Neuroradiology Classics

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Computerized transverse axial scanning (tomography): Part 2. Clinical application*

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ABSTRACT

A new and fundamentally different X-ray method is described. The cranium is scanned in successive layers by a narrow beam of X rays, in such a way that the transmission of the X-ray photons across a particular layer can be measured, and by means of a computer, used to construct a picture of the internal structure.

Employing a suitably designed scanning gantry, a continuously operating X-ray tube, and a narrow collimated X-ray beam, the transmissions of X-ray photons across a slice of tissue may be measured by a system of crystal detectors in such a way that 28,800 readings are obtained. These form the basis of 28,000 simultaneous equations which are solved by a computer. The solutions are transformed into absorption coefficients and by means of a suitable algorithm related to their correct cells in a matrix of chosen size.

The results are stored, computed, and then made available from a magnetic disc to construct a picture on a CRT. The numerical results are available from a print-out.

The examination is, therefore, qualitative and quantitative. Pictures thus obtained are looked at in much the same way as radiographs. Structures are identified and shape, size, and position defined. Changes in tissue density are then looked for.

Lesions are seen as alterations of normal density and are interpreted in the light of pathological changes which are known to occur. Increased density may be due to blood clot, calcium deposition in tumours, and other lesions. In haemorrhage, once clotting has occurred, the concentrated blood constituents show up as an area of high density. Average tissue density is lowered in tissue necrosis, oedema, cyst formation, and haemorrhage where clotting has not occurred.

Tissue density may be artificially enhanced by the intravenous injection of substances containing large atoms;

*This preliminary communication is a slightly expanded version of a short paper which was presented at the Annual Congress of the British Institute of Radiology on April 19, 1972.

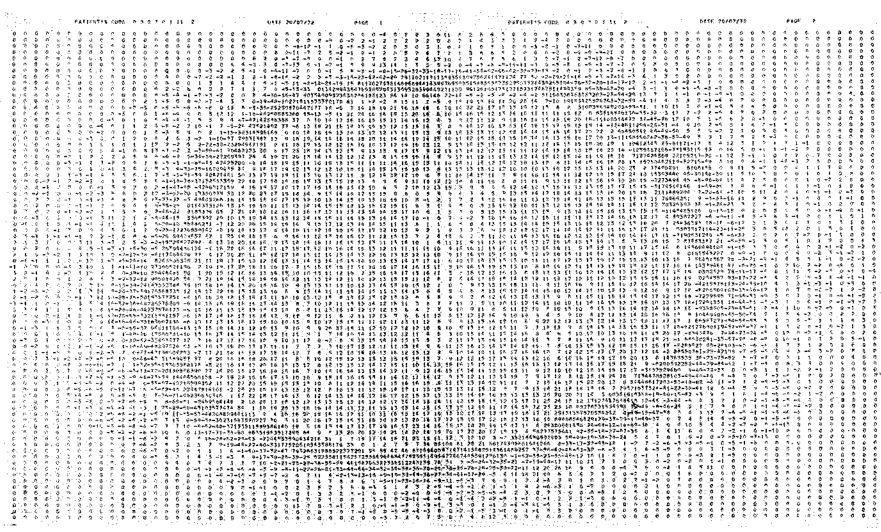

FIG. 1.

Normal scan.

Computer print-out of scan through a section 1·3 cm thick and 3·5 cm above the orbito-meatal line. The matrix size is 80 × 80 and each number is the calculated absorption coefficient of a discrete volume of tissue at that point. *Note:* The highest values are recorded in the surrounding compact bone while the lowest values are found in the fluid filled ventricles.

Historical Perspective

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Whereas the Nobel Prize committee erred in not awarding their prize in medicine or physiology to Moniz for his discovery of cerebral angiography, they did not compound this error by failing to recognize the value of computed axial tomography. In 1979 they awarded the prize to the Englishman, Godfrey Hounsfield, and the South African-born naturalized American, Alan Cormack, for their development of computerized axial tomography. Each Nobel prize has its winners and losers, and the 1979 award was no exception (1). Many feel that William Oldendorf, an American neurologist, should also have been offered the award for a device he built from junk box parts in 1960. The basic challenge of CT was to develop a machine that could reconstruct the internal points in a three-dimensional object, and portray them in a cross-sectional plane. Oldendorf implemented such a device in 1960 but was unable to obtain commercial funding for its further development. A letter from one of the world's major X-ray manufacturers to him ended, ". . . even if it could be made to work as you suggest, we cannot imagine a significant market for such an expensive apparatus which would do nothing but make a radiographic cross-section of a head." (2). A possible factor in the Nobel Committee's decision not to recognize Oldendorf was the consideration of awarding the prize to two Americans and one Englishman while multimillion-dollar litigation was pending between U.S. and British manufacturers of CT scanners (1). Also, there was a conspicuous absence of any mention of mathematics in Oldendorf's paper (3), whereas Cormack, in his papers of 1963 and 1964, described the mathematical algorithm at the core of cross-sectional imaging (4, 5). Another reason for Oldendorf being rejected could have been a reluctance by the Nobel Committee to recognize applied rather than basic research (1). Cormack delayed publication of his results for 6 years because of his belief that someone must have developed an algorithm similar to his, and he did not want to claim priority over another researcher's previously published work. Informed by mathematicians in Boston and in Cape Town that the relevant algorithms were original, he published his articles. In fact, Tetal'baum in 1957 published an article in the Russian literature on line integrals that referred to the mathematical basis of three-dimensional image reconstruction from a two-dimensional plane (6). Cormack was unaware of this publication.*

* Similar algorithms have been attributed to an Austrian, Radon, in 1917, and to a Dutch mathematician-physicist, H. A. Lorenz, in 1905.

Hounsfield's totally independent work began 10 years after Cormack's. Both Oldendorf's and Cormack's inspiration came from a medical environment. In the case of Oldendorf, from a distaste for the discomfort experienced by patients with needles in their carotid arteries or in their lumbar subarachnoid spaces, and in the case of Cormack, from a request from a radiation therapist in Cape Town to deliver a large dose of radiation to a malignancy while simultaneously delivering as small a dose as possible to the normal surrounding tissue (7). Hounsfield's inspiration came from pattern recognition studies at the Central Research Laboratories of Electrical and Musical Industries (EMI) (8). In 1957 he speculated that a mathematical technique might be used to reconstruct the internal structure of a body from a number of X-ray transmission measurements. Like Cormack, Hounsfield realized that a tomographic approach was the most practical; any three-dimensional body could be divided into slices, with each slice being reconstructed from radiation passing through it. As did Cormack and Oldendorf, Hounsfield initially used a radioactive source; after he substituted an X-ray tube for the source, the data gathering took 9 hours rather than 9 days! With the help of two radiologists, James Ambrose and Louis Kreel, numerous human brains, fresh bullock brains, and pig carcasses were scanned before the first clinical machine was installed at the Atkinson Morley Hospital in Wimbledon in 1971. After a period of about 1½ years for the gathering of clinical data, a presentation was made at the April 1972 meeting of the British Institute of Radiology (9), followed by publication of the seminal papers in December 1973 (10, 11).

In May 1972, CT scanning was demonstrated for the first time in the United States, with the initial clinical results being shown by Dr. James Bull at Dr. M. M. Schechter's postgraduate course on neuroradiology in New York. As an attendee and participant at the course, I remember the excitement the first CT pictures generated. News of the exciting advance spread rapidly, and the first two American-installed EMI scanners were placed in the Mayo Clinic and at the Massachusetts General Hospital in June and July of 1973.

In the original rotate/translate scanner (11), the patient's head was initially positioned in an expanding rubber head cap to reduce the volume of surrounding air. The thickness of the scans was standardized at 13 mm so that 10 scans usually encompassed the patient's head. Eight-millimeter scans were also available and the original matrix was 80 × 80, ie, 3 × 3 mm. Each scanning run took approximately 4 minutes. The results of the scans were shown either as numerical printouts of the Hounsfield values, as a cathode ray display of the processed information from magnetic tape, or as a Polaroid picture of the cathode ray display.

In Ambrose's original article, even with the primitive 80 × 80 matrix, calcified tumors, intracerebral hemorrhage, and necrotic or cystic low-density tumors were depicted. Old infarcts, metastases, craniopharyngiomas, and subdural hematomas were diagnosed also. The value of contrast enhancement was recognized in this seminal paper with the diagnosis of a meningioma after the injection of sodium iothalamate. The limitations imposed by patient movement during the scans and difficulties of examining the skull base were stressed by Dr. Ambrose, who felt that pneumoencephalography was still an important diagnostic tool for lesions causing chiasmatic and optic nerve compression as well as small tumors in the cerebellopontine angle cisterns. With the subsequent rapid advance of improved scanner resolution, however, pneumoencephalography died out as a neuroradiologic diagnostic tool and computed tomography took its place.

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