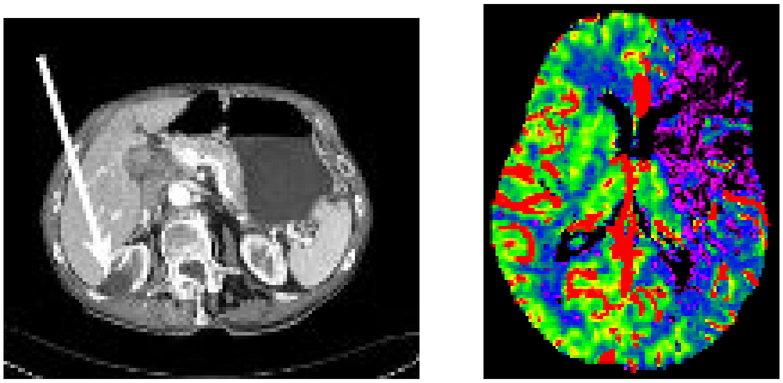
Computed Tomography Imaging

1. Why is CT Performed?



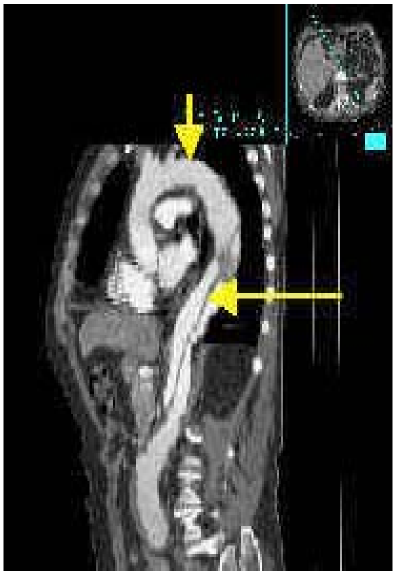
(Left) Axial CT image of the liver and kidneys shows a benign cyst in the right kidney (arrow).
(Right) Colored CT image of the brain, purple area on right of image indicates acute stroke.

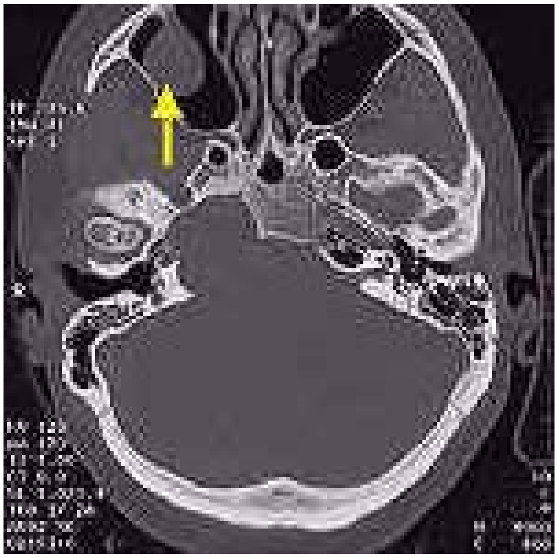
Computed Tomography (CT) imaging, also known as "CAT scanning" (Computed Axial Tomography), combines the use of a digital computer together with a rotating x-ray device to create detailed cross sectional images or "slices" of the different organs and body parts such as the lungs, liver, kidneys, pancreas, pelvis, extremities, brain, spine, and blood vessels. For many patients, CT can be performed on an outpatient basis without requiring admittance to the hospital.

Among the various imaging techniques such as MR and x-ray, CT has the unique ability to image a combination of soft tissue, bone, and blood vessels. For example, conventional x-ray imaging of the head can only show the dense bone structures of the skull. X-ray angiography of the head only depicts the blood vessels of the head and neck and not the soft brain-tissue. Magnetic resonance (MR) imaging does an excellent job of showing soft tissue and blood vessels, but MR does not give as much detail of bony structures such as the skull. CT images of the head allow physicians to see soft-tissue anatomic structures like the brain's ventricles or gray and white matter. Physician then can selectively "window" the digital CT images on the computer monitor to look at the soft tissue, then the bone and then the blood vessels, as needed.

CT is one of the best tools for studying the lungs and abdomen. CT is an invaluable tool in the cancer diagnosis process and is often the preferred method for diagnosing lung, liver and pancreas cancer. CT imaging and CT angiography are finding a greater role in the detection, diagnosis and treatment of heart disease, acute stroke and vascular diseases which can lead to stroke, gangrene or kidney failure. Additionally, CT can be used to measure bone mineral density for the detection of osteoporosis. CT has excellent application in trauma cases and other emergencies. All dedicated shock-trauma centers have a CT scanner in the trauma department so patients can be immediately scanned to scout for major internal injuries such as aortic aneurysm (see image below) or other internal bleeding.

CT is used extensively for diagnosing problems of the inner ears and sinuses because of its ability to generate very high resolution images. The anatomy of the inner ear and sinuses is made up of delicate soft tissue structures and very fine bones. CT is excellent for imaging tumors or polyps in the sinuses and disease that cause degeneration of the small bones in the inner ear.





(Left) Sagittal multiplanar reconstructed CT image of the thorax and abdomen showing an aortic aneurysm. The aorta (short arrow) looks like a white "candy-cane" in the middle of this image. The aneurysm (long arrow) is the thin line running through the candy cane. (Right) High resolution axial CT image of the inner ears and sinuses. A large polyp in the right sinus (arrow) can be seen

CT can provide detailed cross sectional images and diagnostic information for nearly every part of the body including:

the brain, vessels of the brain, eyes, inner ear, sinuses

- the neck, shoulders, cervical spine and blood vessels of the neck
- the chest, heart, aorta, lungs, mediastinum
- the thoracic and lumbar spine
- the upper abdomen, liver, kidney, spleen, pancreas and other abdominal vessels
- the pelvis and hips, male and female reproductive system, bladder, and GI tract
- the skeletal system including bones of the hands, feet, ankles, legs and arms, and jaws

2. How Does CT Work?

Computed Tomography is based on the x-ray principal: as x-rays pass through the body they are absorbed or attenuated (weakened) at differing levels creating a matrix or profile of x-ray beams of different strength. This x-ray profile is registered on film, thus creating an image. In the case of CT, the film is replaced by a banana shaped detector which measures the x-ray profile.

(Left) Outside view of modern CT system showing the patient table and CT scanning patient aperture. (Right) Inside view of modern CT system, the x-ray tube is on the top at the 1 o'clock position and the arc-shaped CT detector is on the bottom at the 7 o'clock position. The frame holding the x-ray tube and detector rotate around the patient as the data is gathered.

A CT scanner looks like a big, square doughnut. The patient aperture (opening) is 60 cm to 70 cm (24" to 28") in diameter. Inside the covers of the CT scanner is a rotating frame which has an x-ray tube mounted on one side and the banana shaped detector mounted on the opposite side. A fan beam of x-ray is created as the rotating frame spins the x-ray tube and detector around the patient (see figure below). Each time the x-ray tube and detector make a 360° rotation, an image or "slice" has been acquired. This "slice" is collimated (focused) to a thickness between 1 mm and 10 mm using lead shutters in front of the x-ray tube and x-ray detector.

As the x-ray tube and detector make this 360° rotation, the detector takes numerous snapshots (called profiles) of the attenuated x-ray beam. Typically, in one 360° lap, about 1,000 profiles are sampled. Each profile is subdivided spatially (divided into partitions) by the detectors and fed into about 700 individual channels. Each profile is then backwards reconstructed (or "back projected") by a dedicated computer into a two-dimensional image of the "slice" that was scanned.

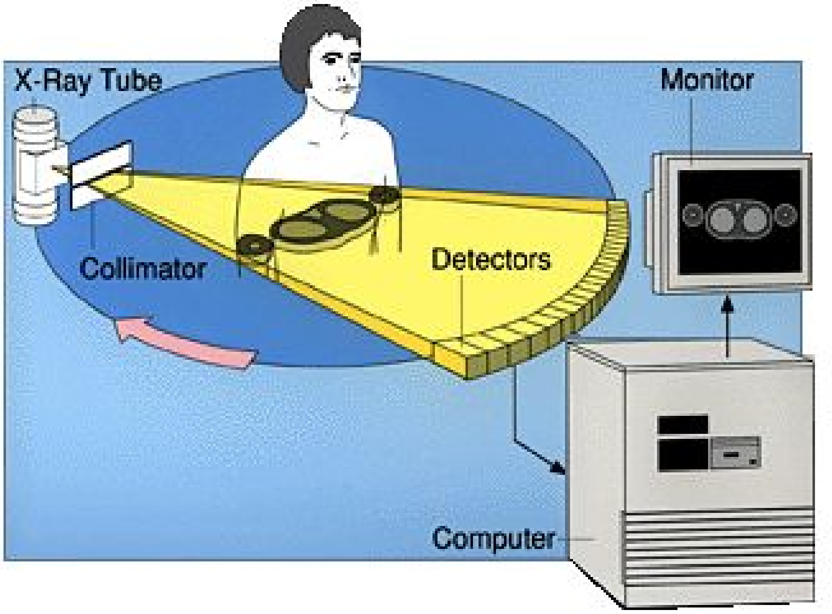


Diagram showing relationship of x-ray tube, patient, detector, and image reconstruction computer and display monitor.

Multiple computers are used to control the entire CT system. The main computer that orchestrates the operation of the entire system is called the "host computer." There is also a dedicated computer that reconstructs the "raw CT data" into an image. A workstation with a mouse, keyboard and other dedicated controls allows the technologist to control and monitor the exam. The CT gantry and table have multiple microprocessors that control the rotation of the gantry, movement of the table (up/down and in/out), tilting of the gantry for angled images, and other functions such as turning the x-ray beam on an off.

3. A Brief History of CT

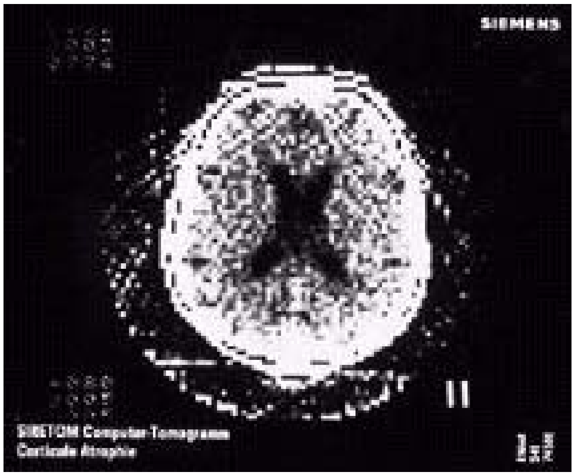
Computed Tomography (CT) imaging is also known as "CAT scanning" (Computed Axial Tomography). Tomography is from the Greek word "tomos" meaning "slice" or "section" and graphia meaning "describing".

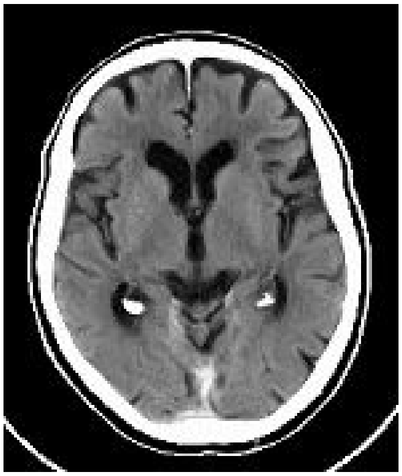
CT was invented in 1972 by British engineer Godfrey Hounsfield of EMI Laboratories, England, and independently by South African born physicist Allan Cormack of Tufts University, Massachusetts. Hounsfield was later awarded the Nobel Peace Prize and honored with Knighthood in England for his contributions to medicine and science.

The first clinical CT scanners were installed between 1974 and 1976. The original systems were dedicated to head imaging only, but "whole body" systems with larger patient openings became available in 1976. CT became widely available by about 1980. There are now about 6,000 CT scanners installed in the U.S. and about 30,000 installed worldwide.

The first CT scanner developed by Hounsfield in his lab at EMI took several hours to acquire the raw data for a single scan or "slice" and took days to reconstruct a single image from this raw data. The latest multi-slice CT systems can collect up to 4 slices of data in about 350 ms and reconstruct a 512 x 512-matrix image from millions of data points in less than a second. An entire chest (forty 8 mm slices) can be scanned in five to ten seconds using the most advanced multi-slice CT system.

During its 25-year history, CT has made great improvements in speed, patient comfort, and resolution. As CT scan times have gotten faster, more anatomy can be scanned in less time. Faster scanning helps to eliminate artifacts from patient motion such as breathing or peristalsis. CT exams are now quicker and more patient friendly than ever before. Tremendous research and development has been made to provide excellent image quality for diagnostic confidence at the lowest possible x-ray dose.





(Left) Original axial CT image from the dedicated Siretom CT scanner circa 1975. This image is a coarse 128 x 128 matrix; however, in 1975 physicians were fascinated by the ability to see the soft tissue structures of the brain, including the black ventricles for the first time (enlarged in this patient) (Courtesy: Siemens)

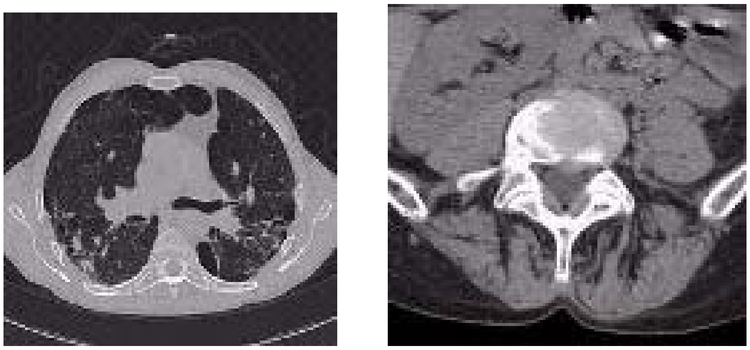
(Right) Axial CT image of a normal brain using a state-of-the-art CT system and a 512 x 512 matrix image. Note the two black "pea-shaped" ventricles in the middle of the brain and the subtle delineation of gray and white matter (Courtesy: Siemens)

4. Applications and Clinical Benefits of CT Imaging

Unlike other medical imaging techniques, such as conventional x-ray imaging (radiography), CT enables direct imaging and differentiation of soft tissue structures, such as liver, lung tissue, and fat. CT is especially useful in searching for large space occupying lesions, tumors and metastasis and can not only reveal their presence, but also the size, spatial location and extent of a tumor.

CT imaging of the head and brain can detect tumors, show blood clots and blood vessel defects, show enlarged ventricles (caused by a build up of cerebrospinal fluid) and image other abnormalities such as those of the nerves or muscles of the eye.

Due to the short scan times of 500 milliseconds to a few seconds, CT can be used for all anatomic regions, including those susceptible to patient motion and breathing. For example, in the thorax CT can be used for visualization of nodular structures, infiltrations of fluid, fibrosis (for example from asbestos fibers), and effusions (filling of an air space with fluid).



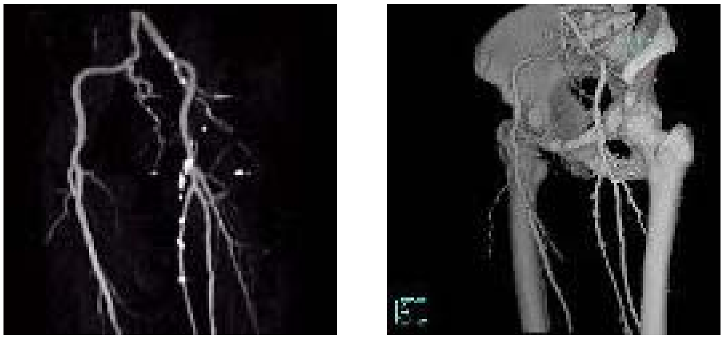
(Left) High resolution axial CT image of the chest showing the vessels of the heart (center of image) and pneumonia in both lungs. (Right) Axial CT image of the lumbar spine showing a slight prolapse of the disk impinging on the spinal cord.

CT has been the basis for interventional work like CT guided biopsy and minimally invasive therapy. CT images are also used as basis for planning radiotherapy cancer treatment. CT is also often used to follow the course of cancer treatment to determine how the tumor is responding to treatment.

CT imaging provides both good soft tissue resolution (contrast) as well as high spatial resolution. This enables the use of CT in orthopedic medicine and imaging of bony structures including prolapses (protrusion) of vertebral discs, imaging of complex joints like the shoulder or hip as a functional unit and fractures, especially those affecting the spine. The image postprocessing capabilities of CT – like multiplanar reconstructions and 3-dimensional display (3D) - further enhance the value of CT imaging for surgeons. For instance, 3-D CT is an invaluable tool for surgical reconstruction following facial trauma.

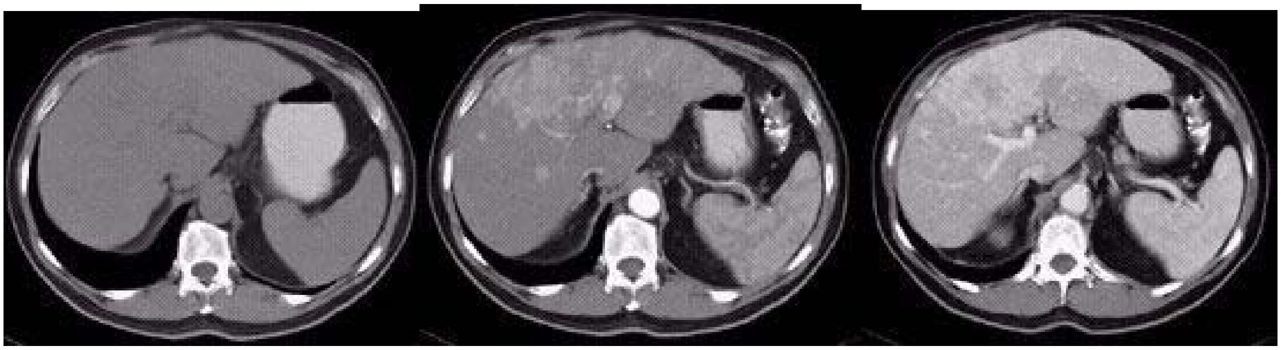
CT is becoming the method of choice for imaging trauma patients. CT exams are fast and simple and enable a quick overview of possibly life-threatening pathology and rapidly enables a dedicated surgical treatment.

With the advent of spiral CT, the continuous acquisition of complete CT volumes can be used for the diagnosis of blood vessels with CT Angiography. For instance, abdominal aortic aneurysms, the renal arteries, the carotids vessels and the Circle of Willis can all now be quickly imaged with CT with minimal intervention.



(Left) CT angiography image of the femoral arteries showing multiple calcifications (bright white lumps) on the femoral branch on the right (Right) 3D Surface reconstruction of the same femoral arteries showing their position relative to the pelvis and the femurs

Due to the short total acquisition time of spiral CT, imaging of the liver is now possible in different contrast enhancement phases. These so-called "multi-phase" studies offer a step towards differential diagnosis of lesions in the liver. In other words, doctors can use differential diagnosis to determine "what kind of abnormality is this?" For example, the three-phase liver study below shows tumor enhancement on the arterial-phase and venous-phase images that is useful in diagnosing the disease.



(Left) CT image of the liver and abdomen with no contrast enhancement. (Center) CT image of the liver and abdomen with arterial phase contrast enhancement. (Right) CT image of the liver and abdomen with venous phase contrast enhancement

5. Advances in CT

Spiral CT and Helical CT

This photo simulates the path that the x-ray beam makes as spiral CT data acquisition of the abdomen is being made. The highlighted area is a man's stomach (man is lying on his back with his arms over his head).

In all original CT scanners (1974 to 1987), the x-ray power was transferred to the x-ray tube using high voltage cables wrapped around an elaborate set of rotating drums and pulleys. The rotating frame (or gantry) would spin 360° in one direction and make an image (or a slice), and then spin 360° back in the other direction to make a second slice. In between each slice, the gantry would come to a complete stop and then reverse directions while the patient table would be moved forward by an increment equal to the slice thickness.

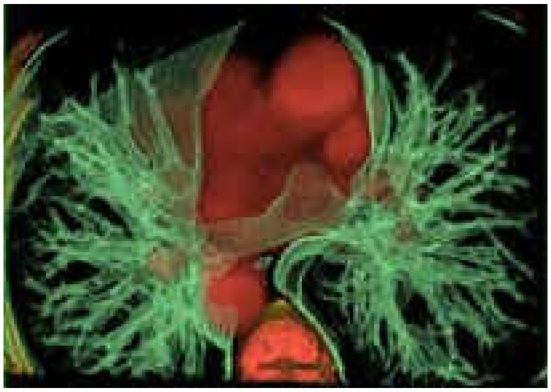
In the mid 1980's, an innovation called the power slip ring was developed so that the elaborate x-ray cable and drum system could be abandoned. The slip ring allows electric power to be transferred from a stationary power source onto the continuously rotating gantry. State of the art CT scanners with slip rings can now rotate continuously and do not have to slow down to start and stop. The innovation of the power slip ring has created a renaissance in CT called spiral or helical scanning.

These spiral CT scanners can now image entire anatomic regions like the lungs in a quick 20 to 30 second breath hold. Instead of acquiring a stack of individual slices which may be misaligned due to slight patient motion or breathing (and lung/abdomen motion) in between each slice acquisition, spiral CT acquires a volume of data with the patient anatomy all in one position. This volume data set can then be computer-reconstructed to provide three-dimensional pictures of complex blood vessels like the renal arteries or aorta. 3D CT images from volume data allow surgeons to visualize complex fractures, for example of facial trauma, in three dimensions and can help them plan reconstructive surgery.

MR, ultrasound and digital x-ray fluoroscopy have all made significant improvements in their ability to image the chest, lungs and abdomen. However, spiral CT has kept computed tomography as the primary digital technique for imaging the chest, lungs, abdomen and bones due to its ability to combine fast data acquisition and high resolution in the same study. CT is also unique in that it can provide detailed information of nearly every organ in the upper abdomen and pelvis in one quick examination.

6. Advanced 3D CT Images and "Virtual Reality" Images

Spiral CT allows the acquisition of CT data that is perfectly suited to three-dimensional reconstruction. A wide range of software techniques and advanced computer systems are being developed that enable creation of amazing 3D "virtual reality" images.



Virtual reality 3-D image of the lungs. The bronchial trees are colored in green and the heart, aorta and vertebrae are colored in red

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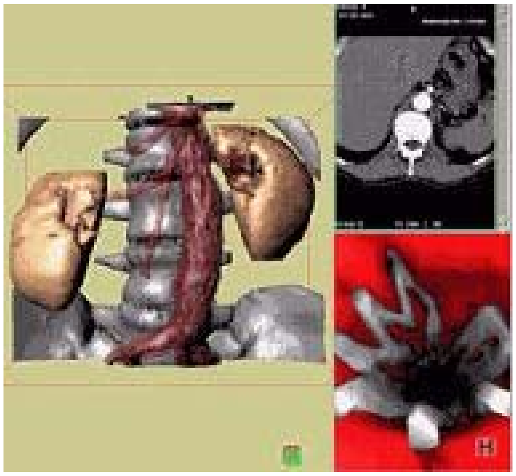
In addition to creating fantastic images of internal anatomy, these new 3D reconstruction techniques enable a number non-invasive "virtual endoscopy" procedures to be performed.

Endoscopy involves the use of an endoscope to see inside organs of the body such as the colon or bronchi. Virtual endoscopy allows physicians to see the inside of these same structures, without the use of an invasive endoscope. Some virtual endoscopy procedures can be performed with CT that could not be acquired with conventional endoscopy, such as the image below of a wire stent (wire support) inside the abdominal aorta.



This collage shows an abdominal aortic stent (metal wire support): outer view (left), inner view (lower right) and original axial CT image (upper right)

New "Multi-slice" Spiral CT Scanners

New "multi-slice" spiral CT scanners are now being developed that can collect up to four slices of data during spiral CT mode and some rotate at speeds up to 120 rpm (rotations per minute). These systems can collect up to eight times as much data versus previous state-of-the-art spiral CT systems that rotate at 60 rpm and only collect one slice of data at a time. Multi-slice CT scanning will allow non-invasive imaging and diagnosis of wider range of conditions in less time and with greater patient comfort.

The combination of multi-slice CT and new 3D reconstruction promises to allow physicians to see even more than ever before. Multi-slice CT systems are at "the cutting edge" in terms of speed, patient comfort, and resolution. CT exams are now quicker and more patient friendly than ever before. As CT scan times have gotten faster, more anatomy can be scanned in less time. Faster scanning helps to eliminate artifacts from patient motion such as breathing or peristalsis.

The latest multi-slice CT systems can collect up to 4 slices of data in 250 ms to 350 ms and reconstruct a 512 x 512-matrix image from millions of data points in less than a second. An entire chest (forty 8 mm slices) can be scanned in five to ten seconds using the most advanced multi-slice CT system. An CT angiography images of the "peripheral runs-off" (leg vessels from the pelvis to the toes) are now being acquired for the first time with multi-slice CT. Finally, multi-slice CT with very short scan times is opening the door for CT to become more important in the management of heart disease and stroke.