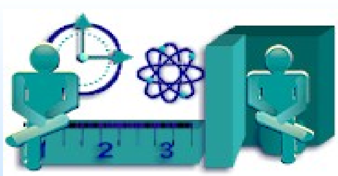
Dose Limits

Occupational workers (annual)	SI unit	vs. Traditional
Effective dose limit *(stochastic effects)*	50 mSv	5 rem
Equivalent dose limit for tissues and organs *(non-stochastic effects)*		
Lens of eye	150 mSv	15 rem
Skin, hands, feet	500 mSv	50 rem
Embryo - fetal exposures:		
Total DE limit for gestation period	5.0 mSv	0.5 rem
Dose Equivalent (DE) limit in a month	0.5 mSv	0.05 rem
Public Exposure		
Effective dose limit frequent exposure	1.0 mSv	0.1 rem
Effective dose limit infrequent exposure	5.0 mSv	0.5 rem
Education & Training (17 or under)		
Effective dose limit (stochastic)	1.0 mSv	0.1 rem

Slide - 140

Cardinal Rules of Radiation Protection

- Time
- Distance
- Shielding



Slide - 141

Cumulative Exposure Guidance

Old Formula - *before 1994*
- Maximum Permissible Dose
  MPD = 5(N-18)
  'rem bank'
- 25-year-old worker
  5 (25 - 18)
  5 (7)
  35 rem
- 50-year-old worker
  5 (50 - 18)
  5 (32)
  160 rem

New Formula
- Cumulative Exposure
  = 1 rem x N
- 25-year-old worker
  1 x 25
  25 rem
- 50-year-old worker
  1 x 50
  50 rem

Reduces allowable exposure!

Slide - 142

Holding Patients

- Try to avoid
  - Remaining on the scan room during the exposure
- Try to use 'straps or bands' to secure the patient during image acquisition.

Holding Patients

Safety straps / bands

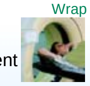
Slide - 143

Patient Shielding in CT

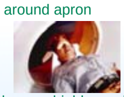
- Patients who should be shielded:
  - All children
  - Patients who have a likelihood of reproducing, (child bearing age)
  - Shield using bismuth shield when part of the ROI
  - Shield front and back of patient using lead when not in ROI
- Don't forget about shielding for somatic effects when possible
  - Breast, thyroid, lens of the eye
- Shield anyone who remains in the scan room

Wrap around apron

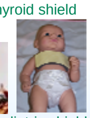
Thyroid shield



Breast shield



eye shield

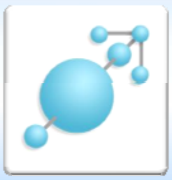


pediatric shield

Lead (Pb)
Aprons:
0.25 mm Pb - 0.5 mm Pb fluoro
Thyroid shields: 0.5 mm Pb
Gloves: 0.25 mm Pb
Glasses: 0.35 mm Pb
Gonadal shielding

Slide - 144

Radiant Reflection…



Radiant Reflection…

Patients who should be shielded include all of the following except:

a. All children
b. Patients who have a likelihood of reproducing (child bearing age)
c. Anyone who stays in the room during image acquisition
d. None of the above

Radiant Reflection…

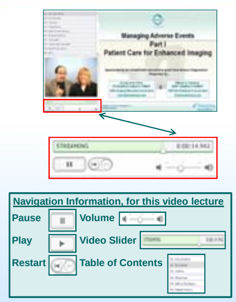
Patients who should be shielded include all of the following except:

a. All children
b. Patients who have a likelihood of reproducing (child bearing age)
c. Anyone who stays in the room during image acquisition
d. None of the above

If you had difficulty answering this "Radiant Reflection" question correctly, or if you would like to re-review this concept: Click back to slide 137 or 144 on the table of contents.
Remember, you are NOW on slide 147. Click slide 147 to continue with this lecture.

Outline

- Public perception
  (the media, gossip, the facts)
- Radiation safety basics
- Units of measure / conversions
- Exposure effects
- Dose response curves
- CT dose & dose calculation
- Factors affecting dose
- Dose reduction for patients
- Occupational dose



Objectives

Upon completion of this course, the learner should:

- Recognize the public perception of radiation safety.
- Describe the basics of radiation safety.
- Identify the units of measure of radiation safety.
- Describe dose response curves.
- Identify CT dose descriptors.
- Demonstrate methods for reducing dose.
- Recognize occupational dose.

Thank you for your attention!
Radiation Safety Update

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