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Basic Concepts and Application of Nuclear Medicine

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Editorial

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Keywords

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Abbreviations

SPECT: Single-Photon Emission Computed Tomography; PET: Positron Emission Tomography; CT: Computed Tomography; MRI: Magnetic Resonance Imaging.

Editorial

Scientific and Technical Concepts Related to Nuclear Medicine

Understanding the scientific and technical concepts related to nuclear medicine is the fundamental approach to ensuring effective and efficient use of radionuclides, either for imaging or treating numerous diseases. Basically, in ancient times, the Greek philosopher Democritus (460–370 B.C.) decreed that all things are composed of small, indivisible bits called atoms [1]. Etymologically, the term atom came from the Greek word "Atomos", meaning "indivisible." The idea of small, inseparable particles of substance existed until the 1800s, when renowned chemist John Dalton (1766–1844) introduced the modern atomic hypothesis. Later, the "plum pudding model" of the atom was proposed by J.J. Thomson (1856–1940), who is credited with discovering the electron [2]. The atom in his model consisted of an equal mixture of positive and negative charges. These men and other scientists contributed to the understanding that protons, electrons, and neutrons make up the structural building blocks of an atom. Protons, which have a positive charge, and neutrons, which have no charge, make up the nucleus, or center, of an atom.

It has been demonstrated that certain atoms are radioactive because they contain an unstable mixture of protons and neutrons [3]. These atoms release energy from the nucleus as a particle or ray in order to reach a more stable state. Radiation is the energy emitted during this process, which is referred to as radioactivity. The three main types of nuclear radiation emitted from radioactive atoms are alpha, beta, and gamma [4]. Alpha and beta radiation consist of actual particles that are electrically charged and are commonly referred to as alpha particles and beta particles. Alpha particles consist of two protons and two neutrons tightly bound together. Beta particles are high-energy electrons that are generated when a neutron in the nucleus splits to form a proton and an accompanying electron. Gamma radiation, however, belongs to a class known as electromagnetic radiation. Electromagnetic radiation consists of energy transmitted in the form of waves. A radioactive isotope (radioisotope) is an unstable form of an element that emits radiation from its nucleus as it decays [5].

Eventually, the end product is a stable, nonradioactive isotope of another element. Radioisotopes can be produced artificially (most frequently by neutron enrichment in a nuclear reactor or in a cyclotron) or may occur naturally. Naturally occurring radioisotopes include uranium and thorium. The vast majority of radioisotopes used in medicine are produced artificially.

The discovery of artificial radioisotopes has led to the existence of nuclear medicine as a specialized branch of modern medicine that exploits the process of radioactivity for imaging, diagnosis, and treatment of numerous diseases [6]. The name nuclear medicine aligns with the fact that this field uses radiation that emanates from the nucleus of an unstable atom. Typically, gamma radiation is a type of radiation exploited in most nuclear medicine procedures. Small doses of radioactive material are injected into the body during many imaging procedures, and the radiation they generate is tracked by a sensing device designed to detect that particular type of radiation. Combinations of radioisotopes coupled to a medication with binding qualities that enable it to concentrate in particular bodily tissues, like the thyroid, bones, or lungs, are known as radiopharmaceuticals [7]. Other names for radioisotopes used in clinical nuclear medicine include radionuclides, radiotracers, and occasionally just tracers. Certain physiologically active substances are absorbed or have a particular affinity for certain body organs. Examples include the thyroid's uptake of iodine, the brain's utilization of glucose, the bones' utilization of phosphates, and the lung capillaries' potential for capturing particles of a particular size. After the radiopharmaceutical is carried to a tissue or organ in the body, usually via the bloodstream, its radioactive emissions allow it to be measured and imaged using a detection device called a gamma camera.

Single-photon emission computed tomography (SPECT) Holly TA et al. [8], positron emission tomography (PET) scans Alavi A, et al. [9], gallium scans, indium white blood cell scans and Iobenguane scans (MIBG), and octreotide scans Hybrid scanning techniques employing X-ray computed tomography (CT) or magnetic resonance imaging (MRI) and other techniques or modalities are all used to perform certain nuclear medicine procedures. In single-photon emission computed tomography (SPECT), multiple two-dimensional images are obtained from various angles using a gamma camera. These images are then computer-reconstructed into a three-dimensional data set that can be edited to create thin slices in any projection. The Gamma camera revolves around the patient to obtain SPECT scans.

PET is used to produce three-dimensional images that depict the body's biochemical and metabolic processes at a molecular level. It is performed using a positron (positive electron)-producing radioisotope attached to a targeting pharmaceutical. The major purpose of PET scans is to detect cancer and monitor its progression, response to treatment, and metastases. It is frequently used to locate hidden metastases from a known tumor or to detect recurrence. Oncologic PET scans make up about 90% of the clinical use of PET. Some tumors take up more of the radiotracer than others. Glucose utilization depends on the intensity of cellular and tissue activity, so it is greatly increased in rapidly dividing cancer cells. Actually, most malignancies' rates of glucose use approximately correspond to their degrees of aggressiveness. F-18 labeled fluorodeoxyglucose or FDG has been demonstrated over the past 15 years to be the most effective radiolabeled glucose molecule available for identifying cancer and its metastatic spread throughout the body.

Gallium scans, indium white blood cell scans, and Iobenguane scans (MIBG) are also used in nuclear medicine procedures. The cells that are highly dividing can be identified by a gallium scan. For some cancer cells, it can aid in detection. Thus, gallium scans may be necessary for those with lymphoma, or cancer of the lymphatic system. It can also assist in identifying cells that are responding to an illness or proliferating quickly in another part of your body. An indium white blood cell scan can be used to locate the infection site and establish a clinical correlation between the patient's presentation of different pathologic diseases, such as: (1) osteomyelitis unrelated to the spine (galium-based radionucleotide scans are better than indium-only scans at identifying osteomyelitis of the spine); (2) prosthetic joint infection; (3) vascular grafts; (4) intra-abdominal infections; and (5) abscesses. (6) Endocarditis; (7) Foot ulcers; (8) Infected implanted devices such as central venous catheters; (9) Fevers of unknown origin when there is a high probability of infection; (10) Inflammatory bowel disease. The Iobenguane scans, or MIBGs for short, are nuclear medicine scans that employ iodine-123 meta-iodobenzylguanidine. For the purpose of identifying neuroendocrine tumors like neuroblastomas and phaeochromocytomas, a MIBG scan is frequently performed. It can also help find medullary thyroid cancer and carcinoma tumors.

Octreotide scans Hybrid scanning techniques employing X-ray computed tomography (CT) or magnetic resonance imaging (MRI) are used in order to obtain accurate information. Neuroendocrine tumors, which originate from cells that create hormones that are transported in the bloodstream, are identified and during treatment are monitor with an octreotide scan. Greater sensitivity is achieved with octreotide scanning for differentiated neuroendocrine tumors. The concept of image fusion is used in hybrid scanning methods that use magnetic resonance imaging (MRI) or computed tomography (CT) scans of X-rays. This process allows positron emission tomography/ MRI (PET/MRI) and single photon emission CT/CT (SPECT/ CT) or MRI/MRI (SPEMRI/MRI) machines to do both exams concurrently. This enables the nuclear medicine specialist to link and decipher data from two distinct exams on a single picture. As a result, more accurate data and a diagnosis are produced.

Patient Preparation for Nuclear Medicine Procedures

Like all medical procedures, nuclear medicine procedures require meticulous preparation of the patients. The rapport between the patients and nuclear medicine should be established. The physician should confirm indications for nuclear medicine. When nuclear medicine indication procedure is conformed, the physician should carefully explain to the patients the risks and benefits of a planned nuclear medicine procedure. The physician obtains informed consent from the patient and proceeds with other patient preparation steps in order to ensure an effective procedure and minimize risks to the patient. Further preparation steps can vary and may depend on targeted organs, existing comorbidities, and planned nuclear medicine procedures.

Fasting is the commonly ordered command, but not all patients will require fasting. For instance, patients who are scheduled for 18F-FDG PET/CT imaging often need to fast for four hours beforehand. Physicians should make the required accommodations for individuals who need insulin, provided they disclose their medical problems. However, for patients for whom 18F-sodium fluoride (18F-NaF) PET/CT imaging is planned, fasting is not necessary.

Nuclear Medicine Cardiac Treadmill and Persantine and Dobutamine Stress Test: This examination is usually performed the same day and will be necessary for some patients. This involves the administration of radionuclides. An image must be taken after three to four hours of the test. Before the procedure, the patient should refrain from eating or drinking anything for six hours, and they should avoid caffeine for twelve hours. In the event that the study is conducted over two days, the patient should schedule this examination for two hours on the first day and one hour on the second. The patient should refrain from eating or drinking anything for six hours on both days before the assessment. Twelve hours before the MRI study, no coffee.

For the patient who has had thyroid diseases and is on medication, the following are recommended prior to the nuclear medicine procedure: (1) No amiodarone for 3 to 6 months before your scan; (2) No IV contrast dye for 12 weeks before your scan; (3) No multivitamins for 2 weeks before your scan; (4) No thyroid medicine for 3 days to 4 weeks before your scan, based on the drug you take; and (5) No eating or drinking for 4 hours before your scan.

Advantages, Risks, and Limitations of Nuclear Medicine

The nuclear medicine procedures are used to display the anatomy, physiology, pathology, and current state of function of various organs, including the liver, heart, kidney, lung, thyroid, and brain. Radiation has also been used to destroy diseased tissue, typically beyond the reach of standard surgical techniques. Studies using nuclear medicine typically result in lower patient exposure than CT and fluoroscopy. Heart studies and PET exams are the scan kinds that give the most radiation in comparison to other nuclear scans. The primary drawback of nuclear medicine is the potential for lengthy operations due to the radiotracer's accumulation in the area of interest, which might take hours or even days. Furthermore, imaging procedures can take many hours to complete. Every diagnostic and interventional technique may have benefits, drawbacks, or patient risks. Risks might be direct, endangering the patient's health, or they can be indirect to the patients and others. Ionizing radiation used in nuclear medicine may damage patients body cells, induce cancer development for patients, patients' relatives who come closer to the patient shortly after the procedure, and staff of the nuclear medicine department. However, in contrast to other ionizing radiation-using modalities, in nuclear medicine investigations, the patient may momentarily be the source of radiation exposure to others (such as technologists). The ideas of extending the distance from the source, reducing the amount of time spent in close contact with the patient, and using suitable shielding are applied to limit exposure to others. Counterbalancing these risks should be among the core priorities of the nuclear medicine physician.

Typical Ailments Diagnosed and Treated Via Nuclear Medicine Procedures

According to estimates from the World Nuclear Association, the demand for radioisotopes is rising, and over 50 million nuclear medicine procedures are performed annually. Considering the body system, the following nuclear procedures can be performed to diagnose and treat different diseases.

Respiratory System: (1) Lung Perfusion and Ventilation Perfusion Scintigraphy (Tc99m MAA), (2) Post-Operative FEV1 Calculation (Tc99m MAA).
Central Nervous System: (1) Brain PET examination (18F-FDG), (2) Brain Perfusion examination (Tc99m HMPAO), (2) Ventricle Shunt Openness Evaluation (Tc99m DTPA), (3) Cisternograph (Tc99m DTPA)
Cardiovascular System: (1) Myocardial Perfusion Scintigraphy (Thallium201 or Tc99m MIBI imaging), (2) Myocardium PET (myocardium vitality examination with 18F-FDG), (3) Myocardium Sympathetic Innervation Scintigraphy (I123 or I131 MIBG), (4) Radionucleoid Ventriculography (MUGA)
Skeletal System: (1) three-phase bone scintigraphy; (2) whole-body bone scintigraphy; (3) bone PET/CCT (F18-NAF); (4) arthroscintigraphy.
Endocrine System: 1) Thyroid scintigraphy, 2) Parathyroid scintigraphy, 3) Dacrioscintigraphy.
Genitourinary System: 1) Dynamic renal scintigraphy (with DTPA or MAG3), 2) Static renal scintigraphy (DMSA), 3) ACE inhibitor dynamic renal scintigraphy (with DTPA or MAG3), 4) Testicular scintigraphy, 5) Vesicoureteral reflux scintigraphy (direct and indirect)
Infection Imaging: 1) Marked leukocyte scintigraphy, 2) Bone Marrow Scintigraphy with nanocolloid
Nuclear Hematology: (1) Spleen imaging (with denatured erythrocytes), 2) Hemangioma Imaging, 3) Lymphoid scintigraphy

Nuclear Oncology: (1) 18F-FDG PET/CCT (Positron Emission Tomography), (2) 18F-NAFTA PET/CCT, (3) Intraoperative gamma probe (99 m colloid, 131I, and 18F-FDG compatible), (4) Iodine-131 Scanning, (5) Breast scintigraphy, (6) Sentinel Lymph Node Examination (breast cancer and malignant melanoma SPECT/CCT anatomical mapping), (7) Penta DMSA (V-DMSA) (medullary thyroid cancer), (8) I123 or I131 MIBG imaging

Example of Nuclear Medicine Therapy Using Radiopharmaceuticals Include: (1) Lodine-131 therapy (low-dose and high-dose treatment), (2) Somatostatin Receptor Treatment, (3) Radionuclide Therapy, SR-89, (4) Radionuclide Therapy, Sm-153, (5) Radionuclide Therapy, Re-186, (6) Radionuclide Therapy, P-32, (7) Radionuclide Therapy, I-131 MIBG, (8) Yttrium 90 (Y90) microsphere therapy: Y90 microspheres are used to treat hepatocellular carcinoma, (9) Y90 anti-CD-20 antibody, (10) Radio synovectomy.

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