What Is Molecular Imaging?

Molecular imaging is a type of medical imaging that provides detailed pictures of what is happening inside the body at the molecular and cellular level. Where other diagnostic imaging procedures—such as x-rays, computed tomography (CT) and ultrasound—predominantly offer anatomical pictures, molecular imaging allows physicians to see how the body is functioning and to measure its chemical and biological processes.

Molecular imaging offers unique insights into the human body that enable physicians to personalize patient care. In terms of diagnosis, molecular imaging is able to:

• provide information that is unattainable with other imaging technologies or that would require more invasive procedures such as biopsy or surgery
• identify disease in its earliest stages and determine the exact location of a tumor, often before symptoms occur or abnormalities can be detected with other diagnostic tests

As a tool for evaluating and managing the care of patients, molecular imaging studies help physicians:

• determine the extent or severity of the disease, including whether it has spread elsewhere in the body
• select the most effective therapy based on the unique biological characteristics of the patient and the molecular properties of a tumor or other disease
• determine a patient’s response to specific drugs
• accurately assess the effectiveness of a treatment regimen
• adapt treatment plans quickly in response to changes in cellular activity
• assess disease progression
• identify recurrence of disease and help manage ongoing care

Molecular imaging procedures, which are noninvasive, safe and painless, are used to diagnose and manage the treatment of:

• cancer
• heart disease
• brain disorders, such as Alzheimer’s disease
• gastrointestinal disorders
• lung disorders
• bone disorders
• kidney and thyroid disorders

How does molecular imaging work?

When disease occurs, the biochemical activity of cells begins to change. For example, cancer cells multiply at a much faster rate and are more active than normal cells. Brain cells affected by dementia consume less energy than normal brain cells. Heart cells deprived of adequate blood flow begin to die.

As disease progresses, this abnormal cellular activity begins to affect body tissue and structures, causing anatomical changes that may be seen on CT or magnetic resonance (MR) scans. For example, cancer cells may form a mass or tumor. With the loss of brain cells, overall brain volume may decrease or affected parts of the brain may appear different in density than the normal areas. Similarly, the heart muscle cells that are affected stop contracting and the overall heart function deteriorates.

Molecular imaging excels at detecting the cellular changes that occur early in the course of disease, often well before structural changes can be seen on CT and MR images.

Most molecular imaging procedures involve an imaging device and an imaging agent, or probe. A variety of imaging agents are used to visualize cellular activity, such as the chemical processes involved in metabolism, oxygen use or blood flow. In nuclear medicine, which is a branch of molecular imaging, the imaging agent is a radiotracer, a compound that includes a radioactive atom, or isotope. Other molecular imaging modalities, such as optical imaging and molecular ultrasound, use a variety of different agents. Magnetic resonance spectroscopy is able to measure chemical levels in the body, without the use of an imaging agent.

Once the imaging agent is introduced into the body, it accumulates in a target organ or attaches to specific cells. The imaging device detects the imaging agent and creates pictures that show how it is distributed in the body. This distribution pattern helps physicians discern how well organs and tissues are functioning.

How is molecular imaging performed?

Molecular imaging procedures are often performed on an outpatient basis.

If an imaging agent is needed, it is injected, swallowed or inhaled. Imaging is performed, depending on the procedure, immediately or hours or even days afterward, depending on the type of procedure. Images created by the device and a computer are reviewed and interpreted by a qualified imaging professional, such as a nuclear medicine physician or radiologist, who shares the results with the patient’s physician.

What molecular imaging technologies are used today?

Gamma camera
A gamma camera is a specialized camera that is capable of detecting a radiotracer. The gamma camera creates two-dimensional pictures of the inside of the body from different angles.

Single photon emission computed tomography (SPECT)
A SPECT scan uses a gamma camera that rotates around the patient to detect a radiotracer in the body. Working with a computer, SPECT creates three-dimensional images of the area being studied. SPECT may also be combined with CT for greater accuracy.
Positron emission tomography (PET)
PET involves the use of an imaging device (PET scanner) and a radiotracer that is injected into the patient's bloodstream. A frequently used PET radiotracer is 18F-fluorodeoxyglucose (FDG), a compound derived from a simple sugar and a small amount of radioactive fluorine.

Once the FDG radiotracer accumulates in the body's tissues and organs, its natural decay includes emission of tiny particles called positrons that react with electrons in the body. This reaction, known as annihilation, produces energy in the form of a pair of photons. The PET scanner, which is able to detect these photons, creates three-dimensional images that show how the FDG is distributed in the area of the body being studied.

Areas where a large amount of FDG accumulates, called ‘hot spots’ because they appear more intense than surrounding tissue, indicate that a high level of chemical activity or metabolism is occurring there. Areas of low metabolic activity appear less intense and are sometimes referred to as ‘cold spots.’ Using these images and the information they provide, physicians are able to evaluate how well organs and tissues are working and to detect abnormalities.

PET-CT is a combination of PET and CT that produces highly detailed views of the body. 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. CT imaging uses advanced x-ray equipment and in some cases a contrast-enhancing material to produce three-dimensional images.

A combined PET-CT study is able to provide detail on both the anatomy and function of organs and tissues. This is accomplished by superimposing the precise location of abnormal metabolic activity (from PET) against the detailed anatomic image (from CT).

Magnetic resonance spectroscopy
MR imaging uses a magnetic field, radio waves and a computer to create detailed images of the body. MR spectroscopy uses MR to measure metabolites, which are substances produced by chemical reactions in the brain and other areas of the body. MR spectroscopy provides information on the location of specific chemicals in the body and on biochemical activity within cells.

Optical imaging
In optical imaging, light-producing proteins are designed to attach to specific molecules—such as brain chemicals or molecules on the surface of cancer cells. Highly sensitive detectors are able to detect low levels of light emitted by these molecules from inside the body. The two major types of optical imaging are:

• bioluminescent imaging, which uses a natural light-emitting protein (luciferase, for example, the substance that produces the glow of fireflies) to trace the movement of certain cells or to identify the location of specific chemical reactions within the body.

• fluorescence imaging, which uses proteins that produce light when activated by an external light source such as a laser.

Molecular ultrasound imaging
Traditional ultrasound imaging uses high-frequency sound waves to produce pictures of the inside of the body. As sound waves directed through the body bounce back when they encounter different tissues, echoes are measured with the help of a computer and are converted into real-time images of organs and tissues. Molecular ultrasound uses targeted microbubbles, extremely small, hollow structures that serve as a contrast agent during an ultrasound exam.

How safe is molecular imaging?
Molecular imaging procedures are noninvasive and very safe.

When used, the amount of radioactivity used in nuclear medicine procedures is very small. The radiation risk is very low compared with the potential benefits. There are no known long-term side effects from nuclear medicine procedures, which have been performed for more than 50 years. Allergic reactions may occur but are extremely rare and usually mild.

Imaging agents are approved by the U.S. Food and Drug Administration.

Is molecular imaging covered by insurance?
Medicare and private insurance companies cover the cost of many molecular imaging technologies. Check with your insurance company for specific information on your plan.

What is the future of molecular imaging?
In addition to increasing our understanding of the underlying causes of disease, molecular imaging is improving the way disease is detected and treated. Molecular imaging technologies are also playing an important role in the development of:

• screening tools, by providing a non-invasive and highly accurate way to assess at-risk populations
• new and more effective drugs, by helping researchers quickly understand and assess new drug therapies
• personalized medicine, in which medical treatment is based on a patient's unique genetic profile

In the future, molecular imaging will include an increased use of:

• fusion or hybrid imaging, in which two imaging technologies are combined to produce one image
• optical imaging
• new probes for imaging critical cancer processes
• reporter-probe pairs that will facilitate molecular-genetic imaging