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NOTES ON DENTAL SUBJECTS

IMPORTANT SYNOPSIS, TABLES AND FLOW CHARTS

- Oral Pathology
- Oral Medicine
- Oral Radiology
- Oral Surgery
- Periodontics
- Prosthodontics
- Conservative Dentistry
- Endodontics
- Pedodontics
- Orthodontics
- Oral Anatomy
- Oral Histology



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ORAL - RADIOLOGY

General

- X-rays were first developed by - **W. C. Roentgen, 1895**
- Concept of paralleling technique by -- **F. McCormack, 1920**
- The first intraoral X-ray was made by **Dr. Edmund Kells in 1896**
- Dr. C Edmund Kells (1880), also known as the Father of Dental Radiology.
- Only **Sir Rolling** had realized the possibility of radiation hazards and had advised certain precautions to be taken to prevent them and hence he is known as the **"Father of radiation protection".**
- Radiology is defined as study and use of radiant energy including Roentgen rays, radium and radioactive isotopes as applied to medicine and dentistry.
- **Roentgenology** is the study and use of Roentgen rays as applied to medicine and dentistry
- Radiography is the production of a photographic image of an object through the use of X-rays
- Radiation is the process of transfer of energy from one point to another in the form of electromagnetic waves eg. light, radio waves, X-rays etc
- X-rays are described as consisting of *wave packets* of energy. Each packet is called *a photon* and is equivalent to one *quantum* of energy. The X-ray *beam,* as used in diagnostic radiology, is made up of millions of individual photons
- X-rays are produced when energetic (high-speed) electrons bombard a target material and are brought suddenly to rest. This happens inside a small evacuated glass envelope called the *X-ray*
- **Ionization** is usually followed by emission of X-radiations; and excitation is followed by the emission of Visible or Ultraviolet radiations

Four types of particulate radiations are recognized :

- Electrons which may be classified as beta particles or cathode rays. They differ in origin only
  - Beta particles are fast moving electrons emitted from the nucleus of radioactive atoms.
  - Cathode rays are streams of high speed electrons that originate in an X-ray tube.
- Alpha particles are emitted from the nuclei of heavy metals and exist as two protons and neutrons, without electrons.
- Protons are accelerated particles, especially hydrogen nuclei, with a mass of 1 and a charge of +1.
- Neutrons are accelerated particles with a mass of 1 and no electric charge

Summary of the main properties and characteristics of radioactive emissions

Property	Alpha particles	Beta particles	Gamma rays	Beta' particles
Nature	Particulate - two protons and two neutrons	Particulate - electrons	Electromagnetic radiation - identical lo X-rays	Particulate - Positron, interects very rapidly with a negative electron to produce 2 gamma rays - annihilation radiation - properties as shown in adjacent column
Size	Large	Small	Nil	
Charge	Positive	Negative	Nil	
Speed	Slow	Fast	Very Fast	
Range in tissue	1-2 mm	1-2 cm	As with X-rays	
Energy range carried	4-8 MeV	100 keV-6 MeV	1.24 keV-12.4 MeV	
Damage caused	Extensive ionization	Ionization	Ionization - similar damage to X-rays	
Use in nuclear Medicine	Banned	Very limited	Main emission used	PET

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Electromagnetic radiation

- Can be defined as the propagation of wave like energy (without mass) through space or matter.
- The energy that is propagated is accompanied by oscillating electric and magnetic fields positioned at right angles to one another.
- These are man- made or occur naturally.
- Electromagnetic radiations are arranged according to their energies in what is termed electromagnetic spectrum.
- Electromagnetic radiations are believed to move through space as both a particle and a wave; hence an explanation of the characteristics of electromagnetic radiation requires a dualistic theory.
- The amount of energy in an electromagnetic radiation depends on the wave length and frequency.

Properties of Electromagnetic Radiations

- They travel through space in a wave motion along a straight line.
- They have neither mass nor weight nor electrical charge.
- They travel at the speed of light, in a vacuum, i.e. 3×10^8 m/sec or 186,000 miles / second.
- As they travel through space they give off an electric field at right angles to the path of propagation and a magnetic field at right angles to both (the path of propagation and electric field).
- They transfer energy from place to place in quanta (photons).
- In passing through matter the intensity of radiation is reduced (attenuation) both because energy is taken up by the material (absorption) and some energy is deflected from its original path to travel in a new direction (scattering).
- In free space the electromagnetic radiation obey the inverse square law, which states that, for a point source, the radiation intensity (I) at any place varies inversely as the square of the distance (d) from the source to the place at which the intensity is being considered.
- $I = k/d^2$ (Where, k is a constant, I = Intensity, d = distance
- All electromagnetic radiations have a measureable frequency and wavelength but different temperature and energy
- All electromagnetic radiations are invisible to the naked eye, with the expectation of those falling within the range of the visible spectrum.

Hertzian waves are used by high altitude transmission satellites, and have a wavelength, 10^{16}Å to 10^{13}Å.

Short wave diathermy or microwaves have wave lengths from 3×10^{-2} m to 3×10^{-4} m; these overlap the wave lengths of the communication waves on one end and infra red waves on the other end.

X-rays are divided into four types depending on their wave lengths:

- 1-2 Å - Grenz of Super Soft X-rays, mainly used to treat superficial lesions and in crystalogy.
- 1-0.5 Å Soft X-rays, mainly used in contact therapy.
- 0.5-0.1 Å-Medium X-rays, mainly used in diagnostic and superficial therapy.
- Å-Hard X-rays, mainly used for deep X-ray therapy and for industrial roentgenography.

Gamma rays

- High powered X-ray, having a wavelength of 0.001Å.

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- These are electromagnetic radiations, but their source is from the radioactive decay process.
- They have shorter wave length and greater penetrating power and are used in the treatment of tumors, e.g. Radon needles or seeds which are implanted at the tumor site, radioactive iridium in nylon threaded seeds, percutaneous radio-tantalum wire implants, etc.

The ultraviolet spectrum can be divided into three groups based on the wave lengths:

- Between 200 and 290 nm, short or germicidal UV rays or UVC, these can cause genetic mutations, altered reproductive cycles and cell death.
- Between 290 and 320 nm, middle or erythemal UV rays or UVB, these can cause skin erythema and are commercially available as sun or mercury vapor lamps.
- Between 320 and 380 nm, long or black light UV rays or UVA, on its own it is not damaging but when used with sensitizing chemicals, it can cause extensive biological damage.
- Cosmic rays these have the shortest wave length, 0.0001Å.

Laser light

- Has four characteristics that distinguish it from the light produced from other sources, like the electric bulb and the sun.
- Laser light is highly directional and travels in a narrow beam, the sides of which stay almost parallel.
- Laser produces coherent light that is it has only one frequency.
- Laser light is of a single color.
- Laser light is very bright, powerful with very high intensity.
- **Advantages**
  - Causes less pain thereby reducing need for anesthesia.
  - Minimizes bleeding and most surgical procedures done with lasers do not require sutures, because the high-energy light beam aids in clotting (coagulation) of exposed blood vessels thus inhibiting blood loss.
  - Bacterial infections are minimized and wound heals faster. The high energy beam sterilizes the area worked on.
  - Damage to surrounding tissue is minimized. Wounds heal faster.
- **In dentistry two types of lasers are used:**
- Soft Tissue Laser (800-990 nm), e.g. Argon soft tissue laser, CO_2 Laser.
- Hard Tissue Laser (2500-3000 nm), e.g. Er : YAG Dental laser system, Erbium hard tissue laser.

Components of the body arranged in order of their power to absorb x-rays, starting from the lowest value.

1. Air
2. Fat
3. Soft tissues, blood, body fluids
4. Medullary bone
5. Cancellous bone
6. Cortical bone
7. Dentin and cementum
8. Enamel

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PHYSICAL PROPERTIES of X-RAYS

1. X-rays belong to a family of electromagnetic radiations having a wavelength between 10 Å and 0.01 Å.
2. They travel through space in a wave motion.
3. In free space they travel in a straight line.
4. They travel with the same speed as that of visible light (i.e. 1,86,000 miles per second).
5. As they travel through space, they can produce an electrical field at right angles to their path of propagation and a magnetic field at right angles to the electric field.
6. They are invisible to the eye and cannot be seen; heard or smelt (they remain undetected by the human senses).
7. They cannot be focused by a lens.
8. They cannot be reflected, refracted or deflected by a magnet or electric field as they do not possess any charge.
9. They show the properties of interference, diffraction and polarization, similar to that of visible light.
10. They do not require a medium for propagation.
11. X-rays are pure energy, no mass and they transfer energy from place to place in the form of quanta (photons). (E = hv).

Property of attenuation and absorption

- when passing through matter the intensity of radiation is reduced (attenuation) both because radiation energy is taken up by the material (absorption) and some is deflected from the original path, to travel in a new direction (scattering).
- **Attenuation depends upon;**
  - Thickness of the object : Thickness increases, attenuation also increases.
  - Atomic number or density of the object : Atomic number increases, density increases, attenuation also increases.
  - Photon energy of the electron : Photon energy increases, there will be decrease in attenuation for the given object.
- Absorption -- when passing through any object the X-rays are differentially absorbed (i.e. there is conversion of their kinetic energy into energy of the absorber electrons). The degree of absorption depends on the atomic structure or density of the matter and the wavelength of the X-rays.

X-rays are produced by the collision of electrons with tungsten atoms. The collisions which occur are of two types, thus giving rise to two types of spectra:

- Continuous Spectra (General Radiation, Bremsstrahlung Radiation or Braking Radiation).
  - The incoming electron penetrates the outer electron shell and passes close to the nucleus of the tungsten atom.
  - The incoming electron is dramatically slowed down and deflected by the nucleus with a large loss of energy, which is emitted in the form of X-rays.
  - The amount of deceleration and the degree of deflection determines the amount of energy lost by the bombarding electron and hence the energy of the resultant emitted photon has a wide range or spectrum of energies and therefore called Continuous Spectrum.
- **Characteristic Spectrum or Line Spectrum :**
- The incoming electron collides with an inner shell tungsten electron, displacing it to an outer shell (excitation), or displacing it from the atom (ionization), with a large loss of energy and subsequently the orbiting tungsten electrons rearrange themselves to return the atom to neutral or ground state.
- This involves electron 'jumps' which results in the emission of X-ray photons with a specific energy called Characteristic Spectrum.

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- Characteristic radiation accounts for a very small part of X-rays produced in the dental X-ray machine and occur only at 70 kVp and above, because the binding energy of 'K' shell electron is approximately 70 kVp.

Classical / Coherent or Elastic Scattering / Thompson

- Process by which radiation is deflected without losing energy.
- X-rays when passing close to an atom causes the "bound electrons" to vibrate momentarily at a frequency equal to that of the incident photon.
- The incident photon then ceases to exist.
- The vibration causes the electron to radiate energy in the form of another X-ray photon of the same frequency and energy as that in the incident beam.
- Usually the secondary photon emitted is at an angle to the path of the incidental X-ray.
- In short, the direction of the incident X-ray has been altered, usually low energy photons undergo coherent scattering.
- At energy levels employed in diagnostic radiology, the effect of coherent scattering is negligible in production of fog.

The clinical significance of photoelectric absorption

- Depends on the fact that the frequency of photoelectric interaction varies directly with the third power of the atomic number of the absorber.
- For example, because the effective atomic number of compact bone (Z = 13.8) is greater than that of soft tissue (Z = 7.4), the probability that a photon will be absorbed by a photoelectric interaction in bone is approximately 6.5 times ($13.8^3/7.4^3 = 6.5$) greater than in an equal thickness of soft tissue.
- This difference is readily seen on dental radiographs as a difference in optical density of the image.
- It is this difference in the absorption that makes the production of radiographic image possible.

- **Phosphorescent materials** : These materials continue to emit light for period of time after the X-ray absorption has taken place. This is called 'afterglow' and it is used in the advertisement hoardings and lightings.
- **Fluorescent materials** : Here the emission of light is instantaneous, quickly completed following X-ray irradiation. This property is used in Intensifying screens and Mass Miniature Radiography (photo fluorography).
- **Thermoluminescent materials** : These emit visible radiations during or after irradiation of X-rays but only if heated to a few 100 degrees centigrade. This is used in comparative dosimetry and TLD badges.

The final shadow density of any object is affected by:

- The specific type of material of which the object is made
- The thickness or density of the material
- The shape of the object
- The intensity of the X-ray beam used
- The position of the object in relation to the X-ray beam and film
- The sensitivity of the film

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Overall image quality and the amount of detail shown on a radiograph depend on:

- Contrast — the visual difference between the various black, white and grey shadows
- Image geometry — the relative positions of the film, object and X-ray tubehead
- Characteristics of the X-ray beam
- Image sharpness and resolution

The ideal X-ray beam used for imaging should be :

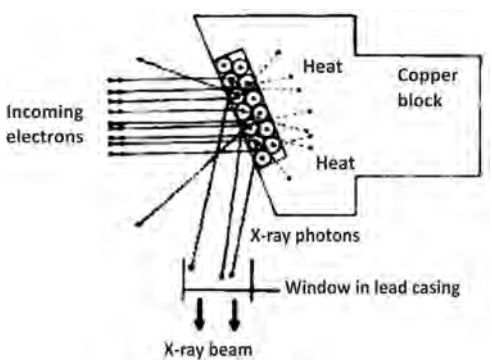
- Sufficiently penetrating, to pass through the patient and react with the film emulsion and produce good contrast between the different shadows
- Parallel, i.e. non-diverging, to prevent magnification of the image
- Produced from a point source, to reduce blurring of the edges of the image, a phenomenon known as the penumbra effect

The electromagnetic spectrum ranging from the low energy (long wavelength) radio waves to the high energy (short wavelength) X- and gamma-rays

Radiation	Wavelength	Photon energy
Radio, television and radar waves	3 x 10'm to 100μm	4.1 x 10^{-11}eV to 1.2 x 10^{-4}eV
infra-red	100 μm to 700 nm	1.2 x 10^{-4}eV to 1.8 eV
Visible light	700 nm to 400 nm	1.8 eV to 3.1 eV
Ultra-violet	400 nm to 10 nm	3.1 eV to 124 eV
X-and gamma-rays	10 nm to 0.01 pm	124 eV to 124 MeV

Main features and requirements of an X-ray tube

- The *cathode* (negative) consists of a heated *filament* of tungsten that provides the source of electrons.
- The *anode* (positive) consists of a *target* (a small piece of tungsten) set into the angled face of a large *copper block* to allow efficient removal of heat.
- A *focusing device* aims the stream of electrons at the *focal spot* on the target.
- A high-voltage (kilovoltage, kV) connected between the cathode and anode accelerates the electrons from the negative filament to the positive target. This is sometimes referred to as kVp or kilovoltage peak
- A current (milli-amperage, mA) flows from the cathode to the anode. This is a measure of the quantity of electrons being accelerated.
- A surrounding *lead casing* absorbs unwanted X-rays as a radiation protection measure since X-rays are emitted in all directions.
- Surrounding *oil* facilitates the removal of heat



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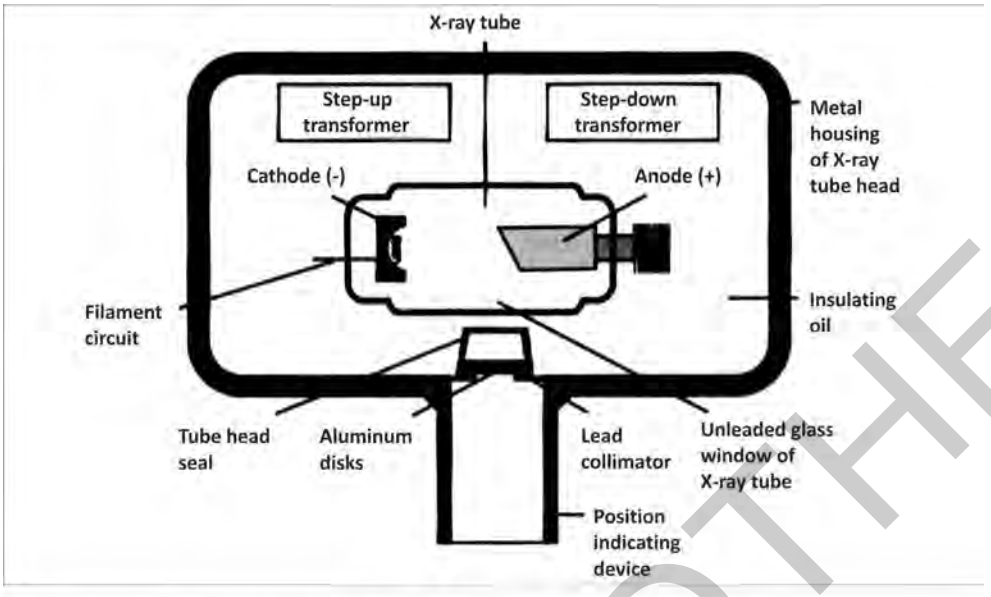

Schematic diagram of the dental X-ray tube head

Dental machines operating :

- At or below 70 kVp require a minimum total filtration of 1.5 mm of aluminum thickness.
- Above 70 kVp require a minimum total filtration of 2.5 mm of aluminum thickness.

The heat generated at the anode is dissipated by :

- Conduction – through the copper stem.
- Convection – through the oil surrounding tube.
- Radiation – through the radiator device attached to copper stem

Related Points :

- **Primary radiation** is the radiation emitted by the focal spot of the target.
- **Stray radiation** is the radiation emitted by any part of the X-ray tube other than the focal spot.
- **Useful beam** is that part of primary radiation which is allowed to emerge out through the collimating device.
- **Scattered radiation** is the radiation which has undergone a change in direction during passage through a substance.
- **Secondary radiation** is the radiation emitted by a substance through which X-rays are passing.
- The two X-ray-producing collisions result in the production of two different types of *X-ray spectra:*
  - Continuous spectrum
  - Characteristic spectrum
- The X-ray photons emitted by the rapid deceleration of the bombarding electrons passing close to the nucleus of the tungsten atom are sometimes referred to as B*remsstrahlung* or *braking-radiation*

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- Low-energy photons have little penetrating power and most will not exit from the X-ray tube itself. They will not contribute to the useful X-ray beam. This removal of low-energy photons from the beam is known as *filtration*
- The maximum photon energy possible (E max) is directly related to the size of the potential difference (kV) across the X-ray tube
- The photon lines are named K and L, depending on the shell from which they have been emitted. Only the K lines are of diagnostic importance since the L lines have too little energy.
- In X-ray equipment operating above 69.5 kV, the final total spectrum of the useful X-ray *beam* will be the addition of the continuous and characteristic spectra
- The diagnostic X-ray beam can vary in its *intensity* and in its *quality :*
  - Intensity = the number or quantity of X-ray photons in the beam
  - Quality = the energy carried by the X-ray photons which is a measure of their penetrating power.
- The factors that can **affect the intensity and/or the quality of the beam** include :
  - Size of the tube voltage (kV)
  - Size of the tube current (mA)
  - Distance from the target (d)
  - Time = length of exposure (t)
  - Filtration
  - Target material
  - Tube voltage waveform
- In practice, the target is inclined at an angle of 20^0 to the central ray of electrons. This causes the effective focal spot to be 1 mm x 1 mm, in contrast to 1 mm x 3 mm of the actual focal spot size. This results in a smaller source of X-rays and sharper image with a larger actual focal spot for effective heat dissipation. This is known as **"Line focus principle"** and the twenty degree angle is called as **"the angle of truncation".**
- Longer-wavelength X-rays sometimes referred to as *soft X-rays,* possess less energy and have little penetrating power. Shorter-wavelength X-rays possess greater energy and can therefore penetrate a greater distance
- **A collimator** is a metallic barrier with an aperture in the middle used to reduce the size of the x-ray beam and thereby the volume of irradiated tissue. Round and rectangular collimators are most frequently used in dentistry. Dental x-ray beams are usually collimated to a circle 2¾ inches (7 cm) in diameter. Use of collimation also improves image quality. Collimating the x-ray beam thus reduces the exposure area and thus the number of scattered photons reaching the film
- The focal spot is the area on the target to which the focusing cup directs the electrons and from which X-rays are produced. The sharpness of a radiographic image increases as the size of the focal spot decreases. The heat generated per unit target area, however, becomes greater as the focal spot decreases in size.
- There are four main interactions at the atomic level, depending on the energy of the incoming photon, these include :
  - Unmodified or Rayleigh scattering - pure scatter
  - Photoelectric effect - pure absorption
  - Compton effect - scatter and absorption
  - Pair production - pure absorption.
- Only two interactions are important in the X-ray energy range used in dentistry :
  - Photoelectric effect
  - Compton Effect.

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- **The important terms in Dosimetry** include:
  - Absorbed dose (D)
  - Equivalent dose (H)
  - Effective dose (E)
  - Collective effective dose or Collective dose
  - Dose rate.
- For X-rays, the radiation weighting factor (WR factor) = 1, therefore the *equivalent dose (H).,* measured in *Sieverts,* is equal to the *radiation-absorbed dose (D),* measured in *Grays*
- The biologically damaging effects of ionizing radiation are classified into three main categories :
  - Somatic DETERMINISTIC effects.
  - Somatic STOCHASTIC effects.
  - Genetic STOCHASTIC effects.

The somatic effects are further subdivided into :

- *Acute* or *immediate* effects — appearing shortly after exposure, e.g. as a result of large whole body doses
- *Chronic* or *long-term* effects — becoming evident after a long period of time, the so called *latent period* (20 years or more), e.g. leukemia

Dose	Whole body effect
0.25 Sv	nil
0.25 – 1.0 Sv	prodromal symptoms. slight blood changes, E.g. decrease in WBC count.
1 – 2 Sv	Mild hematopoietic symptoms. Vomiting in three hours, fatigue, loss of appetite, blood changes Recovery in a few weeks.
2 – 6 Sv	Severe hematopoietic symptoms. Vomiting in two hours, severe blood changes, loss of hair within two weeks, Recovery in one month to one year for 70%.
6 – 10 Sv	Gastrointestinal symptoms. Vomiting in one hour, intestinal damage, and severe blood changes. Death in two weeks for 80-100%.
> 10 Sv	Cardiovascular and central nervous System symptoms. Brain damage, coma, death.

LINEAR ENERGY TRANSFER (LET)

- It is the measure of energy released by the ionizing particle (such as a high speed electron).
- As LET increases, the biological effect of radiation increases.
- As the electron moves along its track, it decelerates till it comes to a stop.

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- The LET increases with the decrease in the speed of the electrons.
- This relation between the speed of the electrons and the linear energy transfer is referred to as Bragg effect.
- In general, the dose required to produce a certain biologic effect is reduced as the linear energy transfer (LET) of the radiation is increased.
- Thus, higher-LET radiations (e.g., α particles) are more efficient in damaging biologic systems because their high ionization density is more likely than x rays to induce double-strand breakage in DNA, Low-LET radiations such as x rays deposit their energy more sparsely, or uniformly, in the absorber and thus are more likely to cause single-strand breakage and less biologic damage.

Radiation effect on embryos and fetuses:

- Embryos and fetuses are considerably more radio-sensitive than adults because most embryonic cells are relatively indifferentiated and rapidly mitotic.
- The fetus of a patient exposed to dental radiography receives less than 0.25 mGy from a full mouth examination when a leaded apron is used.
- The most sensitive period for inducing developmental abnormalities is during the period of organogenesis, between 18 and 45 days of gestation. These effects are deterministic in nature.
- Irradiation during the fetal period (more than 50 days after conception) does not cause gross malformations.
- General retardation of growth may persist through life.
- There is also an increased risk for childhood cancer, (leukemia and solid tumors), after irradiation in utero.

Broad estimate of the risk of a standard adult patient developing fatal radiation-induced malignancy from various X-ray examinations (NRPB 1999)

X-ray examination	Estimated risk of fatal cancer
Dental Intraoral (x 2)	1 in 2 000 000
Dental panoramic tomograph	1 in 2 000 000
Skull (PA)	1 in 670 000
Skull (Lat)	1 in 2 000 000
Chest (PA)	1 in 1 000 000
Lumbar spine (AP)	1 in 29 000
Barium swallow	1 in 13 000
Barium enema	1 in 3000
CT chest	1 in 2500
CT head	1 in 10 000

Radiotherapy - the treatment of choice

Tumors of Limited Sensitivity in Assessable Sites

i. Carcinoma of the mouth, including tongue and lip
ii. Carcinoma of the skin (of face and hands)
iii. Carcinoma of the maxillary antrum
iv. Carcinoma of the ethmoidal sinus
v. Carcinoma of the middle ear
vi. Intrinsic carcinoma of the larynx

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- Equivalent dose (H_T) : It is used to compare the biologic effects of different types of radiation to a tissue or organ. It is the sum of the products of the absorbed dose (D_T) averaged over a tissue or organ and the radiation weighting factor (W_R);

  $H_T = \Sigma W_R \times D_T$

- Equivalent dose is expressed as a sum to allow for the possibility that the tissue or organ is exposed to more than one type of radiation. The radiation weighting factor is chosen for the type and energy of the radiation involved. Thus high-LET radiations (which are more damaging to the tissue than low-LET radiations) have a corresponding higher WR, e.g. the WR of; photon is 1; 5 keV neutrons and high energy protons is 5 alpha particles is 20.
- The unit of equivalent dose is Sievert (Sv).
- For diagnostic radiology 1 Sv equals 1 Gy.
- The traditional unit of equivalent dose was 'rem'.
- [Rem (Roentgen equivalent man) : it is the unit of dose equivalent. This unit is used to facilitate comparison between biological effects of exposure and various types of radiations. 1 Sv = 100 rem]

In intraoral radiography the mean skin exposure per single dental film is :

- 360 mR for peri-apical
- 325 mR for bitewing
- Studies have shown that the exposure to any specific area of the patients face is much less than the total radiation output at the tip of the cone.

Geiger counter

- This works on the principle of 'ionization by collision'.
- It is used to detect and record much smaller amounts of ionization than the ionization and thimble chamber, e.g. ionization caused by radioactive atom decay.
- This counter is also unable to discriminate between different radiations or different energies of the same radiation.

Dosimeter Placement

- Interpretation of the measured dose depends on the placement of the dosimeter.
- All personnel must wear their dosimeters correctly.
- The following list indicates where the dosimeters are to be worn:
  1. Film Badge with no TLD Badge : wear the film badge above any protective clothing at collar level.
  2. Film Badge with a TLD Badge : wear the film badge under the lead apron and the TLD above the apron at collar level.
  3. Ring Dosimeter : wear ring dosimeters so that the employee's name faces outwards.
- Do not expose personnel monitoring devices to extreme heat or humidity.
- **They are screened monthly.**
- Whole Body 125 mrem / calendar quarter
- Extremities 1875 mrem / calendar quarter

Position indicating device (PID)

- Or, open ended lead cylinder, that extends from the opening of the metal housing of the tube head also called the "cone".

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- The PID appears as an extension of the tube head and it aims and shapes the X-ray beam. There are three types of PIDs:
  1. conical
  2. rectangular
  3. round
- The conical PID appears as a closed, pointed plastic cone and when X-rays exit they penetrate the plastic and produce scattered radiation.
- Nowadays, lead lined rectangular or round PIDs are preferred as they do not produce scattered radiation.
- Both rectangular and round PIDs are available in two lengths:
  1. short (8 inches)
  2. long (16 inches)
- The long PID is preferred because less divergence of X-ray beam occurs. The rectangular type is most effective in reducing patient exposure.

Vaporization of the filament occurs over a period of time. When the particles vaporize (turn into gaseous form) they solidify on the glass of the X-ray tube, which is called 'sunburning' or 'sun-tanning' of the tube. This reduces the output of the X-ray tube, destruction of the vacuum and integrity of the tube, resulting in 'arcing' and ultimate tube failure. Thorium (a radioactive metallic element) is added to the filament material to make the tube last longer.

The Heel Effect

- The effective focal spot size may be decreased and the sharpness of the resulting radiographic increased, by continuing to reduce the angle of the anode with respect to the central ray. In practice however, this is limited by **'the heel effect'**.
- The intensity of the beam is not uniform across the exposure field, because the distance from the anode to a point on the film away from the perpendicular is greater than the center of the exposure field. (Inverse Square Law).
- This non-uniform distribution of photons contributes to the heel effect and is accentuated as the angle of the target is reduced. In dentistry as the size of the film is relatively small the heel effect is not seen.

Electric current may be :

- Direct current (DC) : When electrons flow in one direction only.
- Alternating current (AC) : Describes a current in which the electrons flow in two opposite directions.

Rectification: It is the conversion of alternating current to direct current.

Exposure Time

- Changing the time controls the duration of the exposure and thus the number of photons generated.
- When the exposure time is doubled, the number of photons generated at all energies in the x-ray emission spectrum is doubled, but the range of photon energies is unchanged.

Tube Voltage (kVp)

- Increasing the kVp increases the potential difference between the cathode and the anode, thus increasing the energy of each electron when it strikes the target.

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