Medical imaging helps doctors see injuries and disease directly, so they don’t have to rely on external exams or exploratory surgeries. Several tomography techniques have spread widely. In each case, a patient lies on a bed inside a doughnut-shaped machine. Hardware takes images of numerous two-dimensional slices of the person’s body, and a computer assembles them into a three-dimensional picture.

Computed tomography (CT), which creates images with x-rays, is good at showing sharp contrasts in bone and tissue density, indicating broken bones, blood clots and kidney stones. Early machines of the 1970s required five minutes to render a slice 10 millimeters across; today resolution is one millimeter, and a slice takes only one second. If machine cost and speed improve only a bit further, CT could also take over most standard x-ray procedures, says C. Carl Jaffe, professor of internal medicine at Yale University.

In positron emission tomography (PET), a patient is injected with a radioactive element that produces photons, which are sensed slice by slice. Because the element binds to molecules such as glucose, the emissions reveal the relative rates at which cells consume these molecules, a marker of cell metabolism. Unusual activity can indicate cancer cells, neurological diseases such as Alzheimer’s, the malignancy of tumors, and brain activity during mental processes.

Magnetic resonance imaging (MRI) detects subtle fluctuations in the magnetic properties of hydrogen nuclei. The resulting image shows varying tissue density, which reveals injuries such as torn cartilage and herniated disks, as well as tumors. A research format called functional MRI detects how rapidly cells are consuming oxygen—an indicator of which neurons in the brain are active during perception or thinking.

As engineering improves, hybrid machines “are taking the market by storm,” Jaffe says. A CT-PET machine can combine images to distinguish, for example, between a cancerous growth and a routine fibrous mass. The next advance will be software algorithms that can assess what is happening in tissue, not just assemble a picture of it. “We will no longer have to rely solely on what we see,” Jaffe says, “but what the raw data actually indicate.” —Mark Fischetti
NAME GAME: Computed tomography (CT) was originally called computed axial tomography (CAT), because the x-ray slices were taken along a single plane. But newer machines can operate on various planes, voiding the cuddly label. Magnetic resonance imaging (MRI) began as nuclear magnetic resonance (NMR), because it senses changes in nuclei. The public took “nuclear” to mean scary radiation, however, and the medical community euphemized the term.

ELECTRIC VIEW: An MRI exam might one day specify which chains of neurons are communicating during mental activity, not just which cells are metabolically active. Michael Joy, professor of biomedical engineering at the University of Toronto, has developed MRI-based “current density imaging,” which he expects will sense depolarization—when neurons open membrane channels that allow signaling ions to flow between cells. Joy is also using MRI to track the path that charge takes through tissue, which could diagram how a defibrillator current shoots through a failed heart and how deep-brain stimulation flows through the brain of a Parkinson’s patient.

ULTRASOUND: A handheld ultrasound unit placed against a patient’s skin sends high-frequency sound waves into the body and measures the echoes, creating a low-resolution but real-time moving image of internal organs or a fetus. Ultrasound is sometimes not defined as tomography, though, because it does not assemble slices.

MRI: Strong magnets produce a uniform field that causes the magnetic moments, or spins, of hydrogen nuclei (protons) to align preferentially along the field axis. Radio-frequency (RF) coils then emit a pulse that causes the protons to precess briefly in phase like spinning tops; as the precessions decay out of phase, they induce varying currents in RF receiver coils. Adding a magnetic field gradient confines the precession phenomenon to a precise slice of the body. The rate of precession decay varies for fats, proteins, water and other hydrogen-rich molecules, resulting in an image of tissue types and densities. Above: A slipped disk in the neck (fourth from top) pressing on the spinal cord.

CT: A tube sends a plane of 140-keV x-rays through the body. Detectors sense the attenuation of rays, which different tissue densities absorb and deflect to a given degree. The tube and detectors rotate in tandem to complete one image slice. The bed advances the patient several centimeters, and the process repeats, over and over. At right: A large blood clot (just below circle at center) in the lung’s pulmonary artery.