Effects of radiation in biological systems

As stated in the oxford concise colour medical dictionary radiobiology is the branch of science dealing with the effects of radiation on biological systems. It is further stated that a sequence of events that deals with the absorption of energy from ionizing radiation to the efforts of the organism in order to compensate for the effects of this energy absorption and the damage to the organism that may be produced.

There are a number of topics of study in radiobiology. The effect of ionizing radiation together with how it affects living cells will be further explained. Bushong (1998: 29-32) states that the biologic effects of ionizing radiation represent the efforts of living things to deal with energy absorbed by them, after an interaction with such radiation. Maintained by the author it is stated that when ionizing radiation interacts with a cell, ionization and excitations are produced in either critical biologic macromolecule called targets e. g. DND, or in the medium which cellular organelles are suspended eg. Water. Based on the site of these interactions, it can be classified as either direct or indirect.

The effects of radiation on living cells vary, depending on the type, intensity of exposure and the cell as discussed by Tubiana and Dutreix (1990: 22). Radiation is an emission of ionising radiation. Maintained by the above authors, at low levels, radiation damage can be repaired by living cells with no effects, however, higher doses leas to sterility, mutation, which confuses cells resulting in the reproducing rapidly cell death. Cell damage can result in two ways namely direct radiation action, which harms molecules directly and indirect, by ionizing molecules turning them into toxic compounds causing damage.

Some of the other aspects that are going to be discussed and explained below are cell structure, cycle and death; irradiation of cells; direct and indirect effects of radiation; interactions of gamma rays with matter; foetal irradiation; cell survival curves; properties of cell survival curves; therapeutic implications; oxygen effect; factors influencing oxygen effect; the five R's of radiobiology and lastly radiation protection.

CELL STRUCTURE, CELL CYCLE & CELL DEATH:

Discussed by Ford (2001: 5) Atoms form molecules which make macromolecules, then build complex organic structures, and then cell which are the main structural component of tissues as well as reflects all features of life. They have similar structures but specialize according to their location. Cells contain inorganic compounds as well as organic compounds.

Henry and Suntharalingam (2006: 12) explain that there are two categories of cells namely prokaryotic and eukaryotic. Maintained by the above author . Prokaryotic cells have no nucleus and are surrounded with a nuclear membrane. They do not contain any membranous organelles e. g. Mitochondria. However. On the other hand, eukaryotic cells have membranous organelles as well as a real nucleus. They are more highly developed compared to prokaryotic cells.

The cell cycle is defined as the interval between the midpoint of mitosis in a cell and the midpoint of the subsequent mitosis in both daughter cells according to Millar and Levine (1998: 102). Maintained by the above authors it describes the stages through which a cell passes through as it replicates. The length of time a cell may take to complete the cell cycle is highly

variable. The basic division of the cell cycle is mitosis and interphase. Cells may also be in a special state known as the “ resting phase” when not making any effort to divide and cells in this phase are mostly terminally differentiated cells.

According to Tubianna and Dutreix (1990: 86) the M phase is the period where the cell actively divides into two daughter cells. There are two related events namely mitosis and cytokinesis. The synthesis and mitosis of the cell cycle are separate by two gaps, G1 and G2 when respectively, DNA has not been synthesised or DNA has been synthesised but other metabolic processes are taking place. Elizabeth (2003: 1) explains that cells are generally most radio-sensitive in the mitosis and G2 phases and most radio-resistant in the late S phase. Maintained by the above author Cytokinesis completes the M phase, however cells do not always undergo cytokinesis, instead forming multinucleate giant cells. This can either be normal or can be due to errors in mitosis.

Explained by Tubiana and Dutreix (1990: 89) Cell death of static cells is defined as the loss of specific function. For stem cells and other cells capable of many divisions, cell death is defined as the loss of reproductive integrity (reproductive death). the above authors further explain that when cells are exposed to ionising radiation, the biological effects of radiation results mainly from damage to the DNA, however there are also other sites within the cell that, when damaged may lead to cell death. The capability of a single cell to grow into a large colony shows that the cell has retained its reproductive integrity.

IRRADIATION OF CELLS:

Elizabeth (2003: 10) explains that when cells are exposed to ionizing radiation the standard physical effects between radiation and the atoms or molecules of the cell. The biological effects of radiation result mainly from damage to the DNA; however, there are also other sites within the cell that, when damaged, may lead to cell deaths occur. Maintained by the above author a surviving cell that maintains its reproductive integrity and proliferates almost indefinitely into a large number of progeny is said to be clonogenic. Sensitive component for radiation-induced cell killing rests in the cell nucleus and not in the cytoplasm. When ionizing radiation is directly absorbed in biological material, the damage to the cell may occur in either a direct or indirect mechanism.

DIRECT & INDIRECT EFFECT OF RADIATION:

According to Bomford and Kunkler (2006: 265) in direct action, the radiation interacts directly with the critical target in the cell. The atoms of the target itself may be ionized or excited, leading to the chain of physical and chemical events that eventually produce the biological damage. It is the dominant process in the interaction of high linear energy transfer particles such as neutrons or alpha particles with biological material. In direct action, caused by x-ray or gamma ray photons, the photon interaction with an atom in the cell produces a charged particle (electron) which subsequently interacts with DNA directly as discussed by Hendry and Suntharalingam (2006: 24).

Hall and giaccia (2006: 44) explain that in indirect action, the radiation interacts with other molecules and atoms (mainly water) within the cell to

produce free radicals which can, through diffusion in the cell, damage the critical target within the cell. It can be modified by chemical sensitizers of radiation protectors. Further explained by the above authors, Basic radiochemical reactions that may occur in water molecules disrupt by the passing of an ionizing particle which are highly reactive species that are produced in water, through the radiochemical reactions. These reactive species bring about the indirect radiation damage to biological systems by reacting and damaging the molecules in the cell. The free radicals that break the chemical bonds and produce chemical changes that lead to biologclcal damage are highly reactive molecules because they have an unpaired valence electron. About two-thirds of the biological damage by low linear energy transfer radiations e. g. X-rays , is due to indirect action and one-third due to direct action.

INTERACTIONS OF GAMMA RAYS WITH MATTER:

Discussed by Johnston and Fauber (2012: 63)The steps involved in producing biological damage by the indirect action of x-rays are the primary photon interaction which includes he photoelectric effect, Compton scatter and pair production produces a high energy electron, high energy light charged particle in moving through tissue produces free radicals in water. Maintained by the above author the free radicals may produce chemical changes in DNA from the breakage of chemical bonds and the changes in the chemical bonds results in biological effects.

FOETAL IRRADIATION:

According to Isaac (2009: 26) Foetal radiation is known as teratogen (causes birth defects). Between conception and birth, the foetus passes through

different stages of development. When a mother is pregnant, the unborn child can be harmed by radiation which could result in the child having cancer and genetic defects. Due to the fact that the foetus would be highly sensitive to radiation, they are rapidly dividing, undifferentiated and have a long mitotic future.

Elizabeth, M (2003: 16) a human embryo exposed to a large amount of radiation before 2-3 weeks of gestation could result in a miscarriage. 4-11 weeks could result in severe abnormalities of organs and 11-15 weeks in mental retardation. However, after the 20th week, the human foetus is more radiosensitive and functional defects may occur.

Effects of radiation on the foetus depends on two factors namely the dose to the foetus and secondly is the stage of development at the time of exposure. An important factor to note is that an abortion should be considered only when the foetal dose has exceeded 10 cGY. The principle effects of radiation on a foetus are foetal or neonatal death, malformations, growth retardation, congenital defects and cancer induction as maintained by the above author.

CELL SURVIVAL CURVES:

Discussed by Hall and Giacca (2006: 67) Cell survival curves which is the surviving fraction against the absorbed dose describes the relationship between the surviving fractions of cells that is the fraction of irradiated cells that maintain their integrity. Maintained by the above author, the cell survival against dose is graphically represented by plotting the surviving fraction on a logarithmic scale on the ordinate against dose on a linear scale.

Typical survival curves for cells irradiate by densely ionizing radiation (low linear energy transfer).

Tubiana and Dutreix (1990: 26) the type of radiation influence the shape of the survival curve. For densely ionizing radiation (high linear energy transfer) the cell survival curve is almost an exponential function of dose which is shown by an almost straight line on a log-linear plot. However, for sparsely ionizing radiation (low linear energy transfer) the survival curves show an initial slope followed by a shoulder region and then becoming nearly straight at high doses as retained by the above authors. The currently used model for describing the cell survival curve is the linear-quadratic model with constants Alpha and Beta. The ratio alpha/beta gives the dose at which the linear and quadratic components of cell killing are equal.

PROPERTIES OF CELL SURVIVAL CURVES:

Adhikar (2003: 2) explains that for late responding tissues the survival curves are more curved than those for early responding tissues. For early effects the ratio is large and dominates at low doses however for late effects it is small and has an influence at doses lower than for early responding tissues. The above mentioned author goes on to explain that the effects of radiation on tissue as a function of dose are measured with assays and the measured results are presented in the form of cell survival curves and dose response curves.

THERAPUTIC IMPLICATIONS:

Bomford and Kunkler (2003: 99) state that DNA being the target of ionizing radiation leads to several important therapeutic implications. The radiation

damage that occurs in clusters that match the size of a DNA strand may be more effective in causing damage. The above authors further explain that drugs target DNA have synergistic effects with radiation whilst people with genetic defects due to radiation damage response may exhibit increased levels of DNA mutation or cell death. Points in cell cycle where the DNA is more susceptible to damage are also more sensitive to radiation and the cycling of cells has an impact on the radio sensitivity of the cell type.

OXYGEN EFFECT:

Franckowiak (2008: 2) explains that when ionizing radiations transverse through matter, they gradually loose energy through various interaction processes along their path. For certain absorbers the rate of energy loss depends on the type of radiation as well as the density of the material. Maintained by the above author the rate at which energy is deposited as a charged particle travels through matter by a particular type of radiation is known as linear energy transfer which is a function of the mass and charge of the radiation.

Carlton and Adler (2006: 344) explain that Electromagnetic radiation, having no mass or charge produces fast electrons with negligible mass and a negative charge. Due to this, the probability of an electron interacting with an atom is relatively small resulting in the ionizations produced being distant and far from each other hence terming electromagnetic radiation as linear energy transfer radiation. In contrast to electromagnetic radiation, highly ionizing radiations e. g. Alpha-particles that have a predictable mass, have a greater chance of interacting with matter, producing short distance ionizations. Different linear energy transfer radiations produce different

degrees of the same biologic response. However, equal doses of linear energy transfer do not produce the same biologic response. This was retained by the above authors.

Travis (1989: 207) explains that the ability of radiation with different linear energy transfers produce a specific biologic response called the relative biologic effect. It is a comparison of a dose of test radiation that produces the same biological response. Maintained by the above author , when comparing the two types of radiation that differ in nature or energy, the relative biological effectiveness when compared, represents the absorbed dose which results in a given biological effect. Therefore the concept must refer to a well-defined biological effect of a particular level.

FACTORS INFLUENCING OXYGEN EFFECT:

Ford (2001: 10) discusses that some of the factors that influence the oxygen effect are chemical, biological and technical. In chemical, the oxygen concentration may be increased by internal or external methods. In biological, if the patient suffers from chronic airways disease or other problems with oxygen transport, then the oxygen concentration will be lower and prevalence of hypoxic cells will be increased. However, in technical, these have minimal impact on the oxygen effect, maintained by the above author.

THE FIVE R'S OF RADIOBIOLOGY:

Bomford and Kunkler (2003: 236) explain that there are five R's in the radiotherapy process namely; repair, redistribution, reoxygenation,

repopulation and lastly radio sensitivity and these will be further explained below.

REPAIR:

This is one of the primary reasons to fractionate radiotherapy and there are three types of damage that ionizing radiation can cause to cells. These are lethal, sub lethal and potentially lethal damages. Maintained by the above authors, by splitting radiation dose into smaller parts cells are allowed to repair sub lethal damage depending on the ability to recognize damage, repair pathways and cell cycle arrest. However, normal cells with intact repair pathways are able to repair the sub lethal damage by the time the next fraction is delivered. However, if the dose rate is sufficiently low, repair may be able to take place during radiotherapy treatment which reduces the cell death and is one reason low dose treatment show reduces effectiveness to high dose rate treatment as stated by Isaac (2009: 20).

REDISTRIBUTION:

Sunthalingam and Hendry (2006: 12) state that redistribution occurs during low dose rate which may increase cell killing, although it is minimal compare to the increased repair. When radiotherapy is given to a population of cells, they may be in different parts of the cell cycle. A small dose of radiation delivered over a short time period will kill a lot of sensitive cells and less of the resistant cells.

REOXYGENATION:

Oxygenation status may change during treatment due to tumours being acutely or chronically hypoxic. Acute hypoxia is due to the closure of capillaries or arterioles supplying parts of the tumour. While closed, tumour

cells become hypoxic and resistant to the indirect action of radiation. These vessels are usually closed for a short time but may occur during a fractionated dose of radiation. Splitting dose into fractions raises possibility of closed vessels being opened the next time, hence allowing the tumour cells to be killed as explained by Sunthalingam and Hendry (2006: 13).

Maintained by the above authors, chronic hypoxia is due to the poor vasculature of tumours and oxygen has to travel far to reach cells that are far. These cells are resistant to radiation, fractionated radiation therapy kills cells that lie close to capillary more effectively thus being able to move closer to their nutrition source becoming relatively toxic and these cells can be killed.

REPOPULATION:

Bomford and Kunler (2003: 237) explain that repopulation is the increase in cell division that is seen in normal and malignant cells at some point after radiation is delivered. Repopulation of normal tissues occurs at different speeds depending on the tissue. Maintained by the above authors, early responding tissues begin repopulation and by increasing treatment over a certain time period reduces early toxicity in that tissue. However late responding tissue only begin repopulation after the radiation cause has being completed and therefore repopulation has minimal effects.

Adhikar (2003: 4) explains that repopulation of malignant tissues are when some tumours exhibit accelerated repopulation which is a dangerous phenomenon that must be counted if treatment time extends. Methods to do

this include accelerated treatment with hyper fractionation to minimise late effects.

RADIOSENSITIVITY:

Radio sensitivity cells include haematological cell. Radio resistant cells include myocytes, neurons and tumour cells such as melanoma and sarcoma as explained by Adhikar (2003: 4).

RADIATION PROTECTION:

As discussed by Carlton and Adler (2006: 153-155) there are three principles of personnel exposure reduction namely time distance and shielding. A decrease in time working with or in the vicinity of radiation will increase exposure and decrease the dose. Maintained by the above author increasing the distance between the source of radiation and the individual will decrease exposure. Bushong (1998: 54) also mentions that shielding decreases the exposure that is used when time and distance cannot be implemented. Examples of shielding are gonad shields, lead aprons, lead line doors etc.

CONCLUSION:

As we all know now know, radiobiology deals with the effects of radiation in biological systems. Radiation is energy in the form of waves and particles that are emitted from a source that comes in many forms however it may not always be a dangerous thing. The forms of radiation that are especially dangerous to living things are those with energy sufficient to penetrate tissues and then ionize the atoms they pass along the way which damage tissues by disrupting normal cellular chemistry and are mutagenic and carcinogenic.

Cell damage can result in two ways namely direct radiation action, which harms molecules directly and indirect, by ionizing molecules turning them into toxic compounds causing damage. Discussed above and throughout the assignment we see how a cell together with their structure until death occurs due to irradiation of cells by either direct or indirect effects of radiation. We also looked at interactions of gamma rays with matter as well as effects of foetal irradiation. Cell survival curves together with their properties as well as theraputic implications and oxygen effect were explained. The five R’s in radiobiology play an important aspect together with ways of protecting yourself and others from the harmful effects of radiation.