

Advancing Nuclear Medicine: A Review Article

Dr Sumedha Rajput¹, Dr Siddesh Shenoy², Dr Bhushan Thoke³,

Dr Vijay Mehetre⁴

^{1,2}(Department of OMDR, M.A.Rangoonwala Dental College, Pune)

³(Department of Orthodontics, ACPM Dental College, Dhule)

⁴(Department of Periodontics, ACPM Dental College, Dhule)

Abstract: The development of radiopharmaceuticals and evolution of nuclear medicine instrumentation often go hand in hand. There are many examples throughout the history of nuclear medicine where discoveries in one technology have driven discoveries in the other. The major limitation of nuclear imaging is limited resolution power to define precise anatomical location of diseases. To overcome this limitation, the molecular and functional imaging provided by PET and the anatomical imaging provided by CT, have been merged into hybrid imaging using combined scanners such as PET/CT and SPECT. These hybrid modalities allow in single diagnostic procedure and combined evaluation of function.

Keyword: nuclear imaging, PET, radiopharmaceuticals, SPECT, technologies.

I. Introduction

Nuclear medicine is a highly multi-disciplinary specialty that develops and uses instrumentation and radiopharmaceuticals to study physiological processes and non-invasively diagnosis and treat diseases. A radiopharmaceutical is either a radionuclide alone, such as iodine-131 or a radionuclide that is attached to a carrier molecule (a drug, protein, or peptide) or particle, which when introduced into the body by injection, swallowing, or inhalation accumulates in the organ or tissue of interest.

In a nuclear medicine scan, a radiopharmaceutical is administered to the patient, and an imaging instrument that detects radiation is used to show biochemical changes in the body¹. Nuclear medicine imaging in contrast to imaging techniques that mainly show anatomy (e.g., conventional ultrasound, computed tomography (CT) or magnetic resonance imaging (MRI)), can provide important quantitative functional information about normal tissues or disease conditions in living subjects. For treatment, highly targeted radiopharmaceuticals may be used to deposit lethal radiation at tumor sites.

Imaging modalities such as CT and MRI will remain first line modalities in the investigation of cancers. However when a PET study is used in diagnosis of cancer patients it can cause changes in therapeutic decisions in 30-40% of cases⁵.

II. PET/CT

PET produces a three-dimensional picture of functioning processes in the human body, allowing for the evaluation of tissue metabolic activity. In PET a positron emission radionuclide – or tracer – able to track a specific biologic process at molecular level is injected into the patient. As these radioactive tracers decay, they emit positrons, which are then detected using a PET scanner. The resulting images will help distinguish between normal and abnormal cellular/molecular activity.

Positron emitters are radionuclides like fluorine-18, carbon-11, oxygen-15 and nitrogen-13, which in their non-radioactive state are normal constituents of all biologically active molecules (fluorine is a suitable substitute for hydrogen) and are therefore potentially suitable to label any molecule without altering its metabolic pathway.

A simple way to describe the tumor growth process is that tumors need to divide, multiply and invade the neighboring structures or tissues and spread to distant sites, a process called metastasis. To grow and metastasize, tumors require energy and the utilization of glucose – the fuel used by the body to produce energy - provides the necessary elements for this activity. While normal cells use glucose, there is an increased consumption of glucose within tumor cells.

Labeled with fluorine-18, a glucose analogue like FDG is used as a tracer, both because fluorine-18 is quick to decay, thus limiting patient radiation exposure and because it is a natural indicator of cellular metabolic state, particularly increased in cancer cellular deposits and therefore easily detectable in diagnosing cancer with PET/CT, the most commonly used biologically active model is F18-FDG, a glucose analogue labeled with a radioactive element, the positron emitter fluorine-18, which allows the evaluation of glucose metabolism in normal and abnormal cells.

III. SPECT/CT

Another hybrid imaging technology, single photon emission computed tomography (SPECT), also allows visualization of functional information about a patient's specific organ or body system. Like in PET, a radiopharmaceutical or tracer is injected into the patient. Unlike PET, SPECT utilizes single photon emitters as tracers which does not require on-site dedicated cyclotrons for production. As this tracer decays, it emits gamma rays, which are then detected by a gamma camera. An essential tool in nuclear medicine, a sophisticated substitute for the X-Ray, the gamma camera can be used in planar imaging to acquire 2-dimensional images, or in SPECT imaging to acquire 3-dimensional images.

Coupled with CT, SPECT/CT has greatly improved neuroendocrine tumors diagnosis and staging tumor foci⁸. The same is true for other tumor-seeking agents like meta-iodo-benzyl-guanidin (MIBG) and sestamibi labeled with single photon emitters such as indium-111, iodine-123 or technetium-99m. MIBG is a specific agent for neuroblastoma as well as of pheochromocytoma and other paragangliomas¹⁰. It still plays a major role in staging and follow-up of children with neuroblastoma, where it can also be used for radionuclide therapy⁹.

As a general rule, scintigraphic images lack accurate anatomic landmarks for precise localization and diagnosis of specific disease processes. These considerations explain why morphologic (CT) and functional imaging modalities (SPECT and PET) are complementary and not competing techniques, especially if precise image registration is made possible by using a single imaging unit combining the emission based data with the transmission based data (CT, which also serves to correct the emission data for tissue attenuation) (Fig. 1). Called image co-registration, this process determines the geometric relationship between multimodality imaging studies, in order to use information provided by one test in the context of the other modality.



FIG. 1 - Female 65 years old, with a neuroendocrine tumor (Pheochromocytoma). The SPECT – MIBG study shows an increased tracer uptake that is difficult to localize. The CT study shows no anatomical abnormalities. However, SPECT/CT allows one to localize the uptake in the left adrenal gland.

IV. Conclusion

PET and SPECT each have distinct advantages and disadvantages that make them useful for detecting certain conditions. Each technique uses different properties of radioactive elements in creating an image. For example, one the advantages of SPECT compared with PET are that more than one radiotracer can be used at a time. In addition, the longer half-life of radionuclides used with SPECT makes this imaging procedure more readily available to medical community at large. However PET images have higher sensitivity than SPECT by factor 2 to 3 and use radiopharmaceuticals that provide more physiological information.

Nuclear medicine allows physicians to cost effectively obtain medical information that would otherwise be unavailable or would require more invasive procedures, such as surgery or biopsy.

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