Term Paper

Diagnostic Medical Imaging

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Table of Content:

Introduction: In nuclear medicine imaging, radiopharmaceuticals are taken internally, for example, through inhalation, intravenously or orally. Then, external detectors (gamma cameras) capture and form images from the radiation emitted by the radiopharmaceuticals. This process is unlike a diagnostic X-ray, where external radiation is passed through the body to form an image. There are several techniques of diagnostic nuclear medicine. For example: Scintigraphy (from Latin scintilla, "spark"), also known as a gamma scan, is a diagnostic test in nuclear medicine, where radioisotopes attached to drugs that travel to a specific organ or tissue (radiopharmaceuticals) are taken internally and the emitted gamma radiation is captured by external detectors (gamma cameras) to form two-dimensional images in a similar process to the capture of x-ray images. In contrast, SPECT and positron emission tomography (PET) form 3-dimensional images and are therefore classified as separate techniques from scintigraphy, although they also use gamma cameras to detect internal radiation. Scintigraphy is unlike a diagnostic X-ray where external radiation is passed through the body to form an image. Scintillography is an imaging method of nuclear events provoked by collisions or charged current interactions among nuclear particles or ionizing radiation and atoms which result in a brief, localized pulse of electromagnetic radiation, usually in the visible light range (Cherenkov radiation). This pulse (scintillation) is usually detected and amplified by a photomultiplier or charged coupled device elements, and its resulting electrical waveform is processed by computers to provide two- and three-dimensional images of a subject or region of interest. Scintillography is mainly used in scintillation cameras in experimental physics. For example, huge neutrino detection underground tanks filled with tetrachloroethylene are surrounded by arrays of photo detectors in order to capture the extremely rare event of a collision between the fluid's atoms and a neutrino. Another extensive use of scintillography is in medical imaging techniques which use gamma ray detectors called gamma cameras. Detectors coated with materials which scintillate when subjected to gamma rays are scanned with optical photon detectors and scintillation counters. The subjects are injected with special radionuclides which irradiate in the gamma range inside the region of interest, such as the heart or the brain. A special type of gamma camera is the SPECT (Single Photon Emission Computed

Tomography). Another medical scintillography technique, the Positron-emission tomography (PET), which uses the scintillations provoked by electron-positron annihilation phenomena. Diagnostic imaging describes various techniques of viewing the inside of the body to help figure out the causes of an illness or injury and confirm a diagnosis. Doctors also use it to see how well a patient’s body responds to treatment for a fracture or illness. In nuclear medicine imaging, radiopharmaceuticals are taken internally, for example, through inhalation, intravenously or orally. Then, external detectors (gamma cameras) capture and form images from the radiation emitted by the radiopharmaceuticals. This process is unlike a diagnostic X-ray, where external radiation is passed through the body to form an image. Diagnostic imaging allows physicians to view the inside of your body to help them find any indications of a health condition. Some machines and methods can produce pictures of the activities and structures inside your body. Your doctor will decide which medical imaging tests they’ll need to use based on the body part they’re evaluating and your symptoms. Many imaging tests are noninvasive, easy and painless. Some will require you to remain still inside the machine for a long time, however, which can get a little uncomfortable. Some tests involve a small amount of radiation exposure.

For other imaging tests, the doctor will insert a small camera attached to a thin, long tube into your body. This device is referred to as a “scope.” They’ll then move the scope through a bodily opening or passageway to view the inside of a particular organ, like your lungs, heart or colon. You may need anesthesia for these procedures. Nuclear medicine imaging is a method of producing images by detecting radiation from different parts of the body after a radioactive tracer is given to the patient. The images are digitally generated on a computer and transferred to a nuclear medicine physician, who interprets the images to make a diagnosis. Radioactive tracers used in nuclear medicine are, in most cases, injected into a vein. For some studies, they may be given by mouth. These tracers aren’t dyes or medicines, and they have no side effects. The amount of radiation a patient receives in a typical nuclear medicine scan tends to be very low.

History: The history of nuclear medicine contains contributions from scientists across different disciplines in physics, chemistry, engineering, and medicine. The multidisciplinary nature of nuclear medicine makes it difficult for medical historians to determine the birthdate of nuclear medicine. This can probably be best placed between the discovery of artificial radioactivity in 1934 and the production of radionuclides by Oak Ridge National Laboratory for medicine-related use, in 1946. The origins of this medical idea date back as far as the mid-1920s in Freiburg, Germany, when George de Hevesy made experiments with radionuclides administered to rats, thus displaying metabolic pathways of these substances and establishing the tracer principle. Possibly, the genesis of this medical field took place in 1936, when John Lawrence, known as "the father of nuclear medicine", took a leave of absence from his faculty position at Yale Medical School, to visit his brother Ernest Lawrence at his new radiation laboratory (now known as the Lawrence Berkeley National Laboratory) in Berkeley, California. Later on, John Lawrence made the first application in patients of an artificial radionuclide when he used phosphorus-32 to treat leukemia.

Many historians consider the discovery of artificially produced radionuclides by Frédéric Joliot-Curie and Irène Joliot-Curie in 1934 as the most significant milestone in nuclear medicine. In February 1934, they reported the first artificial production of radioactive material in the journal Nature, after discovering radioactivity in aluminum foil that was irradiated with a polonium preparation. Their work built upon earlier discoveries by Wilhelm Konrad Roentgen for X-ray, Henri Becquerel for radioactive uranium salts, and Marie Curie (mother of Irène Curie) for radioactive thorium, polonium and coining the term "radioactivity." Taro Takemi studied the application of nuclear physics to medicine in the 1930s. The history of nuclear medicine will not be complete without mentioning these early pioneers.

Nuclear medicine gained public recognition as a potential specialty when on May 11, 1946 an article in the Journal of the American Medical Association (JAMA) by Massachusetts General Hospital's Dr. Saul Hertz and Massachusetts Institute of Technology's Dr. Arthur Roberts, described the successful use of treating Graves' Disease with radioactive iodine (RAI) was published. Additionally, Sam Seidlin. brought further development in the field describing a successful treatment of a patient with thyroid cancer metastases using radioiodine (I-131). These articles are considered by many historians as the most important articles ever published in nuclear medicine.[9] Although the earliest use of I-131 was devoted to therapy of thyroid cancer, its use was later expanded to include imaging of the thyroid gland, quantification of the thyroid function, and therapy for hyperthyroidism. Among the many radionuclides that were discovered for medical-use, none were as important as the discovery and development of Technetium-99m. It was first discovered in 1937 by C. Perrier and E. Segre as an artificial element to fill space number 43 in the Periodic Table. The development of a generator system to produce Technetium-99m in the 1960s became a practical method for medical use. Today, Technetium-99m is the most utilized element in nuclear medicine and is employed in a wide variety of nuclear medicine imaging studies.

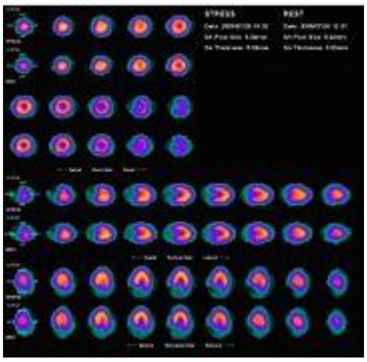
Widespread clinical use of nuclear medicine began in the early 1950s, as knowledge expanded about radionuclides, detection of radioactivity, and using certain radionuclides to trace biochemical processes. Pioneering works by Benedict Cassen in developing the first rectilinear scanner and Hal O. Anger's scintillation camera (Anger camera) broadened the young discipline of nuclear medicine into a full-fledged medical imaging specialty.

By the early 1960s, in southern Scandinavia, Niels A. Lassen, David H. Ingvar, and Erik Skinhøj developed techniques that provided the first blood flow maps of the brain, which initially involved xenon-133 inhalation; an intra-arterial equivalent was developed soon after, enabling measurement of the local distribution of cerebral activity for patients with neuropsychiatric disorders such as schizophrenia. Later versions would have 254 scintillators so a two-dimensional image could be produced on a color monitor. It allowed them to construct images reflecting brain activation from speaking, reading, visual or auditory perception and voluntary movement. The technique was also used to investigate, e.g., imagined sequential movements, mental calculation and mental spatial navigation. By the 1970s most organs of the body could be visualized using nuclear medicine procedures. In 1971, American Medical Association officially recognized nuclear medicine as a medical specialty. In 1972, the American Board of Nuclear Medicine was established, and in 1974, the American Osteopathic Board of Nuclear Medicine was established, cementing nuclear medicine as a stand-alone medical specialty. In the 1980s, radiopharmaceuticals were designed for use in diagnosis of heart disease. The development of single photon emission computed tomography (SPECT), around the same time, led to three-dimensional reconstruction of the heart and establishment of the field of nuclear cardiology. More recent developments in nuclear medicine include the invention of the first positron emission tomography scanner (PET). The concept of emission and transmission tomography, later developed into single photon emission computed tomography (SPECT), was introduced by David E. Kuhl and Roy Edwards in the late 1950s. Their work led to the design and construction of several tomographic instruments at the University of Pennsylvania. Tomographic imaging techniques were further developed at the Washington University School of Medicine. These innovations led to fusion imaging with SPECT and CT by Bruce Hasegawa from University of California San Francisco (UCSF), and the first PET/CT prototype by D. W. Townsend from University of Pittsburgh in 1998. PET and PET/CT imaging experienced slower growth in its early years owing to the cost of the modality and the requirement for an on-site or nearby cyclotron. However, an administrative decision to approve medical reimbursement of limited PET and PET/CT applications in oncology has led to phenomenal growth and widespread acceptance over the last few years, which also was facilitated by establishing 18F-labelled tracers for standard procedures, allowing work at non-cyclotron-equipped sites. PET/CT imaging is now an integral part of oncology for diagnosis, staging and treatment monitoring. A fully integrated MRI/PET scanner is on the market from early 2011.

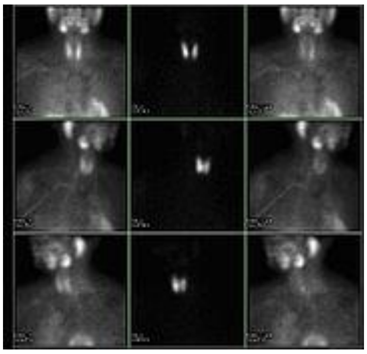
Types of Diagnostic Imaging: There are several techniques of diagnostic nuclear medicine:

- 2D: Scintigraphy ("scint") is the use of internal radionuclides to create two-dimensional images. Scintigraphy (from Latin scintilla, "spark"), also known as a gamma scan, is a diagnostic test in nuclear medicine, where radioisotopes attached to drugs that travel to a specific organ or tissue (radiopharmaceuticals) are taken internally and the emitted gamma radiation is captured by external detectors (gamma cameras) to form two-dimensional images in a similar process to the capture of x-ray images. In contrast, SPECT and positron emission tomography (PET) form 3-dimensional images and are therefore classified as separate techniques from scintigraphy, although they also use gamma cameras to detect internal radiation. Scintigraphy is unlike a diagnostic X-ray where external radiation is passed through the body to form an image.

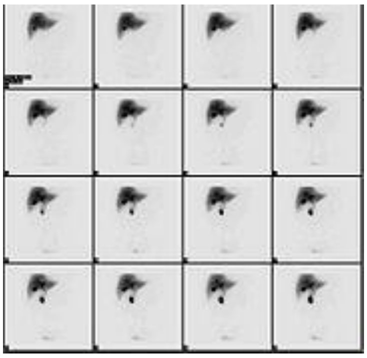
A nuclear medicine whole body bone scan. The nuclear medicine whole body bone scan is generally used in evaluations of various bone-related pathology, such as for bone pain, stress fracture, nonmalignant bone lesions, bone infections, or the spread of cancer to the bone.



Nuclear medicine myocardial perfusion scan with thallium-201 for the rest images (bottom rows) and Tc-Sestamibi for the stress images (top rows). The nuclear medicine myocardial perfusion scan plays a pivotal role in the noninvasive evaluation of coronary artery disease. The study not only identifies patients with coronary artery disease; it also provides overall prognostic information or overall risk of adverse cardiac events for the patient.



A nuclear medicine parathyroid scan demonstrates a parathyroid adenoma adjacent to the left inferior pole of the thyroid gland. The above study was performed with Technetium-Sestamibi (1st column) and iodine-123 (2nd column) simultaneous imaging and the subtraction technique.



Normal hepatobiliary scan (HIDA scan). The nuclear medicine hepatobiliary scan is clinically useful in the detection of the gallbladder disease.

- 3D: SPECT is a 3D tomographic technique that uses gamma camera data from many projections and can be reconstructed in different planes. Positron emission tomography

(PET) uses coincidence detection to image functional processes. Single-photon emission computed tomography (SPECT, or less commonly, SPET) is a nuclear medicine tomographic imaging technique using gamma rays. It is very similar to conventional nuclear medicine planar imaging using a gamma camera (that is, scintigraphy), but is able to provide true 3D information. This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required. The technique needs delivery of a gamma-emitting radioisotope (a radionuclide) into the patient, normally through injection into the bloodstream. On occasion, the radioisotope is a simple soluble dissolved ion, such as an isotope of gallium(III). Most of the time, though, a marker radioisotope is attached to a specific ligand to create a radioligand, whose properties bind it to certain types of tissues. This marriage allows the combination of ligand and radiopharmaceutical to be carried and bound to a place of interest in the body, where the ligand concentration is seen by a gamma camera. Nuclear medicine tests differ from most other imaging modalities in that diagnostic tests primarily show the physiological function of the system being investigated as opposed to traditional anatomical imaging such as CT or MRI. Nuclear medicine imaging studies are generally more organ-, tissue- or disease-specific (e.g.: lungs scan, heart scan, bone scan, brain scan, tumor, infection, Parkinson etc.) than those in conventional radiology imaging, which focus on a particular section of the body (e.g.: chest X-ray, abdomen/pelvis CT scan, head CT scan, etc.). In addition, there are nuclear medicine studies that allow imaging of the whole body based on certain cellular receptors or functions. Examples are whole body PET scans or PET/CT scans, gallium scans, indium white blood cell scans, MIBG and octreotide scans.

PET Scan: Positron emission tomography (PET) is a functional imaging technique that uses radioactive substances known as radiotracers to visualize and measure changes in metabolic processes, and in other physiological activities including blood flow, regional chemical composition, and absorption. Different tracers are used for various imaging purposes, depending on the target process within the body. For example, 18F-FDG is commonly used to detect cancer, NaF18F is widely used for detecting bone formation, and oxygen-15 is sometimes used to measure blood flow. PET is a common imaging technique, a medical scintillography technique used in nuclear medicine. A radiopharmaceutical—a radioisotope attached to a drug—is injected into the body as a tracer. Gamma rays are emitted and detected by gamma cameras to form a three-dimensional image, in a similar way that an X-ray image is captured. PET scanners can incorporate a CT scanner and are known as PET-CT scanners. PET scan images can be reconstructed using a CT scan performed using one scanner during the same session. One of the disadvantages of a PET scanner is its high initial cost and ongoing operating costs.

Hybrid Scanning Techniques: In some centers, the nuclear medicine scans can be superimposed, using software or hybrid cameras, on images from modalities such as CT or MRI 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. The fusion imaging technique in nuclear medicine provides information about the anatomy and function, which would otherwise be unavailable or would require a more invasive procedure or surgery.

Practical concerns in Nuclear imaging: Although the risks of low-level radiation exposures are not well understood, a cautious approach has been universally adopted that all human radiation exposures should be kept As Low As Reasonably Practicable, "ALARP". (Originally, this was known as "As Low As Reasonably Achievable" (ALARA), but this has changed in modern draftings of the legislation to add more emphasis on the "Reasonably" and less on the "Achievable".) Working with the ALARP principle, before a patient is exposed for a nuclear medicine examination, the benefit of the examination must be identified. This needs to take into account the particular circumstances of the patient in question, where appropriate. For instance, if a patient is unlikely to be able to tolerate a sufficient amount of the procedure to achieve a diagnosis, then it would be inappropriate to proceed with injecting the patient with the radioactive tracer. When the benefit does justify the procedure, then the radiation exposure (the amount of radiation given to the patient) should also be kept as low as reasonably practicable. This means that the images produced in nuclear medicine should never be better than required for confident diagnosis. Giving larger radiation exposures can reduce the noise in an image and make it more photographically appealing, but if the clinical question can be answered without this level of detail, then this is inappropriate. As a result, the radiation dose from nuclear medicine imaging varies greatly depending on the type of study. The effective radiation dose can be lower than or comparable to or can far exceed the general day-to-day environmental annual background radiation dose. Likewise, it can also be less than, in the range of, or higher than the radiation dose from an abdomen/pelvis CT scan. Some nuclear medicine procedures require special patient preparation before the study to obtain the most accurate result. Pre-imaging preparations may include dietary preparation or the withholding of certain medications. Patients are encouraged to consult with the nuclear medicine department prior to a scan.

Regulatory Frameworks: Different countries around the world maintain regulatory frameworks that are responsible for the management and use of radionuclides in different medical settings. For example, in the US, the Nuclear Regulatory Commission (NRC) and the Food and Drug Administration (FDA) have guidelines in place for hospitals to follow. With the NRC, if radioactive materials aren't involved, like X-rays for example, they are not regulated by the agency and instead are regulated by the individual states. International organizations, such as the International Atomic Energy Agency (IAEA), have regularly published different articles and guidelines for best practices in nuclear medicine as well as reporting on emerging technologies in nuclear medicine. Other factors that are considered in nuclear medicine include a patient's medical history as well as post-treatment management. Groups like International Commission on Radiological Protection have published information on how to manage the release of patients from a hospital with unsealed radionuclides.

Conclusion: Nuclear imaging, also known as gamma scintigraphy, is a medical imaging technique that is often combined with CT to assess disease severity and treatment effect. Although the technique by itself is noninvasive, small doses of radiopharmaceuticals (short-lived gamma radioisotope) are administered via oral, intravenous, or inhalation route for emitting gamma rays. The emitted radiation is then scanned using gamma detectors such as single-photon emission CT or the positron emission tomography to obtain 3D computerized images. Nuclear imaging is used in various types of cancers, neurological disorders, and cardiovascular, gastrointestinal, and endocrinal diseases. Radionuclide (tracers) imaging has become the most attractive and powerful modality for molecular imaging in personalized cancer therapy.

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