Dose units and dosimetry

- Radiation Absorbed Dose
- Dose Equivalent
- Effective Dose Equivalent
- Collective Effective Dose Equivalent or Collective Dose
- Dose Rate

Radiation Units

<table>
<thead>
<tr>
<th>OLD</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roentgen (R)</td>
<td>Measure of air exposure</td>
</tr>
<tr>
<td>RAD</td>
<td>Measure of absorbed dose i.e. amount of energy absorbed from beam</td>
</tr>
<tr>
<td>REM</td>
<td>Allows for different biological effects of different types of radiation. Provides a common unit of DOSE EQUIVALENCE</td>
</tr>
</tbody>
</table>

CONVERSION

- 100 RAD = 1 GRAY (Gy)
- 100 REM = 1 Sievert (Sv)

Dose Equivalent

- Measures the Relative Biological Effectiveness (RBE) of different types of radiation - i.e. the damage caused by different types of radiation;
- Converts to a common unit

\[
\text{DOSE EQUIVALENT} = \text{RADIATION ABSORBED DOSE} \times Q
\]

\(Q=\text{Quality factor}\)

- X-rays, gamma rays \(Q = 1\)
- Neutrons \(Q = 10\)
- Alpha particles \(Q = 20\)

Effective Dose Equivalent or “Dose”

- Measure which allows doses from investigations of different parts of the body to be compared, by converting all doses to an equivalent whole body dose

\[
\text{Effective dose equivalent} = \text{Dose equivalent} \times W
\]

\(W=\text{weighting factor, i.e.}\)

- Testes, ovaries = 0.25
- Breast = 0.15
- Thyroid = 0.03

S.I. unit - Sievert (Sv); subunit - milliSievert mSv

Example of Effective Dose Equivalent or “Dose”

- Thyroid examination

Measured Radiation Absorbed Dose = 10 mGy

<table>
<thead>
<tr>
<th>Dose equivalent (Q = 1)</th>
<th>= 10 mSv</th>
</tr>
</thead>
</table>

Effective dose equivalent \(W = 0.03\) = 10 \(\times\) .03

\[
\text{DOSE} = 0.3 \text{ mSv}
\]
Low Dose Effects

- Principle effects are non-lethal changes in cells
- Usually occur at doses less than 10 cgy (rad)

Ionizing Radiation as a Mutagen (Weak)

- First shown by H.J. Muller in 1927
- Using fruit flies (won Nobel Prize)
- Radiation increases spontaneous mutation rate
- No evidence for a threshold

Radiation Carcinogenesis

Direct Damage: I

- DNA or RNA in a chromosome takes direct hit from x-ray photon
- Disrupting bonds between nucleic acids.
- May cause:
  - Cell death
  - Abnormal replication (cancer)
  - Failure of transfer of information i.e. protein synthesis

Direct Damage: II

- Somatic cells (non-reproductive) → radiation induced malignancy
- Genetic cells → congenital abnormalities

Indirect Damage

- 70% of cells is water
- Radiation + H₂O → H₂O⁺ + e⁻
- H₂O⁺ → H⁺ + OH⁻
- H₂O + e⁻ → H₂O⁻
- H₂O⁻ → H + OH⁻
- H and OH are free radicals
- H + H → H₂ (Hydrogen gas)
- OH + OH → H₂O₂ (Hydrogen peroxide)
- H₂ + H₂O₂ → Tissue damage
Indirect Damage (Summary)

- Irradiation results in ionization of tissues at the atomic level
- Ionization
  - Physical damage > atoms highly reactive
  - Chemical change > molecule now has different chemical structure
  - Biological function > changed or impaired

  Biological effect may result in cell damage

Somatic vs Genetic Radiation Effects

- Somatic: non-reproductive cells e.g. muscle, bone.
  - High doses > cataracts, reduced blood supply, cancer
- Genetic: Reproductive cells if damaged by radiation can produce congenital abnormalities

Radiation Effects at Tissue/ Organ Level

- If few cells die – no clinical change
- As dose increases, cell deaths increase → clinical changes
- Severity of changes are proportional to cell loss
- Short term: hypoplasia → atrophy
- Long term: changes related to blood vessel necrosis, fibrosis, stenosis, O₂ transport decreases

Radiation damage

- Additive with repeated exposures
- Repair processes may not be complete following initial exposure
- Subsequent exposures thus cause more damage

Laws of Bergonie and Tribondeau

Radiation response of tissues depend on:

- Number of cells in active proliferation
- Number of cells in differentiation
- Number of future divisions/mitotic future

Other factors:

- Also: Oxygen tension and the capacity of cells to repopulate.
Cell/tissue/organ types

- More sensitive to ionizing radiation
  - Embryonic cells
  - Rapidly multiplying cells – ex. Bone marrow, some blood cells, reproductive

Stochastic and non-stochastic effects

- Stochastic: Can occur at any dose
  ex. Cancer, mutations, genetic defects

- Non-stochastic effects: Effect is directly proportional to the radiation dose/dose rate.
  ex. skin erythema, cataract, whole body radiation syndromes etc.

Acute radiation syndromes

- Prodrome: subclinical
  - Hematopoietic
  - GIT
  - CNS

- Prodrome: subclinical
  - Loss of appetite
  - Nausea
  - Vomiting
  - Apathy
  - Listlessness
  - Fever, sometimes
  - Anemia
  - Diarrhoea

Hematopoietic syndrome

- Main tissue affected: Bone marrow
  - Threshold: 100 rad
  - Latent period: 2-3 weeks
  - Death threshold: 200 rads
  - Death time: 2-8 weeks

- Underlying pathology: Bone marrow atrophy:
  - Infection
  - Hemorrhage
  - Anemia

- Treatment: Blood/plasma/platelet transfusion; antibiotics; isolated environment and in severe cases, bone marrow transplant.

Gastrointestinal Syndrome

- Main tissue affected: Small intestine
  - Threshold: 500 rad
  - Latent period: 3-5 days
  - Death threshold: 1000 rads
  - Death time: 3 days - 2 weeks

- Underlying pathology: Depletion of intestinal epithelium and neutropenia from H. syndrome
  - Malaise, GI malfunction, anorexia, fever, nausea, vomiting, dehydration, diarrhoea, circulatory collapse, electrolyte imbalance etc.
CNS Syndrome

Main tissue affected: Brain
- Threshold: 2000 rads
- Latent period: 1/4 - 3 hours
- Death threshold: 5000 rads
- Death time: < 3 days: Usually 24-48 hrs.

Underlying pathology: Vasculitis, encephalitis, meningitis, edema
- Symptoms: Lethargy, tremors, convulsions, ataxia, coma

Background Radiation 3.6 mSv (360 mrem) per year

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon</td>
<td>55%</td>
</tr>
<tr>
<td>Cosmic</td>
<td>8%</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>8%</td>
</tr>
<tr>
<td>Internal</td>
<td>11%</td>
</tr>
<tr>
<td>Medical/artificial</td>
<td>18%</td>
</tr>
</tbody>
</table>

Is there a safe dose of x-rays?

- No.

Unproven assumption of no threshold dose but a linear relationship between dose and probability of damage.

Decision to Use Radiodiagnostic Procedures

Numerical Comparisons of Risks

RISK ESTIMATION, PROTECTION AND SAFETY
Basic question

What is the benefit to the patient from the radiographs you prescribe?

Patient benefit is directly linked to the diagnostic information provided by the radiograph.

Types of Ionizing Radiation

Electromagnetic and Particulate radiation:

- Electromagnetic radiation: pure form of energy with no mass; emitted in wave form.
- Particulate radiation: Constituted by sub-atomic particles that have mass, energy, and sometimes, charge;
  Eg. Alpha, beta (negative & positive), protons, neutrons etc. as in radioactive decay.

Electromagnetic radiation

X-rays: Formed from energy transfers involving electrons

Y-rays: From the nucleus when excess energy is emitted in the unstable state, interactions of nucleus with other particles in the region of the electrostatic field of the nucleus. Ex. Radioactive decay.

X and gamma radiation are penetrating radiation

Stopped by lead

Found in medical uses

Naturally present in soil and cosmic radiation

and are EXTERNAL HAZARDS
Ionizing Radiation can deposit energy in neighboring atoms resulting in the removal of electrons.

Non-Ionizing Radiation does not have enough energy to remove electrons from surrounding atoms.

Particulate radiation:

Alpha Radiation is only a hazard when inside your body (internal hazard)

Beta Radiation is a Skin, Eye and Internal Hazard

Neutrons have no charge & can penetrate deep

Alpha: $\alpha$
Beta: $\beta$
Proton: $p^+$
Positron: $^+\bar{e}$

Neutrons: $n^0$
UNSTABLE atoms emit energy

<table>
<thead>
<tr>
<th>low energy</th>
<th>high energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-ionizing</td>
<td>ionizing radiation</td>
</tr>
</tbody>
</table>

ALARA

As
Low
As
Reasonably
Achievable

Sources of human exposure to radiation

Background & manufactured radiation in the U.S. contributes 360 mrem per year

Manufactured sources of radiation contribute an average of 60 mrem/year

- Cigarette smoking – 1300 mrem
- Medical – 53 mrem
- Round trip US by air – 5 mrem per trip
- Smoke detectors – 0.0001 mrem
- Fallout < 1 mrem
- Building materials – 3.6 mrem

Altitude

- Higher the altitude, the more the exposure to cosmic radiation
- People in Denver, CO exposed to more radiation than Floridians, for example
Annual Dose Limits

<table>
<thead>
<tr>
<th>Region</th>
<th>Classified Workers</th>
<th>General Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Body</td>
<td>50 mSv</td>
<td>1 mSv</td>
</tr>
</tbody>
</table>

50 mSv per year OR 1 mSv per week (with two weeks of annual vacation)

Occupational exposure

- Dental Office (1988) 0.2 mSv per year (3 weeks background)\(^1\)
- World data for 1990-1994 show a mean annual occupational dose of only 0.06 mSv for dental workers (UNSCEAR, 2000)
- Dental personnel are not expected thus, to receive occupational exposures greater than recommended threshold for monitoring of 1 mSv per year.

Ref:

Instructions Concerning Prenatal Radiation Exposure

NCRP Regulatory Guide June 1999

- Pregnant worker should notify dentist in writing, the approximate date of conception
- Dentist must counsel worker that because of very low doses it is safe to continue working with x-rays

Dental rad studies on pregnant patients

- You may expose: if the benefits outweigh the risks
  - at any part of the pregnancy
- However, you should not expose anybody to ROUTINE x-ray exams (i.e every 6, 12 months …) including pregnant women
- Reassure the patient that there is minimal risk to the baby – use lead apron for reassurance
- Unless the primary beam is directed at the abdomen, lead aprons are not necessary.

RADIATION PROTECTION

PATIENT PROTECTION

- Radiographic selection criteria – avoids unnecessary exposures
- Use fastest film: currently, “F” speed, or better still, direct digital
- Use rectangular collimators
- Avoid retakes
- Do NOT need lead aprons with highest speed film and tight collimation; used only to alleviate patient concerns & to comply with policy

Benefits of Using Selection Criteria

- 43% reduction in number of intraorals ordered versus use of all FMX

Use Fastest Film Speed (if working with film)

- Kodak has "F" speed (20% less radiation than "E" speed)
- "E", in turn, needs 50% less than "D"

FILM SPEED AND RELATIVE EXPOSURE

Lead Aprons

- Not required by Federal or Florida State Laws since exposure so minimal, and possible cross infection hazard
- Can be offered for the patient's reassurance
- Many States still require their use but from tradition not science
- Similarly the ADA and UF handbook recommend their use

Reduction of exposure from Primary Beam

- Must use a collimator or beam limiting device - exit beam diameter max 2.75"
- Use a rectangular collimator to reduce exposure by 50%
- Or use a rectangular plug into round collimator to convert to rectangular

BEAM COLLIMATION
**PERIAPICAL EXAMINATION**

- Paralleling Technique
- Bisecting-Angle Technique

**Image Interpretation**
- Label the mount – name, date
- Check the dot position on film
- Mount the films in a dark mount
- View with a masked-out view box to preserve visual contrast sensitivity
- Magnifying glass, darkened room
- Know NORMAL anatomy

**Mounting and viewing radiographs**

**Viewing and interpreting radiographs**

**RADIATION PROTECTION FOR OPERATOR**
Radiation wall barriers & shields

- In general 2-3 sheets of plaster-board or 1/16” lead sheet
- Lead glass windows to view patient
- Consult health physicist for shield design

Operator must stand outside the room behind protective barrier

Operator position

Inverse Square Law

Radiation is reduced by the square of the distance

<table>
<thead>
<tr>
<th>Distance (feet)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose units</td>
<td>1</td>
<td>1/4</td>
<td>1/9</td>
<td>1/16</td>
<td>1/25</td>
</tr>
</tbody>
</table>

The operator should never hold the film in the patient’s mouth when the patient cannot hold it steady.

Monitoring radiation exposure

- Radiation dosimeters measure radiation dose to people.

Unnecessary for the average office
Not required by law as dosage is low
Government Regulations

- Federal
  - OSHA (Occupational Safety Health Administration) – staff
  - FDA (Food and Drug Administration) NEXT surveys of dental radiation exposures
  - NCRP (Nat Council of Radiation Protection)
- Florida State
  - Regulations, equipment registration, inspections

Dental Radiology State Regulations

State of Florida
Department of Health,
Control of Radiation Hazard,
Chapter 64E-5.506 Intraoral dental radiographic systems
Florida Administrative Code

pages 34, 35

Minimize Dose by Good Practices

- TIME - reduce time of exposure
- DISTANCE - increase distance
- SHIELDING - use shielding

Radiation equipment sticker

State of FL requires
"WARNING: This x-ray unit may be
dangerous to patient and operator
unless safe exposure factors and operating
instructions are observed."

Registration of X-ray equipment

- State of Florida requires registration of x-ray equipment
  when installed with an annual fee of $31 (1997) plus $11
  for each additional unit.
- Every 5 years the State will inspect equipment