FUTURE OF NUCLEAR MEDICINE

Abstract

Nuclear medicine is a rapidly evolving field with the potential to revolutionize healthcare. In the past, nuclear medicine has been primarily used for diagnostic imaging, but it is now expanding into the realm of targeted therapy and theranostics. Theranostics combine diagnostic and therapeutic capabilities, allowing for more personalized and effective treatment of diseases. Several key trends are shaping the future of nuclear medicine like The development of new radiopharmaceuticals, The advancement of imaging technologies and The integration of artificial intelligence (AI). Nuclear medicine is expected to play an increasingly important role in the diagnosis and treatment of a cancer, cardiovascular diseases and neurological disorders. The future of nuclear medicine is bright, but there are also some challenges that need to be addressed. Despite of the challenges, the future of nuclear medicine is promising. Nuclear medicine has the potential to revolutionize healthcare by providing more accurate diagnoses, more effective treatments, and more personalized care for patients.

Keywords: SPECT, PET, CT, Radioactive Traces, Therapy.

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I. INTRODUCTION

To detect and cure anomalies that initially manifest themselves incredibly early in the course of a disease like thyroid carcinoma, this area of radiography is widely used. **[5]** Radiology and nuclear medicine both employ radiation. In nuclear medicine, the body is injected with radioactive substances known as radiopharmaceuticals or radioisotopes. X-rays are introduced into the body externally in radiology. Soft tissue, like the intestine, is difficult to see on a routine X-ray without the application of a contrast agent because X-rays pass through it. **[1]**

The use of radio-pharmaceuticals (RPh) for every treatment makes nuclear medicine a special due to its complicated and crucial reliance on them. A carrier molecule that provides bio-specificity for the organ, lesion, or dysfunction being treated is combined with a radioisotope created in a research reactor or particle accelerator, such as a medical cyclotron, to deliver radiation for detection-based imaging or targeted therapy. **[3]**

For the care of patients, diagnostic radiological tests such as computed tomography (CT) and magnetic resonance imaging (MRI), as well as nuclear medicine imaging, are crucial, especially for making an accurate diagnosis and staging or restaging of a disease.**[4]**

II. NUCLEAR MEDICINE IN TREATMENT [1]

Radioactive iodine (I-131) is one illustration. It has been used for more than 50 years to treat hyperthyroidism, or an overactive thyroid, and thyroid cancer. Additionally used to treat non-Hodgkin lymphoma and cancer-related bone discomfort. Radioactive iodine is injected into the body during iodine-131 targeted radionuclide treatment (TRT). This chemical destroys thyroid or cancer cells when they ingest it. I-131 can bead ministered orally or via a beverage. **[1]**

It could be feasible to include chemotherapy with drugs to create imaging agents that only bind to cancer cells. Only the targeted cells, not the adjacent healthy tissue, are killed by chemotherapy. Some of the negative effects of chemotherapy might be lessened. **[1]**

Nuclear medicine (radiation treatment) and immunotherapy are combined in radioimmunotherapy (RIT). There are several radionuclides utilized. I-131, sometimes known as radioactive iodine treatment, is the most popular. Treatments for 90Y-ibritumomab-tiuxetan or Zevalin-lymphoma are further alternatives. Treatment for lymphoma and multiple myeloma with tositumomab or bexxar. **[1]**

Researchers in the fields of molecular biology, sophisticated polymer chemistry, nanotechnology, and biomedical engineering are looking into ways to transport medications to the right spot without damaging nearby tissues. If they are breastfeeding, pregnant, or think they could be pregnant, health practitioners should be aware of this**. [1]**

1. **Therapy [1]:** There is no specific equipment required when a patient receives I-131 thyroid therapy. It is a one-time-only procedure. On the day of therapy, the patient shouldn’t eat or drink after midnight. If a thyroid condition is being treated, regular thyroid

medication should be stopped three to seven days prior to therapy. The radioactive iodine will continue to exit the body during the following two to five days since the body won't be able to absorb it completely.**[1]**

Avoid interacting with others, especially children and expectant women. The body releases iodine through the urine. Additionally eliminated feces, perspiration, vaginal discharge, saliva, and tears. Women are advised to put off getting pregnant for six to twelve months after therapy.**[1]**

2. **Safety in Nuclear Medicine [1]:** Radiation exposure that is too high may harm tissues or organs or raise the risk of cancer. Imaging techniques and nuclear medicine are regarded as non-invasive and generally safe. The advantages often outweigh the risks due to their efficiency in detecting illness. Nuclear medicine involves administering large doses of radioactive material. The advantages frequently outweigh the hazards since the therapy frequently targets deadly conditions. To protect patients, the USFDA and the nuclear regulatory commission (NRC) strictly control the use of radioactive materials in nuclear medicine.**[1]**

III. RADIOACTIVE TRACERS [2]

Radioactive tracers are composed of carrier molecules that are tightly linked to a radioactive atom. Even the patient's cells and molecules can be used in some tracers to study how a certain protein or sugar in the body interacts with the patient. For instance, if doctors need to pinpoint the exact cause of intestinal bleeding, they may radio label a sample of the patient's RBCs. A SPECT scan is used to follow the blood's path inside the patient after it is reinjected. If there is any radioactive buildup in the intestines, doctors can identify the problem.

Imaging techniques include single-photon emission computed tomography (SPECT) and positron emission tomography (PET). These two approaches provide in-depth explanations of "how a body organ is operating."

Single-photon emission computed tomography (SPECT) is a diagnostic tool that generates three-dimensional (tomography) pictures of the placement of radioactive tracer molecules inside a patient's body. The gamma rays that are emitted from the tracers that have been injected into the patient can be detected by the gamma camera detectors on SPECT imagers.

Positron emission tomography (PET) Radiopharmaceuticals are also used in PET scans to provide 3D pictures. The kind of radiotracer utilized differs between SPECT and PET scans.

The radiotracers used in PET scans decay to become positrons, which are tiny particles with nearly the same mass as electrons but with the opposite charge. Generates a little quantity of energy in the form of two photons that go in opposing directions when it reacts with electrons. This reaction causes the two particles to annihilate one other. In PET, photons are detected by detectors, and images of interior organs are made using this data.

IV. USE OF NUCLEAR MEDICINE SCANS [2]

The main purposes of SPECT scans are to identify and monitor the development of cardiac disease, including blocked coronary arteries. Intestinal hemorrhage, gallbladder disease, and other conditions can all be detected with radiotracers. Recent developments in SPECT technology have made it easier to diagnose Parkinson's disease in the brain.

The primary goals of PET scans are to identify cancer and track its development, progression, response to treatment, and detection of metastasis. Utilization of glucose relies on the level of cellular and tissue activity, and it is significantly higher in cancer cells that divide quickly. Most tumors' level of aggressiveness and rate of glucose uptake are approximately correlated.

F-18 labeled deoxyglucose, often known as FDG, has been demonstrated to be the greatest tracer for identifying cancer and its metastatic spread in the body during the past 15 years.

The PET/CT scanner, a hybrid device that produces both PET and CT scans of the same body areas, has emerged as the primary imaging technique for the staging of most malignancies worldwide.

The FDA has authorized a PET probe to help in the proper detection of Alzheimer's disease, which was previously only possible to identify accurately after a patient passed away. Without this PET imaging test, it may be challenging to distinguish between Alzheimer's disease and other types of dementia that affect older individuals.

1. **PET/CT [6]:** PET/CT is a procedure that combines the image from positron emission tomography (PET) and computed tomography (CT) it is done simultaneously with the same machine due to which more detailed images with better information of areas inside the body than either scan given by itself.

   - **Historical Background of PET/CT:** It was developed as a research device by investigators constructed by David Townsend (at the University of Geneva), first of all, a prototype is developed and funded by NCI and installed at "The University of Pittsburgh" and was used to study selected patients with cancer this new innovation not only helped to diagnose the cancer but also enhanced the information by PET/CT.

     Later it was commercialized by manufacturers of CTI PET systems in Knoxville, TN (now Siemens molecular imagining), and new devices were made for clinical use.PET/CT is being used since November 2001.

2. **Implications for the Nuclear Medicine Community [6]:** According to the presentation of initial clinical PET/CT data during the year 2002 scientific gatherings (SNM, EANM, and RSNA), the nuclear medicine and radiology community appears to be split into three groups: supporters, critics/opponents, and objective observers. Some opponents questioned the clinical utility of data presented by "inline" PET/CT systems, primarily citing their own or institutional experiences with concurrent PET/CT data displays on adjacent monitors for self-made fusion software programs and reassuring that a similar, if

not identical, result could have been obtained with software image fusion of separate CT and PET data as compared to all PET/CT users who supported the clinical use of this technology.

Future and PET/CT Technology: Despite the fact that there is still much to be done, it is obvious from the research and data that have been gathered using PET/CT that it reduces the amount of time spent imaging each patient and sharply decreases the frequency of ambiguous PET interpretations. Additionally, it enhances the accuracy of PET imaging and influences clinical decision-making. **[6]**

The population is a major factor in determining whether PET/CT should be included in certain nuclear medicine or radiology practice equipment. **[6]** A combined PET/CT has significant advantages over either PET alone or traditional image fusion techniques, "one image speaks a thousand words."

3. Clinical Examination by Nuclear Medicine [7]

- Radiological imaging of heart, kidney, gall bladder, and thyroid.
- Position emission tomography (PET), a type of nuclear medicine used to examine the proper functioning of the cell or any damage to the body cells.
- To provide three-dimensional (3-D) imaging, PET combinedly used with computed tomography or magnetic resonance imaging (MRI)

4. Examination by PET Imaging [7]

- In the examination of heart diseases, Alzheimer’s disease, and brain disorders.
- It makes the diagnosis of the Myeloma cells more informative so the best treatment can be given to the patient.

5. Steps for the Clinical Use Nuclear Medicine [7]: Follow the specified guidelines when using nuclear medicine on pregnant women and Children.

- Decide the route of administration (I.V., Oral or Inhalation)
- Now wait for the distribution of the nuclear medicine throughout the body So that the treatment and diagnosis of a disease can be performed.
- Now the patient will lie down or walk or sit into or on the pathway of the imaging machine.
- Now the camera situated in the machine will examine the body organ or tissue.
- Imaging report will be provided to the patient so the healthcare professionals can diagnose the disease and proper functioning of the body organ or tissue.
- Nuclear medicine will be excreted from the body within some hour and also depend on the type of nuclear medicine used.

V. IMPACTOF NUCLEAR MEDICINE AND RPh ON HEALTHCARE DELIVERY [3]

Currently, it’s estimated that approximately 40 million nuclear medicine diagnostic investigations are performed worldwide each year, with 10 to 15 million of those studies being for therapeutic purposes.[3] Nuclear medicine has made advancements and reached important turning points.

Nuclear medicine saw a significant upsurge in the 1980s and 1990s with the introduction of 99mTc-based imaging agents (planar at first, then SPECT later), and more recently with PET tracers, particularly F-18 (since 2000), after the widespread use of I – 13l for both diagnosis and therapy. The RPh evolution has progressed along a more reliable pathway of interdisciplinary efforts, which has been further enhanced by the adoption of better targeting tactics by meticulously identifying relevant moieties of biochemical origin, connected with a particular lesion or malfunction of clinical concern. [**3]**

Several RPh, particularly in 3 key areas, were developed and released as a result of the R&D focus on clinical needs:

- For the skeletal system, as the bone is a common site forcancer metastasis.
- For myocardial imaging, as a management tool for the large-volume cardiac patient; utility demonstrated initially with 201 TICI and subsequently more widely with ^{99m}Tc-based RPh (sestamibi, tetrofosmin).
- For tumor targeting in cancer patients, for both imaging and therapy**. [3]**

VI. ONE CAN CITE THE FOLLOWING MAJOR MILESTONES OF HIGH CLINICAL SIGNIFICANCE [3]

The introduction of 99mTc generators and its RPh, as well as "kits" for user-friendly compounding. 201TICI is used for myocardial perfusion imaging (MPI), while 99mTc products (sestamibi, tetrofosmin) are later introduced for a purpose comparable to this.

Enhancements in the strategic targeting of tumors for imaging and therapy (I and T, theranostics) and examples of successful use of small molecule vectors with the RI pair, 68Ga, and 177Lu for PET imaging and therapy. A method used primarily in cancer and neurology that combines highly-specific biological tracers like 18F, 11C, and other positron emitters like 68Ga, 64Cu, etc. with high-resolution PET/CT imaging.

Since then, nomenclature in nuclear medicine that was formerly obscure has become commonplace, such as MC-produced 18 F (110min) and 18F- fluorodeoxy glucose (FDG). Another important development in radionuclide therapy (RNT) based on RPh. The use of 177 Lu (6.7d) as an appealing therapeutic RI for targeted tumor therapy has increased dramatically over the past decade years, with Indian contributions being widely acknowledged on a worldwide level. Two alpha emitters are being tested: 223 Ra to alleviate bone pain and 225 Ac to take the place of 177 Lu for more effective tumor treatment.

Theranostic techniques are gaining popularity since they employ the same vector molecule for imaging with diagnostic RI (18F, 68Ga) and treatment with therapeutic RI(177Lu, 98Y).**[3]**

VII. NUCLEAR MEDICINE IMAGING

Nuclear medicine imaging is a method for producing images by detecting radiation from various physiological regions after a patient receives a radioactive tracer.

A nuclear medicine physician uses digital images made on a computer and sends them to patients in order to diagnose them. Radioactive tracers used in nuclear medicine are often injected into a vein. They could be taken orally to conduct some research. These tracers have no negative effects because they are neither dyes nor medications.

Nuclear imaging can reveal the composition and operation of organs and tissues. Nuclear imaging is used to examine the functioning of organs and tissues. The radioactive substances, also known as radionuclides, are taken up by body tissue. Radionuclides include things like technetium, thallium, gallium, iodine, and xenon.

A particular radionuclide will be used according to the investigation's type and the bodily portion under study. Radiation is captured by a detector. The most widely used kind of detector is the gamma camera. Radionuclide measurement can assess and identify a variety of diseases, including tumors, infections, hematomas, organ enlargement, and cysts. Additionally, evaluate blood circulation and organ function. **[6]**

"Hot spots" refer to areas where radionuclide collection is higher, and "Cold spots" refer to areas where it is lower. Nuclear imaging tests are required since they are primarily used to identify and treat illnesses. **[6]**

Nuclear medicine imaging is used to diagnose a variety of conditions, including: Kidney disease including infections, scars, or blockages, Cancer, Heart disease, Gall bladder disease, Lung trouble, Bone difficulties, infections, and fractures, thyroid disease including Hypothyroidism.

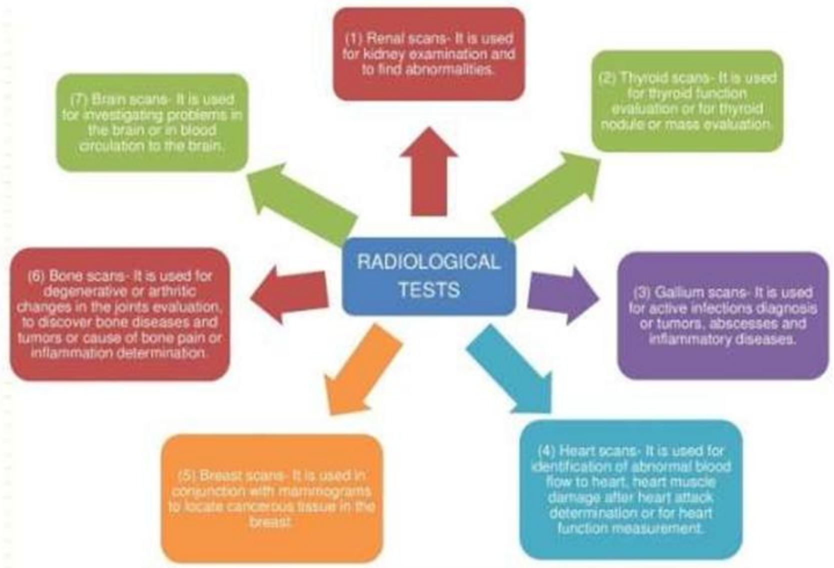
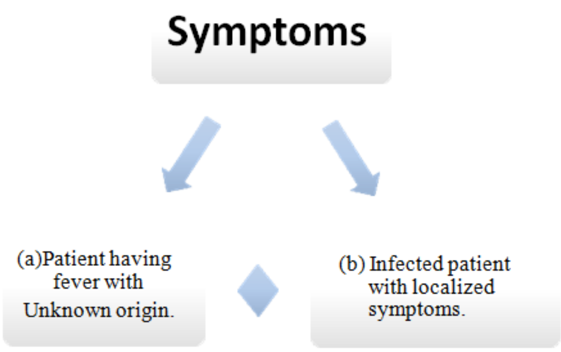


FIG. - SOME COMMON RADIOLOGICAL TESTS

VIII. MICROBIAL INFECTION CAUSED BY NUCLEAR MEDICINE [8]

Radiological imaging may cause infection while using nuclear medicine with two major symptoms. **[8]**



Nowadays to minimize or cure the infection some radioactive medicaments are used these are- technetium-99m nano colloids, gallium-67 citrate, indium-111- and 99mTc-labelled white blood cells, 99mTc-antigranulocyte antibodies, and 99mTc-or111In-labelled unspecified human immunoglobin**. [8]**

The information on changes in pathophysiological and pathobiochemical is provided by nuclear medicine imaging**. [8]**

IX. PATHOPHYSIOLOGY OF INFECTION CAUSED BY RADIOLOGICAL IMAGING USING NUCLEAR MEDICINE [8]

The infection caused by nuclear medicine act as the host defense mechanism of the body. [**8]**

This defense mechanism may be specific or non-specific. Non-specific mechanisms of defense mechanism act against many microbial infections, while specific mechanisms act against a particular or specific microbe. [**8]**

Specific microbe causes specific infection while radiological imaging using nuclear medicine explained a monoclonal antibody against pneumocyst is carinii that reported85.7% sensitivity and 86.7% specificity.

Non-specific defense mechanisms have physical barriers to the onslaught, secretion at primary sites or entry, and integrant and phagocytic cells (monocytes and granulocytes). **[8]**

X. RADIOACTIVE MEDICAMENTS USED IN THE INFECTION CAUSED BY NUCLEAR MEDICINE [8]

The main mechanism of uptake of radioactive medicaments will increase capillary permeability that instantly precedes leucocytic dwelling and it's also an indication of infection but also inflammation.**[8]**

Radiopharmaceuticals	Half-life	Energy	Uptake mechanism
^{67}Ga citrate	78hr	93, 185, 300 and 394 keV	Transferrin/lactoferrin Receptor binding
^{99m}Tc-nanocolloids	6hr	140 keV	Non-specific via Capillary permeability/ active Uptake in activated endothelial cells
^{99m}Tc/^{111}In-labelled human Immunoglobulin (HIG)	6hr/67hr	173 and 247 keV	Non-specific via increased capillary permeability
^{111}In oxine/^{99m}Tc-HMPAO- labelled leucocytes	67hr/6hr	173 and 247keV/140 keV	Specific Chemotactic activation
^{99m}Tc-labelledgranulocyte	6hr	140keV	Increased capillary Permeability and specific binding Specific Chemotactic activation

XI. PREVENTION FOR HARMFUL EFFECTS OF NUCLEAR MEDICINE [7]

- Wash your hands and foot frequently so that the radiation from the body will be reduced.
- Take a large amount of water intake.
- Consult with your physician if you are facing any problems.
- Be aware of your radiologist before examination if you are pregnant or breast feeding women.

XII. BENEFITS AND RISKS OF NUCLEAR MEDICINE [7]

1. Benefits

- Reports the image examination about the proper functioning of all the body organs or tissue.
- Used in the treatment of Cancer, thyroid, etc. disease.

2. Risk

- High use of nuclear medicine may increase the chances of cancer to the patient.
- Nuclear medicine can cause skin reddening and hair loss.

XIII. USES OF NUCLEAR MEDICINE IN THE HEALTHCARE SYSTEM [7]

Nuclear medicine are being administered to the body to check the proper functioning of all the body organs or tissue and to act on specified organs or tissue in the treatment of a particular disease.

1. Working comparison between Nuclear Medicine and X-rays

- **Nuclear Medicine**
  - Nuclear medicines are administered via I.V., Oral, or inhalation.
  - Absorption of nuclear medicine can be seen in the imaging of the body tissues.
  - Nuclear medicine shows the functioning of the body parts or organs.
  - Nuclear Medicine is used in the treatment as well as in the diagnosis of a disease.

- **X-rays:** High-energy electromagnetic radiation passes through the body.
  - To examine the structure of the body with imaging by X-rays.
  - X-rays show the structural frame of the body (i.e., bones and joints)
  - X-rays are used in the diagnosis of a disease.

Either a high degree of radiation from the environment or nuclear medicine affects the human body and increases the chances to cause carcinogenicity to the human body.

REFERENCES

[1] https://www.medicalnewstoday.com/articles/248735
[2] https://www.nibib.nih.gov/science-education/science-topics/nuclear-medicine
[3] RamamoorthyN.ImpactofNuclearMedicineandRadiopharmaceuticalsonHealth-care Delivery: Advances, Lessons, and Need for an Objective Value-matrix.IndianJNuclMed.2018Oct-Dec;33(4):273-276.doi: 10.4103/ijnm.IJNM_56_18.
[4] Roysri K, Chotipanich C, Laopaiboon V, KhiewyooJ. Quality AssessmentofResearch Articles in Nuclear Medicine Using STARD and QUADAS-2 Tools. AsiaOceanJ NuclMedBiol.2014Fall;2(2):120-6.
[5] (https://www.hopkinsmedicine.orghttps://www.hopkinsmedicine.org)
[6] Schoder H, Erdi YE, Larson SM, Yeung HWD (2003) PET/CT: a new imagingtechnologyinnuclearmedicine.EurJNuclMedMolImaging,30:1419–1437
[7] https://www.cdc.gov/nceh/radiation/nuclear_medicine.htm[Accessedon25/7/23]
[8] Becker, W. The contribution of nuclear medicine to the patient with infection. Eur JNuclMed22,1195–1211(1995).