CHAPTER
53

Applications of Isotopes in Medicine

CHAPTER AT A GLANCE

The reader will be able to answer questions on the following topics:

1. Isotopes.
2. Radioactive decay and half life.
3. Units of radioactivity.
4. Research applications.
5. Diagnostic applications.
6. Treatment applications.
7. Biological effects of radiation.

INTRODUCTION

Lord Ernest Rutherford (Nobel prize, 1908) put forward the nuclear theory of atom. Accordingly, the atoms are composed of a central dense positively charged *nucleus,* around which negatively charged *electrons* revolve. Subatomic stable particles are proton, neutron and electron.

Proton carries one positive charge ($+4.8 \times 10^{-10}$ esu) (esu = electrostatic unit). Proton is generally abbreviated as P^+. The nucleus of hydrogen contains only one proton. Therefore ionized hydrogen is otherwise called as proton. Although protons are said to be stable in the ordinary sense, in the cosmological sense, protons also decay. The half-life of proton is 10^{15} years. The body of a person contains about 10^{40} protons.

Neutron is abbreviated as 'n'. It carries no net charge. It has the same mass as that of proton. Protons and neutrons together constitute the nucleus of atoms. Therefore, the atomic weight of an element will correspond to the total number of protons and neutrons present in the nucleus.

Electron is generally abbreviated as e^- . It is negatively charged (-4.8×10^{-10} esu) and revolves around the nucleus. The mass of an electron is only 1/2000 of a proton. Electrons are the fundamental units of electricity. An electric current is produced by a stream of electrons.

Valency: Electrons are taking part in all chemical reactions. The electrons revolve around the nucleus at different energy levels or in shells. Sodium has the atomic number 11. It contains 11 electrons, distributed as 2 in K shell, 8 in L shell and the remaining 1 in M shell. The natural tendency for an atom is to completely fill up the shells with electrons. Hence sodium atom tends to lose the electron from the outermost shell, and exist as Na^+ ion. Similarly chloride contains 17 electrons, 2 in K, 8 in L and 7 in M shells. If one more electron is accepted by the atom, the outermost shell will be completed. Hence the tendency for chlorine to gain one electron to become ionized. Thus sodium can donate one electron and chlorine can receive it. This is the basis of the chemical reaction between sodium and chloride. In the above example, the valency of both sodium and chlorine is said to be one, because they exchange one electron.

ISOTOPES

Isotopes are the elements having the **same atomic number** (protons) but **different mass number** (varying number of neutrons). The Greek word "iso" means equal and "tope" means place; that is, isotopes occupy the same place in the periodic table. The accepted convention is that mass number is written on the upper left side of the symbol letters to denote the particular isotope. Atomic number may be shown on the left lower corner of the symbol.

For example, ^1H is normal hydrogen with 1 proton. It is present 99.985% of hydrogen ions in nature. ^2H is heavy hydrogen or **Deuterium**. It has 1p + 1n. It is present only 0.015% in nature. ^3H is **Tritium** with 1p + 2n. It is not present in nature, but

Ernest Rutherford
NP 1908
1871-1937

Wilhelm Rontgen
NP 1901
1845-1923

Antoine Becquerel
NP 1903
1852-1908

Willard Frank Libby
NP 1960
1908-1980

Pierre Curie
NP 1903
1859-1906

Marie Sklodowska Curie
NP 1903,1911
1867-1934

Frederic Joliot
NP 1935
1900-1958

Irene Joliot Curie
NP 1935
1897-1956

may be produced artificially. These three isotopes of hydrogen will react similarly in chemical reactions, because all of them contain only one electron.

To take another example, ^{16}O is normal oxygen, ^{17}O is unstable and ^{18}O is stable isotope.

Isobars are atoms having same mass number, but are having different atomic numbers, e.g. ^{14}C and ^{14}N.

Atomic Number and Atomic Weight

The number of protons (or electrons) in an atom will determine the **mass number** or its place in the periodic table. The presence of neutrons will add on the mass of the atom. The **atomic weight** or mass number is equal to the number of protons plus neutrons in the atom.

The atomic weight of chlorine is actually 35.457. When calculated from the theoretical "p + n", the value should be the round figure of 35. This difference is because, in nature, chloride is made up of atoms having mass numbers of 35 and 37, in approximately 3:1 ratio.

RADIOACTIVITY

Isotopes may be stable or unstable (radioactive), and the latter may be naturally occurring or artificially made. In the above example, Deuterium is stable, which will not alter its nuclear composition during passage of time. But tritium is unstable and will transform by nuclear decay. **The spontaneous degradation of nucleus** and transmutation of one element to another with consequent emission of rays or particles is known as radioactivity. Chemical reactions are based on the activity of electrons, while radioactivity is due to subnuclear components. Elements capable of undergoing radioactive decay are called **radionucleides**.

Antoine Becqueral was the pioneer in demonstrating spontaneous radioactivity (Nobel prize, 1903). Marie Curie and Pierre Curie were awarded Nobel prize in 1903 in physics, for their study on radiation phenomena. Marie Curie was awarded the Nobel prize again in 1911, but this time in chemistry, for the isolation of radium and polonium. In 1935, Nobel prize was awarded to Frederic Joliot (son-in-law of Madam Curie) and Irene Joliot (daughter of Curie) for artificial production of radioactive phosphorus from aluminium.

Radioactive Decay

1. Alpha Decay

When the alpha particle (2p + 2n) is released, the element changes, the atomic number is reduced by 2 and mass number is lowered by 4. For example,

$$\underset{88}{^{226}\text{Radium}} \rightarrow \underset{86}{^{222}\text{Radon}} + \underset{2}{^{4}\text{He}}\ (\alpha \text{ particle})$$

The nucleus of Radium, being unstable, emits 2 protons and 2 neutrons (one helium nucleus) to become Radon-222. The alpha particles will carry 2 positive charges and produce maximum ionization in their path. Thus they are **most damaging** to tissues. Alpha particles emitted have a high mass and therefore a high momentum. They do not travel far and can be stopped by a few layers of paper. However they collide with other molecules and cause a lot of damage, hence considered to be most hazardous. The alpha radiations are not useful in clinical medicine. In fact, radium needles are covered so that alpha particles are absorbed, before applying to tissues. If not, the radiation in the vicinity of the needle will be hazardously high. The penetration power being negligible, the alpha radiation is stopped even by a few sheets of paper (see Table 53.1).

2. Beta Radiation

When a neutron is split, one proton, one electron (beta particle) and one nutrino are generated. The element is changed to one having a higher number in periodic table.

Table. 53.1. Different forms of radiation

Type of radiation	Composed of	Mass	Charge	Ionization ion pairs per cm of travel in air	Range in air	Stopped by	Application
Alpha	2p+2n	4	+2	20,000	3 -8 cm	Few sheets of paper	Radiation hazard
Beta	e^-	negligible	-1	100	15-100 cm	Few sheets of aluminum	Research/diagnosis
Gamma	electromagnetic waves	Nil	0	1	100 m	Few cm thick lead	Diagnosis/treatment

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + e^{-} + \text{nutrino}$$

One neutron from carbon is changed to a proton. Therefore mass remains the same, but the element is changed with one number more in atomic number. The electrons thus emitted become the beta rays. So they are negatively charged. Since their mass is negligible, they can penetrate more distance. But they can be absorbed by metal sheets. The interaction with matter is less. Tritium (^{3}H) gets converted to helium on losing a beta particle. These beta particles have low velocity and tritium is said to be a soft beta emitter. ^{32}P on the other hand has more kinetic energy is a hard beta emitter.

3. Gamma Radiation

While alpha and beta radiations are particles, gamma radiation is in the form of **electromagnetic waves**. Gamma ray has no mass and no charge, and therefore penetration power is maximum. It is now widely used for treatment of cancer cases. X-rays and gamma rays are similar electromagnetic waves (Table 53.1). But the former is less powerful (wavelength 100 A° to 1 A°), whereas gamma rays are more penetrating (wavelength 1A° to 1/1000 A°). The gamma radiation is produced by:

$$^{131}_{53}\text{Iodine} \xrightarrow{(-\beta)} {}^{131}_{54}\text{Xenon (metastable)} \xrightarrow{(-\gamma)} {}^{131}_{54}\text{Xenon}$$

The first part of the nuclear reaction is similar to the beta radiation described previously. Thus the element with one more proton is produced. Here the resulting xenon is at a metastable state. It will release further energy in the form of gamma irradiation within a fraction of second to form the stable xenon. A comparison of different forms of radiation is given in Table 53.1.

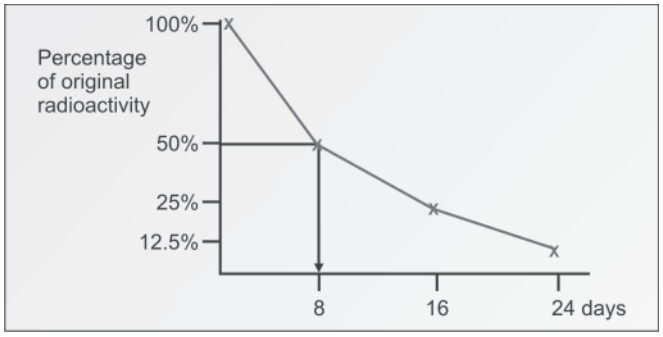

Fig. 53.1. Radioactive decay and half-life of ^{131}I

Half-life of Radioactivity

The radioactivity is halved within a fixed time. For example, if 100 mCi of ^{131}I is kept, after 8 days the activity is seen to be 50 mCi. The half-life of ^{131}I is 8 days (Fig. 53.1). **The half-life is the time taken for a radioactive isotope to become half of its original activity.** The rate of decay or the half-life is a constant for a particular isotope. A decay time of 7 half lives reduces the radioactivity to < 1% and that after 10 half lives is less than 0.1%. This is important in planning experiments and disposal of radioactive waste. Commonly used isotopes are listed in Table 53.2.

Units of Radioactivity

Originally the units used for expressing the radioactivity were Curie and Rads. But the present system uses SI units, Becqueral and Gray

Table 53.2. Commonly used radioisotopes

Element	Isotope	Approximate half-life	Major radiation	Important applications
Carbon	^{14}C	5600 years	Beta	Research in metabolism, carbon dating
Hydrogen	^{3}H	12 year	Beta	Research in cell biology
Phosphorus	^{32}P	14 day	Beta	Nucleic acid research, treatment for polycythemia
Chromium	^{51}Cr	28 day	Gamma	RBC kinetics in diagnosis
Iodine	^{125}I	60 day	Gamma	Radio immunoassay
Iodine	^{131}I	8 day	Gamma	Treating hyperthyroidism and thyroid cancer
Technetium	^{99}Tc	6 hour	Gamma	Blood flow experiments; gamma imaging
Radium	^{226}Ra	1600 years	Gamma	Interstitial implantation for treating cancer
Cobalt	^{60}Co	5.3 years	Gamma	Teletherapy for cancer
Caesium	^{137}Cs	30 years	Gamma	Teletherapy for cancer

1. Curie (Ci)

One Curie, abbreviated as Ci, is equivalent to 3.7 x 10^{10} disintegrations per second (dps) or 37 giga becquerals (gBq). This unit is used to measure the radioactivity of the source.

2. Becqueral (Bq)

Becqueral (Bq) is defined as decay per second,(dps). 1 Bq = 1 dps. It is often expressed as kilobecquerals (kBq). Since bq is very small and Curie very large, their multiples and submultiples are used to express radioactivity. 1 micro Curie = 37 mega Bq. In clinical practice, it is not the radioactivity of the source, but the effect produced in the tissue that is more important. Therefore for therapeutic purposes, the following units are used.

3. Rontgen (R)

It is the measurement of exposure dose. The radioactivity produces ionization in tissues. This is dependent on the quantity of radioactivity at the source, the distance from the source and the time of exposure. 1 R is the radiation which will give rise to 2 x 10^9 ion pairs/cc of air. One mCi source kept at a distance of 1 cm will produce 12.9 R/hour.

4. Rad and Gray

Rad is the absorbed dose by tissue. 1 Rad = 1.5 x 10^{12} ion pairs/g tissue. One Gray (Gy) = 10^7 ergs /kg tissue = 100 rads.

The biological effect of absorbed physical dose is expressed in Rads or Kilo Gray. Biological dose in SI units is expressed in Sievert (Sv).

5. Rem

It is the Rontgen equivalent in man; where absorbed dose of rads is multiplied by the quality factor of the type of radiation. The biological effect of 1000 rads given as a single dose or in divided doses will be different. This biological effect of radiation is expressed in Rem.

Applications of Radioactivity in Research

Isotopes of an element will have identical chemical reactions. Hence when a radiolabelled compound is administered, these molecules are metabolized by the body similar to normal molecules. This is called **Tracer technique.** Almost all biochemical research will utilise such tracer methods. A few examples are given below.

i. Almost all the **pathways** described in earlier chapters were studied by using tracers. For example, ^{14}C-labelled aceto acetic acid is shown to be incorporated into palmitic acid. Suppose labelled "A" is administered to an animal. After a few minutes, liver contains labelled "B" and after one hour, labelled "C" is seen in liver. Thus we can say that the pathway is A to B to C.

ii. The **turnover rate** of a substance in the body, that is, the rate of synthesis and breakdown could also be studied by tracer techniques. For example, if ^{131} I-labelled immunoglobulin is injected, the quantity of the labelled molecules in the circulation will be proportional to the catabolism of the Ig. By such methods, it is shown that the half-life of IgG is 15 days, of albumin is about 21 days.

iii. ^{32}P is useful to trace the nucleic acid synthesis *in vivo* and *in vitro*. It is therefore employed in genetic research. ^{3}H-labelled thymidine is incorporated in the newly synthesized DNA and therefore used in assessing cell division kinetics. ^{51}Cr is taken up by living cells and the label is liberated when the cell is lysed. Therefore it is used *in vitro* to quantitate the cell lysis by immunological or pathological mechanisms.

iv. The total body content of a particular substance (also designated as the "**pool**" of the substance) can be quantitated by the **isotope dilution technique.** To cite an example, 1 ml of ^{131} I-labelled albumin is seen to have 1 million dps. This is injected intravenously to a man. The radioactivity will be uniformly mixed in the total blood volume. After 10-15 minutes, a blood sample is withdrawn. One ml of blood is shown to have a radioactivity with 200 dps. The volume injected and removed is the same 1 ml, but the original count is now diluted 5,000 times. Thus the intravascular space is 5,000 times more than the volume injected. Therefore the blood volume is 5,000 ml.

v. Similarly extracellular volume (intravascular + interstitial spaces) is determined by ^{24} Na-labelled NaCl, and the total body water by means of ^{3} H-labelled water. From such experiments it is shown that intracellular compartment is 40%, interstitial compartment is 16% and intravascular volume is 4% of the total body weight (Chapter 30).

vi. ^{14}C is the most widely used isotope as a tracer in biochemical research, especially to study the pathways.

vii. Autoradiography for detection of specific nucleotide sequences (See Chapter 55). Radio labeling of nucleic acids by nick translation using ^{32}p.

viii. Irradiation of food for packaging is carried out under the strict provisions of food safety procedures prescribed by FDA and radiation protection agencies. The radiations that can be used for irradiating food are specified. These include gamma rays from sealed units ^{60}Cobalt and ^{137}Caesium.

ix. **Carbon dating** technique is an important tool in paleobiology, the technique was developed by Willard Libby who was awarded Nobel prize in 1960.

Applications of Radioactivity for Diagnosis

The branch of medicine that deals with the diagnostic applications of radioactivity is referred to as **Nuclear Medicine.** A quick and accurate diagnosis can be made by radioimaging of organs like thyroid, liver,

bone etc. In some cases radioisotopes are used in the treatment of neoplasms in these organs. Diagnostic uses of radioactive tracers are using gamma ray emitters. These are short lived isotopes linked to chemical compounds that permit the observation of specific physiological processes. They may be given by injection, inhalation or orally. The earliest application of radioisotopes was in the 1950s, ^{131}I for the diagnosis and treatment of thyroid disease

i. RBCs can be tagged with ^{51}Cr. These cells when injected back will remain in circulation till the RBC is lysed. Therefore **lifespan of RBC** and intravascular hemolysis, if any, may be detected.

ii. **Thyroid uptake studies** by ^{131}I are used to detect functional derangements of thyroid gland. About 15 mCi of ^{131}I is given intravenously. After a few hours, the patient is monitored at the neck region by a movable gamma-ray counter, which will pick up the radiation emitted by the thyroid gland. The normal values are about 25% uptake by thyroid within 2 hours and about 50% uptake within 24 hrs. In hyperthyroidism there will be increased uptake and hypothyroidism shows the reverse effect.

iii. **Thyroid scanning:** Twenty four hours after administering the dose of ^{131}I intravenously, the patient is placed under the scanner, which detects the radioactive emissions from the neck region. The actual distribution of radioactivity, with a picture of approximate size and shape of thyroid gland is produced. In hyperthyroidism, the increased radioactivity uptake is shown as heavily shaded areas. Sometimes the uptake of iodine is seen defective in certain circumscribed region of the gland, such a "silent nodule" is suggestive of cancer thyroid.

iv. **Bone scanning:** ^{90}Sr (radioactive strontium) is employed. Osteoblastoma (cancer arising from bone forming cells) could be detected very early by this method, even before the appearance of radiological changes.

v. **Kidney scanning** is done by injecting ^{131}I-labelled hippuran or ^{131}I-labelled diodrast. Both are excreted by kidney within a few minutes after injection. Anatomical and physiological defects in the renal excretion could be easily identified.

vi. **Technetium for blood flow studies:** Blood flow of heart could be analysed by ^{99}Tc (radioactive technetium). The half-life of ^{99}Tc is less than 6 hrs. The method is sometimes called "nuclear stethescope".

vii. **Positron emission tomography (PET) scan** is a more precise and sophisticated technique. Here the isotope is produced on the spot by a cyclotron. The emission of positrons and their combination with an electron resulting in the simultaneous emission of two gamma rays is detected by a PET camera. PET scan is widely used in Oncology with ^{18}F as a tracer. Combination of PET and CT (PETCT) improves the diagnostic accuracy. The abnormality may be either lesser uptake of the isotope by the organ (cold spot) or more uptake (hot spot). A series of images taken over a period of time will give specific patterns that indicate normal or malfunction of the organ concerned. An advantage over X-ray imaging is that both bone and soft tissues can be studied. The mean effective dose is 4.6 mSv per procedure.

viii. **Targetting:** A more recent use of radio nucleides is by tagging them to monoclonal antibodies so that they can be specifically targeted to tissues.

ix. **Radioimmuno Assays (RIA):** Assays using ^{125}I-labelled antigens are used to quantitate hormones, tumor markers and other biological substances present in blood in very small quantities. Details are given in Chapter 54. ^{125}I with a half-life of about 60 days is used for tagging the proteins *in vitro,* as in the case of RIA. Another isotope of iodine, ^{131}I with half-life of about 8 days is employed for *in vivo* purposes, such as thyroid scanning and for treatment purposes. The reduced half-life is advantageous *in vivo* to reduce the side effects of radioactivity to the patient.

Applications of Radioactivity in Treatment

Radioactivity is used for treatment of cancer. The radiations when absorbed by the tissues, produce ionization in the path. The nucleic acid in the cell is damaged, so that the next cell division is not possible. The radiotherapy is mainly affecting the cells in the division phase. Since cancer tissue contains more dividing cells than the normal tissue, cancer cells are preferentially affected by radiation. The radiotherapy may be classified as:

A. Unsealed Sources

These are radioactive substances kept in liquid form. The beta rays are the main effective radiation in these sources. For **thyroid cancer** and secondaries of thyroid cancer, ^{131}I (dose 50–100 mCi) is administered. Similarly, ^{32}P is used to treat **polycythemia vera**.

B. Sealed Sources

They utilise gamma irradiation. The source is applied on the cancer or sometimes implanted as a needle into the tissue.

Radium needles have the advantage of very long half-life. However during the decay, radioactive gas xenon is generated which may escape out if there is a leak in the covering. Because of this hazard, radium needles are now rarely used.

^{137}Cs (**caesium**) with a half-life of 30 years, is the preferred sealed source nowadays. Application of such sources directly on cancer tissue is called **Brachytherapy.** Intracavitary applications (for cancer of body of uterus, cancer of cervix uteri, cancer of vagina) and interstitial applications (buccal cancer, tongue cancer) are common.

Table 53.3. Effect of radiotherapy differs

Day	Dose in rads	Initial number of cells	Fraction of cells in division	No. of remaining cells	No. of cells killed
1.	400	$1x10^{10}$	10%	$9x10^{9}$	$1x10^{9}$
2.	400	$1x10^{9}$	10%	$9x10^{8}$	$1x10^{8}$
3.	400	$1x10^{8}$	10%	$9x10^{7}$	$1x10^{7}$
4.	400	$1x10^{7}$	10%	$9x10^{6}$	$1x10^{6}$

C. Teletherapy

The term "tele" means distant (as in the case of telescope, telephone, etc.). Here the source of radiation is kept at a distance from the patient. Historically, teletherapy started with deep X-ray. X-ray was discovered by Wilhelm Rontgen in 1895 (Nobel prize, 1901). Due to its inefficiency, deep X-ray is no more used for cancer treatment. Instead, **gamma rays** from cobalt (^{60}Co) or caesium (^{137}Cs) are used for teletherapy. Here the energy equivalent is in the order of 2 MV (1 mega volt = 1 million volts). Therefore penetration power is more, and deep-seated cancers can be irradiated satisfactorily.

Linear Accelerator (LINAC): Caesium-based radiotherapy is no more used in western countries. In India also, gamma ray treatment is being slowly replaced by Linear Accelerator. Here electrons are accelerated to higher energy levels of 8-12 MV and directed into the cancer tissue. It has more penetrating power and accurate beam focussing capabilities. As there is no permanent radioactive source in the machine, the radiation hazards are minimal. LINAC) is used for external beam radiation treatments for patients with cancer. The linear accelerator can also be used in stereotactic radiosurgery similar to that achieved using the gamma knife on targets within the brain; for Intensity-Modulated Radiation Therapy (IMRT) and Image Guided Radiation Therapy (IGRT) The linear accelerator uses microwave technology to accelerate electrons, then allows these electrons to collide with a heavy metal target. As a result of the collisions, high-energy X-rays are produced from the target. These high energy X-rays will be directed to the patient's tumor and shaped as they exit the machine to conform to the shape of the patient's tumor.

Radiosensitivity

The effectiveness of radiotherapy varies with different tumors. In general, lymphomas, Hodgkin's disease and neuroblastoma are *highly radiosensitive*. Epithelioma, cancer of oral cavity, cancer cervix, cancer breast and cancer lung are *moderately* radiosensitive. Poorly radiosensitive tumors are osteosarcoma, and malignant melanoma.

Fractionation of Doses

Cancer cells are more actively dividing. In a cancer tissue, about 5-10% cells are in division, while in normal cells only less than 1% cells are dividing at particular time. Radiotherapy takes advantage of this difference between normal and cancer cells. Since radiotherapy affects only cells in division cycle (especially S phase), the radiation affects mainly the cancer cells. Recovery from radiation damage is quicker in normal cells than in cancer cells. The aim is to inflict maximum damage to cancer cells, while retaining the power of repair of the surrounding normal tissues.

However, radiation given in a single dose is not effective. Because dividing cells are only 5% in the cancer population and radiation kills only this fraction. Moreover, a single large dose will be lethal. Instead, small divided doses are given to the cancer tissue. Thus the fractionated dose is employed. By the next day more cells are entering in the S phase which are killed by the second dose. A usual radiation dose for cancer is 5,000 to 6,000 rads, given in 15-20 fractions, administered within 25-35 days.

Cellular death after radiation depends on the number of cells in division. This produces a curious effect, each increment in dose kills a constant fraction of the cancer cells; but not a constant number of cells. An arbitrary example is shown in Table 53.3. While the first dose kills $1x10^{9}$ cells, the 3rd dose can kill $1x10^{7}$ cells only. However the percentage of cells killed is the same by each dose. In other words, the size of tumor is rapidly diminished in the initial phases of radiotherapy, but the last few cells are difficult to destroy. In fact, all the cancer cells cannot be eradicated by radiotherapy. The last few residual cells are annihilated by the immunological system.

BIOLOGICAL EFFECTS OF RADIATION

1. Direct Effects on Cancer Tissues

The radiation damages DNA molecules. No effects are visible immediately. But the damage is observed during the next mitosis. Since new DNA cannot be synthesized, cells die at the attempt of the next division. Chromosome breakage is often noticed. Radiation produces large quantities of free radicals in tissues. The catastrophic effects of free radicals on different biological compounds (including DNA) are described in Chapter 20.

2. Indirect Effects on Cancer Tissues

Damage to local blood supply cuts off the nutrition and causes local necrosis and cell death.

3. Effects of Radiation on Normal Tissues

In 1904, Madam Curie went for a lecture-demonstration class, keeping a few mg of impure radium

ore in her breast pocket. Within 1 hour, this caused severe dermatitis. That was the first indication of a health hazard by radioactivity. Madam Curie succumbed to radiation-induced leukemia in 1934.

3-A. Effects on Skin

Radiation will produce epilation, however hair may grow after 3 months. Sweat glands may be permanently damaged. There may be erythema and sometimes blisters. This is called **acute** radiodermatitis. **Chronic** radiodermatitis is seen after a few months of radiotherapy. There will be atrophy of skin, hypopigmentation, fibrosis, loss of elasticity, etc.

3-B. Effects on Mucous Membrane

The gastrointestinal mucosa is very sensitive to radiation. These include nausea, vomiting, diarrhea and in severe cases ulceration and bleeding. Late sequelae such as adhesions, fibrosis, stenosis and obstruction may appear many months after radiotherapy.

3-C. Effects on Blood Cells

Bone marrow and lymphoid tissues are highly radiosensitive because of the higher rate of cell division in these organs. Leukopenia and thrombocytopenia is an accepted side effect of radiotherapy. If WBC count is below 2,000/cu mm and platelet count is below 80,000/cu.mm, the therapy is temporarily stopped till recovery is effected.

3-D. Effects on Reproductive Organs

Gonads (ovary and testis) are highly radiosensitive. Complete sterility is effected at 1000 rads. Even low doses of radiation, too low to have any obvious effect on mitosis, can still affect the genes, so as to produce genetic alterations in the offspring. This is especially important when radiation is given in pelvic region.

3-E. Radiation Sickness

Dose above 700 rads given, as whole body irradiation, is usually fatal. Even 150 rads to the whole body will cause severe illness. In clinical practice, this is avoided by shielding the tissues in such a way that the beam is focussed to the cancer tissues only.

3-F. Carcinogenic Potential

During the period 1900-1910, people were working with X-rays without any precautions. This caused non-healing ulcers in many of them. During 1910s and 20s, lip cancer was common among painters of watch dial with radioactive stain. Gradually, along with the increasing knowledge on radiation hazard, stringent safeguard for radiation protection was introduced.

Acute Radiation Syndrome (ARS)

This may occur in accidents in nuclear reactors (e.g., Chernobyl accident) or the use of nuclear weapons in war (Hiroshima and Nagasaki). 15 to 25 rads will alter the blood count in exposed people, whereas the threshold for death in an individual is 150 rads. Other high dose effects are skin burns, hair loss, sterility and cataracts. Skin burns result from erythema, desquamation and blisters. Hair loss can occur after 500 rads. Cataracts (200 rads) are produced by neutrons because of the high water content in the lens.

Radiation Protection

There is always some amount of background radiation, of about 150 m Rem/year. Out of this, about 50% is from the cosmic rays, about 30% from terrestrial environment and 20% from internal environment (e.g. decay of ^{40}K). Granite and brick walls will increase external background. At higher elevation, cosmic rays are more. At an altitude of 2000 m, (e.g., Gangtok, Sikkim state), the background irradiation is 20% more. In some coastal areas (e.g; Kerala state) natural deposits of radioactive thorium is seen, where background is 20-30% high. One diagnostic X-ray exposure may cause 75 milliRem.

Maximum Permissible Dose

The MPD of radiation for whole body among radiation workers, (doctors, technicians) is 5 mRem/year, and for general population is 0.5 mRem/year. Small doses (less than 10 cGy) of radiation may be good to living systems, while large doses are harmful; this is called **Hormesis**.

Radiation Monitoring and Precautions

Doctors, nurses, radiographers and research workers using the radioactive substances should wear a badge containing a piece of film. If radiation is reaching the film, it is blackened, and hence exposure could be detected. The following precautions will reduce the radiation hazards:

1. Keep the source farther away.
2. Shield the radioactive sources; cover them with lead bricks.
3. Handling is done by remote devices. Use lead-rubber gloves and aprons.
4. Radioactive materials are to be handled with speed. The shorter the time spent near the source, the lower the dose received.