

Nuclear medicine and radiopharmaceuticals for treatment of diseases: An overview

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ABSTRACT

The increase of chronic diseases worldwide led to the development of various newer medicines and diagnostic techniques. Over the past decades with the advancement in science and technology health sector has witnessed significant advancement in identification and treatment of critical diseases like cancer, cardiovascular diseases etc. One of the important processes is the use of radioactive compounds. The clinical use of trace number of radionuclides is referred to as nuclear medicine. It is used for the diagnosis, therapy and monitoring the diseases. The radionuclides used in treatment or diagnosis process are also termed as radiopharmaceuticals. The radioisotopes decay radiations like, alpha, beta or gamma radiation. The alpha and beta emitted radio isotopes are used for the treatment of cancer where as isotopes that decay gamma radiation are used in combination with cameras and scanners to take the images of the processes and structure in side, the body for the diagnosis of disease. The nuclear images help in visualizing, characterizing and quantifying the progress and stages of diseases like cancer. In this manuscript the role of nuclear medicine in the evaluation of acute diseases using nuclear imaging techniques and its disposal has been discussed.

Keywords: Nuclear medicine, radiopharmaceuticals, radioisotopes, nuclear imaging, radiation hazard, radiation disposal

INTRODUCTION

Millions of people are infected by different chronic *diseases* irrespective of sex, age, region or country. These diseases require accurate and timely diagnosis and treatment. With the advent of science and technology several newer medicines along with tools and techniques have been evolved over time providing high-quality healthcare services. The discovery of radioactivity by Henri Becquerel and Marie Curie in 20th century paved the path towards modern day novel health care system. Advancement in the use of radio-isotopes other than atomic energy production comes up as a savior to trace, diagnose and treat

various chronic diseases. Isotopes are distinct nuclear species of the same chemical element that contain same number of protons but different number of neutrons in their nuclei. Isotopes are of stable and unstable type where the unstable isotopes are termed as radio isotopes which changes over time with the emission of alpha or beta particles to transform into more stable form. Moreover, all decaying process of radioisotopes emits gamma radiation. Radio-isotopes are effectively used in health-care, industrial applications, environmental studies etc. The use of radio-isotopes or radionuclides in health-care system is termed nuclear medicine (Cherry,

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Sorenson and Phelps, 2012). There are around hundred radio-isotopes are used as nuclear medicine based on its suitability in different organs of the body (Krane, 1955). Soon after the discovery of X-ray by Roentgen in 1895, medical science made use of this technology in diagnosis [Fig. 1]. Radiology techniques for repairing fractured bones result from X-rays' ability to pass through soft tissues with ease. X-rays are attenuated when they come into contact with bones. The radiopharmaceutical study commonly requires Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) to trace the radioisotopes using emitted gamma radiations to form images for better visualization of internal organs at a molecular level (Kong, Zhu and Yang, 2024). The nuclear imaging gives images of both tissue and bone as well as provides their functions, unlike X-rays which gives only the image of bone. The radioactive doses are given to the patient by injection, inhalation or orally and images are captured using gamma rays' detection cameras, Positron Emission Tomography (PET)/ computerized axial tomography (CAT) scanners, and other specialized equipment to provide information regarding variety of diseases.

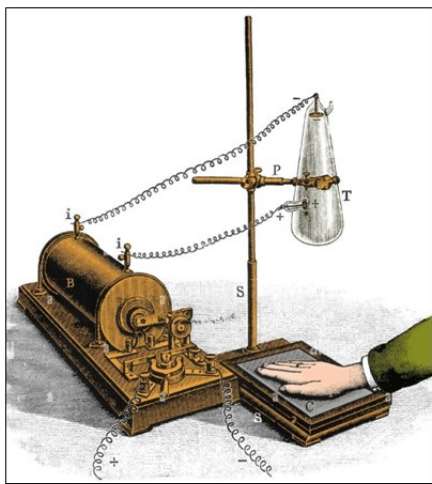


Fig. 1: Representative image, Roentgen X-ray discharge tube (<https://www.alamy.com/stock-photo-wilhelm-conrad-roentgen-1845-1923-german-experimental-physicist-and-104020180.html>)

Tomography is an imaging technique which uses internally, inserted radio-isotopes or externally incident X-rays to image a specific slice of the body's interior anatomy. It has seen some of the most notable advancements in imaging techniques. These days, a lot of X-ray photons are passed across the area of interest to provide tomography images. Since the X-ray beam typically scans in a circle around the patient, a computer is required for these reconstructions, which is known as computerized axial tomography, or CAT. In PET isotopes such as ^{15}O , ^{13}N , ^{11}C , and ^{18}F having half-lives 2 min, 10 min, 20 min, 110 min respectively are used. Since all of these isotopes have brief half-lives, a cyclotron is required for their production, and one must be located near the diagnostic facility. PET has benefits over CAT. While PET scans of the brain can show dynamic effects like blood flow, CAT scans are static.

Nuclear Magnetic Resonance (NMR) imaging is the most recent advancement in the field of imaging. In nuclear magnetic resonance (NMR), a sizable static magnetic field and a time-varying radiofrequency (rf) field perpendicular to the static field are applied to the sample simultaneously. Protium (^1H) an isotope of hydrogen is found abundantly in human body. Resonance with ^1H can be used for medical purposes for imaging. Other stable isotopes like ^{17}O and ^{13}C has an own resonance frequency because of its nuclear magnetic dipole moment. In NMR imaging the patient are not subjected to ionization radiation. Thus, NMR imaging approach offers advantage over gamma, X-ray and PET imaging modalities. Nuclear radiation is mostly used to destroy undesired or malfunctioning tissue within the body, such as an overactive thyroid gland or a malignant tumor. This impact stems from nuclear radiation's capacity to ionize. Radiopharmaceuticals are directed to the patient through inhalation, injection or ingestion (Ramamoorthy, 2018). The radioactive material travel to specific spot in the patient's body and release gamma ray. The emitted gamma rays are then detected and recorded with the aid of gamma cameras. The concentration of radiative material and its distribution within the body is

obtained from the images obtained. Thus, nuclear medicine is used to evaluate blood flow to the heart muscle, bone cracks and to detect thyroid gland for any anomalies. It is used to detect blood clots or other conditions in the lungs, inflammation or infection in the body and to diagnose and monitor conditions like epilepsy, dementia, certain tumors and diseases like cancer. This study provides an overview of nuclear medicine while highlighting its evolution, mechanisms, challenges, and future potential.

Mechanism of nuclear medicine scans

Nuclear medicine scans are irreplaceable for monitoring and diagnosis of diseases like cancer, thyroid disorder, neurological syndrome, heart ailment etc. This scan provides useful information that improves the results of other procedures when comes to patient treatment (Kong, Zhu and Yang, 2023). Nuclear medicine scan not only provides the images of the body but also delivers evidence concerning the functioning of the organs or the tissues involved (Anderson 2019). The information collected through a nuclear medicine scan provides a comprehensive view of the patient's well-being and also complements other imaging techniques used. The principle of its operation is to detect and measure gamma radiations emitted by radioactive elements known as radiopharmaceuticals which are introduced in

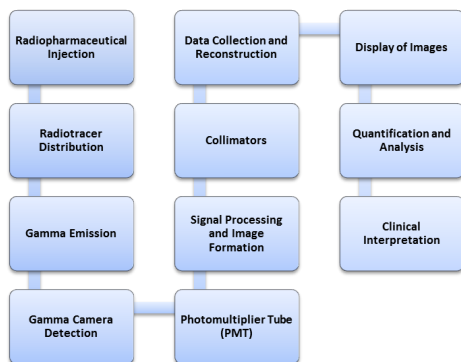


Fig.2: Mechanism of nuclear medicine scans

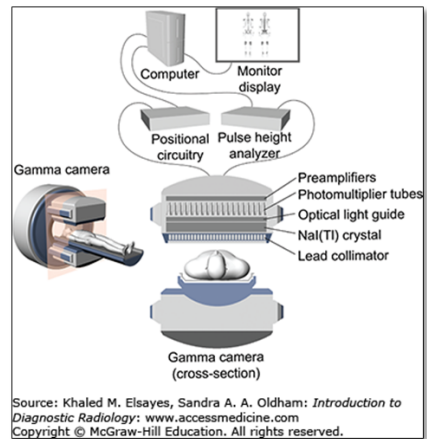


Fig. 3: Components of Gamma Camera
([https://accessmedicine.mhmedical.com/content.aspx?bo/p\]/pop-666666-2](https://accessmedicine.mhmedical.com/content.aspx?bo/p]/pop-666666-2))

the patient's body. The schematic analysis of the mechanism of nuclear medicine scan is shown in Fig. 2 and the main components of Gamma camera which are responsible for image processing and display are depicted in Fig. 3.

The scanning technique's drawback is that it only measures a small percentage of the decaying activity at a time; the remainder is lost and adds to the patient's needless radiation exposure.

Radiation Exposure

Medical imaging (Parker and Patton 2013) is the key cause of radiation exposure. The absorbed dose of ionizing radiation in living tissues are quantified by means of units such as sieverts (Sv) and millisieverts (mSv). The radiation levels due to natural background can differ significantly and it is reliant on the area of living. For instance, some regions have higher radiation levels due to ecological factors while other may have low. The usual background radiation exposure from natural sources is typically about 1 to 3 mSv per year. During Chest X-ray the radiation exposure met by a patient is nearly 0.1 mSv per procedure. However, during CT scan of the abdomen or pelvis the exposure

might range from 10 to 20 mSv depending on the explicit etiquette and part being scanned. For Breast cancer scanning the mammogram necessitates not more than 0.5 mSv per examination. For radiation workers the annual occupational exposure limit is usually set at 20 mSv averaged over five years, with no year surpassing 50 mSv. This is followed in many nations. For the general public, the annual exposure limit is typically set at 1 mSv per year above background levels. In radiation therapy much higher dose is used compared to diagnostic procedures. Doses are carefully calculated and administered to the specific target inside the body which is affected by cancer. The doses used in radiation therapy are much higher than those used in diagnostic procedures. Dose is carefully calculated and directed to the target specific parts of the body which is affected by cancer. The total dose that can be administered in a body can range from a few grays to tens of grays (where 1 Gy = 1000 mSv). While in most diagnostic procedures the dose ranges from 1 to 10 mSv. Nevertheless, there can be exclusions also depending on the definite radiopharmaceutical and the practice. If the radiation level overdoes 1 mSv above background levels, evacuation is typically considered in the instance of nuclear emergency. Due to the absence of earth's shielding atmosphere astronauts traveling to the International Space Station (ISS) and out there are exposed to higher levels of radiation. This can range from a few mSv for a stay on the ISS to possibly several hundred mSv for deep space missions.

Radiation hazards associated with nuclear medicine

There is a potential radiation hazards linked with nuclear medicine although it is cautiously regulated and used in controlled settings. In the procedures discoursed above the radioactive materials used expose patients and healthcare workers to radiation hazards, together with probable long-standing dangers such as cancer and genetic mutations. To minimalize the

risk of radiation hazard and to ensure that the exposure remains inside safe limits, strict protocols and safety regulatory rules has to be maintained. The energy confined in ionizing radiation can be used to disrupt free electrons from atoms that are closely associated. This might cause possible damage to living tissues and henceforth the main concern in nuclear medicine is the potential exposure of patients, healthcare workers, and the environment to ionizing radiation emitted by the radiopharmaceuticals. With time the radioactivity of the radiopharmaceuticals decreases i.e. the half-life of radiopharmaceuticals is particular. Nuclear medicine professionals follow strict protocols to lessen radiation exposure. This comprises using the minimum operative dose of radiopharmaceuticals and taking protections to safeguard and contain the radioactive material. For prenatal or breastfeeding patients' different protection measures are set aside. During pregnancy unless absolutely essential nuclear medicine treatments are avoided but if done, breastfeeding is discontinued for a while. The risks connected with the prudent use of radioactive materials are generally balanced by the benefits of nuclear medicine in recognizing and treating certain medical conditions. Cautious adherence to legal necessities and safety measures is crucial to ensure that radiation risks are kept to the minutest.

Disposal of Nuclear Medicine

Disposing of nuclear medicine waste is another serious aspect, demanding adherence to strict rules to avoid environmental contamination. The disposal of radiopharmaceuticals is carefully regulated to ensure the safety of both humans and the environment (IAEA, 2005). The general method of disposal includes decay-in-storage for short-lived isotopes, sewer removal of patient excretions, and transmission to certified services for longer-lived radioactive elements. Proper disposal helps to mitigate the risks associated with the use of radioactive substances in medical sceneries. The general steps and considerations for

the disposal of nuclear medicine (Fig. 4) are discussed below:

A) Identification and Segregation: Identification and Segregation is the primary phase in the disposal of nuclear medicine. Nuclear medicine constituents should be stored in a selected zone away from non-radioactive materials. The zone of storing must be marked cautiously and entree to it should be provided only to the authorized employees. Labelling with specific identification and information is to be made in all packages, containers and vials containing the radioactive material. Details including the activity, date of preparation, and any required radiation warning symbols are to be provided on the labels. To visually differentiate containers of radioactive materials from non-radioactive one's stickers or color-coded labels may be used. This may help in preventing accidental mixing of materials. To store radioactive materials containers made of suitable shielding materials such as lead which is non-reactive can be used. The lead containers are designed to prevent leakage and act as shield against emitted radiation. Detailed record and accuracy must be maintained for each batch of radiopharmaceuticals including relevant quality control tests. Geiger-Muller counters, scintillation detectors, or other radiation monitoring devices are used to verify the presence and level of radiation around containers and storage areas. Periodic inspections and audits of the storage area and containers help ensure that segregation and identification practices are being followed correctly.

B) Radiopharmaceutical Decay: Radioactive nuclei are unstable. They stabilize themselves by emitting α particles, β particles and γ radiations (Knoll, 2010, Martin, 2019, Serway and Jewett 2018). In nuclear medicine, radiopharmaceutical decay is a natural process in which the radioactive elements decay over a particular period of time. The decay occurs due to the emission of ionization radiation from the unstable nuclei present in the

radiopharmaceutical. The half-life ($T_{1/2}$) of the radioactive element is the time required for half of the element to decay. It is a characteristic property of any radionuclide and may vary from fraction of a second to millions of years. With the decay of radionuclide, the total number of atoms present in the sample decrease resulting in the reduction of activity. The power of the released radiation also declines over time. So, in therapeutic nuclear medicine based on the wanted extent of treatment, the radio nuclides with precise half-lives are selected. Technetium-99m has a short half-life of approximately 06 hours and Iodine-131 has a comparatively long half-life of around 8 days which is why it is used in the treatment of thyroid cancer. Once a radiopharmaceutical has decayed to a harmless level, the resulting waste is managed according to conventional radioactive waste disposal measure. This guarantees that there is no damage to the environment or public health from the waste. The use and handling of radiopharmaceuticals in nuclear medicine are subject to strict regulatory oversight by organizations such as the Nuclear Regulatory Commission (NRC) in the United States (NRC, 2020). This ensures that safety protocols are followed for safe disposal.

C) Authorized Radioactive Waste Disposal Facilities: There are authorized facilities well equipped to contain and handle radioactive materials safely (Ravichandran, Binukumar, Sreeram, and Arunkumar 2011). Disposal of radioactive waste, including outdated or unused radiopharmaceuticals, must be done appropriately through those authorized facilities. During transportation of radioactive waste to disposal facilities extreme care must be taken and certified transporters must be involved who are competent to handle radioactive materials. The disposal should be in accordance with local and national regulations. Radiopharmaceuticals should be securely packaged in containers that are designed to prevent leakage or breakage during transport. Detailed records of the type, quantity, and

disposal of radioactive waste should be maintained for regulatory compliance and auditing purposes. Before and after disposal, the disposal area should be monitored for any residual radiation to ensure that no contamination has occurred. As we have discussed earlier that there are specialized facilities equipped to handle radioactive materials, certain types of solid radioactive waste which are contaminated with low-level radioactive substances, may be burned in that case. Liquid radioactive waste may further undergo treatment processes to reduce its radioactivity or to separate the radioactive component for further processing or disposal. The Atomic Energy Regulatory Board (AERB) sets severe adherence to safety etiquettes and strategies during trials and disposal and directs the nuclear medicine procedures in India to tune with it. The main authority to monitor and supervise the usage of ionizing radiation, included in nuclear medicine trials is the AERB, under the Department of Atomic Energy (DAE). These trials are in position to confirm that both patients and healthcare specialists are exposed to the lowest possible levels of radiation while still gaining precise analytical data or therapeutic benefits. Nuclear medicine follows the principle of ALARA

(As Low As Reasonably Achievable). This means that every single effort is made to curtail radiation exposure while still gaining the obligatory diagnostic or therapeutic statistics.

Discussion and Conclusions

Scientific improvement and innovative paths of enduring research has vastly contributed to the field of nuclear medicine which is evolving incessantly. To further improve diagnostic precision and treatment efficacy new radiopharmaceuticals and imaging techniques are being developed. Nuclear medicine delivers thorough diagnostic evidence which is extremely accurate and which might not be obtained through other imaging modes. Nuclear medicine is vital for treating an extensive range of ailments, even outside diagnosis, including certain forms of cancer and hyperthyroidism. It is used to selectively mark and terminate abnormal cells. In conclusion, nuclear medicine is a vital constituent of contemporary healthcare, contribution a variety of diagnostic and therapeutic competences. Its importance in present-day medical practice is highlighted owing to its capability to deliver accurate information at the molecular level,

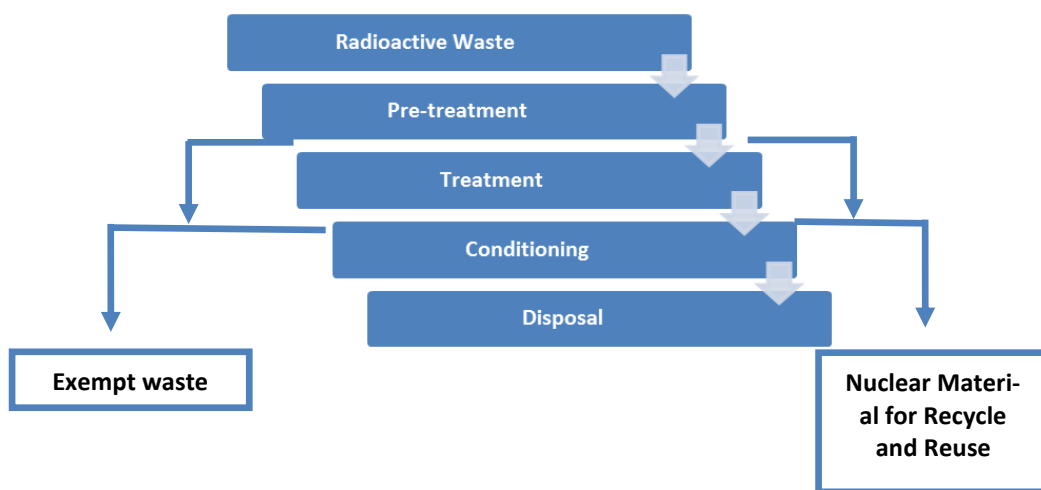


Fig. 4: Schematic steps involved in the disposal of radioactive waste

coupled with improvements in treatment opportunities. Even though nuclear medicine has countless benefits, it also encounters challenges. It can be expensive, non-accessible and there are regulatory issues concerning the management and disposal of radioactive elements.

There is a need for a holistic approach from government agencies and professionals in implementing and following the standard norms in the utilization and scientific disposal of nuclear waste. The enduring technological improvements embrace promise for the future and potential leading to additional cheap, harmless, and accessible treatments that improve patient care even better.

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Conflict of Interest

The authors declare no conflicts of interest.

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