INTRODUCTION TO MEDICAL RADIATION SCIENCE

Describe the role of Medical Imaging.

Medical imaging is several different technologies that are used to view the human body in order to **diagnose**, **monitor**, or **treat** medical conditions. The use of diagnostic imaging services is paramount in **confirming**, correctly **assessing** and **documenting** course of the disease as well as in assessing response to treatment. Each type of technology gives different information about the area of the body being studied or treated, related to possible disease, injury or the effectiveness of medical treatment. All types of medical radiation science use **ionising radiation**.

Begin to develop an understanding of general x-ray and CT imaging technologies.

X-rays are made by a piece of film being placed in a cassette and placed under the patient, an exposure is made and the film is them removed from the cassette in either a dark room or automatic processor to be developed and have a hard copy produced. **Computer Tomography (CT)** involves an x-ray tube spinning around gantry and detectors record the images. It can be used to gather 3D/4D reconstructed views on **axial (transverse)**, **coronal** and **sagittal** planes.

Begin to develop an understanding of nuclear medicine imaging technology.

Nuclear medicine imaging is the use of **radioactive materials** in the diagnosis and treatment of various diseases. **Biological compounds** that concentrate in specific organs of their human body are chemically labelled with specific **radioactive materials**, that emit gamma rays to create a **radiopharmaceutical**. The radiopharmaceutical, once administered, concentrates within the organ or organ system and the distribution of the radioactivity is recorded by a gamma camera. Treatment of diseased tissue, based on metabolism or uptake may also be accomplished. The treatment effects of radiopharmaceutical rely on the tissue-destructive power of short-range ionising radiation - usually beta or alpha.

Patient is administered radiopharmaceutical, it travels around the body in the blood and localises to areas known to utilise the chemical; radioactivity is emitted from the radionuclide, emitted radiation (gamma rays) is absorbed by detectors in a gamma camera and a digital image of the distribution of the radiopharmaceutical is produce.

Begin to develop an understanding of radiation therapy techniques.

Radiation therapy uses **high-energy** radiation to kill cancer cells and shrink tumours. X-rays, gamma rays, and charged particles (alpha, beta, protons) are types of radiation used for cancer treatment. The radiation may be delivered by a machine outside the body (**external-beam RT**), or it may come from **radioactive material surgically implanted** in the body near cancer cells (brachytherapy). There are three phases of radiation therapy - simulation, planning and treatment. Patients having **external beam radiation** will have a flexi-mask on to immobilise the patient. Images are taken in a simulation to plan how the cancer site can be treated with radiation with minimal effect to surrounding organs and tissues. Mostly CT based imaging. Radiation therapy is combination of CT, MRI and PET. Energy levels for normal scans such as x-rays are around 50-100kVp; radiation treatment using x-rays uses energy levels of around 6MV and up.

ANATOMICAL PLANES AND MEASURES OF DIAGNOSTIC AND THERAPEUTIC OUTCOMES

Superior or **cranial (cephalic)** indicate that a structure is located closer to the head. **Inferior** or **caudal** indicate that a structure is located at a lower level. **Proximal** means closer to the attached end of the limb, and **distal** means further away from the attached end of the limb. **Anterior** or **ventral (palmar)** refers to the front of the body or surface. **Posterior** or **dorsal** refers to structure near to the back of the body. **Medial** and **lateral** refer to the position in relation to the **medial plane; medial** being closer to the midline and **lateral** being further away. **Superficial** indicates that a structure is closer to the surface and **profundal** indicates that it is located more deeply. **Ipsilateral** tells us that two structures are located on the same side of the body and **contralateral** being the opposite side of the body. **Transverse** = axial = horizontal, divides the body into superior and inferior and is the most common plane used in imagining. **Frontal** = coronal, divides the body into posterior and anterior. **Sagittal** = median, divides the body into left and right halves.

Nuclear Structure and Radioactivity

Describe a simple nucleus and understand nuclear notation.
A = Mass Number = Z + N (proton + neutron)
Z = Atomic Number = number of protons
N = number of neutrons

Classify Nuclides.
Isotopes have the same Z, but different number of neutrons. The cannot be separated chemically from each other.
Isobars have the same atomic mass, they can be different elements.
Isotones have the same number of neutrons and can also be different elements.

Understand that nuclei have excited states and describe radioactivity.
Like atoms, nuclides have a ground state and an excited state. These excited states last for very short times <10^-11s.
Some excited states can be much longer, of the order of seconds, minutes or more. These long lived excited states are known as **metastable**.
Most nuclides are stable in their ground state, some however, are unstable due to imbalance between attractive and repulsive forces; these emit radioactivity to become more stable.
Radioactivity originates in the nucleus.

Explain alpha, beta and gamma decay.
Alpha particles will stop at outer layer of skin if you put your hand up as they love interacting with matter.
Beta particles can be slowed down by your hand but will still pass through, they can be stopped by a thin sheet of aluminium or concrete.
Gamma particles can pass through much denser materials such as concrete and lead.
When an unstable nuclide emits radioactivity, the mass of the parent should be greater than the mass of the decay products, and the slight excess mass is available as KE (kinetic energy - speed), based on E=mc^2.
An **alpha particle** is a helium nucleus, with two protons and two neutrons. When a nucleus emits an alpha particle, its neutron number and proton number each decrease by 2 and its mass by 4.
Beta decay involves transforming a proton to a neutron or a neutron to a proton. B- decay is emission of an electron and B+ is emission of a positron. The electron will be emitted from the nucleus not an orbital. This electron is created during decay itself as it does not normally exist, this process results in a neutron being converted to a proton.
A neutriono or antineutrino is also emitted during beta decay, thus kinetic energy of the electron is not fixed.
Gamma decay results in the emission of a photon from a nucleus in an excited state. Nuclei have energy levels 1,000,000 times larger than atomic energy levels, they normally exist in the ground state. Excited nuclei are produced as daughter nucleus. Gamma rays are massless and uncharged, they can be sufficiently thick.
Electron capture is a nuclide that can decay via B+ but instead of emitting a positron the nucleus absorbs an orbital electron.

Explain decay rate, activity and half life.

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Decay rate is proportional to the number present:
^ = decay constant = probability of decay/unit time
Activity (decay rate) = R = number of decays/unit time
^ x t1/2 = 0.693
1/t/12(eff) = 1/t1/2 + 1/t1/2(bio)

Understand that attenuation is exponential.

$$I_x = I_o e^{-\mu x}$$

Io = Initial Intensity
Ix = Intensity after passing through absorber
x = thickness of absorber

・ = linear attenuation coefficient The unit for ・ is cm-1

Attenuation depends on the thickness of absorber, and the linear attenuation coefficient. This attenuation coefficient itself depends on the energy of the photons, the nature of the absorber and its density.

Distinguish between linear and mass attenuation coefficient.

The **linear** attenuation coefficient varies with the density, even for the same medium.
The **mass** attenuation coefficient is obtained by dividing the linear attenuation coefficient by the density of the material.

Describe the process of attenuation (photoelectric effect, compton effect) and understand the energies of these processes.

Coherent scattering is when the incoming photon interact with and excites the total atom as opposed to individual electrons as in **compton** scattering. The atom subsequently emits a photon with the same energy as the incoming photon, thus the only change being a change in direction of the photon. As for other photons that undergo a change in direction, this leads to a degradation in image quality if the photon is detected, this interaction usually occurs with very low energy x-rays such as those used in mammography. Coherent scattering accounts for less than 5% of x-rat interactions about 70keV and 10% of those at 30keV.

Photoelectric effect occurs when the energy of the photon is greater than the binding energy of the electron, the photon gives all its energy to the electron and disappears. The electron leaves the atom giving it energy equal to its binding energy (atom now excite and emits auger electron - characteristic radiation). The remainder of the energy appears as the kinetic energy of the photoelectron. Photoelectric absorption is beneficial in x-ray imaging as there are no scattered photons to degrade the image. **Auger electrons** have a target of tungsten.

EP = EBE + KE where, EP = energy of incident photon, EBE = binding energy of electron in its shell and EKE = kinetic energy of photon electron.

T = linear attenuation coefficient.
T/P = probability of photoelectric effect.
Z = Atomic number of absorber.
E = energy of photon.

$$\tau/\rho = Z^3/E^3$$

Although probability of PE decreases with energy, there are sharp discontinuities called absorption edges. The photoelectric process predominates when lower energy photons interact with high Z materials. Photoelectric absorptions is the primary mode of interaction of diagnostic x-rays with image receptors, radiographic contrast materials and radiation shielding, all of which have much higher atomic numbers than soft tissue. This process can be used in x-ray imaging to amplify differences in attenuation between tissues with slightly different atomic numbers, thereby improving contrast. This differential absorption is exploited to improve image contrast through the selection of x-ray tube targets and filters in mammography.

Compton effect occurs when energy of the photon is much larges than the binding energy of the electron. The photon loses some energy and changes direction and the electron is ejected from the atom.

EP = EBE + EKE + ‘EP where, EP = energy of the incident photon, ‘EP = energy of the scattered photon, EBE = binding energy of the electron in its shell and EKE = kinetic energy of compton recoil electron.

o = the component of the linear attenuation coefficient due to the compton effect.

$$\sigma/\rho \sim 1/E$$

Pair production only EP = EBE + EKE when the energy of the photon exceeds 1.02 MeV. The photon interacts with the nucleus, is absorbed and its energy is transformed into an electron and a positron - energy required for this is 2 x 0.511 MeV (E=mc2). Energy in exess of 1.02 MeV is shared equally between particles as kinetic energy.