Module Two: Radiation Biology and Radiopharmaceuticals

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SECTION ONE: CLINICAL APPLICATIONS OF MONOCLONAL ANTIBODIES

Overview

This section focuses on the naturally produced ionizing radiation used in treating non-Hodgkin's lymphoma and the underlying scientific principles of a novel type of therapy called radioimmunotherapy (RIT). It begins with a discussion of the atom, how radiation is produced, and the units of measurement for radiation. It continues with an overview of important radiation biology concepts, specifically, the effects of radiation on living tissue. The Module also includes an introduction to the concept of dosimetry. It describes the use of radiopharmaceuticals for diagnostic and the therapeutic applications and concludes with a discussion of radiation safety.

Objectives

After completing this section, you will be able to:

- Explain basic concepts of nuclear science including atomic structure and how ionizing radiation is produced
- Define radiation biology and explain the effects of ionizing radiation on cells and tissues of the body
- Define common terms used in radiation biology and nuclear science
- Describe dosimetry and its applications
- List and define radiopharmaceuticals and differentiate between diagnostic and therapeutic uses
- Discuss radiation safety in terms of exposure and protection

radiation: The process of emitting energy in the form of photons (gamma ray and X-rays) or particles.

nuclear medicine: The branch of medicine concerned with the use of radionuclides in the study, diagnosis, and treatment of disease.

radioactive decay: Disintegration of the nucleus of an unstable atom by the spontaneous emission of charged particles and/or photons.

Introduction

Sources of Radiation Exposure

We are continually exposed to radiation in our daily lives. We live in the midst of a continuous flow of radiation from external as well as internal sources. The two most common sources of external radiation exposure are cosmic rays, which originate in outer space, and radioactive emissions from earth's crust (known as terrestrial radiation), which has contained radioactive materials since its formation. Constituents of the earth's crust that lead to radiation exposure are Uranium-238, Uranium-235, and Thorium-232. Most of our daily exposure is due to radon, which is a naturally occurring gas produced by the decay of uranium in soil, rock, and water. Radon can enter a home or building through dirty floors, cracks in the foundation floor and walls, and openings around floor drains, pipes, and sump pumps. Other sources of external radiation exposure include medical and central X-rays, airline travel, television receivers, and computer screens.

We are also exposed to radiation from within our own bodies. The major contributors to this exposure are potassium-40, carbon-14, and hydrogen-3. In nature, a small fraction of the naturally occurring potassium, carbon, and hydrogen is radioactive. As we ingest these elements, mostly in the form of food, our bodies retain small amounts of these radioactive substances. Another potential source of internal exposure is from nuclear medicine procedures.

atomic number: The number of protons in the nucleus of an atom.

periodic table: A table that lists elements according to their atomic number in a manner that groups elements according to similar chemical properties.

Atomic Structure

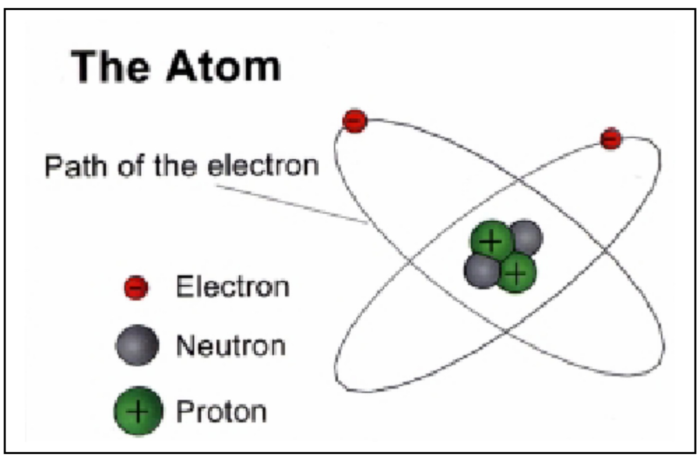
To understand radiation, it is essential to be familiar with the structure and chemistry of atoms. An **atom** is the smallest unit of matter that retains the chemical properties of an individual element. Examples of familiar elements are hydrogen, oxygen, iron, and lead. Atoms are incredibly tiny. Each atom is more than a million times smaller than the thickness of a human hair. However, tiny as atoms are, they consist of even smaller subatomic particles:

- Protons that have positive electrical charges
- Neutrons that have neutral electrical charges
- Electrons that have negative electrical charges.

Protons and neutrons are crowded into the exceedingly tiny nucleus – or center – of the atom. The nucleus is surrounded by electrons that occupy a much larger area. The electrons whirl through this mostly empty space, completing billions of trips around the nucleus each millionth of a second.

Atoms are often compared to the solar system, with the nucleus corresponding to the sun and the electrons corresponding to the planets that orbit the sun. This comparison is not completely accurate, however. Unlike the planets, the electrons do not follow regular, orderly paths. In addition, the protons and neutrons constantly move about at random inside the nucleus. Figure 1-1 depicts the basic structure of an atom.

Figure 1-1: The Structure of an Atom



cell cycle: the cycle of biochemical and morphological events occurring in a reproducing cell population

mitosis: the process of cell division in which a single cell produces two genetically identical daughter cells

G1 phase: the phase immediately following cell division (mitosis) in which the cell prepared itself for DNA synthesis

DNA synthesis: a process whereby a cell makes an exact copy of its genetic material (DNA) in preparation for cell replication

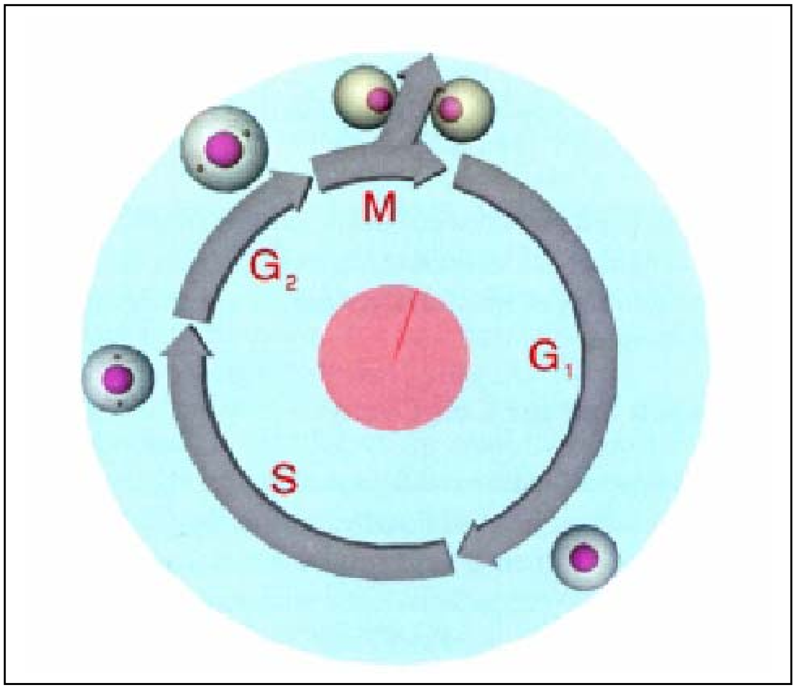
S phase: segment of the cell cycle when DNA is synthesized in preparation for cell division

G2 phase: phase when cellular components other than DNA are being synthesized in preparation for cell division

The Cell Cycle

Normal cells cycle through various stages during their lifespan, fluctuating between a state in which they are preparing cellular components for cellular replication and a period in which they actually divide. This is known as the cell cycle, and it is depicted in Figure 1-2.

Figure 1-2: The Cell Cycle



Wrist Dosimeter

Pocket Dosimeter

Film Badges and Dosimeters

Film badges are most commonly used to measure the radiation exposure of personnel over periods of weeks or months. They are typically worn for several weeks or months, then turned in for evaluation. Film badges are quite simple in operation. They consist of a small piece of X-ray film in a holder and are worn by a person who might be exposed to radiation. The amount of exposure to the person wearing the badge can be estimated by the amount of X-ray film blackening.

Pocket Dosimeter

Pocket dosimeters are used to measure short-term radiation exposure. They provide an immediate readout of radiation exposure. Pocket dosimeters determine radiation exposure by measuring ionizations. This is done with an electrically charged wire. When the pocket dosimeter is exposed to radiation, ionizations occur that cause the electrically charged wire to deflect. The amount of radiation exposure can be determined by measuring the deflection of the wire.

Thermoluminescent Dosimeter (TLD)

Like film badges, thermoluminescent dosimeters are most commonly used to measure the radiation exposure of personnel over periods of weeks or months, then turned in for dose evaluation. A TLD contains a small chip of lithium fluoride in a badge worn by personnel who might be exposed to radiation. When lithium fluoride is exposed to radiation and later heated, it gives off visible light. The exposure of the TLD (and thus the worker) is determined by measuring the light given off by the chip in a measuring unit.

Thermoluminescent Dosimeter (TLD)

scintigraphic imaging (also referred to as scintigraphy): photographing the emissions that come from an administered radionuclide in the body. Scintigraphy is used to determine the outline and function of organs and tissues in which the radioactive substance collects or is secreted

collimator: a device made of lead with many holes to allow the gamma rays to pass through

Gamma Camera

Detectors to Measure Absorbed Dose

Gamma cameras and thyroid scans are the most common detectors used to measure absorbed dose in a RIT patient.

Gamma Camera (also referred to as scintillation camera or Anger camera)

Gamma cameras are used to provide counts and images to diagnose cancers, evaluate cardiovascular problems, detect kidney malfunction, and identify other abnormalities in bone, tissues, and organs. The process of determining the *in vivo* location of a radiopharmaceutical is called **scintigraphic imaging**. The image is obtained from a gamma camera through the use of a sodium iodide crystal that detects the gamma radiation emanating from the patient and a **collimator** that “focuses” gamma rays emitted from a patient positioned under it. There are different types of collimators for different purposes, e.g. low, medium and high energy, also high sensitivity and high resolution. The collimator appropriate for the radionuclide must be selected. For example, Tc-99m requires a low-energy collimator while iodine 131 requires a medium- or high-energy collimator. Once the image is obtained, electronic and computer components aid in image formation and analysis.

Thyroid or Stationary Probe

A stationary or thyroid probe is a scintillation detector that uses a sodium iodide crystal to detect and count the photons that are emitted from the patient’s thyroid. To measure the thyroid, the patient is placed directly against the probe. To measure radiation coming from the total body, the patient is positioned at a distance from the probe.