Radioisotopes (radionuclides) are playing an increasingly important part in human life. They are widely used in medicine, industry and scientific research and new applications for their use are constantly being developed. Based on radionuclides, nuclear medicine has been developed as an independent medical field [1-3]. Clinical uses of radionuclides fall into three general areas: 1) \textit{in vitro} diagnostic studies, 2) \textit{in vivo} diagnostic studies-medical imaging and 3) \textit{in vivo} therapeutic procedures:

(1) \textit{in vitro} diagnostics mean that samples of the patient (blood, body fluids, tissues) are analyzed for various materials (e.g., tumour and viral markers, thyroid and sex hormone, drugs, vitamins, etc.) with radionuclide laboratory methods such as radioimmunoassay (RIA) and immunoradiometric assay (IRMA) [4].

(2) During \textit{in vivo} examinations radionuclides/radio- pharmaceuticals are delivered to the patient’s body in various ways (usually intravenously, sometimes orally, with inhalation or with direct injection to the tissues) [5]. By the process of radioactive decay radionuclide is detected from outside by special types of cameras, while it shows different distribution patterns in the human body to provide very precise pictures about the area being imaged. Imaging modalities widely used in nuclear medicine include \(\gamma\) camera scintigraphy, single photon emission computed tomography (SPECT) and positron emission tomography (PET) [6,7].

(3) Although in nuclear medicine nearly 95 % of the radionuclides are used for diagnostic purposes, it is possible to use radionuclides for the treatment of some pathologic processes in patients. The radionuclides/radiopharmaceutical can be delivered to a targeted location in tissue and therapeutic radiation can take place locally with the preservation or with minimal impact on surrounding organs (isotope therapy) [8,9].

In this review article the most common radiotracers routinely used for diagnosis \textit{in vitro} (H-3, C-14, P-32, P-33, I-125, Cr-51) and \textit{in vivo} (Tc-99m, I-131, I-123, Ga-67, Ga-68, In-111, Ti-201, F-18, O-15, C-11, N-13) are described and discussed. The basic introduction of SPECT and PET are also incorporated in the text. For better understanding the topic, particularly for the readers who are not familiar with the issue, some fundamentals about radioactivity are included.

\textbf{Basic terms about radioactivity:} All elements can exist as two or more isotopes that differ in the number of neutrons in the nucleus. Some isotopes are stable indefinitely, while others are unstable-radioactive. The term radionuclide relates to a radioactive element, man-made or from natural sources, with a specific atomic weight. Radioactivity is the property of a nucleus in unstable atoms that causes them to spontaneously decompose in the form of subatomic particles or photons. Radioactive decay is the spontaneous transformation of one nuclide into another nuclide or different energy state; in the transformation process, radiation is emitted. Radioactive isotopes decay with a defined half-life (the time required for...
the amount of a particular radionuclide to decrease to one half of its original value), primarily through release of helium nuclei (α-particles), electrons or positrons (β-particles) and γ-radiation [10]. The general properties of radiation are presented in Table-1.

The System International (SI) unit for radioactivity is becquerel (Bq), which is defined as one disintegration per second. For practical application, Bq is too small unit; therefore, the prefixes like kBq, MBq and GBq are common. Another unit of radioactivity is curie (Ci) - quantity of radioactive material which decays at the rate of $3.7 \times 10^{10}$ disintegrations per second. Dose (radiation dose) is a general term used to express (quantify) how much radiation exposure something (a person or other material) has received. The exposure can subsequently be expressed in terms of the absorbed, equivalent and effective dose. The unit of measure for absorbed dose is the gray (Gy). The ability of some types of radiation to cause more significant levels of biological damage, taken into account with radiation weighting factor used to determine equivalent dose, is expressed in sieverts (Sv). Effective dose, also expressed in Sv, is based upon the estimates of the relative risk of stochastic effects from the irradiation of the different tissues [11,12].

**Radiolabeling:** The basic concepts of radioisotopes as radiotracers were laid down by a Hungarian scientist, György Hevesy (1885-1966) who was awarded the Nobel Price (1943) for the invention of tracer and radioisotope labeling methods with which very small amounts and concentrations of substance can be tracked. In general, labeling involves the application of known synthetic methods to target molecules in which at least one atom is present as an isotope other than its naturally most abundant one. Molecules that contain such an isotope are referred to being “labeled” because such isotopically distinct atoms serve to mark the molecule for later detection by various means. The special case of isotopic labeling is radioisotopic labeling- a technique where the substance is labeled by including radioactive isotopes (radionuclides) in its chemical composition. These radionuclides or radiotracers can be determined by detecting the radiation generated in the isotope-decay process. A solo radionuclide or a labeled compound with radionuclide used in nuclear medicine is called a radiopharmaceutical (terms commonly used in literature such as radiotracer, radiodiagnostic agent, or tracer, are terms all referred to as a radiopharmaceutical) [13].

**Radiotracers for in vitro diagnostic studies:** The concentrations of biological compounds in body fluids, even hormones and vitamins present in extremely small quantities, may be measured using radionuclides by techniques such as RIA, competitive protein binding analysis, receptor-ligand binding, enzyme assays, protein-protein and protein-DNA interactions. Although radiotracers for in vitro measurements have been replaced progressively by non-radioactive markers (such ELISA), many laboratories still use this techniques.

Radionuclides routinely used as in vitro tracers have half-lives ranging from several days to thousands of years. Such half-lives and the related specific activities of such radionuclides make them ideally suited to applications such as DNA synthesis studies, RIA, binding studies, drug screening and ADME work. In contrast, when the half-life of a radionuclide is very short, any compound labeled with it will be difficult to prepare, use and measure within the time of decay. This group of radioisotopes decay by emission of β particles and/or γ-rays. Applications using α-emitters are limited due to limited penetration ability. β-Emitters can be measured by liquid scintillation counting, autoradiography and thin end-window ionization counting. γ-Emitters are usually measured by solid scintillation methods [14].

Table-2 gives more detailed information regarding the most commonly used radioisotopes for in vitro measurements, along with handling precautions and potentially affected organs upon exposure. Radioisotopes of hydrogen, carbon, phosphorus, sulphur and iodine have been used extensively to trace the path of biochemical reactions. Peptides or proteins are mostly labeled with I-125, C-14 and H-3, in order to enhance the sensitivity of detection, to quantitative the binding of peptides to other molecules, or for RIA. Radiolabeling with P is predominantly applied to the incorporation of labeled phosphate into nucleic acids and phospholipids. Cr-51 is used for labeling red blood cells; by reinjecting chromium-tagged red cells into their original host, it might be possible to measure the longevity of erythrocytes in their native environment, etc.

**Radiotracers for in vivo diagnostic studies:** The nuclear characteristics of the radioisotopes, such as chemical properties, mode of decay and half-life, determine their potential application in medicine for in vivo diagnostic studies [5]. The two most desirable characteristics of radionuclides used for imaging are: no particle emission (particular radiation does not penetrate tissue completely) and low energy of γ radiation. High energy absorption may result in cellular damage and cannot be used to produce an image; oppositely, if energy of γ photon is too low (e.g., < 50 keV), radiation will not be able to penetrate completely from within the body. Thus, the ideal characteristics of the radioisotopes for in vivo diagnostic are: pure γ-emitter, relatively short half-life (6 h to 3 days), γ energy: 100-250 keV, readily available and inexpensive [1].

**Single photon emission computed tomography and its radionuclides:** Single photon emission computed tomography (SPECT) is a technique in which single photons are detected by a γ-camera which can view organs from many different angles.

| Property                  | α            | β+          | β-          | γ        |
|---------------------------|--------------|-------------|-------------|----------|
| Type of radiation         | α            | β+          | β-          | γ        |
| Charge (g)                | 2+           | 1-          | 14+         | No charge |
| Mass (g)                  | 6.64 × 10⁻²⁴ | 9.11 × 10⁻²⁸| 9.11 × 10⁻²⁸ | No mass  |
| Relative penetrating power| 1            | 100         | 100         | 10.000   |
| Penetrating in tissue     | 0.001 mm     | 7 mm        | 7 mm        | Total penetration |
| Nature of radiation       | Helium nuclei| Electrons   | Positrons   | High-energy photons |
Radioisotopes Used as Radiotracers for *in vitro* and *in vivo* Diagnostics: A Review

| Isotope | Half-life $T_{1/2}$ | Decay mode $E_{\gamma}$/MeV | Max range in air | Shielding required | Critical organ | Special consideration | Use for labeling |
|---------|---------------------|-----------------------------|------------------|--------------------|---------------|----------------------|-----------------|
| H-3     | 12.3 years          | $\beta^-$ 0.0086            | 4.6 mm           | none               | Whole body    | Not an external hazard (can not penetrate gloves or the dead layer of skin), but an internal hazard that may be absorbed through the skin or inhaled. | Proteins, peptides, nucleic acids, drugs and toxins, ADME* work |
| C-14    | 5730 years          | $\beta^-$ 0.158             | 22 cm            | 1 cm plexiglass    | Whole body, especially body fat | Most $^{14}C$-labeled compounds are rapidly metabolized and exhaled as $^{14}CO_2$ which could be inhaled. | Proteins, peptides, nucleic acids, drugs and toxins, ADME work |
| I-125   | 60 days             | $\gamma$ 0.0355             | n/a              | none; for quantities up to 1 mCi 0.78 mm lead shielding | Thyroid | About 30 % of free iodine taken into the body will concentrate in the thyroid. | Proteins, usually at tyrosine residues, peptides, wide range of drugs, pesticides, herbicides, environmental pollutants and other molecules of biochemical interest, foremost isotope for RIA Nucleotides, phosphoproteins, DNA, RNA |
| P-32    | 14.3 days           | $\beta^-$ 1.710             | 5.5 m            | 1 cm plexiglass    | Bone (internal), skin, eyes (external) | $^{32}P$-labeled compounds are readily absorbed through the skin. Eye protection is recommended. | Nucleotides, phosphoproteins, DNA, RNA |
| P-33    | 24.4 days           | $\beta^-$ 0.248             | 45 cm            | 1 cm plexiglass    | Bone | Large quantities (> 1 mCi) and volatile compounds must be handled in a fume hood. Some compounds, such as $^{35}S$-methionine, may vaporize upon opening of container. | Proteins that incorporate sulfur-containing amino acids (methionine), nucleic acids |
| S-35    | 87.4 days           | $\beta^-$ 0.167             | 24 cm            | 1 cm plexiglass    | Testes, whole body | Cr is slowly eliminated from the body. 5 % of the uptake is transferred to bone and retained with a biological half-life of 1000 days. | Red blood cells |
| Cr-51   | 27.7 days           | EC 0.320                     | n/a              | 3 mm lead          | Lower large intestine | | |

*ADME = administration, distribution, metabolism, elimination

Single photon emission computed tomography images are produced from multiple 2D projections by rotating one or more $\gamma$ cameras around the body. The advantages of SPECT over planar scintigraphy can be seen in the improvement of contrast between regions of different function, better spatial localization, improved detection of abnormal function and importantly, greatly improved quantification [15].

The most commonly used radionuclides for SPECT are: technetium-99m ($^{99m}Tc$), iodine-123, gallium-67, indium-111 and thallium-201. The radioisotope decays and emits $\gamma$ rays, which can be detected by a $\gamma$ camera to obtain 3D images [16].

**Technetium-99m**: The ideal radioisotope for SPECT imaging is technetium-99m, due to its favourable physical and radiation characteristics, its availability through commercially available generator systems and its low cost per dose [17, 18]. A recent bulletin of the World Nuclear Association (WNA) on nuclear medicine stated: “Over 10,000 hospitals worldwide use radioisotopes in medicine and about 90 % of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99m (in technical jargon: $^{99m}Tc$), with some 30 million procedures per year, accounting for 80 % of all nuclear medicine procedures worldwide” [19]. The element technetium (from the Greek word technetos, meaning artificial) was discovered in 1937 by Carlo Perrier and Emilio Segré [20].

There are currently more than 20 known isotopes of technetium, all being radioactive. Its metastable $^{99m}Tc$ isotope has become the mainstay of diagnostic nuclear medicine. The nuclear properties of $^{99m}Tc$ are ideal for diagnostic imaging: it has a 6.02 h half-life and $\gamma$-ray emission energy of 141 keV with 89 % abundance. The decay is long enough to allow a radiochemist to carry out the preparation, quality control, administration of labeled compound to the patient and all nuclear medicine practitioners to collect images with commercial $\gamma$ cameras. At the same time, the absence of tissue-damaging radiation allows the injection of activities higher than 30 mCi with low time exposure for the body. Another reason for the wide clinical use of this nuclide was the development of the $^{99m}Mo^{99m}Tc$ generator, which is commonly present in every department of nuclear medicine. $^{99m}Tc$ is readily available as pertechnetate ($^{99m}TcO_4$-) in a sterile, pyrogen-free and carrier-free state from $^{99m}Mo^{99m}Tc$ generators, is relatively low cost and is easy-to-label kit preparations for in-house use. Another advantage is the low radiation to patients, due primarily to its short half-life. The decay within hours also facilitates the handling of waste. The chemistry of technetium allows it to form a stable complex with a relatively wide range of chemical chelation agents [21]. An intensive search for new $^{99m}Tc$-radiopharmaceuticals based on a rational approach (e.g. cationic complexes...
for myocardial perfusion agents [22], neutral lipophilic compounds for brain perfusion tracers [23,24]) and a steadily growing knowledge of Tc-complexation chemistry has resulted in efficient tracer agents for measurement of kidney function ($^{99m}$Tc-mertiatide), myocardial perfusion ($^{99m}$Tc-sestamibi, $^{99m}$Tc-tetrofosmin) and brain perfusion ($^{99m}$Tc-exametazime, $^{99m}$Tc-bicisate) [25-29].

Table-3 gives more detailed information regarding the most commonly used radioisotopes, primarily Tc-99m, its physical half-life, forms and diagnostic use for SPECT.

| Isotop Name (Symbol) | Physical half-life T$_{1/2}$ | Mode of decay (%) | $\gamma$-Ray energy (MeV) | Form | Diagnostic use |
|----------------------|-----------------------------|------------------|---------------------------|------|----------------|
| Sodium pertechnetate | 6.0 h                       | IT (100)         | 0.140                     | Thyroid scintigraphy; salivary gland scintigraphy; gastric mucosa imaging; Brain scintigraphy, lachrimal duct scintigraphy; | |
| Sodium pertechnetate labeled red blood cells (Tc-RBC) | | | | In vivo labeling of RBC for regional blood pool imaging, first-pass cardiac radionuclide angiography, detection of occult gastrointestinal bleeding | |
| Tc-albumin colloid (Nanocolloid) | | | | Bone marrow scintigraphy; inflammation scintigraphy and lymphoscintigraphy | |
| Tc-albumin macroaggregated (MAA) | | | | Lung perfusion scintigraphy, radionuclide venography | |
| Tc-albumin microaggregated | | | | Liver and spleen scintigraphy | |
| Tc-acipitate | | | | Acute venous thrombosis imaging | |
| Tc-Iminodiacetic acid (IDA) derivatives (lidofenin, disofenin, mebrofenin) | | | | Hepatobiliary scintigraphy (to evaluate hepatocyte function, biliary duct obstruction, control after surgical intervention) | |
| Tc-etidronate/medronate/ oxonidrate | | | | Skeletal scintigraphy, diagnosis primary and metastatic bone tumors, metabolic bone disease, localization of fractures, evaluation of bone pain | |
| Tc-Ethyl-cysteinate dimer (ECD) | | | | Brain perfusion imaging, diagnosis of acute cerebral infarction when CT is negative, detection of an abnormal focus in patients with head trauma after accidents, differentiation of focal abnormalities in cerebral blood flow typical in multi-infarct dementia and degenerative dementia | |
| Tc-hydroxy-methyl-propyleneamine oxime (HMPAO; Tc-exametazime) | | | | Brain perfusion imaging, diagnosis of acute cerebral infarction when CT is negative, diagnosis of cerebrovascular disease and differentiation of focal abnormalities in multi-infarct dementia and degenerative dementia | |
| Tc-glucetate | | | | Renal and brain imaging | |
| Tc-labeled red blood cells | | | | Determination of red cell volume; short-term red cellsurvival studies | |
| Tc-Metoxy-isobutyl-isonitride (MIBI) | | | | Detection of myocardial perfusion abnormalities, diagnosis and localization of myocardial infarction, asessment of global ventricular function, detection of breast tumors and hyperparathyroidism; tumor viability and proliferation | |
| Tc-Mercaptoacetyltriglycine (MAG3) | | | | Renal imaging/renography (anatomical and functional, evaluate renal tubular function, control after kidney transplants, diagnose urinary obstruction | |
| Tc-pentetate (DTPA) | | | | Renal studies, determination of glomerular filtration rate (GFR); inhalation scintigraphy to measure regional lung ventilation; cerebral scintigraphy based on leaks in the blood-brain barrier (BBB) | |
| Tc-pyrophosphate | | | | Bone imaging; myocardial infarct imaging; blood pool imaging; detection gastrointestinal bleeding | |
| Tc-Dimercaptosuccinic acid (DMSA) | | | | Renal scintigraphy, detection of medullary thyroid cancer | |
| Tc-fanolesomab/sulesomab | | | | Imaging and diagnosis of infections and inflammation | |
| Tc-sulfur colloid | | | | Liver and spleen imaging; bone marrow imaging; Detection of intrapulmonary and gastrointestinal bleeding; Esophageal transit studies; Lung ventilat. imaging | |
| Tc-teboroxime; -tetrofomnin | | | | Myocardial perfusion imaging (detection of reversible myocardial ischemia and myocardial infarction) | |
| Radioisotope       | T1/2 (days) | Mode of decay | Emission Energy (keV) | Uses                                                                 |
|-------------------|-------------|---------------|-----------------------|----------------------------------------------------------------------|
| Iodine-123 (123I) | 13.2 h      | EC (100)      | 0.159                 | Sodium iodide                                                         |
|                   |             |               |                       | Thyroid function studies; thyroid imaging                             |
|                   |             |               |                       | Iodobenguane (MBG)                                                    |
|                   |             |               |                       | Adrenomedullary imaging and tumor detection, detection of pheochromocytoma |
|                   |             |               |                       | Iodohippurate sodium                                                  |
|                   |             |               |                       | Determination of renal function, renal imaging; renal blood flow; urinary tract obstruction |
|                   |             |               |                       | Iofetamine hydrochloride                                             |
|                   |             |               |                       | Cerebral imaging                                                      |
|                   |             |               |                       | Sodium iodide                                                        |
|                   |             |               |                       | Thyroid function studies; thyroid imaging                             |
|                   |             |               |                       | Iodinated fats and fatty acids                                       |
|                   |             |               |                       | Pancreatic function; intestinal fat absorption                       |
|                   |             |               |                       | Cerebral and periferal vascular flow; plasma volume determination; brain scan;placenta localization |
|                   |             |               |                       | Iodinated human serum albumin                                        |
| Calcium-47 (47Ca) | 4.5 d       | β and γ       | 0.670, 1.297          | Chromium disodium edetate                                            |
| Chromium-51 (51Cr)| 27.7d       | EC (100)      | 0.320                 | Chronic chloride                                                     |
| Cobalt-57 (57Co)  | 271 days    | EC (100)      | 0.122                 | Sodium chromate labeled red blood cells                               |
| Cobalt-58 (58Co)  | 71 days     | EC, β (14.9); β (100) | 0.811, 1.173          | Radioactive vitamin B12                                              |
| Cobalt-60 (60Co)  | 5.2 years   | β (100)       |                       | In Schilling test for absence of intrinsic factor (pernicious anemia) or other defects of intestinal vitamin B12 |
| Gallium-67 (67Ga) | 78.2 h      | EC (100)      | 0.093                 | Galium citrate                                                       |
|                   |             |               |                       | Detection of malignant diseases such as Hodgkin’s disease, lymphomas and bronchogenic carcinoma; localization of acute inflammatory diseases and infections |
| Indium-111 (111In)| 2.8 days    | EC (100)      | 0.171                 | Indium oxine labeled red blood cells                                 |
|                   |             |               |                       | Detection of gastrointestinal bleeding                                |
|                   |             |               |                       | Indium oxine labeled leukocytes                                       |
|                   |             |               |                       | Detection of abscesses, infections and inflammation                  |
|                   |             |               |                       | Indium oxine labeled platelets                                       |
|                   |             |               |                       | Detection of deep vein thrombosis; cardiac thrombosis                |
|                   |             |               |                       | Indium chloride                                                      |
|                   |             |               |                       | Tumor detection; Hematopoietic bone marrow imaging                    |
|                   |             |               |                       | Indium pentetreotide                                                 |
|                   |             |               |                       | Primary and metastatic neuro-endocrine tumors detection (neuroblastomas, pituitary adenomas, medullary thyroid carcinomas |
|                   |             |               |                       | Red cell maturation studies                                          |
| Iron-55 (55Fe)    | 2.73 years  | β and γ       | 1.999                 | Labeled red blood cells                                              |
| Iron-59 (59Fe)    | 45 days     | β (100)       | 1.099                 | Ferric chloride, -citrate; -sulfate Potassium chloride               |
| Potassium-43 (43K)| 22.3 h      | β and γ       |                       | Selenomethionine                                                     |
|                   |             |               |                       | Imaging of pancreas and parathyroid glands                           |
| Selenium-75 (75Se)| 120 days    | γ             |                       | Sodium chloride                                                      |
| Sodium-24 (24Na)  | 14.66 h     | β and γ       |                       | Determination of sodium space, total exchangeable sodium             |
| Thallium-201 (201TI) | 73 h | EC (100) | 0.167 | Thallous chloride Thallium-201                                      |
|                   |             |               |                       | Myocardial perfusion imaging in order to delineate between ischemic and infarcted myocardium; detection of hyperparathyroidism and brain tumors, Tumor viability and proliferation |
| Xenon-133 (133Xe)| 5.24d       | β and γ       | 133Xe Gas             | Lung ventilation studies; pulmonary perfusion imaging; assessment of cerebral blood flow |

**Positron emission tomography and its radionuclides:**

Positron emission tomography (PET) is a 3-D nuclear medicine imaging technique which is based on detection of the annihilation radiation emitted from a certain positron-emitting radionuclide. When the radionuclide decays, the positron will annihilate with an electron nearby, thus creating two 511 keV photons emitted opposite to each other (180°). This can be observed by PET detectors arranged in an array of full or partial ring around the patient body axis. Data are then reconstructed using a standard algorithm. By using this coincidence-detection method, the traditional collimator of the SPECT scanner can be removed, therefore, the spatial resolution and sensitivity can be highly improved [7,30,31].

The common radioisotopes used in PET are short-lived: carbon-11, nitrogen-13, oxygen-15, fluorine-18, as well as gallium-68 and rubidium-82, all β⁺-emitters [32].
Fluorine-18 (often associated with the compound fluoro-deoxyglucose, FDG) is the most employed tracer with the PET technique since it allows imaging in a large variety of malignant tumors and metabolism diseases. In cancer imaging the radioactive sugar can help in locating a tumor, because cancer cells take up or absorb sugar more avidly than other tissues in radioactive imaging. In cancer imaging, the technique since it allows imaging in a large variety of malignant tumors and metabolism diseases. In cancer imaging, radioactive imaging can help in locating a tumor, because cancer cells take up or absorb sugar more avidly than other tissues. In radioactive imaging, the technique since it allows imaging in a large variety of malignant tumors and metabolism diseases. In cancer imaging, radioactive imaging can help in locating a tumor, because cancer cells take up or absorb sugar more avidly than other tissues.

**Radionuclides:** C-11, N-13 and O-15 are the same atoms which naturally comprise the organic molecules used in the body. Labeling with these radionuclides, a compound is chemically and biologically identical to the original. In that way, it is possible to label both naturally occurring compounds such as neurotransmitters, sugars, etc. and synthesized compounds (such as drugs) and follow them through the body.

Other than those cyclotron-produced PET radionuclides mentioned above, generator-produced gallium-68 and rubidium-82 have also shown high potentials in PET imaging. The advantage of in-house generator produced radionuclide is that the generator itself serves as a top-of-the-bench source far from a cyclotron facility. Besides, it is quite simple to obtain radionuclides from the generator and less expensive compared to cyclotron-produced radionuclides.

In the past decade, copper-64 and zirconium-89, because of their long half-lives (12.7 h and 78.4 h, respectively), have been increasingly recognized for labeling nanoparticles or slowly localizing antibodies.

Commonly used PET imaging radionuclides are listed in Table-4.

### Table-4

| Isotop Name (Symbol) | Physical half-life T_{1/2} | Mode of decay | Form | Diagnostic Use |
|----------------------|--------------------------|--------------|------|---------------|
| Fluorine-18 (18F)    | 110 min                  | β⁻ (97)      | 18F-Fluorometitfluoride | Blood flow (CBF) |
|                      |                          |              | 18F-Fluorodeoxyglucose | For the study of metabolism in the brain and heart and for the detection of epilepsy and various tumors, Glucose metabolism; Tumor viability and proliferation |
|                      |                          |              | 18F-Fluorodopa | For the assessment of the presynaptic dopaminergic function in the brain |
|                      |                          |              | 18F-fluoro-L-tyrosine | Protein synthesis and amino acid transport; Tumor viability and proliferation |
| Oxygeen-15 (15O)     | 2 min                    | β⁺ (100)     | 15O-Carbon-dioxide; 15O-Water; Molecular oxygen (15O2) 15Carbon-monoxide-labeled RBC | Blood flow (CBF); For myocardial and cerebral perfusion studies. |
| Nitrogen-13 (13N)    | 10 min                   | β⁺ (100)     | 13N-ammonia | Oxygen extraction fraction (OEF) and metabolism Blood volume |
| Carbon-11 (11C)      | 20.4 min                 | β⁺ (100)     | 11C-Butanol 11C-methionine | Blood flow (CBF) measurement in brain and other organs Tumor viability and proliferation For the detection of different types of malignancies, reflecting the amino acid utilization (protein synthesis and amino acid transport) Detection of various neurologic and psychiatric disorders (Parkinson’s disease and schizophrenia) |
|                      |                          |              | 11C-Raclopride | Tumor viability and proliferation For the measurement of oxygen consumption in the heart and brain For the neuroradionuclide characterization in humans To determine the dopamine-2-receptor density in patients with neurologic diseases |
|                      |                          |              | 11C-Thymidine | |
|                      |                          |              | 11C-sodium acetate | |
|                      |                          |              | 11C-Flumazenil | |
|                      |                          |              | 11C-Methlysipiperone | |
|                      |                          |              | 18F-fluoroDopa | |
|                      |                          |              | 18F-fluoroL-tyrosine | |
|                      |                          |              | 18F-Fluorodopa | |
|                      |                          |              | 18F-Fluorodeoxyglucose | |
|                      |                          |              | 18F-Fluorometitfluoride | |

Sometimes, prophylactic formulations, known as classical radioprotectors, may be used before procedure that includes the application of radiotracers to prevent risk of potential tissue damage [35].

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