Physical Basis of Positron Emission Tomography

[1]Elmurotova Dilnoza Bahtiyorovna	Tashkent Medical Akademy
[2]Zuparov Ilxom Baxodirovich	Tashkent Medical Akademy
[3]Bozarov Ulug'bek Alisher o'g'li	Tashkent Medical Akademy
[4]Mamadaliyeva Umida Pulatovna	Tashkent Medical Akademy
[5]Bozorov Erkin Hozhievich	Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan

ABSTRACT

The physical properties of a charged positron particle and the emission scheme are given. Two main research methods in positron emission tomography. The properties of radiopharmaceuticals used in positron emission tomography are given.

Keywords: Nuclide, detection, dynamics, statistics, radiopharmaceuticals, drug, fluorodeoxyglucose, gamma, quantum, positron.

The nucleus of any nuclide is capable of positron decay and is unstable due to having more protons than neutrons. To transition to a stable state, it needs to get rid of one proton. This occurs in the form of the following reaction:

proton > positron (+) + neutrino (0) + neutron (0)

The result is a stable atom, where the number of proton-nucleons is equal to the number of electrons. The positron is the product of this reaction. A positron is a positively charged particle with a mass equal to that of an electron. After emission from the nucleus of an atom, the positron travels a distance of 1-3 mm in the surrounding tissues and interacts with the electron. Now of stopping in the electron shell of an atom, a positron combines with an electron, and the mass of both particles turns into two high-energy γ-quanta, scattering in strictly opposite directions (annihilation). The energy of each of these quanta is 511 keV (Fig. 1).

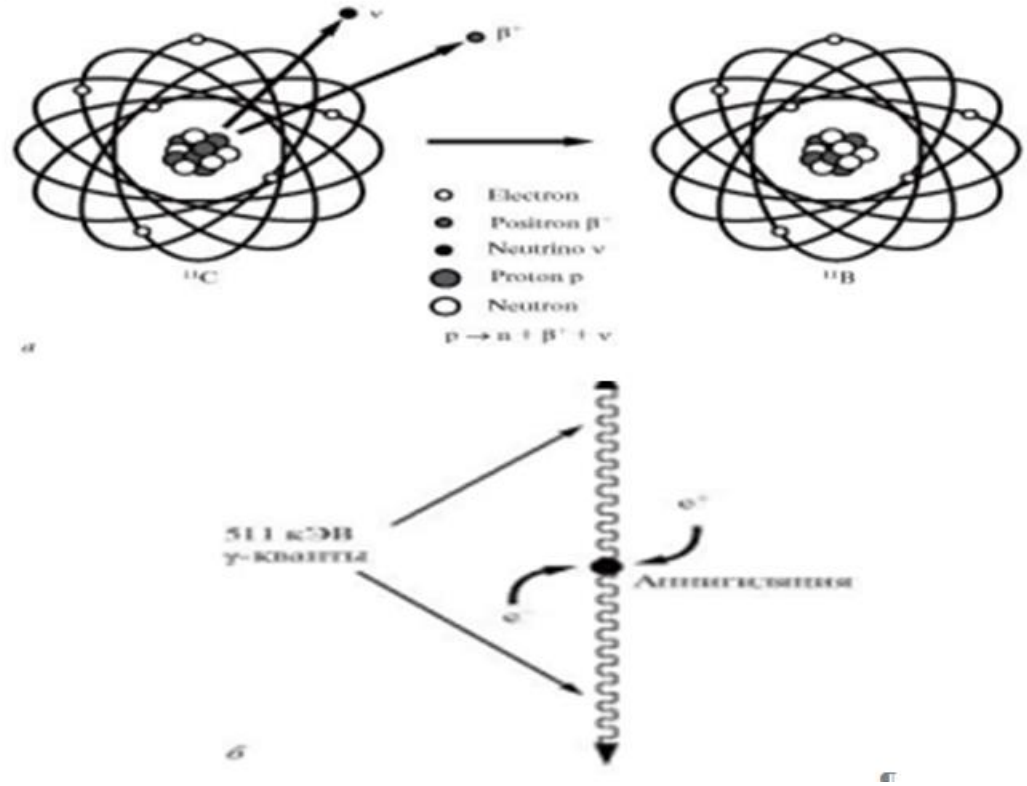

Fig. 1. Scheme of the emission of a positron from the nucleus of an atom and its interaction with an electron: a - the process of stabilization of the nucleus of an atom with the transformation of a proton into a neutron and the emission of a positron; b- interaction of a positively charged positron and a negatively charged electron (annihilation) with the formation of two γ-quanta [1]

In a positron emission tomograph, γ quanta are recorded using several rings of detectors. If two γ rays are detected simultaneously by two oppositely located detectors (for a short time), then it is assumed that they arose from annihilation along the line connecting these detectors. This principle is called coincidence detection.

Subsequently, the processing of the received information does not differ from that with other methods of radionuclide imaging: a γ-quantum, falling on the detector crystal, causes a flash (scintillation), photomultipliers convert the total value of such flashes into digital form, which is then displayed on the display screen [2].

The detectors are arranged in a ring around the object under study, which allows all annihilations to be recorded using a coincidence pattern.

The positron emission tomography system sums up all response lines from detector pairs recorded during recording and reconstructs the image using an algorithm similar to computed tomography, magnetic resonance imaging, and single photon emission computed tomography.

Thus, layer-by-layer images are obtained of the accumulation of the radiopharmaceutical in the studied area or in the entire body at once, and the main task is to determine the exact localization of these changes, taking into account data previously obtained by other research methods.

Methods of conducting research in positron emission tomography: There are two main methods of scanning in positron emission tomography - dynamic and static.

Dynamic scanning is based on collecting information from the same area of the body at certain intervals in order to monitor the dynamics of accumulation of a radiopharmaceutical, for example, to determine the rate of accumulation, residence time and rate of elimination of radiopharmaceuticals in a pathological formation. In the future, with full statistical processing, these parameters can clearly

characterize the pathology, allowing the correct diagnosis to be formulated.

Static scanning is a technique based on a one-time collection of information from a particular area or from the entire body some time after the administration of a radiopharmaceutical drug. Using this type of scan, one must know the levels of accumulation administered - the radiopharmaceutical is normal and be able to distinguish them from accumulation in pathological conditions. Often the technique is complemented by delayed scanning to determine the dynamics of removal of the radiopharmaceutical from the formation. For example, in the differential diagnosis of inflammatory changes and a malignant process, faster removal of glucose from the pathological area will indicate inflammatory changes. The resulting picture of radiopharmaceutical accumulation is compared with the results of other (morphological) radiation research methods - computed tomography or magnetic resonance imaging.

Modern combined positron emission tomography-computed tomography scanners allow you to simultaneously perform two studies (positron emission tomography and computed tomography) and accurately combine positron emission tomography data with computed tomography results in order to assess morphological changes in terms of changes in cell metabolism.

Positron emission tomography uses radiopharmaceuticals - natural metabolites labeled with radioactive oxygen, carbon, nitrogen, and fluorine. These drugs are included in the metabolism. As a result, it is possible to evaluate the processes occurring at the cellular level.

For positron emission tomography, only ultra-short-lived nuclides are used. Data on the nuclides used are presented in table. 1.

Table 1. Nuclides used for positron emission tomography

Radionuclide	Half-life, min	Stable atom	Positron energy, meV
^{11}C	20,4	^{11}B	0,96
^{13}N	9,9	^{13}C	1,19
^{15}O	2,1	^{15}N	1,72
^{18}F	110	^{18}O	0,64
^{68}Ga	68	^{68}Zn	1,89
^{82}Rb	1,3	^{82}K-	3,35

Positron emission tomography with 18F-fluorodeoxyglucose is a highly informative technique; it is used in the diagnosis of malignant tumors.

The half-life is several minutes and even seconds. Ultra-short-lived radionuclides for the production of radiopharmaceuticals are synthesized in cyclotrons. The next step is the addition of the resulting nuclide to a natural metabolite (carbohydrate, amino acid or fatty acid), for example:

^{18}F + glucose = ^{18}F-deoxyglucose (^{18}F-fluorodeoxyglucose).

This happens in a radiochemical laboratory. Glucose, entering the bloodstream through the mediation of carriers (hexokinase), enters the cell in the form of glucose-6-phosphate and subsequently undergoes changes along two main biochemical pathways in the form of gluconeogenesis and glycolysis. In this case, the radiopharmaceutical would be destroyed and lose its purpose. ^{18}F-fluorodeoxyglucose reaches only the intermediate metabolic form - ^{18}F-fluorodeoxyglucose-6-phosphate - and undergoes no further changes, remaining inside the cell. This makes it possible to observe the accumulation of glucose in tissues with positron emission tomography (Fig. 2).

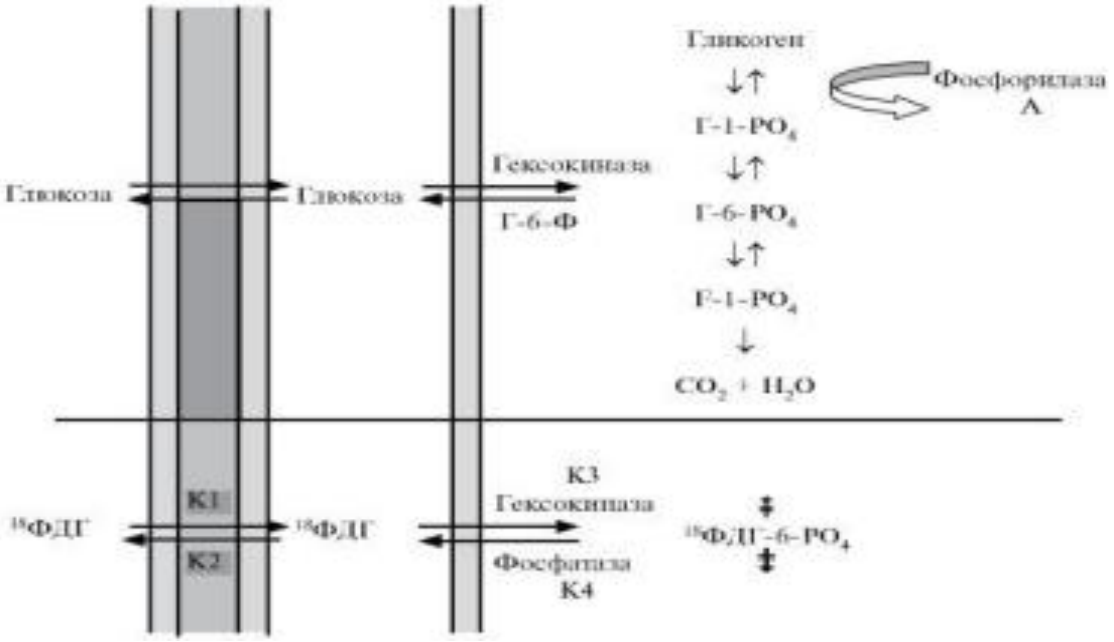

Fig. 2. Scheme of metabolism of glucose and 18-fluorodeoxyglucose. 18-fluorodeoxyglucose, unlike regular glucose, is not metabolized beyond the glucose-6-phosphate stage and remains intracellular.

Thus, it becomes possible to record the accumulation concentration of a radiopharmaceutical. 1 hour after administration, high uptake of fluorodeoxyglucose is observed in the brain, myocardium and kidneys. Increased uptake of fluorodeoxyglucose is also possible at sites of tissue repair (eg, after biopsy) and during infectious processes. Normally, fluorodeoxyglucose uptake is high in the gastrointestinal tract, thyroid gland, salivary glands, skeletal muscle, bone marrow and urinary organs.

Recently, studies using amino acids or their analogues labeled with positron-emitting nuclides have become increasingly important.

Amino acid transport increases during tumor cell transformation. Tumor growth requires an increased supply of nutrients necessary for energy metabolism and protein synthesis, so an increase in amino acid transport may be associated with specific changes on the surface of the tumor cell. These data provided the basis for the use of labeled amino acids as a radiopharmaceutical for tumor imaging, since replacing the carbon atom with an ^{11}C carbon nuclide does not chemically change the molecule [3-5].

A noticeable advantage of using an amino acid-based radiopharmaceutical, compared with the introduction of ^{18}F-fluorodeoxyglucose, is the large difference in the levels of their accumulation in tumor tissue compared to normal tissue. Of the amino acids, ^{11}C-methionine is the most commonly used, mainly due to its simple and efficient radiochemical synthesis. Energy metabolism is assessed with ^{18}F-fluorodeoxyglucose, and amino acid transport and metabolism with ^{11}C-methionine. Different physiological mechanisms of accumulation determine the different roles of these two radiopharmaceuticals in positron emission tomography [6-7].

There are radiopharmaceuticals based on biologically active substances such as choline, acetate, artificially synthesized amino acids: [^{11}C]-choline for the diagnosis and staging of prostate cancer, [^{11}C]-acetate for the diagnosis of prostate cancer and primary liver cancer, [^{15}O]-water in the diagnosis of brain perfusion disorders, [^{13}N]-ammonium in the diagnosis of metabolic disorders of the myocardium, [^{11}C]-sodium butyrate in the diagnosis of brain formations.

However, to date there is no consensus in choosing the most diagnostically significant

radiopharmaceutical for positron emission tomography. All radiopharmaceuticals have their advantages and disadvantages.

List of references:

1. Г.Е. Труфанов и др. Лучевая диагностика // учебник. М. ГЭОТАР-Медиа, 2015. 496 с. ISBN 978-5-9704-3468-0
2. Quebec Agency for Health Services and Technology Assessment, www.aetmis.gouv.qc.ca, October 2001.
3. C.J Thompson. Instrumentation. In: Wahl RL, Buchanan JW, eds. Principles and Practice of Positron Emission Tomography. Philadelphia: Lippincott Williams & Wilkins; 2002:48-64.
4. А.П. Черняев, Д.В. Волков, Е.Н. Лыкова. Физические методы визуализации в медицинской диагностике: Учеб. Пособие, М.: МГУ, 2019. 112-с. ISBN 978-5-6042768-0-8.
5. Н.Б. Кузьмина. Что такое ядерная медицина? М.: НИЯУ МИФИ, 2012. 32 с.
6. Элмуротова Д.Б., Таубалдиев А.А. Развитие ядерной физики в Узбекистане //«Polish science journal». ISSUE 2 (35). Part 3. Warsaw, Poland P. 2021, 270-272. elibrary.ru.
7. Отахонов П.Э., Чариева Г.Ю., Элмуротова Д.Б. Современная позитронно-эмиссионнная томография // «Ta'lim fidoyilari» Respublika ilmiy-metodik jurnali, 5-son, 1-jild may-2021, 1-qism, ISSN 2180-2160, Узбекистан, С.831-838. www.Talimfidoyilari.uz.