**Nuclear medicine**

Nuclear medicine is a medical specialty involving the application of radioactive substances in the diagnosis and treatment of disease. Nuclear medicine, in a sense, is "radiology done inside out" or "endoradiology" because it records radiation emitting from within the body rather than radiation that is generated by external sources like X-rays. In addition, nuclear medicine scans differ from radiology as the emphasis is not on imaging anatomy but the function and for such reason, it is called a physiological imaging modality. Single Photon Emission Computed Tomography or SPECT and Positron Emission Tomography or PET scans are the two most common imaging modalities in nuclear medicine.

**Diagnostic medical imaging**

In nuclear medicine imaging, radiopharmaceuticals are taken internally, for example, 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.

**2D: Scintigraphy ("scint") is the use of internal radionuclides to create two-dimensional images.**

**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.**

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.

While the ability of nuclear metabolism to image disease processes from differences in metabolism is unsurpassed, it is not unique. Certain techniques such as fMRI image tissues (particularly cerebral tissues) by blood flow and thus show metabolism. Also, contrast-enhancement techniques in both CT and MRI show regions of tissue that are handling pharmaceuticals differently, due to an inflammatory process.

Diagnostic tests in nuclear medicine exploit the way that the body handles substances differently when there is disease or pathology present. The radionuclide introduced into the body is often chemically bound to a complex that acts characteristically within the body; this is commonly known as a tracer. In the presence of disease, a tracer will often be distributed around the body and/or processed differently. For example, the ligand methylene-diphosphonate (MDP) can be preferentially taken up by bone. By chemically attaching technetium-99m to MDP, radioactivity can be transported and attached to bone via the hydroxyapatite for imaging. Any increased physiological function, such as due to a fracture in the bone, will usually mean increased concentration of the tracer. This often results in the appearance of a "hot spot", which is a focal increase in radio accumulation or a general increase in radio accumulation throughout the physiological system. Some disease processes result in the exclusion of a tracer, resulting in the appearance of a "cold spot". Many tracer complexes have been developed to image or treat many different organs, glands, and physiological processes.

**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.

**Analysis**

The end result of the nuclear medicine imaging process is a "dataset" comprising one or more images. In multi-image datasets the array of images may represent a time sequence (i.e. cine or movie) often called a "dynamic" dataset, a cardiac gated time sequence, or a spatial sequence where the gamma-camera is moved relative to the patient. SPECT (single photon emission computed tomography) is the process by which images acquired from a rotating gamma-camera are reconstructed to produce an image of a "slice" through the patient at a particular position. A collection of parallel slices form a slice-stack, a three-dimensional representation of the distribution of radionuclide in the patient.

The nuclear medicine computer may require millions of lines of source code to provide quantitative analysis packages for each of the specific imaging techniques available in nuclear medicine.[citation needed]

Time sequences can be further analysed using kinetic models such as multi-compartment models or a Patlak plot.

**History**

The history of nuclear medicine is rich with contributions from gifted 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.[4]

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.[5][6]

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.[4] 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 on December 7, 1946 when an article was published in the Journal of the American Medical Association by Sam Seidlin.[7] The article described a successful treatment of a patient with thyroid cancer metastases using radioiodine (I-131). This is considered by many historians as the most important article ever published in nuclear medicine.[8] 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;[9] an intra-arterial equivalent was developed soonafter, enabling measurement of the local distribution of cerebral activity for patients with neuropsychiatric disorders such as schizophrenia.[10] 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.[11] The technique was also used to investigate, e.g., imagined sequential movements, mental calculation and mental spatial navigation.[12][13]

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.[14] 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 .[citation needed] 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 .[citation needed]

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.