Nuclear Medicine for Diagnosis and Treatment

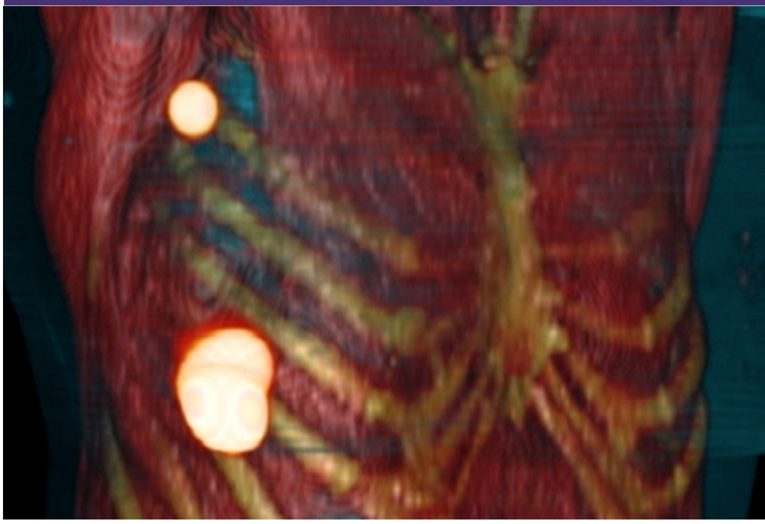
Why is it important?

Nuclear medicine is a field of medicine that uses a trace amount of radioactive substances for the diagnosis and treatment of many health conditions such as certain types of cancer, and neurological and heart diseases.

Over the past decade, the medical sector has witnessed significant advances, particularly in the understanding of biological and pathological processes at the molecular level. The increase of chronic diseases worldwide, including cancer and cardiovascular diseases has led to the development of a new biomedical research discipline, called 'molecular imaging', which enables the visualization, characterization and quantification of biological processes taking place at the cellular and subcellular levels in the living human body.

The IAEA has worked for over 60 years to promote the use of nuclear techniques in medicine by collaborating with its Member States and other organizations through several mechanisms that include improving infrastructure and training of human resources. The IAEA's aim is to help build or strengthen Member States' capabilities to address their needs in relation to the prevention, diagnosis and treatment of health problems through the application of nuclear techniques, including nuclear medicine.

Nuclear technology can help save lives. As one of the tools used in the human health area, nuclear medicine can be harnessed for a variety of techniques to diagnose and treat diseases.



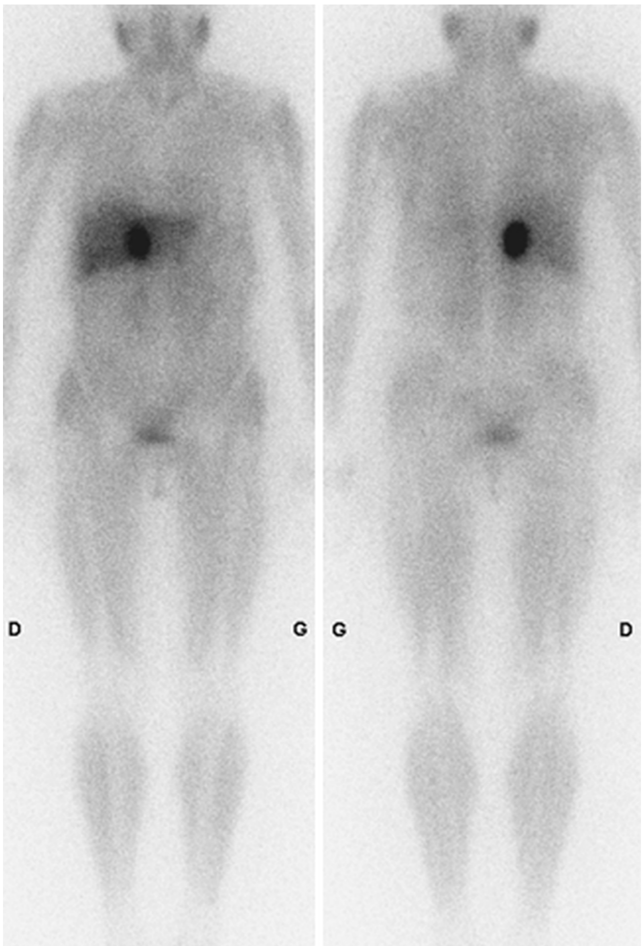
A SPECT/CT 3D display of a patient with breast cancer, showing the tumour in the lower left side and the corresponding axillary sentinel lymph node in the upper left side of the image.
(Image: Francesco Giammarile/IAEA)

What do I need to know?

Nuclear medicine is a medical specialty that involves the application of radionuclides as unsealed sources. Radioisotopes are most frequently attached to drugs to form radiopharmaceuticals that travel to a specific organ or tissue in the body.

Radiopharmaceuticals are used in small amounts to evaluate the function of different organs. A radiopharmaceutical can be designed to seek out only desired tissues or organs. It enables doctors to observe physiological functions and metabolic activity inside the human body and to learn more about the health of individual organs.

After being administered, the medical isotope emits electromagnetic waves from the place where it is



A scintigraphy that shows the anterior and posterior view of a patient with a tumour discovered in the right adrenal gland. The image clearly shows a tumour site (the black spot), above the right kidney.
(Image: Francesco Giammarile/IAEA)

located within the patient's body. Special imaging devices are used to precisely detect the waves and generate images for diagnostic purposes. When properly used, the amount of radiation exposure a patient receives is very low and considered safe.

The radioisotopes given to patients for diagnosis or treatment decay and become stable (non-radioactive) elements within minutes or hours depending on their half-lives or they are rapidly eliminated from the body.

Nuclear medicine has clinical applications in virtually all organs of the body. It is used for diagnostic purposes in a broad range of medical areas such as cardiology, pneumology, gastroenterology, neurology, endocrinology, haematology, orthopaedics, infection and oncology. Nuclear medicine also has therapeutic applications in the treatment of some thyroid diseases, metastatic bone pain, neuroendocrine tumours and other malignancies, as well as to relieve arthritic pain.

How do we use radioisotopes in medicine?

Some radioisotopes that decay with alpha or beta radiation are used for treating diseases such as cancer. Others that decay with gamma or positron radiation are used in conjunction with powerful medical scanners and cameras to take images of processes and structures inside the body for disease diagnosis.

In medicine, two of the most commonly used radioisotopes are technetium-99m and iodine-131. The gamma emitting technetium-99m is mainly used to image the skeleton and heart, but also to image the brain, thyroid, lungs, liver, spleen, kidney, gallbladder, bone marrow, and infections, as well as for other specialized medical studies.

Iodine-131 is widely used to treat overfunctioning thyroid glands and thyroid cancer, and to image the thyroid.

Radioisotopes are also used for medical research to study normal and abnormal functioning of organs and systems.

Why do we use radioisotopes in medicine?

Radioisotopes are special because certain organs in the body respond in unique ways to different substances. For example, the thyroid absorbs iodine more so than any other chemical, so radioiodine is widely used to treat thyroid cancer and in imaging the thyroid. Similarly, specific radioactive compounds are picked up and metabolized by other organs like the liver, kidney and brain.

Radioisotopes are unique because they provide early and detailed diagnostic information that will improve patient management and in many cases will lead to a change in the therapeutic approach. Furthermore radioisotopes allow targeted treatment to all visible and invisible sites of disease in the body.

In comparison to conventional radiology, diagnostic nuclear medicine is essentially a functional imaging process reflecting physiological processes, whereas conventional radiology aims predominantly at obtaining anatomical images reflecting form and structure.

What are these diagnostic techniques?

In the area of diagnosis, special devices are used to image the body. Depending on the type of examination required, the radiopharmaceutical may be administered by injection, ingestion or inhalation to trace, map and identify the area of health concern in a patient. The resulting radioactive emissions are captured through a special device that enables visualization with the help of a computer.

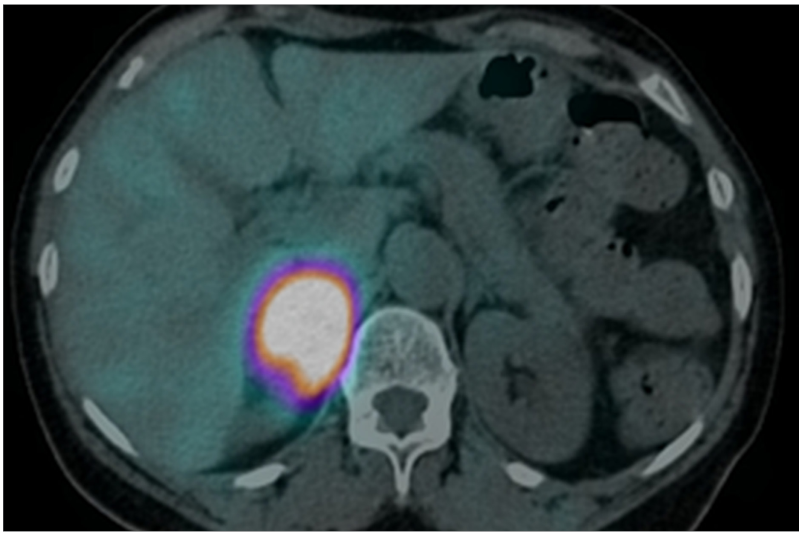
The diagnostic techniques that play vital roles in nuclear medicine imaging are:

Scintigraphy, a two-dimensional imaging process, is a diagnostic technique in nuclear medicine. Taken internally, the radiotracer emits gamma radiation that is captured by external detectors, known as gamma cameras, to form two-dimensional images for medical assessment.

Clinical images can also be acquired at multiple angles creating a replica of the body's cross section, a technique called **single photon emission computed tomography (SPECT)**.

SPECT systems use a rotating gamma camera to obtain images of the distribution of the radiopharmaceutical within the patient's body from different angles. This technique is particularly valuable because of its unique ability to precisely locate the abnormality in the body through a three-dimensional (3D) image of the distribution of the radiopharmaceutical.

Positron emission tomography (PET), especially valuable in the detection and management of cancer, works in the same way as SPECT, but uses radioisotopes that generally decay faster and produce two rays that move in opposite directions. The special configuration of a PET system enables



A single photon emission tomography-computed tomography scan of a patient shows a pathological spot (in colour) in right adrenal, corresponding to a localized pheochromocytoma, which is a type of adrenal tumour.
(Image: Francesco Giammarile/IAEA)

a 3D reconstruction of the distribution of the radiopharmaceutical.

The nuclear medicine 3D images can be superimposed, using software or hybrid cameras, on images from modalities such as computed tomography (CT) or magnetic resonance imaging to highlight the part of the body in which the radiopharmaceutical is concentrated. This practice is often referred to as image fusion or co-registration, for example SPECT/CT and PET/CT. Fusion imaging techniques in nuclear medicine provide information about anatomy and function.

The combination of anatomical and functional information, provided by the hybrid imaging systems, increases the sensitivity and specificity of medical examinations, particularly in difficult cases.

Overall usage of nuclear medicine procedures is expanding rapidly mainly due to the improvement of medical devices and the production of an ever increasing number of specific radiotracers, which allows the visualization of more diseases.

Therapeutic relief: reducing pain using nuclear medicine

The administration of a radionuclide to destroy targeted cells is called radiometabolic therapy. Radionuclide therapies are widely used in the

A PET scan of a patient with a metastatic neuroendocrine tumour. This 3D image shows multiple pathologic tumour sites (the black spots), which indicate a primary pancreatic tumour and bone, liver and lymph node metastases.
(Image: Francesco Giammarile)

treatment of diseases, such as hyperthyroidism and thyroid cancer.

More recently, applications for the treatment of prostate cancer, neuroendocrine tumours, bone metastasis and lymphoma, among others, are becoming available. To control the disease, or to prevent recurrence through spreading of loose cancerous cells which can lead to metastatic cancer, all malignant tumour cells must be completely destroyed.

In nuclear medicine therapy, the radiopharmaceuticals emit ionizing radiation that travels only a short distance in the body, thereby minimizing unwanted side effects and damage to other organs or nearby structures.

Ensuring safety when using nuclear medicine

Apprehensions about radiation exposure are common among the general public, but nuclear medicine procedures are safe. Moreover, these procedures are relatively painless and free of side effects. The benefits definitely outweigh the risks.

Medical staff follow strict rules and are trained to ensure the safety of those patients who are given radioisotopes for diagnostic or therapeutic purposes.

Referral guidelines to guide the proper selection and application of medical images should be used by the medical doctors involved in patient management.

The two general principles of radiation protection — justification and optimization — are applicable for medical radiological procedures:

Justification of medical exposure entails weighing the diagnostic or therapeutic benefits of exposure against the potential for harm, and taking into account the benefits and risks of available alternative techniques that do not involve ionizing radiation exposure.

Optimization of protection and safety in diagnostic and interventional medical exposure entails keeping the exposure of patients to the minimum necessary to achieve the required diagnostic or interventional objective. Dose limits do not apply to medical exposure, as they may limit the benefits for the patient.

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