NUCLEAR MEDICINE

Abstract

Nucleology involves the use of radioisotopes labeled with the suitable pharmaceuticals. They are popularly known as radiopharmaceuticals. Nuclear medicine imaging technique is used to evaluate physiologic, pathologic and metabolic conditions of the body at the molecular level. Nuclear medicine field has undergone remarkable changes over decades. The advent of skilled technology imaging systems like Single-photon emission computed tomography/ computed tomography (SPECT), Positron emission tomography (PET), PET/ Computed Tomography (CT), PET/ Magnetic Resonance Imaging (MRI) enhances the quantification efficiency through detecting procedures. Nuclear medicine technique gives more reliable information to physicians and patients to detect diseases at earliest stages. The technique is a non-invasive and a painless test that has enhanced the treatment options, digitally and technically, to diagnose and assess medical conditions.

Keywords: PET-MRI, Patient Safety, Radiology, SPECT, CT.

Author

Dr. Deepa Iyer
Principal Investigator
(WOS-A)- DST Project
Madhya Pradesh Council of Science and Technology Vigyan Bhawan
Bhopal, Madhya Pradesh, India.

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I. BACKGROUND

Nucleology or Nuclear medicine is the division of medical field that is concerned with the tracer principle with regard to radiopharmaceuticals to assess physiologic, pathologic, metabolic conditions of the body at the molecular level for the diagnostic purposes including therapy and research. It involves the use of radioisotopes labeled with suitable pharmaceuticals to form "radiopharmaceuticals".

Nucleology heavily relies on imaging technique using radioactive tracers to evaluate cellular function. It may lead to the detection (diagnosis) of disease and its treatment depending on patient's condition. Radiopharmaceuticals (Radioisotopes) are applied in this technique due to their penetrating power and ionizing characteristics as a result of emission from decaying atoms [1].

Nuclear medicine imaging involves the uses of radioactive material in small amounts. The technique utilizes a computer and a special camera to create inside images of the body. It helps to provide unique information as compared to other imaging procedures that can lead to diagnose many types of pathological conditions related to heart disease, neurological, endocrine and gastrointestinal disorders, cancers and other health conditions. The technique may lead to detect disease at preliminary stages as nuclear medicine technique procedures are capable of determining molecular activity within the body [2].

The tracing path of these radioactive tracers could be easily tracked by doctors using cameras specially designed to fulfill the purpose. Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) scans are the two commonly used imaging modalities or techniques in nucleology or nuclear medicine.

As compare to conventional radiology the diagnostic nuclear medicine is fundamentally a functional imaging process that manifests physiological processes whereas conventional radiology essentially aims at obtaining anatomical images form and structure. The main advantage of function assessment of an organ is that it helps medical physicians or practitioners to diagnose and setting up the treatment course plans for the body part being evaluated [3].

1. **Radioactive Tracers:** Due to its intricate and essential dependence, the nuclear medicine field is distinct regarding the procedural use of radioisotopes or radio markers. These radiopharmaceuticals containing radioisotopes are produced in a particle accelerator or research reactor like medical cyclotron. The emitted radiations so delivered can be used for specific therapy and detection-based imaging for the organ, lesion or any dysfunctional status related to organ.

A radioactive atom is tightly bonded to carrier molecules to act like a radiotracer. These carrier molecules can be chosen substantially depending as per the desired scan need. Some of the tracers utilize sugar molecules or a specific protein in the person's body. For example, sample of red blood cells (RBC's) could be taken from the patient to know the exact source of intestinal bleeding. After radiolabeling, the sample can be re-injected in the blood to scan the blood path in the patient [4]. Accumulation of radioactivity manifests the problematic intestinal region.

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2. **Routes of Administration:** In most cases of the nucleology diagnostic studies, the patient is administered by radioactive tracer through intravenous (i.v.) injection. The tracer may also be given by means of oral route, inhalation or by injecting directly into an organ of the patient. The administration mode of a radioactive tracer depends on the disease condition.

The tracers have negligible side effects. They are neither dyes nor medicines. In typical nuclear medicine scan, the amount of radiation given to the patient tends to be very low.

One can easily produce images by radioactive tracer administration to the patient and detecting radiation from different parts of the body. Nuclear radiologists then evaluate the digitally generated images to diagnose the disease.

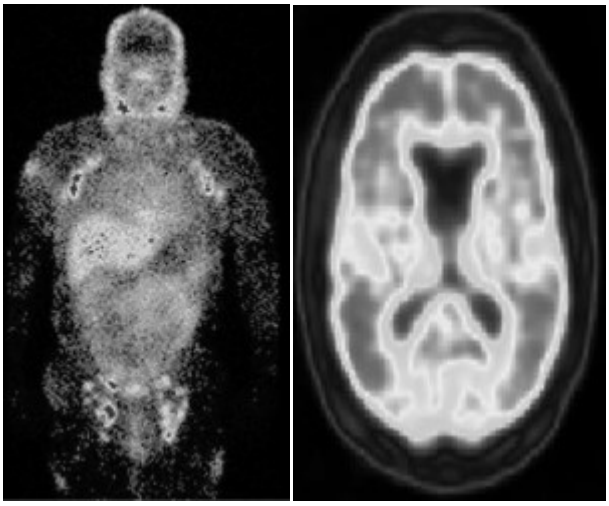

Figure 1: SPECT and PET scanned images

3. **Types of Radioactive Tracers:** Radioactive elements are actually the energetic unstable nuclides due to their excess of energy. These can be stabilizing by either electromagnetic (EMR) radiation or charged particles that used to be emitted during the process of radioactive decay. There are mainly three types of radiations: alpha, gamma and beta minus. Radiation energy contains both electric and magnetic charges that propagate at a certain speed. It is generated by either natural sources or by artificial devices e.g. cyclotron. Energy emitted by an unstable nucleus results in the generation of ionizing radiation in artificial form or by a cyclotron.

The first radiopharmaceutical was commercialized in 1950. The first commercially available isotope was ^{I31} Iodine for medical uses.

The important metal complexes which are used as radiopharmaceuticals are: gallium (^{67}Ga, ^{68}Ga), technetium (^{99m}Tc), indium (^{111}In), iodine (^{123}I and ^{131}I), sulphur (^{35}S), thallium (^{201}Tl), phosphorus (^{32}P), chromium (^{51}Cr), sodium fluoride (Na^{18}F) and fluorodeoxyglucose (^{18}F-FDG). They are commonly used for diagnosis in imaging technique and have been a lot of significance in early diagnosis of various diseases including cancer [5].

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Radiopharmaceuticals are called as approved tracers if they meet the exacting standards of Food and Drug Administration (FDA). It is necessary for the safety and accurate performance of tracers in terms of clinical use. The appropriate tracer is decided by nuclear medicine physician for providing the most detailed information about health condition of the patient. The use of a desirable tracer depends on the need of SPECT or PET scan.

4. **Diagnostic Use:** Nuclear medicine is a non-invasive and a painless test that help to diagnose and assess medical conditions. The injected radiotracer starts build up in examined areas of the body, such as inflamed or cancerous/ tumor area. They may also bind to few proteins or proteinous structures in the body.

   Fluorodeoxyglucose (^{18}F-FDG) is the most commonly used radiotracer compound which is similar to sugar or glucose molecules. Cancerous cells needed increased energy than normal cells. As a result of which cancerous cells absorb more glucose. Thus, an imaging device creates pictures and shows the location of the radiotracer in the body by detecting the energy given off by FDG [6].

   The diseases or a pathological condition which are primarily detected by nuclear medicine imaging technique includes:

   - Cancer
   - Heart disease
   - Disorders related to the blood
   - Bone problems, infections or breaks
   - Thyroid pathological condition like hypothyroidism
   - Gallbladder associated disorders
   - Lung associated diseases
   - Kidney diseases: scars, ailments and blockages

5. **Techniques in Nuclear Medicine:** SPECT- Single photon emission computed tomography and PET- positron emission tomography are widely used imaging techniques in nucleology for providing metabolic and functional information unlike Magnetic resonance imaging (MRI) and Computed Tomography (CT).

   - **CT:** Computed Tomography (CT) is an X-ray imaging computerized procedure that generates signals to produce cross-sectional images or “slices” of a person's body by the help of machine’s computer. These slices are called tomographic images that contain detailed information about the scanned internal organs compare to X-rays.

   - **MRI:** Magnetic resonance imaging (MRI) is a non-intrusive imaging technology which is used to explore the healthy and pathological state without the use of damaging ionizing radiation. It helps to investigate anatomy and physiology of the body in normal or diseased condition, Therefore, it is widely used for diagnosis, treatment and monitoring of an ailment. It is based on the advanced technology that involves excitation and observation of protonic changes in water molecules. Nerves, spinal cord, brain, ligaments, tendons and muscles can be seen with clarity in MRI as compared to X-rays and CT. MRI is used to create images related to knee and shoulder injuries.

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- **SPECT:** A single photon emission computed tomography (SPECT) scan utilizes gamma emitting radioisotopes to show how blood flows to tissues and organs. Gamma rays are very different from visible light that moves at a different wavelength. This imaging test may be used to diagnose seizures, stroke, fractures, infections and tumors in the spine. SPECT scan instruments generate 3-D tomography images of the radiotracer molecules which get distributed in the body of the patient. Projection images of the body are recorded at different angles that result in the generation of 3-D images by means of a computer. SPECT imagers can detect the emitted gamma rays from the radiotracer due to the presence of gamma camera detectors.

- **PET:** A positron emission tomography (PET) scan also involves a radioactive tracer that can help to reveal the typical and atypical metabolic activities or biochemical function of tissues and organs through imaging test. PET scans also create three-dimensional (3-D) images. PET scans produce small particles called positrons having same mass as an electron but with opposite charges. They interact with the electrons in the body. The combination of these two particles results in annihilation process. This process further produces a small amount of energy in the form of two photons that shoots off in the opposite directions. As a result the PET scanner detectors measure these photons to create internal organs images. The most prominent clinical role of PET scan is in oncology using ^{18}F as the tracer. It has proven to be the most accurate non-invasive method for detection and evaluation of various types of cancers. Cardiac and brain imaging could be done using PET scans [7-9].

The prominent distinct feature between SPECT and PET scan depends on the type of used radiotracers. SPECT scans measure gamma rays while PET scan produces positrons as a result of the radiotracer decay.

Table 1- Difference between SPECT and PET Techniques

S.No.	SPECT	PET
1.	It is cost effective as compare to PET.	It is very expensive as compare to SPECT.
2.	It uses gamma emitting radioisotope (tracer).	It involves positron emitting radioisotope (tracer).
3.	It provides poorer spatial resolution/ contrast as compare to PET scan.	It provides better spatial resolution/ contrast as compare to SPECT scan.
4.	It utilizes usually one large crystal based detector.	It utilizes a ring of multiple detectors.
5.	Examples: Technetium (^{99m}Tc); iodine ($^{123}I$and ^{131}I)	Examples: F F- 18 fluorodeoxyglucose (^{18}F-FDG); F -18 Sodium Fluoride (^{18}F-NaF)

Combining PET with computed X-ray tomography scan gives co-registration of the two images (**PET-CT**). This technique enables 30% high quality diagnosis as compare to traditional gamma camera alone. It's a very important tool for providing unique information

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on various diseases from dementia to cardiovascular disease and cancer. Combination of PET with MRI (**PET-MRI**), enables diffusion-weighted scanned image of soft tissue with dynamic contrast and magnetic resonance imaging for e.g. brain imaging.

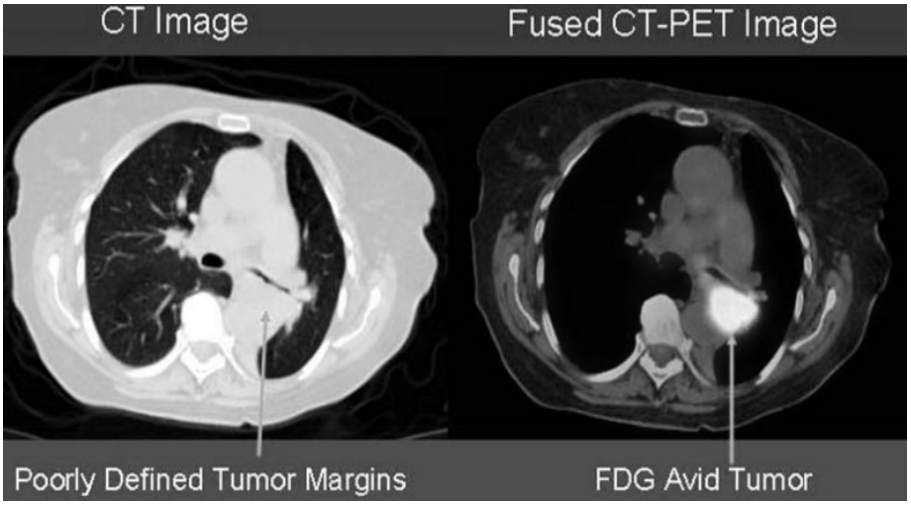

Figure 2*:* Fused CT-PET scans showing more cleared tumor

Fundamental difference between other imaging techniques like X-Rays and nuclear medicine imaging is the positioning of the radiation source within the body. Gamma imaging helps to view the position and concentration of the radioisotope in the body. The isotope is either partially taken up in the organ (cold spot) or taken up in excess (hot spot) thus indicating the malfunctioning of organs. The rate of isotope movement with an unusual pattern could indicate malfunctioning in the organ with the help of images [10-11].

The common use of nuclear imaging techniques in developed countries is increasing due to a distinct advantage of nuclear imaging over X-ray technique. Nuclear imaging can be done for both soft tissues and bone with accuracy.

II. CLINICAL APPLICATION AND SIGNIFICANCE

SPECT scans are primarily used to diagnose gall bladder disorders, intestinal bleeding and bone diseases to track as well as detect the progression of various conditions of heart disease like coronary arteries blockage etc. SPECT agents have now become accessible for diagnostic use in case of Parkinson's disease and thus differentiating this ailment from dementias and other anatomically-related movement disorders associated with the brain.

The PET scans are more often used to detect metastases condition of cancer and monitoring its progression in response to treatment. Rapidly dividing cancer cells are marked with increased glucose utilization due to intense cellular and tissue activity. As a result, the aggressiveness of most cancer cells could be paralleled by their glucose utilization rate. In last fifteen years, slightly modified radiolabel glucose molecules (F-18 FDG) have been shown to be the best available radiotracer to detect metastatic spread of cancer in the body.
An instrument that produces combine PET and CT scans in one examination using PET/CT scanner has now become a primary imaging tool to detect different stages of cancers in the body [13-14].

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A PET probe was approved by the FDA to aid in the proper diagnosis of Alzheimer's disease which previously could be possible to diagnose only after a patient's death. Without PET imaging test, Alzheimer's disease can be difficult to distinguish between vascular or other forms of dementia affecting older people.

III. ADVANTAGES OF NUCLEAR MEDICINE

1. Nuclear imaging scan technique provides an anatomical and physiological detail that is unattainable by means of other procedures. The unique aspect of a nuclear medicine test is its extreme sensitivity towards abnormalities in structure or functioning of the organ.

2. It provides an important diagnostic tool in the treatment of various diseases. These tests have the ability to detect diseases at earliest stages and sometimes even before revealing symptoms.

3. Nuclear medicine technique has enhanced the treatment options, digitally and technically, for different medical conditions especially in cancer. Cancer treatment involves radiotherapy and chemotherapy. The malignancy and benign condition of tumors can be ascertained by PET scans. Nuclear medicine has been a blessing as it can prevent a patient from getting a more dangerous or costly surgery.

4. Nuclear medicine is an apt technique for detection of highly serious medical conditions with clarity. It has proved to be very beneficial to detect difficult possibilities in early stage of treatments.

5. The accuracy of the technique has made many complicated medical procedures simpler. It allows in depth examination and analysis of pathological condition. This is the prime advantage of nuclear medicine technique. Advancement in this technology with precise procedures has led to investigate a disease in a systemic manner. Nuclear medicine has made it much easier and has become an integral part of modern healthcare medical system.

IV. LIMITATIONS OF NUCLEAR MEDICINE

1. There are many challenges in design and development of specific and efficacious radiopharmaceuticals to provide effective patient management options in neurology, cardiology, oncology and other disorders.

2. Nuclear medicine technique faces dosimetric issues in getting the same vector-based radiopharmaceuticals for imaging and therapeutic applications. The main concern of this technique is the clearance of radiopharmaceuticals from the blood to the excretory organs and to avoid non-target sites accumulation of the radiopharmaceutical product.

3. Nuclear medicine technique is expensive as much as it is effective. It requires heavy expenditure in terms of the purchase cost, equipment cost, setting up cost, operations and maintenance. This is one of the major limitations of nuclear medicine.

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4. Unfortunately it results in some serious health issues due to prolonged exposure to nuclear medicine. As the equipment and dealing procedures give away harmful radiations, it can be proved fatal especially to elderly patients and pregnant women. There is a threat of severe hypersensitivity or allergic reactions and also some incurable ill effects with nuclear medicine.

5. Nuclear medicine does not give 100% assurance to cure in spite of the reported benefits and accuracy. There is still a little room for doubt. Medical science is full of predictions, possibilities and failures too.

V. CONCLUSION

Nucleology has undergone both evolutionary and revolutionary changes over decades. The dynamic and responsive trends in the global development and deployment of radiopharmaceuticals are quite remarkable. The advent of skilled technology imaging systems like single-photon emission computed tomography/computed tomography, PET/ CT, PET/magnetic resonance enhances the quantification efficiency through detecting procedures. Nuclear medicine scans and treatments help to detect and diagnose the severity of a variety of pathological conditions and diseases like cancers, gastrointestinal, endocrine, and neurological and heart related disorders. Nuclear medicine gives more reliable information to physicians and patients to help them understand about the status of disease. It can detect problems even before they start to experience symptoms. Although it may not provide many solutions to treat the problem but the imaging options that are available make it faster to reach a diagnosis compared to conventional methods.

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