Development of CT imaging

White Paper
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White Paper

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Computed Tomography (CT) first became feasible with the development of modern computer technology in the sixties, but some of the ideas on which it is based can be traced back to the first half of the twentieth century.

In 1917, the Bohemian mathematician J.H. Radon proved in a research paper of fundamental importance that the distribution of a material in an object layer can be calculated if the integral values along any number of lines passing through the same layer are known[1]. Although it was nearly forty years before the first practical application of reconstruction mathematics, some early work was done on optical reconstruction. For example, in 1938, G. Frank of C.H.F. Müller in Hamburg (now the German Philips Medical Systems organization) proposed an optical backprojection technique for reconstructing transaxial X-ray images (Figure 1)[2].

Probably the first application of Radon's reconstruction mathematics was by Bracewell in 1956[3]. A radio astronomer, Bracewell created an algorithm for reconstruction of astronomical images that was later universally adopted for use in CT scanners.

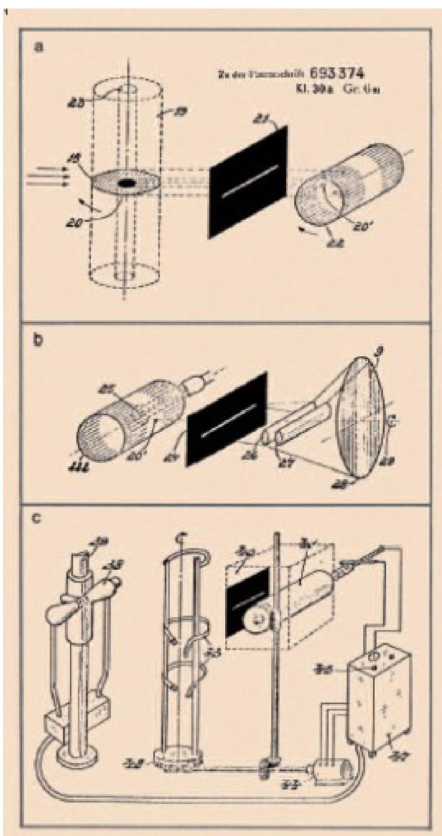

Fig 1
Optical image reconstruction from projections as patented by Gabriel Frank in 1938. Fig 1a. Projection of object (18) onto a cylindrical film

(22) which rotates for each new profile. Fig 1b. Profiles on film (232) are projected via a slit (24) and cylindrical lenses (26, 27) onto a film (9) which rotates to correspond to the object positions during recording of the scan. Fig 1c. Practical application with X-ray tube (38), rotating patient support (43), and recording film (41)

The first experiments on medical applications of this type of reconstructive tomography were carried out by the physicist A. M. Cormack, who worked on improving radiotherapy planning at Groote Schuur Hospital, Cape Town, South Africa. Between 1957 and 1963, and without knowledge of previous studies, he developed a method of calculating radiation absorption distributions in the human body based on transmission measurements. He postulated that, for radiological applications, it must be possible to display even the most minute absorption differences, i.e. different soft-tissue structures. However, he never had occasion to put his theory into practice and first learned of Radon's work much later. A successful practical implementation of this theory was first achieved in 1972 by the English engineer G. N. Hounsfield (Figures 2,3), who is now generally recognized as the inventor of computed tomography.

Figure 2
The inventor of clinical computed tomography, Dr. Godfrey Hounsfield

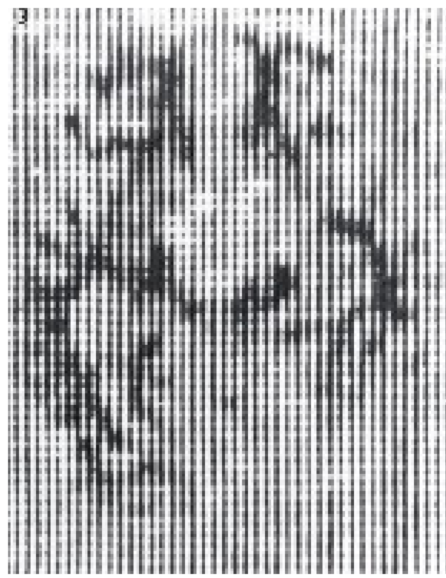

Figure 3
The first brain scan performed on the laboratory CT machine.

Like his predecessors, Hounsfield worked without knowledge of the above-mentioned earlier findings. His success took the entire medical world by surprise, and he achieved his remarkable breakthrough neither at a renowned university nor with a leading manufacturer of radiological equipment, but with the British firm EMI Ltd. His invention gave EMI, which had until then manufactured only records and electronic components, a monopoly in the CT market that lasted for two years, and the terms "EMI Scanner" and "CT-Scanner" became almost synonymous.

In 1974, the first traditional manufacturer of radiological equipment marketed a head CT Scanner, after which many other companies quickly followed. The subsequent boom reached its peak in the late seventies with 18 companies offering CT equipment. Most of these, including EMI, have withdrawn from the market by now.

The first clinical CT images were produced at the Atkinson Morley Hospital in London in 1972. The very first patient examination performed with CT offered convincing proof of the effectiveness of the method by detecting a cystic frontal lobe tumor. CT was immediately and enthusiastically welcomed by the medical community and has often been referred to as the most important invention in diagnostic radiology since the discovery of X-rays.

In 1979, Hounsfield and Cormack, an engineer and a physicist, were awarded the Nobel Prize for medicine in recognition of their outstanding achievements. The EMI scanner (Figures 4, 5, 6) was designed for brain scanning, and its applications were limited to the head.

Figure 4
First clinical prototype EMI brain scanner installed at Atkinson Morley's Hospital, London. Note the water bag surrounding the patient's head.

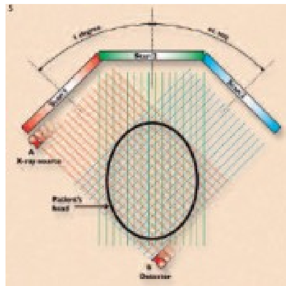

Figure 5
Simplified illustration of the scanning sequence (1973)

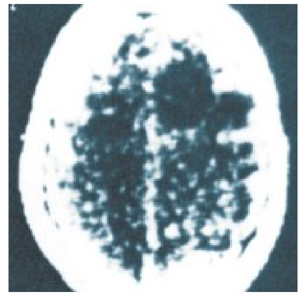

Figure 6
First clinical image obtained from EMI prototype unit. In a woman with a suspected brain lesion, the scan clearly shows a dark circular cyst.

In the United States, a dentist named Ledley became intrigued with the possibility of applying the technique to other regions of the body. He parlayed this interest into funding for construction of the first whole-body scanner[4]. The first clinical unit was named the ACTA scanner and installed at the University of Minnesota in 1973. Anatomical motion remained a significant problem in applications of this scanner to regions other than the head and extremities.

Since the development of the so-called first generation CT scanners, the major technical advances have been directed toward dramatically increasing the speed of scanning and image reconstruction. This has been accomplished by simultaneous data acquisition through more extensive detector arrays (Figure 7).

The pencil beam employed in the first generation scanner resulted in poor geometrical utilization of the X-ray beam and consequently long scanning times. In the second-generation scanner, the X-ray beam was collimated to a 10-degree fan, which encompassed an array of 8 to 30 radiation detectors, rather than the previous pencil beam with only a single detector. Although the second-generation scanner also used the complicated translate-rotate mechanical motion, the fan beam permitted multiple angles to be obtained with a single translation across the patient. The fastest second-generation CT units could achieve a scanning time of 18 seconds per slice. The image quality was substantially improved. In addition, the cumbersome water bag was omitted on this and subsequent CT scanners. However, the second-generation units had definite speed limitations resulting from the inertia of the heavy X-ray tube and gantry, as well as the use of the complicated translaterotate motion.

To increase speed, third- and fourth-generation systems were developed that used rotation only (Figures 8, 9). These devices eliminated the necessity for a back-and-forth translation and permitted the rotation to be accomplished in a continuous smooth motion. Because the back-and- forth motion was eliminated, it was necessary for the fan of the X-ray beam to be wide enough to completely envelop the patient from side-to-side.

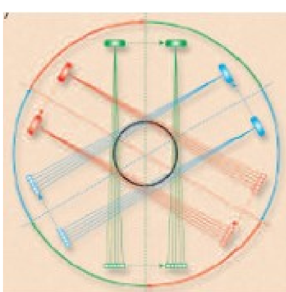

Figure 7

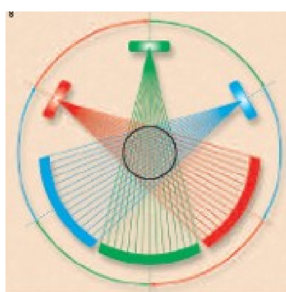

Figure 8

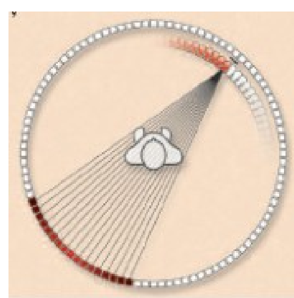

Figure 9

Second-generation CT scanner.There are a small number of beams (approximately 8 to 30) in a narrow fan configuration with the same translate-rotate motion used in first generation machines. Each linear traverse produces several projections at differing angles, one view for each X-ray beam.

Third-generation CT scanner. There are a large number of X-ray beams (approximately 500 to 700) in a wide fan configuration. Both the X-ray tube and the detectors rotate.

Fouth-generation CT scanner. There are an intermediate number of X-ray beams (approximately 50 to 200) in a wide fan configuration with a rotating X-ray tube and a stationary circular array of approximately 600 to 2,400 detectors surrounding the patient.

The major difference between the third- and fourth-generation rotational scanners was the motion of the detectors.

In the third-generation system, the X-ray tube and detector array are mounted opposite one another and pivot around the patient in a single rotational movement during which the views are acquired.

In fourth-generation systems, the detector array is a stationary circle, and only the X-ray tube rotates through a circle within the array. As many as 1,200 to 2,400 detectors may be used, compared with 500 to 700 in third-generation units.

Both third- and fourth-generation scanners could obtain individual slices in two to four seconds. A variation on the fourth-generation design was the "ultrafast" CT scanner. Designed by Douglas Boyd and collaborators at Imatron for the purpose of imaging the heart, this unit has no moving parts and can acquire an image in as little as 17 ms. By successively steering a small focal-spot size electron beam at four fixed tungsten target rings, the heart can be imaged without moving the patient and virtually free of motion artefacts.

Today, so-called third-generation CT's are standard (i.e. conventional). In these the patient is scanned one slice at a time. The X-ray tube and detectors rotate for 360 degrees or less to scan one slice while the table and patient remain stationary. This slice-by-slice scanning is time-consuming, and therefore efforts were made to increase the scanning of larger volumes in less time. This notion led to the development of a technique in which a volume of tissue is scanned by moving the patient continuously through the gantry of the scanner while the x-ray tube and detectors rotate continuously for several rotations. As a result, the X-ray beam traces a path around the patient. Some manufacturers call this beam geometry "Spiral CT" while others refer to it as "Helical CT".

The idea of this approach to scanning can be traced to three sources. In 1989, the first report of a practical spiral CT scanner was presented at the RSNA meeting in Chicago by Dr. Willi Kalender[5]. The spiral/helical CT scanners developed after 1989 were referred to a single slice spiral/helical or volume CT scanners. In 1992, a dual-slice spiral/helical CT scanner (volume CT scanner) was introduced to scan two slices per 360-degree rotation, thus increasing the volume coverage speed compared with single-slice volume CT scanners.

In 1998, a new generation of CT scanners was introduced at the RSNA meeting in Chicago. These are referred to as multislice CT scanners because they use multidetector technology to scan up to 64 slices per gantry rotation.

A state-of-the-art 64-slice scanner, such as the Philips Brilliance 64-channel CT configuration (Figure 10), can cover about 40 millimeters in a single 0.4 second pass. This means that a high-resolution scan of an organ such as the heart or brain can be acquired in about five seconds, while a whole-body scan can be performed in about 30 seconds.

Volume scanning has resulted in the routine application of such advanced techniques as CT fluoroscopy, CT angiography, three-dimensional imaging and virtual reality imaging. Its main applications are in cardiovascular studies, functional imaging, trauma and oncology. In cardiology, gated studies with the 64-slice scanner can provide clear non-invasive images of the heart and its major vessels, as well as fast coronary artery imaging including distal segments and multiple branches.

The speed and precision of the 64-slice scanner has also changed the approach to the diagnosis and treatment of cancer. Instead of just studying the morphology of a tumor and monitoring changes in size, it is now possible to follow the perfusion of a contrast agent through and around the tumor, providing early information on the response to therapy.

Other emerging applications for multislice scanners include evaluation of carotid artery plaque, detection of pulmonary emboli, and low-dose pediatric applications.

Figure 10
A state-of-the-art multislice scanner: The Philips Brilliance CT 64-channel configuration with 8.0 MHU MRC X-ray tube, 0.34 mm x 0.34 mm x 0.34 mm isotropic resolution, optional 0.4 second rotation time, and high-resolution 7682 and 10242 reconstruction matrices.

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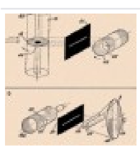

Development of CT imaging
This technology story traces the development of CT imaging from the first research conducted by J.H. Radon to the introduction of the Brilliance CT 64-channel configuration.

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