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BACKGROUND

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PRINCIPLES OF CT SCANNING

CT scanning builds on the principles of conventional X-ray films: structures are differentiated by their ability to absorb energy from X-rays. The denser* a structure is, the more energy it will absorb. Thus, less energy will reach the film or other receptor, and the image of that structure will be lighter. Bone or metal, which are dense, appear white on the X-ray film; air or gas, which are much less dense, appear black. Structures with intermediate densities appear as shades of gray.

CT scanners use these principles in a new way **(184,236,237,245,331,408).** Each CT scanner has four basic elements (figure 3):

- A source, or X-ray tube, which emits a beam of X-rays.
- A detector, which collects energy from the X-ray beam after it has passed through the body. It then determines how much energy is still present in the beam.
- A computer, which collects, stores, and processes information from the detector.
- An imaging device (a cathode-ray tube**), which has a television-like screen on which the reconstruction produced by the computer can be displayed.

Except in the more recent models of CT scanners, the source and detector are mounted on a gantry (frame) as a single unit, attached to a table for the patient. When activated, the gantry moves around the patient's head or body in many small steps. At each position, the source emits a beam of X-rays which passes through the patient and is collected by the detector. The energy reading at each position and the beam's geometrical coordinates are stored by the computer. Depending on the model, *30,000* to *300,000* readings per scan are taken and stored. Each reading indicates how much energy was lost by the beam of the X-rays through the body. The computer then uses the complete set of readings to determine the density of the material or tissue through which X-rays passed (195,196). An image of a thin cross section (or slice) through the body is then displayed on the screen of the cathode-ray tube. Sample images are shown in figures 4 and 5:

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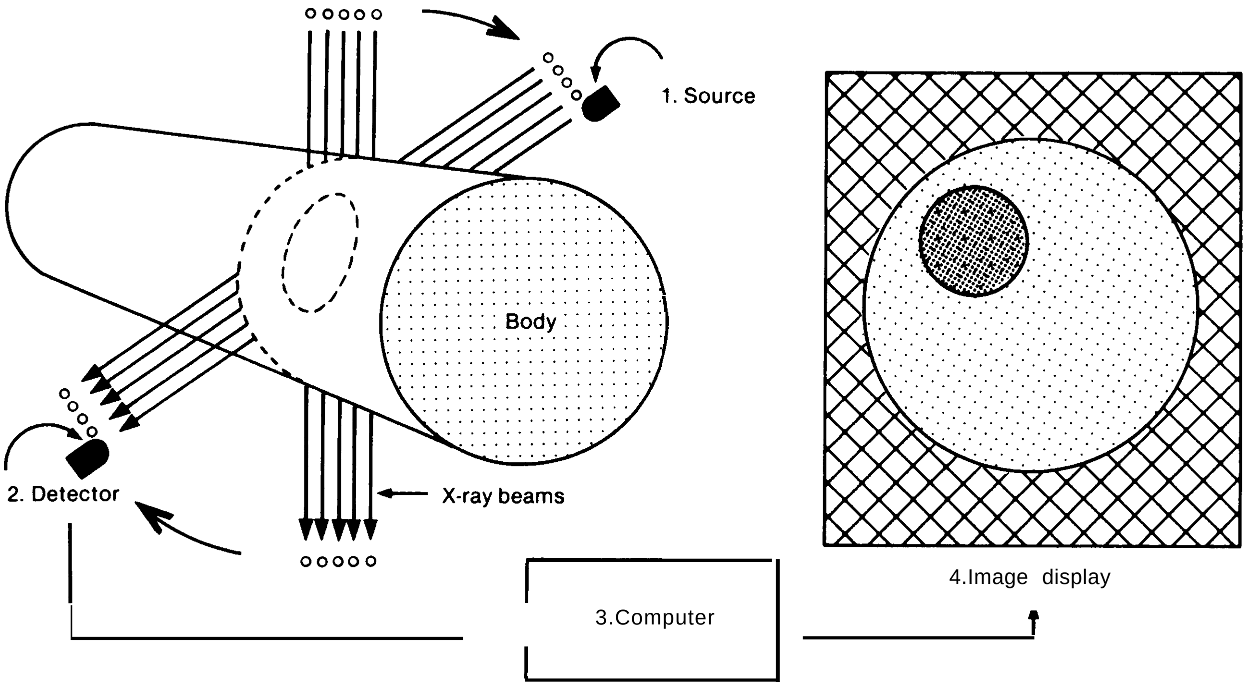
* Technically, radiation absorption is a complex function associated with the energy spectrum and the atomic number as well as density.

** The picture tube of a television set is a cathode-ray tube.

Figure 3.—Schematic Illustration of CT Scanner



The source and detector are mounted on a single frame and move around the body together in a large number of small steps. X-rays emitted by the source pass through the body and are collected by the detector. Information from the detector is fed into a computer, which reconstructs and displays an image of a cross section of the body.

Source. Off Ice of Technology Assessment

CT scanning overcomes two shortcomings of conventional X-rays. First, in conventional X-rays, various organs overlap on the film and obscure each other. By rotating the beam and producing cross-sectional images, the CT scanner eliminates this problem. Second, conventional X-rays do not always differentiate between adjacent structures of similar density. A radiologist may be unable to distinguish among the shades of gray on the film. By using many exposures from different angles to produce one image, CT scanning can make slight differences in density apparent (441). CT scanning resolves (distinguishes) densities that are one-tenth as great as can be seen with conventional methods. These two advantages make CT scanning especially useful for visualizing soft, low-density tissues as in the brain. The brain's tissue is not "washed out" by the overlapping image of the skull, and subtle differences of density within the brain can be detected.

OPERATION OF THE CT SCANNER

A typical CT installation fills two rooms (figure **6).** The scanning unit, consisting of the gantry, source, detector, and patient table, is in one room. The computer, display equipment, and control unit are in the other. During a CT examination, the patient is positioned on the table, and the scanner is activated. The patient must

Figure 4.–Normal Brain Cross Section (left), CT Scan (right)

1 = Falx cerebri
2 = Cornu anterius ventriculi lateral is (tip)
3 = N. caudatus, caput
4 = Putamen
5 = Insula and lateral cistern
6 = Ventriculus tertius
7 = Corpus mamillare and fossa interpeduncularis
8 = Hippocampus and cornu inferius
9 = Aquaeductus cerebri and quadrigeminal cistern
10= Tentorium cerebelli (cut)
11 = Vermis superior cerebelli
12= Eminentia cruciata

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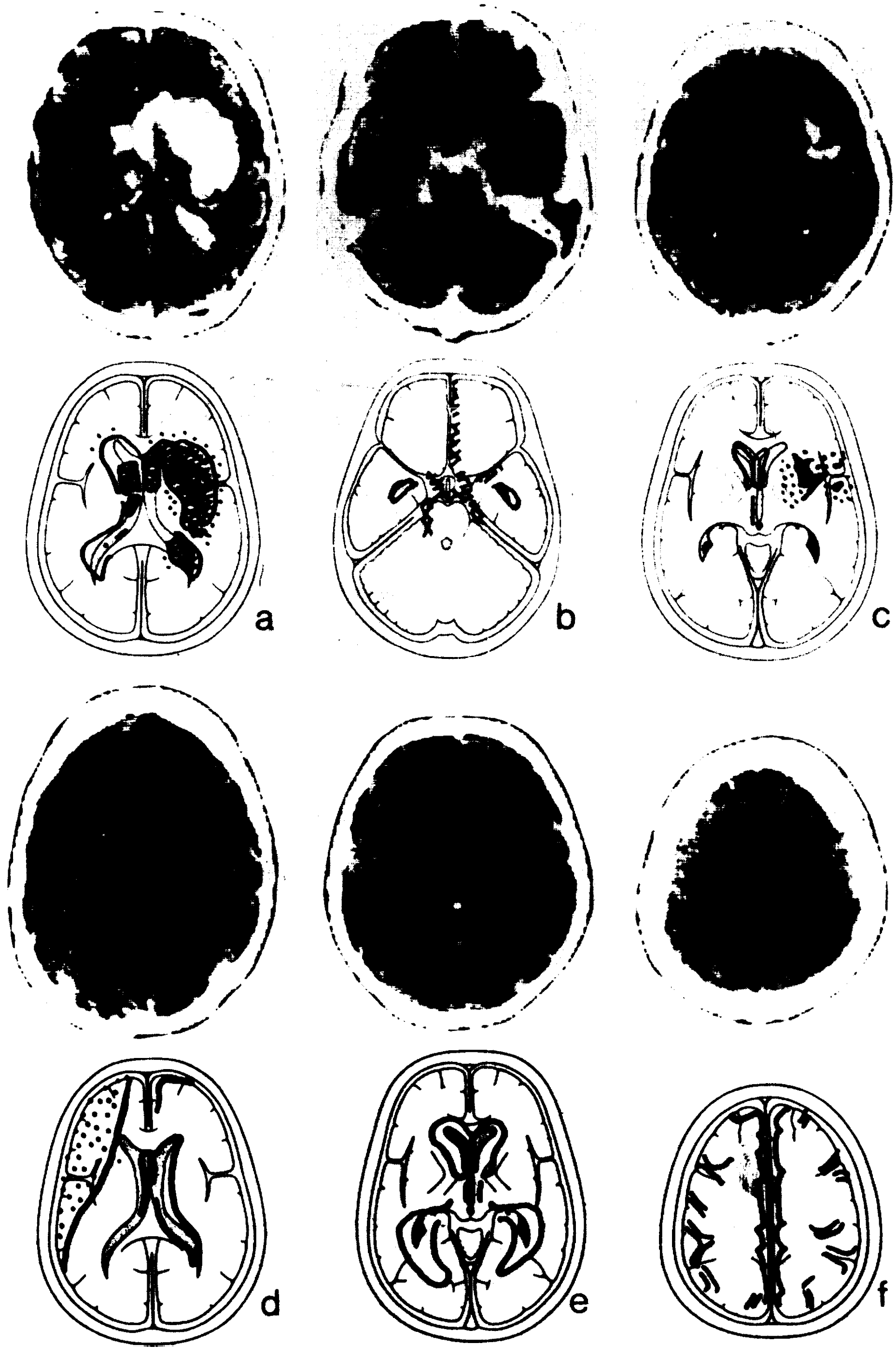
remain still while the gantry is moving. Motion is not a problem for most patients, but sedation, anesthesia (3), or immobilization devices **(387)** are sometimes required for children, patients in severe pain, or agitated patients. In early machines, each scan took about 5 minutes, but the newest models take only 5 seconds (see below). After the gantry has completed its rotation around the head or body, the computer may require up to *2½* additional minutes to process the information and to display the image. It appears on the screen of the cathode ray tube for immediate inspection, and it can be photographed for later examination. The computer can also make permanent records on tape, paper, or magnetic discs.

Because each CT cross section is quite narrow (usually about) centimeter) the procedure is often repeated at several places to cover the area of interest. A complete

Figure 5.—Examples of Graphically Reported CT Findings



(a) Basal Ganglia Hematoma With Ventricular Perforation. (b) Subarachnoid Hemorrhage. (c) Olgodendroglioma. (d) Chronic Subdural Hematoma. (e) Occlusive Hydrocephalus. (f) Cortical Atrophy.

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Figure 6.—Typical Computed Tomography Installation Involving Divided Rooms

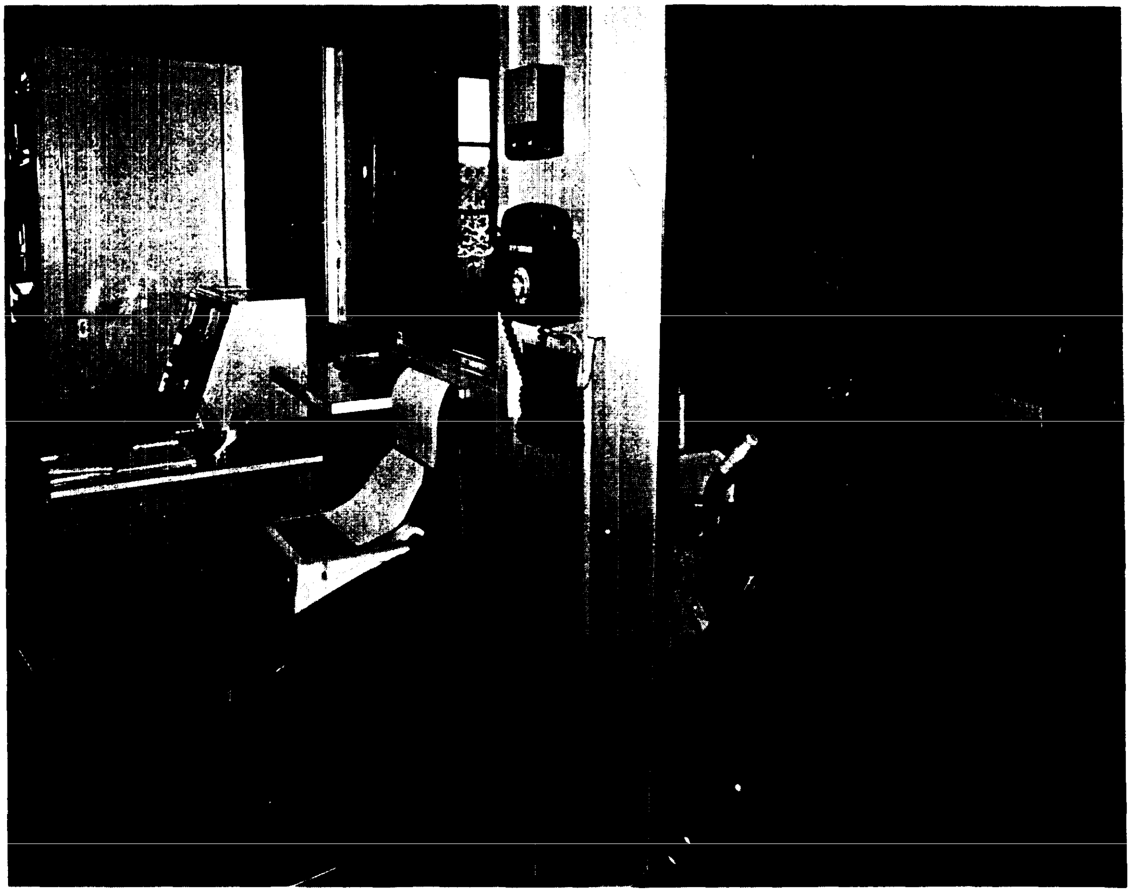

Photo: Courtesy of Clinical Center, National Institutes of Health

CT study usually includes images of at least six to eight sections. Most head scanners produce images of two adjacent sections during each traverse; thus, three or four scans are usually required. Most body scanners produce only a single section per traverse, so more scans may be necessary. In addition, a patient is often scanned, injected with contrast material, and then scanned again to get additional information. Thus, a full CT examination may take at least one-half hour to complete. In many hospitals, a radiologist is present during the examination. In some institutions, however, radiological technicians perform the examination, and a radiologist or other physician interprets the images later **(239).** This approach can be less costly than having a radiologist present; but if the scan is of poor technical quality or if the radiologist decides that additional sections are needed, the patient may need to return for another examination **(14,15,50,125,161,382,383,388,389,397,4 60).**

DEVELOPMENT OF THE CT SCANNER

The first CT scanner was developed in 1967 by Hounsfield, an engineer working at EM I Ltd., in Britain. Earlier, in the United States, Oldendorf (395) and Cormack

(117), had independently constructed tomographic devices that used some of the principles found later in the CT scanner. Both Oldendorf and Cormack realized the diagnostic potential of their devices. Oldendorf, a neurologist, could interest neither physicians nor corporations in developing his ideas **(379,396).** Cormack, a physicist, published his results in a journal of applied physics, but the article apparently went unnoticed by the medical community. Hounsfield, researching pattern recognition devices, developed a theoretical basis for CT scanning in **1967 and** built a device to test his ideas. Using inanimate objects first and diseased brain tissue later, he showed that his machine could produce images of sections difficult to visualize with conventional radiological techniques **(17,37,60).**

The British Department of Health was interested in Hounsfield's work, and in **1970** it supported the construction of a CT unit that could be used to examine patients (60). A prototype was installed at Atkinson Morley's Hospital in London in October 1971. Ambrose, a physician at that hospital, was soon successful in using the EMI scanner to image lesions of the brain, including tumors (22). The EMI scanner was shown publicly at professional meetings in **1972.** In June 1973, the Mayo Clinic installed the first commercial unit in the United States (47).

The early success of the EMI scanner encouraged a number of corporations to develop CT scanners. Ledley, at Georgetown University Medical School, developed a scanner that could image sections of the head and the entire body. Marketed as the ACTA scanner, it was operational by February 1974 **(315,316,317).** Soon thereafter, Ohio-Nuclear and Siemens also began to market scanners (Delta and Siretom scanners, respectively). By the end of 1975, some **20** corporations had developed or were developing CT scanners **(37,79,161,290,402,583).**

During the past 3 years, CT technology has not only extended scanning from the head to the entire body, but also has continually decreased the time required to complete a scan. Because motion by the patient during the scan can destroy the image, decreased scanning time is important. The first scanners—EMI, ACTA, Delta, and Siretom—required about 5 minutes to complete one scan. They used a single source and detector per section and are referred to as first generation CT scanners **(79,290).**

The next generation was equipped with a single source producing either a fan beam or multiple pencil beams and with multiple detectors. Such scanners gathered more information at each position of the gantry's traverse than did first generation scanners. The gantry moved in larger steps, and scanning time was reduced to between 20 seconds and 2 minutes per scan. Third generation scanners, which are now being marketed, reduce scanning time still further. Rather than thin beams of X-rays, they use a fan-shaped beam aimed at a bank of up to several hundred detectors. The gantry rotates, but unlike first and second generation scanners, no lateral motion is required. A scan can be completed in only 5 seconds. Some of the principal features of first, second, and third generation CT scanners are compared in table 1 and figures 7 and **8.**

Increasing the speed of CT scanning is desirable to minimize problems associated with patient motion and to permit imaging of motile organs such as the heart. But scanning speed must be balanced against the other variables of radiation dose and image quality (resolution). An ideal CT scanner would be one that produced high quality images using small amounts of radiation (thus causing little risk to the patient) in a short time period. A limiting factor in decreasing scanning time has been movement of the source and detector on the gantry, a mechanical motion requiring

Table I—Characteristics of CT Scanners

GENERATION [a]	I	II	III
Time to Produce One Section	4-6 min.	20 sec. -2 min.	under 20 sec.
X-ray Source	single pencil beam	2 or more pencil beams or single fan beam	single fan beam
Detectors	1	2 or more (up to 60)	hundreds - contiguous
Motion of Gantry	Source and detector move together in small lateral and small rotational steps	Sources and detectors move together in larger lateral and rotational steps than Generation 1	Rotational motion only. In most models, source and detectors move together, but in some, only source moves
Operational [b] Commercial Models	EM I Brain Scanner (H)[c] Pfizer ACTA 0100 (B)[c] Siemens Siretom (H) General Electric - Neuroscan CT/N (H)	EM I CT 1010 (H) EM I CT 5005 (B) Ohio-Nuclear DELTA (H and B) Syntex System 60 (H) Syntex System 90 (B)	Artronix Neuroscanner 1100 or 1110 (H) General Electric CT/T (B) Varian (B) American Science & Engineering (B) Searle Pho/Trax (B)
Models not yet installed [b]		Phillips Tomascan (B)	Artronix Whole-Body scanner 1120 (B)

a Nomenclature of Brownell (79).
b As of June 1, 1978.
c H = Head, B = Body.

several seconds. In order to overcome this problem, the latest models of CT scanners will employ a large number of sources and detectors, all of which can operate at the same time. This approach will not only overcome problems of motion, thus increasing image quality, but will make it theoretically possible to reduce radiation dose to very low levels.

Improvements in technical capabilities may soon introduce new uses for CT scanners. New computer programs can produce images in a variety of planes or even in three dimensions from information now used to image cross sections, although at the cost of a higher radiation dose **(46,189,190,444).** Other programing changes can permit statistical analysis of data from scans to reveal differences in density or shape

Figure 7.—Configuration of First and Second Generation CT Scanners With Parallel Beam Data Acquisition

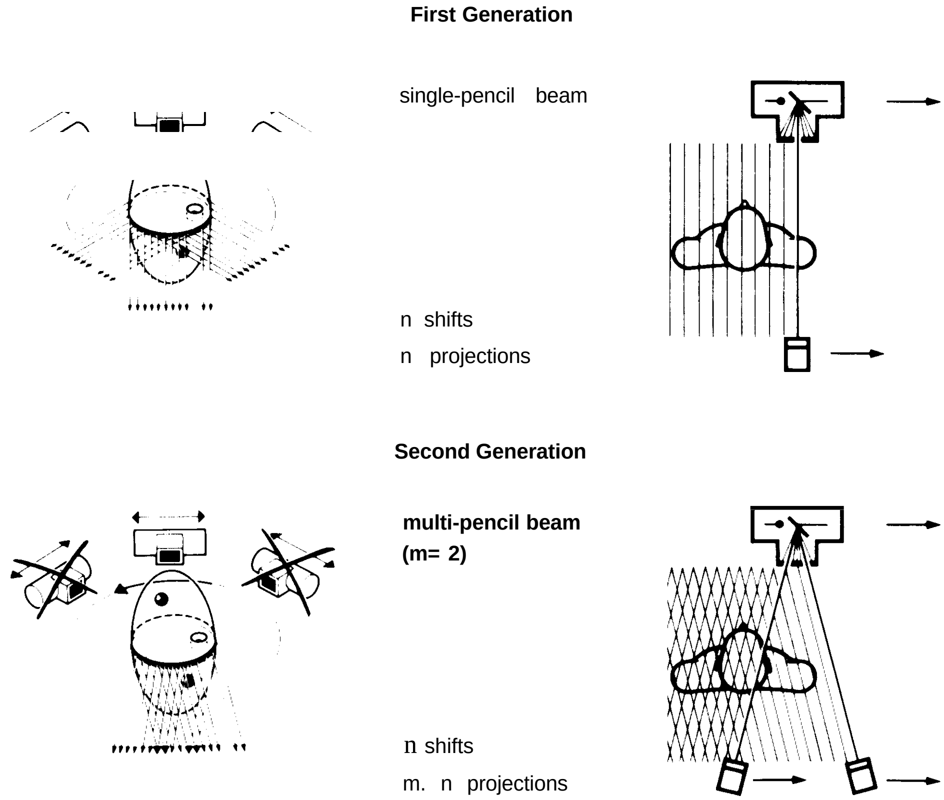

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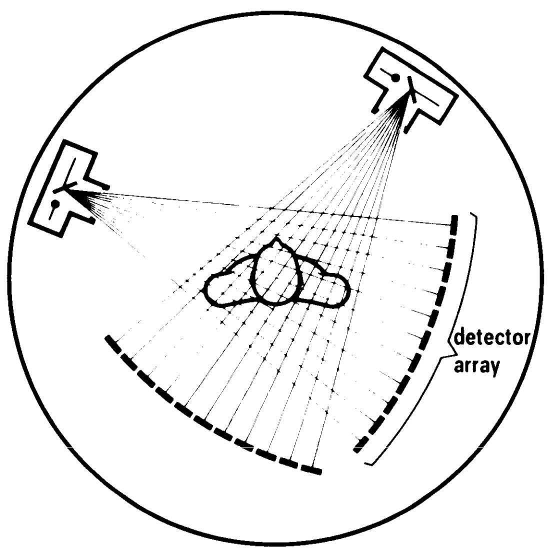
Figure 8.—Third Generation CT Scanner Configuration With Fan-Beam Data Acquisition



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undetected by visual inspection **(64,436).** The computer can also subtract normal from contrast-enhanced scans to reveal areas that have accumulated contrast material (64,415). This capability might be particularly useful if contrast agents for specific organs can be developed. Even without great reductions in scanning time, early evidence indicates that exposures can be synchronized with rhythmic motions so that organs that are now difficult to image, such as the heart, can be scanned **(2,486).**

Physicians also anticipate increased use of CT scanning in conjunction with other techniques. For example, biopsy needles may be more accurately positioned with CT scanning than with present methods **(11,272,324).** Also, CT units have been linked with cobalt or other radiation sources to form an integrated system for radiation therapy (96,244,272). Use of a calibrated head-holding device (a stereotaxic apparatus) permits more accurate radiosurgery on lesions discovered by CT scanning **(63).** Finally, periodic CT scans of some patients are being ordered to monitor responses of tumors to chemotherapy or radiation therapy **(272).**

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