

# What is Nuclear Medicine and Molecular Imaging?

## What is Nuclear Medicine and Molecular Imaging?

The discovery of x-rays more than a century ago profoundly changed the practice of medicine by enabling physicians and scientists to see inside the living body. Today, modern medicine is undergoing another major transformation—and nuclear medicine and molecular imaging are on its leading edge, probing deep inside the body to reveal its inner workings.

Unlike conventional imaging studies that produce primarily structural pictures, nuclear medicine and molecular imaging visualize how the body is functioning and what's happening at the cellular and molecular level. The evolution in diagnostic imaging—from producing anatomical pictures to imaging and measuring the body's physiological processes—is critically important to all facets of medicine today, from diagnosing disease at its earliest stage and developing more effective therapies to personalizing medical treatment.

With the help of nuclear medicine and molecular imaging, scientists and healthcare providers are:

- Gaining a better understanding of the pathways of disease
- Quickly assessing new drugs
- Improving the selection of therapy
- Monitoring patient response to treatment
- Finding new ways to identify individuals at risk for disease

## Why are Nuclear Medicine and Molecular Imaging unique?

In conventional diagnostic imaging, an external source of energy such as x-rays, magnetic fields, or ultrasound waves is used to produce pictures of bone and soft tissue. In nuclear medicine and molecular imaging procedures, the energy source is introduced into the body, where it gets incorporated in a specific tissue, organ, or process and is then detected by an external device (gamma camera, SPECT or PET scanners) to provide information on organ function and cellular activity.

Because disease begins with microscopic cell changes, nuclear medicine and molecular imaging have the potential to identify disease in an earlier, more treatable stage, often before conventional imaging and other tests are able to reveal abnormalities.

The unique information obtained by nuclear medicine and molecular imaging tests either would require more invasive procedures—such as biopsy or surgery—or would simply be unattainable.

With their ability to identify the early signs of disease and other abnormalities, nuclear medicine and molecular imaging offer the potential to change medical care from reactive to proactive, saving and improving countless lives.

## How are Nuclear Medicine and Molecular Imaging used?

Nuclear medicine and molecular imaging are playing an increasingly important role in patient care, medical research, and pharmaceutical development.

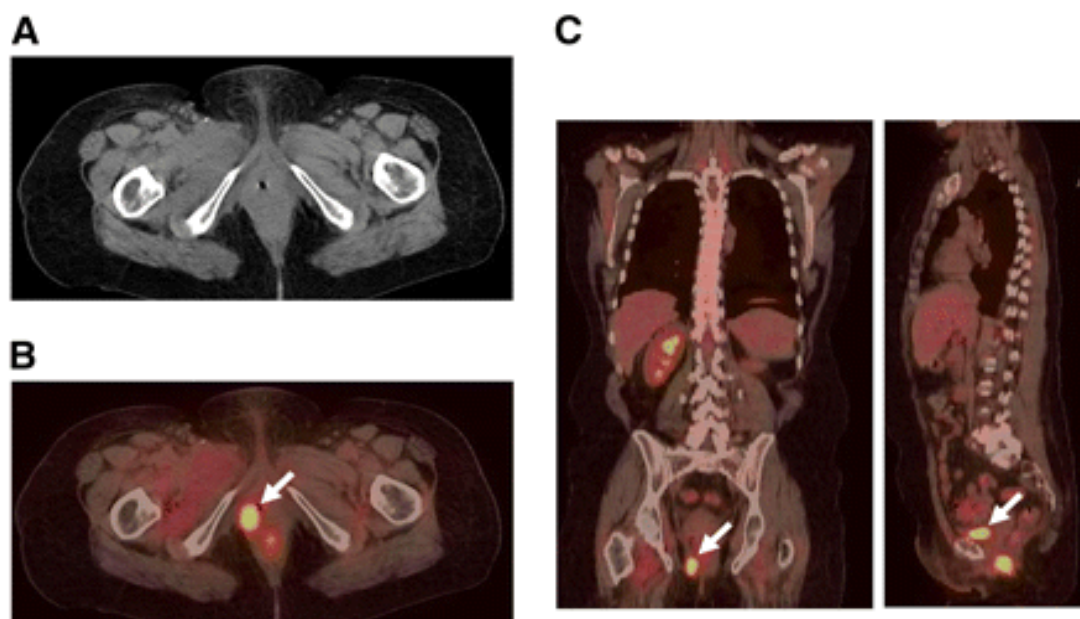
Today, nuclear and molecular diagnostic imaging studies are available for virtually every major organ system in the body. The number of nuclear medicine-based therapies for cancer and other disorders is also expanding.

Nuclear medicine and molecular imaging are integral to the care of patients with cancer, heart disease, and brain disorders.

Lymphoma and esophageal, colon, and lung cancer are just a few of the many types of cancer in which nuclear and molecular imaging can truly change the direction and outcome of patient care.

Nuclear medicine—through myocardial perfusion imaging—offers a very accurate test for diagnosing coronary artery disease in patients who may be at risk for a heart attack.

In addition to helping physicians diagnose dementia, nuclear imaging now offers imaging agents that successfully identify early changes in the brain associated with Alzheimer’s disease.



Examples of anatomical imaging (CT) compared to functional imaging (PET). In this patient, the CT scan (A) is negative for disease recurrence. However, the PET scan (B) shows a spot suggesting malignancy. The PET/CT fusion image (C) gives a clearer picture of what is happening.

Reference: <http://jnm.snmjournals.org/content/49/6/938.full>

In the laboratory, nuclear medicine and molecular imaging technologies are helping scientists in a variety of disciplines gain a better understanding of the molecular pathways and mechanisms of disease. By helping researchers quickly assess new therapies, nuclear medicine and molecular imaging are also contributing to the accelerated development of new and more effective drugs.

### How do Nuclear Medicine and Molecular Imaging work?

Nuclear medicine and molecular imaging involve a signal-producing imaging agent (radiopharmaceutical or probe) that is introduced into the body, usually by injection, and an imaging device capable of detecting and using the probe’s signals to create detailed images. Probes, which are designed to accumulate in a specific organ or attach to certain cells, enable cell activity and biological processes to be visualized and measured.

In nuclear medicine, the imaging agent is a compound that includes a small amount of radioactive material called a radiotracer. Radiotracers (which are also called radiopharmaceuticals or

radionuclides) produce a signal that can be detected by a gamma camera or a positron emission tomography (PET) scanner.

Non-nuclear molecular imaging modalities, including optical imaging and targeted ultrasound, use nonradioactive probes such as light or sound. MR spectroscopy uses differences in magnetism to measure chemical levels in the body without the use of a probe.

## **PET Imaging**

PET imaging with the radiotracer FDG is one of the most significant diagnostic imaging tools ever developed. Most PET studies today are combined with computed tomography (CT) studies to better locate areas of abnormal cell activity.

FDG is a compound like glucose, or sugar, which accumulates in areas of the body that are most metabolically active (using glucose at a high rate). After FDG is injected into the patient's bloodstream and allowed to accumulate for a short time, the PET scanner then creates images that show the distribution of the radiotracer throughout the body, which helps determine if abnormalities are present. For example, highly active cancer cells show higher levels, or "uptake," of FDG, whereas brain cells affected by dementia consume smaller amounts of glucose and show lower FDG uptake.

In addition to FDG, other PET radiotracers are available to visualize a large variety of cancerous and noncancerous processes.

## **SPECT Imaging**

Single-photon emission computed tomography (SPECT) is a very significant and common imaging procedure that also involves the injection of a radiotracer into the patient's bloodstream, where it accumulates in a target organ or attaches to specific cells. A gamma camera then rotates around the patient, collecting data to create three-dimensional images of radiotracer distribution that reveal information on blood flow and organ function. Many SPECT studies are combined with CT studies.

## **Uses of PET and SPECT**

PET is a powerful tool for diagnosing cancer and determining the severity and extent of cancer. PET scans are one of the most effective means of detecting a recurrence of the disease.

PET scans are also increasingly being used to quickly assess how a patient responds to cancer treatment. In some cases, PET can determine within several days whether a therapy is working rather than waiting months to evaluate a change in the size of the tumor with CT.

Researchers hope that information from PET studies will soon help physicians predict which patients will respond to a specific chemotherapy drug. New radiotracers are also being designed to identify biological conditions within the body (called biomarkers) that signal the presence of cancer and to capture important information on tumors that will guide physicians in selecting the most effective treatment plan.

PET and SPECT studies are regularly used to detect blockages in the coronary arteries, assess muscle damage following a heart attack, and determine whether the heart is pumping blood adequately—especially when stressed. New radiotracers offer the potential to identify individuals at risk for sudden cardiac death and the signs of congestive heart failure.

Both PET and SPECT are highly useful in detecting dementia, evaluating ongoing cognitive decline, and identifying the area of the brain involved in seizure disorders. Researchers using new PET radiotracers recently scored a major breakthrough when they identified the early changes in the brain associated with Alzheimer's disease.

PET scans with amyloid imaging agents (such as the FDA approved agents Amyvid®, Vizamy® and Neuraceq®) reveal the extent and location of amyloid plaque in the brain, which may, in conjunction with a clinical evaluation and other diagnostic tests, help in diagnosing Alzheimer's disease.

SPECT is also helpful in identifying the location and cause of a stroke, as well as areas of the brain that are at risk following a stroke. A newly approved radiotracer for SPECT (called DaTscan®) is expected to help evaluate the cause of tremors and to differentiate between essential tremor and Parkinsonian syndromes.

Researchers using PET and SPECT are gaining new insights into the biology of psychiatric disease, drug addiction, and neurological disorders. Understanding how brain circuitry is altered in people with brain disorders is critical to the development of new treatments and prevention strategies.

Today, optical imaging and targeted molecular ultrasound are primarily used in research labs. However, several optical technologies are undergoing initial clinical testing—and new procedures may be available to patients in the near future.

## Optical Imaging

The field of optical imaging includes numerous technologies that use light to measure cell function and characteristics. Scientists engineer tiny molecules, such as proteins that naturally emit light, to attach to specific cells or chemicals inside the body. Highly sensitive optical detectors are able to track the movement and activity of these imaging agents and to measure how tissue absorbs light.

An essential tool for basic research, optical imaging has the potential to help patients in the future by:

- Detecting lymphoma and ovarian, skin, and breast cancer
- Monitoring patient response to therapy
- Delivering medication directly to cancer cells
- Guiding surgery

## Targeted Molecular Ultrasound

Traditional ultrasound imaging, which uses high-frequency sound waves to produce pictures of the inside of the body, is a standard imaging procedure with many applications. In targeted molecular ultrasound imaging, microbubbles—extremely small, hollow structures—or other microscopic particles (called nanoparticles) serve as an imaging agent.

Scientists can chemically modify microbubbles to target specific tissue within the body, where they produce signals that reveal molecular information.

Targeted molecular ultrasound may be useful for:

- Diagnosing breast, ovarian, head and neck, and other cancers
- Measuring blood flow within the heart and other organs
- Identifying coronary artery disease and other blood vessel abnormalities

By encapsulating medication within microbubbles, targeted molecular ultrasound technology also has potential as a means of targeted drug delivery.

## Magnetic Resonance Spectroscopy

Magnetic resonance (MR) spectroscopy is a variation of conventional MR imaging that provides information on the concentration of chemical compounds—called metabolites—inside the body. MR spectroscopy aids in the diagnosis and treatment of cancer and metabolic disorders—especially those affecting the brain. Researchers also hope MR spectroscopy will prove helpful in detecting recurring cancer, as a guide for radiation therapy, and in distinguishing malignant from healthy tissue in the breast and prostate.

## Therapy

The cell-targeting ability of nuclear and molecular imaging agents offers an excellent means of delivering treatment. In fact, one of the earliest applications of nuclear medicine—[radioactive iodine \(I-131\) ablation](#)—has been a highly successful treatment for [thyroid](#) and [hyperthyroidism](#) for more than half a century. In I-131 targeted radiopharmaceutical therapy (RPT), radioactive iodine is introduced into the body and absorbed by the thyroid cells or thyroid cancer cells, where it kills them.

RPT is now being used to treat other forms of cancer and to provide pain relief to some bone cancer patients. Strontium-89 is available for bone pain relief from metastatic disease. Compounds such as Radium-223 dichloride and now Lutetium-177 PSMA have proved effective treatments for advanced prostate cancer that have not responded to other treatments. Lutetium-177 DOTATATE is an effective treatment for many neuroendocrine tumors, and Iodine-131 mIBG has been used successfully in a sub-class of malignancies in paragangliomas, pheochromocytomas, and neuroblastomas.

Other forms include Yttrium-90 microspheres in liver-directed therapies for tumors in the liver. In some benign arthritic conditions, radiosynovectomy is also used effectively. Moreover, there are several products in development that not only improve on the profile of the existing therapies, but will also treat other diseases, from breast to lung cancers, and many more.

Researchers also are looking for ways to combine RPTs with other more traditional drugs to make those treatments more effective, so that RPTs will become a routine part of many advanced treatments.

## Are Nuclear Medicine and Molecular Imaging safe?

Nuclear medicine diagnostic procedures use small amounts of radioactive material, sometimes about the same amount of radiation a person receives in a year of normal living. As a result, the radiation risk involved in such procedures is very low compared to the potential benefits.

Nuclear medicine specialists use the ALARA principle (As Low As Reasonably Achievable) to carefully select the amount of radiotracer that will provide an accurate test with the least amount of radiation exposure to the patient. The actual dosage is determined by the patient's body weight, the reason for the study, and the body part being imaged. In addition, newer imaging technologies are constantly emerging to reduce radiation exposure to patients while maintaining the diagnostic accuracy of the test.

Nuclear medicine procedures have been performed for more than 50 years on adults and for more than 40 years on infants and children of all ages without any known adverse effects.

## **Are Nuclear Medicine and Molecular Imaging procedures covered by insurance?**

Medicare and private insurance companies cover the cost of many nuclear medicine and molecular imaging procedures. You should check with your insurance company for specific information on your plan.

## **What is the future of Nuclear and Molecular Imaging?**

Every day, nuclear and molecular imaging procedures make a difference in the lives of patients by contributing to the detection, diagnosis, treatment, and monitoring of disease. With the development of new technologies and imaging agents, many of which are now in clinical trials, nuclear medicine and molecular imaging promise to continue to deliver improvements to patient care. Information on clinical trials can be found at [www.clinicaltrials.gov](http://www.clinicaltrials.gov) and [www.discovermi.org](http://www.discovermi.org)

## **Hybrid Imaging**

The combination of two imaging techniques—called co-registration, fusion imaging, or hybrid imaging—allows information from two different types of scans to be viewed in a single set of images. PET/CT and SPECT/CT, a combination of PET or SPECT and CT, have become standard diagnostic tools because they provide detail on both the anatomy and the function of organs and tissues.

New forms of hybrid imaging are in use or in development, including PET/MR, PET/ultrasound, and various optical technologies fused with conventional imaging techniques.

## **New Molecular Imaging Agents and Nanoparticles**

In addition to new imaging agents designed to detect specific cancer processes, researchers are working on other agents, including one capable of identifying high-risk plaque in the arteries of the heart—as well as laser-activated nanoparticles that will seek and destroy the fatty build-up.

## **Biomarkers**

Researchers are working on using molecular imaging biomarkers—specific biochemical conditions in the body that can be revealed on images—that will help physicians tailor the treatment plan to individuals and their disease and quickly assess the effectiveness of the therapy. In the future, scientists hope these biomarkers will also help detect disease and identify at risk patients. Elevated glucose metabolism—a possible warning sign of a tumor or other abnormal cellular function—is an example of a molecular imaging biomarker currently used by physicians.

## **Personalized Treatment**

Nuclear medicine and molecular imaging are on the forefront of the trend toward personalized treatment of cancer and heart disease. In personalized care, treatment is individualized on the basis

of specific biochemical markers found in the patient and characteristics of his or her disease. The goal is to identify patients for particular therapies and optimize patient response to treatment while minimizing side effects.

### **About SNMMI**

The Society of Nuclear Medicine (SNMMI) is an international scientific and medical organization dedicated to raising public awareness about nuclear and molecular imaging and therapy and how they can help provide patients with the best health care possible. With more than 18,000 members, SNMMI has been a leader in unifying, advancing and optimizing nuclear medicine and molecular imaging since 1954.

The material presented in this pamphlet is for informational purposes only and is not intended as a substitute for discussions between you and your physician. Be sure to consult with your physician or the nuclear medicine department where the treatment will be performed if you want more information about this or other nuclear medicine procedures.