CHAPTER 12

Radionuclide imaging

Q12.1 THE FOLLOWING STATEMENTS ARE TRUE OF THE RADIONUCLIDE TECHNETIUM-99M

A It is produced in a cyclotron.

B It can easily be attached to physiological molecules.

C It has a half-life of eight hours.

D It emits gamma rays principally at 140 keV.

E As well as gamma emission a beta particle is also emitted when it decays to technetium-99.

Q12.2 THE FOLLOWING ARE TRUE OF POSITRON EMITTERS

A They are produced in a nuclear reactor.

B Upon decay they emit positive beta particles.

C They are used in positron emission tomography (PET).

D Their nuclei are proton deficient.

E They directly emit two gamma photons of 511 keV.

Q12.3 THE FOLLOWING ENTITIES ARE COMMONLY USED FOR NUCLEAR MEDICINE IMAGING

A Alpha particles.

B Negative beta particles.

C Positive beta particles.

D Gamma photons.

E X-ray photons.

Q12.4 THE FOLLOWING ARE TRUE OF KRYPTON-81M

A It is a liquid at normal atmospheric pressure and room temperature.

B It has a half-life of 13 seconds.

C It is a daughter product of Rubidium-81.

D It emits gamma photons at 190 keV.

E It is produced in a generator adjacent to the patient.

Q12.5 THE FOLLOWING ARE DESIRABLE PROPERTIES OF RADIOPHARMACEUTICALS

A Pure gamma emission.

B Very high energy emission.

C A long half-life.

D For solid organ imaging there should be increased or reduced uptake in pathological tissue compared to normal tissue.

E Single energy of gamma emission.

Q12.6 CONCERNING THE BIOLOGICAL HALF-LIFE (T½) OF A RADIONUCLIDE

A It is affected by the patient's renal function.

B It is interchangeable with the term physical half-life.

C It is not important in calculating the effective half-life.

D If the biological half-life is reduced, the patient dose will increase.

E It is variable.

Q12.7 THE FOLLOWING ARE TRUE OF THE PHYSICAL HALF-LIFE OF A RADIONUCLIDE

A It can be altered by binding to a hydrocarbon chain.

B It is affected by body temperature.

C If the effective half-life is also known, the biological half-life can be calculated.

D It is affected by renal function.

E It is used to calculate the administered dose.

Q12.8 THE EFFECTIVE HALF-LIFE OF A RADIONUCLIDE

A Can be calculated if the physical and biological half-lives are known.

B Is the same for every patient.

C Is not affected by rate of excretion.

D Is used to calculate the effective dose received by the patient.

E Is dependent on the activity of the parent radionuclide.

Q12.9 REGARDING RADIONUCLIDE GENERATORS

A It is possible for a generator to produce radionuclides both in solution and as a gas.

B While in the generator and in equilibrium the parent and daughter radionuclides decay at the half-life of the parent.

C They never need to be refilled.

D They should be easily transportable.

E They do not need a sterile interior as the radioactivity will kill any bacteria.

Q12.10 REGARDING DOSE RECEIVED IN NUCLEAR MEDICINE

A It is expressed as effective dose.

B It is measured in megabecquerels.

C It is dependent on the radioactivity administered.

D It is dependent on the clearance of the radiopharmaceutical.

E The doses received in nuclear medicine cause negligible risk of malignancy.

Q12.11 THE GAMMA CAMERA SCINTILLATION CRYSTAL

A Is commonly made from sodium iodide.

B Is deliberately rendered impure by adding small amounts of elements such as thallium.

C Exhibits fluorescence when exposed to gamma radiation.

D Emits photons of shorter wavelength than that of the incident gamma photons.

E Is robust and waterproof.

Q12.12 THE FOLLOWING STATEMENTS REGARDING IMAGE QUALITY USING THE GAMMA CAMERA ARE TRUE

A If scattered gamma rays are detected and used in image formation they will reduce image contrast.

B The closer the gamma camera head to the patient the better the resolution.

C Resolution can be increased by using a thicker crystal.

D Sensitivity can be increased by using a thicker crystal.

E Resolution can be tested using a thin linear trough filled with technetium-99m.

Q12.13 THE FOLLOWING ARE TRUE OF THE GAMMA CAMERA

A The purpose of the pulse height analyser is to filter out signal from scattered radiation.

B Different energy gamma rays from different radionuclides can be detected simultaneously.

C The purpose of the collimator is to remove scattered radiation.

D The photomultiplier tube converts light photons into electrical signals.

E Light photons produced in the crystal from a gamma photon only illuminate one photomultiplier tube.

Q12.14 REGARDING QUALITY CONTROL OF THE GAMMA CAMERA

A Uniformity of field is tested using a flood field phantom.

B A faulty photomultiplier tube appears as a linear defect in the image.

C A bar phantom can test both linearity and resolution.

D The intrinsic resolution of a gamma camera is typically 3–4 mm.

E By using collimators in radionuclide imaging spatial resolution is reduced.

Q12.15 REGARDING THE COLLIMATOR USED IN NUCLEAR IMAGING

A The smaller the width of the holes in a collimator the higher the resolution.

B The larger the width of the holes in a collimator the higher the sensitivity.

C The use of collimators limits spatial resolution to around 10 mm.

D Collimator resolution reduces with increasing distance from the patient.

E Collimators can be used to magnify or minify images.

Q12.16 REGARDING A PARALLEL HOLE COLLIMATOR

A Resolution is increased by lengthening the holes.

B Resolution is decreased by reducing the diameter of the holes.

C Its principal role is to absorb scattered radiation.

D Collimator sensitivity is constant with distance.

E Collimators define the geometrical field of view of the gamma camera.

Q12.17 REGARDING SINGLE PHOTON EMISSION TOMOGRAPHY (SPECT)

A A gamma camera is used as the detector.

B The camera constantly rotates around the patient during image acquisition.

C Back projection is used in image formation.

D Planar views are reconstructed to form a 3D image.

E Contrast is improved compared to single gamma camera images.

Q12.18 REGARDING POSITRON EMISSION TOMOGRAPHY (PET)

A The PET scanner detects positrons.

B The purpose of the PET scanner is to detect single emission events.

C Collimation is similar to that of a gamma camera.

D Image noise is less than that produced by the gamma camera.

E PET tracer production needs to be on site or nearby as they have short half-lives.

Q12.19 REGARDING THE DETECTION OF GAMMA PHOTONS

A To distinguish between photons that have only small differences in energy the detector must have a high energy resolution.

B For resolution to occur between two photons of differing energy their energies must be sufficiently different to lie outside each other's photopeak spread.

C A detector with a large dead time is required to measure high count rates.

D An ionisation chamber can detect gamma photons.

E A Geiger-Müller tube can be used to detect gamma photons.

Q12.20 THE FOLLOWING ARE TRUE OF SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

A It produces two dimensional images.

B Noise levels are greater than conventional gamma camera images.

C Spatial resolution is better than conventional computerised tomography using x-rays.

D Superimposition of overlying structures is a problem.

E Image acquisition is performed using rotating detectors.

Q12.21 CONCERNING POSITRON EMISSION TOMOGRAPHY

A Annihilation photons are detected using a ring of detectors.

B Annihilation photons have energy of 511 keV.

C Annihilation photons are directly produced by unstable nuclei.

D Scintillation detectors are made from bismuth germinate.

E Can be combined with conventional x-ray computerised tomography equipment.

Q12.22 REGARDING THE MEDICINES (ADMINISTRATION OF RADIOACTIVE SUBSTANCES) REGULATIONS 1978

A Any fully qualified doctor may administer radioactive medicinal products.

B A radioactive medicinal product is defined as a medicinal product which contains or generates a radioactive substance.

C The Administration of Radioactive Substances Advisory Committee (ARSAC) certificate is issued by the employer.

D An ARSAC licence is valid for six years.

E An ARSAC research licence is valid for two years.

Q12.23 ARSAC CERTIFICATES

A Specify the purpose for which the radioactive substance can be administered.

B The application for an ARSAC licence must be signed by a Radiation Protection Supervisor.

C The employer is responsible for ensuring that the relevant clinicians hold an ARSAC licence.

D The ARSAC certificate holder is responsible for discharging the radioactive patient with the appropriate advice.

E There are three categories of certificates: for diagnostic procedures, therapeutic procedures or research.

Q12.24 CONCERNING NUCLEAR MEDICINE

A The regulatory authority for the use, storage and disposal of radioactive materials is the Environment Agency in England and Wales.

B Aqueous liquid can be disposed of into the sewer.

C Women of child bearing age receiving treatment should be advised regarding future pregnancy.

D Lead aprons are a necessity, providing radiation protection.

E A child should receive a radiopharmaceutical of less activity.

Q12.25 CONCERNING NUCLEAR MEDICINE

A The absorbed dose is calculated from the physical properties of the radionuclide and the bio-distribution data.

B The physical half-life is the result of physical decay and biological clearance.

C The effective half-life cannot be longer than the physical half-life or the biological half-life.

D Absorbed dose is measured in Sv.

E Effective dose is measured in Gy.

Q12.26 THE EFFECTIVE DOSE IN NUCLEAR MEDICINE

A Is 1–10 Gy for common radionuclide procedures with ^{99m}Tc labelled radiopharmaceuticals.

B Is 3–5 Gy for bone scans.

C Is 1–2 Gy for renal studies.

D Is 3–7 Gy for heart studies.

E Is 5–10 Gy for brain scans.

Q12.27 CONCERNING NUCLEAR MEDICINE

A Diagnostic reference levels are not dose limits.

B DRLs are produced by the Administration of Radioactive Substances Advisory Committee.

C DRLs should not be exceeded except in particular circumstances.

D All doses must be kept As Low As Reasonably Practicable.

E Bladder doses can be minimised by drinking plenty of fluid and frequent bladder emptying.

Q12.28 RADIATION PROTECTION IN NUCLEAR MEDICINE

A Before an MIBG scan, blocking the thyroid with potassium iodide will reduce the effective dose.

B The activity administered for a child should be reduced according to age.

C After administration of radionuclides with a long half-life, women are advised to avoid pregnancy for one year.

D Breast feeding should be stopped for 24 hours if procedures with high activities of ^{99m}Tc are used.

E The Ionising Radiation Medical Exposure Regulations 2000 provides for the protection of staff.

Q12.29 WHEN HANDLING AND INJECTING RADIOPHARMACEUTICALS

A Preparation of radiopharmaceuticals should be carried out behind lead glass or thick perspex.

B Lead aprons should be worn.

C A thermoluminescent device is not required for dosimetry.

D Pot shields and syringe shields should be used.

E Safe disposal of sharps is required.

Q12.30 FOLLOWING ADMINISTRATION OF RADIOPHARMACEUTICALS

A Patients become a source of external radiation from beta emitters.

B There are restrictions on contact with children and pregnant women.

C Incontinent patients can easily be treated with ^{131}I for thyrotoxicosis as outpatients.

D Urine, sweat, faeces, saliva and blood are often radioactive.

E Advice should be given to reduce the risk of radioactive contamination.

Q12.31 IN RADIONUCLIDE IMAGING, SENSITIVITY IS

A The ability to produce an image where count values are equal in every pixel when irradiated by a uniform source.

B A measure of the sharpness of the image.

C A measure of the spatial distortion of an image.

D A measure of the proportion of gamma rays emitted from a radionuclide source which are detected within the photopeak of the collimated gamma camera.

E The ability of the gamma camera to register the count rate linearly in response to incident count rates.

Q12.32 QUALITY ASSURANCE IN RADIONUCLIDE IMAGING INVOLVES MEASURING

A Uniformity.

B Spatial resolution.

C Linearity.

D Sensitivity.

E Count rate capability.

Answers

A12.1 THE FOLLOWING STATEMENTS ARE TRUE OF THE RADIONUCLIDE TECHNETIUM-99M

A False – It is produced in a generator.

B False – Technetium is difficult to attach to physiological molecules.

C False – Technetium-99m has a half-life of six hours.

D True.

E False – It is a metastable radionuclide and therefore decays by gamma emission only.

A12.2 THE FOLLOWING ARE TRUE OF POSITRON EMITTERS

A False – They are produced in a cyclotron.

B True.

C True.

D False – Their nuclei are neutron deficient.

E False – It is the annihilation with nearby electrons that produce two 511 keV photons.

KEY CONCEPT

TECHNETIUM-99M

- Produced by decay of its parent molybdenum-99.
- It can then be eluted from a generator.
- It is a metastable radionuclide and decays by emitting 140 keV gamma photons.
- Has a half-life of six hours.
- Can be labelled to various physiological molecules for imaging purposes.

A12.3 THE FOLLOWING ENTITIES ARE COMMONLY USED FOR NUCLEAR MEDICINE IMAGING

A False – They cannot escape the body.

B False – Negative beta particles are high speed electrons and have very limited imaging potential as their path length in solid tissue is short.

C True – These are positrons.

D True.

E False – X-rays are not used in nuclear imaging.

A12.4 THE FOLLOWING ARE TRUE OF KRYPTON-81M

A False – It is a gas and can be used in ventilation studies.

B True.

C True.

D True.

E True – The half-life of krypton-81m is so short it needs to be produced in a generator located next to the patient.

A12.5 THE FOLLOWING ARE DESIRABLE PROPERTIES OF RADIOPHARMACEUTICALS

A True.

B False – If the energy of the gamma photons is too high, there will be too little attenuation in the detector.

C False – Half-life should not be too long as this will increase patient dose.

D True.

E True – This allows correct detection of true signal. Any other energies detected can be rejected as scatter.

A12.6 CONCERNING THE BIOLOGICAL HALF-LIFE ($T_{1/2}$) OF A RADIONUCLIDE

A True.

B False.

C False – Both the physical and biological half-lives are required to calculate the effective half-life.

D False – The shorter the biological half-life the quicker the radionuclide is being eliminated from the patient.

E True.

KEY CONCEPT

EFFECTIVE HALF-LIFE, PHYSICAL HALF-LIFE AND BIOLOGICAL HALF-LIFE

- Physical half-life is the actual half-life of the radionuclide atoms and takes no account of physical, chemical and biological conditions.
- Biological half-life is due to the rate of elimination of the radionuclide atoms from the patient
- Effective half-life is calculated from the above two half-lives using the following formula:

1/effective half-life = 1/physical half-life + 1/biological half-life

A12.7 THE FOLLOWING ARE TRUE OF THE PHYSICAL HALF-LIFE OF A RADIONUCLIDE

A False.

B False.

C True.

D False.

E True.

A12.8 THE EFFECTIVE HALF-LIFE OF A RADIONUCLIDE

A True.

B False.

C False – This affects the biological half-life.

D True.

E False.

A12.9 REGARDING RADIONUCLIDE GENERATORS

A True.

B True – The parent and daughter radionuclides are described as being in transient equilibrium.

C False.

D True.

E False.

A12.10 REGARDING DOSE RECEIVED IN NUCLEAR MEDICINE

A True.

B False – Effective dose is measured in sieverts.

C True.

D True.

E False.

A12.11 THE GAMMA CAMERA SCINTILLATION CRYSTAL

A True.

B True.

C True.

D False – The emitted photons from a fluorescent process have lower energy than the incident photon, therefore the wavelength will be longer.

E False – The crystals are very fragile and are also susceptible to water damage.

KEY CONCEPT

FLUORESCENCE

- The incident photon imparts energy to an electron in the valence band.
- This more energetic electron can jump to a conduction band if it has sufficient energy.
- The electron loses energy and returns from the conduction band to the valence band.
- This process results in a photon being emitted. Its energy will be the difference between the energy levels of the conduction band and the valence band.

A12.12 THE FOLLOWING STATEMENTS REGARDING IMAGE QUALITY USING THE GAMMA CAMERA ARE TRUE

A True.

B True – The closer the gamma camera head the less opportunity emitted gamma rays have to diverge.

C False – Resolution is increased by using a thinner crystal.

D True – The thicker the crystal the more gamma photons will be captured.

E True.

A12.13 THE FOLLOWING ARE TRUE OF THE GAMMA CAMERA

A True – The pulse height analyser is set to only accept pulses within a certain energy range.

B True.

C False – The pulse height analyser removes scattered radiation. The collimator allows the location of the source within the patient to be defined.

D True.

E False – Numerous adjacent photomultiplier tubes may detect the light photons emitted by one gamma photon interaction.

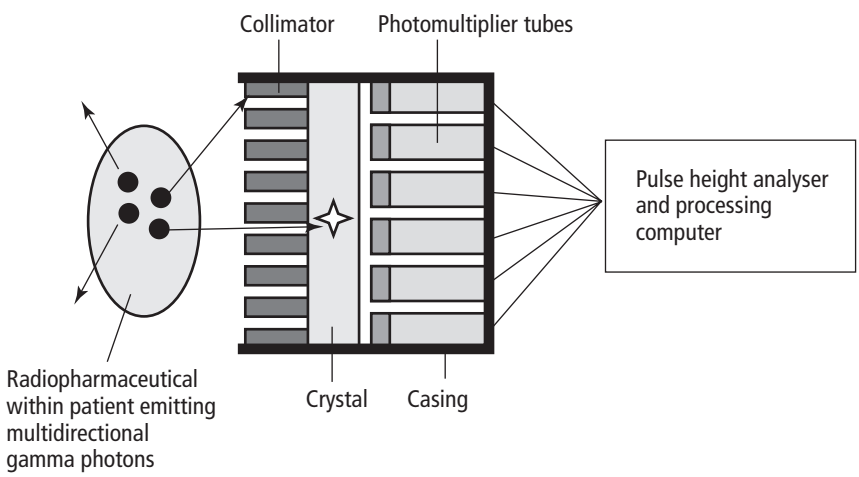

FIGURE 12.1 Schematic view of the gamma camera

A12.14 REGARDING QUALITY CONTROL OF THE GAMMA CAMERA

A True.

B False – It will appear as roughly the shape of the photomultiplier head.

C True.

D True.

E True – Collimators reduce the spatial resolution of the gamma camera from around 3–4 mm to 10 mm.

A12.15 REGARDING THE COLLIMATOR USED IN NUCLEAR IMAGING

A True.

B True.

C True.

D True.

E True – A pinhole collimator can be used to magnify a small area onto the gamma camera head (e.g. thyroid scans). A divergent collimator can image a larger area and project it onto a smaller gamma camera (e.g. lungs).

A12.16 REGARDING A PARALLEL HOLE COLLIMATOR

A True.

B False – The resolution increases by reducing the diameter of the holes.

C False – Its principal role is to allow localisation of the radionuclide within the patient. Scattered radiation is eliminated by energy selection by the pulse height analyser.

D True.

E True.

A12.17 REGARDING SINGLE PHOTON EMISSION TOMOGRAPHY (SPECT)

A True.

B False – It pauses and acquires images in small increments as it rotates around the patient.

C True.

D True.

E True.

A12.18 REGARDING POSITRON EMISSION TOMOGRAPHY (PET)

A False – The PET scanner detects the gamma rays emitted as a result of annihilation events between positrons and electrons.

B False – The concept behind the PET scanner is to simultaneously detect two gamma photons of 511 keV emitted in opposite directions.

C False – Collimation is not required.

D True.

E True – The most commonly used tracer is glucose labelled with fluorine-18 (18-FDG), which has a half-life of only 110 minutes.

A12.19 REGARDING THE DETECTION OF GAMMA PHOTONS

A True.

B True.

C False – A detector with a small dead time is required.

D True.

E True.

A12.20 THE FOLLOWING ARE TRUE OF SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

A False – It produces three-dimensional images.

B True – Noise is greater because the images are made up from fewer photons.

C False – It is worse.

D False – In SPECT overlying structures are resolved during 3D reconstruction.

E True – The camera heads rotate around the patient.

A12.21 CONCERNING POSITRON EMISSION TOMOGRAPHY

A True.

B True.

C False – Annihilation photons are produced by positron-electron annihilation events.

D True.

E True – This is PET-CT.

A12.22 REGARDING THE MEDICINES (ADMINISTRATION OF RADIOACTIVE SUBSTANCES) REGULATIONS 1978

A False – Procedures should only be carried out under the supervision of a person holding an ARSAC licence.

B True.

C False – This certificate is issued by the Administration of Radioactive Substances Advisory Committee of the Department of Health.

D False – It is valid for five years.

E True.

A12.23 ARSAC CERTIFICATES

A True – ARSAC certificates are issued to individual clinicians for specified procedures.

B False – The application has to be signed by a Radiation Protection Advisor.

C True.

D True.

E True.

A12.24 CONCERNING NUCLEAR MEDICINE

A True – The Scottish Environment Protection Agency and the Environment and Heritage Service are the responsible regulatory authorities in Scotland and Northern Ireland respectively.

B True.

C True.

D False – Lead aprons are not worn by radiographers in nuclear medicine as they provide little protection.

E True – Administered activity is reduced according to the child's weight.

KEY CONCEPT

DISPOSAL OF RADIOACTIVE WASTE

Routes of disposal of radioactive waste

This is determined by the Radioactive Substances Act 1993.

- Gas can be disposed of into the atmosphere.
- Aqueous liquid can be disposed of into the sewer.
- Organic liquid must be disposed of via a contractor who has authorisation for the transfer and final disposal of the radioactive substance.
- Solid radioactive waste must be disposed of by a contractor in an incinerator.
- Records of disposal must be sent to the environment agency; these records are available for public viewing.

A12.25 CONCERNING NUCLEAR MEDICINE

A True – The physical properties of radionuclides are the emissions/energies. The bio-distribution data is the uptake and clearance of the radionuclide which is obtained from temporal sampling.

B False – Effective half-life is the result of physical decay and biological clearance.

C True.

D False – Absorbed dose is measured in Gy.

E False – Effective dose is measured in Sv.

A12.26 THE EFFECTIVE DOSE IN NUCLEAR MEDICINE

A False – Effective doses are measured in Sv.

B False – All these questions are false because of the incorrect units.

C False.

D False.

E False.

A12.27 CONCERNING NUCLEAR MEDICINE

A True – There are no dose limits for medical exposures, but doses must be kept ALARP for the intended purpose.

B True.

KEY CONCEPT

DOSIMETRY IN NUCLEAR MEDICINE

- **Absorbed dose** will depend on the cumulated activity in the source organ and the fraction of energy absorbed in the target organ. Measured in **Gy**.
- **Effective doses** are used to consider the different sensitivities of different organs and tissues to stochastic radiation effects. Measured in **Sv**.

The annual average natural background radiation dose in the UK is approximately 2.3 mSv.

Common radionuclide procedures with ^{99m}Tc labelled radiopharmaceuticals are 1–10 mSv. They include the following.

- Renal studies 1–2 mSv.
- Bone scans 3–5 mSv.
- Heart studies 3–7 mSv.
- Brain scans 5–10 mSv.

Some diagnostic procedures involve higher doses as follows.

- Indium imaging 3–20 mSv.
- Thallium imaging 18–37 mSv.

C True – These include obesity, additional views and SPECT.

D True.

E True – This effectively reduces the dose as many radionuclides are excreted by the kidneys.

A12.28 RADIATION PROTECTION IN NUCLEAR MEDICINE

A True.

B False – The administered activity should be reduced according to the child's weight

C False – Women are advised to avoid pregnancy for a few months. The absorbed dose to the foetus should not exceed 1 mGy.

D True.

E False – IR(ME)R (2000) provides for the protection of patients. IRR 99 provides for the protection of staff.

A12.29 WHEN HANDLING AND INJECTING RADIOPHARMACEUTICALS

A True.

B False – They provide little protection against high energy gamma radiation.

C False.

D True.

E True.

A12.30 FOLLOWING ADMINISTRATION OF RADIOPHARMACEUTICALS

A False – External radiation is from gamma emitters.

B True – Restricted contact is recommended.

C False – Incontinent patients present a particular problem due to contamination of pads and clothing.

D True.

E True.

A12.31 IN RADIONUCLIDE IMAGING, SENSITIVITY IS

A False – This is uniformity.

B False – This is spatial resolution.

C False – This is spatial linearity.

D True.

E False – This is the count rate capability.

A12.32 QUALITY ASSURANCE IN RADIONUCLIDE IMAGING INVOLVES MEASURING

A True.

B True.

C True.

D True.

E True.