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Computed Tomography: A Brief Historical Perspective

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Abstract
Radiology, diagnostic imaging, organ imaging, call it what you will, logically may be regarded as part of the physical examination of a patient. It is a more extreme example of the process that started with the invention of the stethoscope, the process of augmentation of our senses. This process may be extended beyond our normal senses so we may now appreciate the electrical activity of the brain or the heart, using the electro-encephalogram or electro-cardiogram. The very complexity of the technical processes involved, however, tends to make us see them as remote from the diagnostic relationship of patient and doctor.

The diagnosis of diseases of the brain provides us with a unique example of the role of these "augmented senses". The inaccessibility and delicate nature of the brain restrict the diagnostic tools we may use. The presence of a rigid bony box, the skull, protecting the brain prevents us from using our senses directly to examine the organ. Indeed, if we could examine it in our usual manner, the brain tissue might be destroyed by the use of percussion or palpation. The relative opaqueness of bone to X-rays limits the use of almost all plain radiographs. It is this very limitation that has provided an incentive to devise techniques to demonstrate the brain without damaging the brain tissue.

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COMPUTED TOMOGRAPHY: A BRIEF HISTORICAL PERSPECTIVE

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The purpose of this article will be to document briefly the pursuit of effective "non-invasive imaging methods", to use the current jargon, that has led to computed tomography (Table 1).

TABLE 1: Methods of Visualising the Brain

	Method	Image
(1)	History and examination of the patient	Imaginary picture of anatomical location of the lesion.
(2)	Electroencephalography	Surface electrical activity of the brain.
(3)	Skull radiography	Distribution of calcium in the head.
(4)	Pneumoencephalography	Position of the cerebrospinal fluid compartment.
(5)	Cerebral angiogram	Anatomy of the cerebral blood vessels.
(6)	Radio-isotope scan	Distribution of the blood brain barrier.
(7)	Echoencephalogram	Position of 3rd ventricle.
(8)	Computerised Tomography	Distribution of the radio-density of tissues in the head.

Skull Radiography

The first step in the pursuit was the introduction of radiography to medical practice early in 1896. Wilhelm Roentgen announced the discovery of X-rays in November 1895, and made public his first radiograph using a photographic emulsion plate a month later. It is doubtful if any technical innovation has been so rapidly introduced and commercially exploited. This could be achieved because the apparatus required to build an X-ray machine was available in many laboratories.

When Thomas Edison heard of the discovery of X-rays, he turned his attention to the problem of visualising the rays. During January 1896 he screened several thousand fluorescing crystals hoping to find one better than the barium platinocyanide used accidentally by Roentgen in his discovery. Edison discovered that calcium tungstate fluoresced some ten times more brightly and he coated a sheet of card with the crystals as a fluorescent screen. This device for use in fluoroscopy was advertised in Edison's mail catalogue later in the same year.

Figure 1: **Plain lateral radiograph of the skull. This demonstrates exquisite bone detail of the cranial vault and base, facial bones and cervical spine. The cerebral tissue is not seen.**

Other technical improvements produced skull radiographs which showed bones with exquisite detail but could only detect intra-cranial structures if they were calcified (Fig. 1). Thus, radiographs could be used to detect (a) asymmetry of volume of the cerebral hemispheres by displacement of a calcified pineal gland, (b) calcified brain lesions, and (c) infer chronically increased intra-cranial pressure because of erosion of intra-cranial bony structures such as the dorsum sellae. Because of the facility with which skull radiography visualised bone, it is still the first and best method to demonstrate fractures of the skull.

Pneumo-encephalography

Inspection of radiographs of the skull, chest or abdomen show that the structures that cast shadows of easily recognised different radiodensities are bones containing calcium, soft tissues containing chiefly water, structures containing fat and hollow organs containing air. The reason why air is so much less radio-dense than soft tissues is related to the fact that air is approximately 800 times less dense than water. It therefore might be expected that should air be introduced within the cranial vault, it would be easily detected on a radio-graph.

The first demonstration of the ventricular system by air came about, not as a result of a planned clinical procedure, but from an accident. On 24th November, 1912, a 47-year old man was knocked down by a New York tram, fracturing his skull and cutting his forehead above the right eyebrow overlying the fracture. Radiographs of the skull confirmed the fracture and the man was in hospital for 12 days and then took his own discharge. Seven days later he was re-admitted complaining of headache and vomiting. Examination showed papilloedema and a right extensor plantar response. Radiographs of the head at the second admission showed the ventricular system clearly seen and "enormously dilated with what was probably gas or air." At surgery, a cranial decompression was performed. One lateral ventricle was tapped and "the removal of the trochar was followed by two or three quick spits of air and fluid, and then clear cerebrospinal fluid to the amount of 8cc". The patient died one week later and at postmortem the dura over the frontal lobes was adherent to the fracture site and a connecting tract was traced from the right frontal sinus to the frontal horn of the right lateral ventricle. It was postulated that air had been forced through the sinus and then into the ventricle when the patient sneezed or blew his nose.

What had happened was that the accident had introduced air, a contrast medium, into the brain which had been then detected radiographically. In retrospect it may seem a small step from this accidental demonstration of the ventricular system to the introduction of a deliberate procedure for injection of air to aid diagnosis. This does not seem to be the case, because it was not until 1918 that a surgeon, Walter Dandy, described the first injection of air into the head and in his report he makes no mention of the previous observations of accidental intracranial air. Initially, air was put into the ventricles by direct puncture having made a burr hole in the skull vault. This procedure is called ventriculography. The introduction of air into the subarachnoid space by lumbar puncture was subsequently described by Dandy in 1919 and is called pneumo-encephalography. (Fig. 2).

Figure 2: **A frontal view of an air encephalogram showing air outlining both lateral ventricles.**

Pneumo-encephalography was an important step in the evolution of imaging of the brain because it was the first method that provided information about structures inside the cranial vault during life. It did not show the brain tissue directly, but allowed inference as to the location of intracerebral masses by showing displacement of the normal anatomy of the ventricular systems and the cisterns. Unfortunately, the method causes considerable discomfort and is not without risk. It is a method that has been largely superseded by later methods, but it should be remembered that it was the most commonly performed brain contrast procedure for more than four decades.

Cerebral Angiography

In January 1896 within a month of the announcement by Roentgen of the first radiograph of a hand, E. Haschek, at the suggestion of a colleague, O.T. Lindenthal, injected the brachial artery of a cadaver with Teichmann's mixture and demonstrated the blood vessels of the hand.

The major landmark in the development of clinical angiography occurred in Lisbon, Portugal in 1926, where the Portuguese neurologist, Egaz Moniz, performed the first angiogram in a living patient. Moniz and his associate, Almeida Lima, appreciated that they must find a substance opaque enough to X-rays to be seen against the density of the calcium of the cranium and which was sufficiently non-toxic not to harm the patient. They tested several substances and strontium bromide was selected. Moniz and Lima proceeded to inject a 70% solution of strontium bromide into the carotid artery of a dog and produced a clear radiographic picture of the cerebral arteries (Fig. 3).

Figure 3: **A lateral view of a cerebral angiogram showing the internal carotid artery and its intra-cranial branches.**

After this successfu! pilot study the first living human patient had 10mls of 70% strontium bromide solution injected into the carotid artery after the artery had been surgically exposed. The first successful cerebral angiogram was performed on a 48- year old man with severe post-encephalitic Parkinsonism, using 14mls of 60% strontium bromide solution. Unfortunately, shortly after injection the patient showed signs of cerebral ischaemia on the site of injection and died the same day. Moniz was profoundly affected by this post-operative death, but with the support of his colleagues, continued his investigations using a 25% solution of sodium iodide instead of the strontium bromide solution. The third patient receiving the sodium iodide solution had a rapid injection of 5mls after temporary ligation of the carotid artery below the injection site. The cerebral anatomy was demonstrated and was shown to be distorted by the presence of an intracranial tumour.

The technique of cerebral angiography was received by the medical profession with some doubt, particularly with respect to its safety, but the technique became accepted because of its usefulness and within 10 years Moniz was able to report on the first 1,000 cerebral angiograms.

Modern cerebral angiography employs contrast agents which are much less toxic, possibly the least toxic pharmaceutical agents used by the medical profession. Although direct percutaneous puncture may be employed, increasingly, the use of catheters introduced via a femoral artery is used.

The pre-operative location of intracranial tumours became possible with an entirely new level of confidence following the introduction of cerebral angiography. Not only were cerebral tumours accurately located but because of the very nature of the technique abnormalities of the cerebral blood vessels could be identified. Aneurysms of the medium sized arteries are unique to the cerebral circulation and may be treated surgically. In order to do this satisfactorily, their location has to be accurately identified and cerebral angiography is the only wholly reliable method available to do this. Cerebral angiography may always have a place in the diagnosis of intracerebral lesions because although other techniques may demonstrate the presence of a lesion, the surgeon will require to know the vascular anatomy to plan his surgical approach and as there are variations in the anatomy of the cerebral circulation this must be characterised for each patient when the surgical approach that needs to be employed to remove a tumour may compromise the blood supply to the remaining brain.

Radioisotope Brain Scanning

Radioisotope imaging employs the principle that selected radioisotopes either alone or attached to other chemicals may localise either in an organ or in part of an organ and, because of the emission of energy due to radioactivity, be detected remotely outside the body.

In 1947 George E. Moore working in the University of Minesota Hospital was testing the usefulness of intravenous injections of fluorescein dye during surgery to localise brain tumours. This compound fluoresces brilliantly when illuminated by ultra-violet light. When the tumour was visualised directly by ultra-violet illumination, the lesion fluoresced brilliantly but the adjacent healthy tissue did not. Moore was stimulated by this observation and he reasoned that if a tumour accumulated more fluorescein than healthy brain, it might be possible to locate it without opening the skull by labelling the fluorescein dye with a radio-active isotope and detecting it remotely.

Although we no longer use the radio-isotope used by Moore, iodine 131, and we employ very much more sophisticated devices to detect the location of the radioactivity within the cranium, we still exploit the unique property of intra-cranial capillaries observed by Moore in his fluorescein experiments. The capillaries of the cerebral vessels are impermeable to a wide range of substances that pass readily through the capillaries in the rest of the body. The 'Blood — Brain Barrier' as this property is often referred to, is frequently destroyed by adjacent disease and is absent in the vessels of tumours. Thus, normal brain does not 'take up' radio-isotopes and abnormal brain will therefore show as an area of radioactivity (Fig.4).

Figure 4: A radio-isotope brain scan, lateral view showing activity (the dark area) in the territory of the middle cerebral artery. The appearances suggest a cerebral infarct.

Radio-isotope brain scanning has been largely replaced by computed tomography except in vascular disease where it is used as a simple non-invasive form of arteriography (via an intravenous injection) to observe the pattern of blood flow, the dynamic radio-isotope brain scan.

Echo-encephalography

The concept of measuring distance using sound is familiar to anybody who has observed a flash of lightning and then counted the seconds to when they hear the peal of thunder. The use of sound to measure distance is used by both bats and porpoises in a more complicated manner, they both generate the sound and listen to the echo and have evolved very accurate ranging and locating senses.

The sinking of the steam-ship Titanic by an iceberg in 1912 precipitated the proposal to detect icebergs by sound echoes. More sophisticated underwater echo locating devices were developed during both World Wars and became the 'sonar' which is used today.

The use of ultrasound — the name given to sound waves of very high frequency and short wave-length well above the range audible to the human ear — to image internal organs in the human body is familiar to many people now because of its use in estimating foetal maturation during pregnancy. One of the earliest applications of ultrasound, however, was in a simple form to demonstrate the symmetry of the volume of cerebral hemispheres. A Swedish neurosurgeon, Lars Leksell, demonstrated in 1956 that a pulse of ultrasound introduced at right angles through the squamous temporal bone produced an echo from a midline soft tissue structure (Fig. 5). This echo is

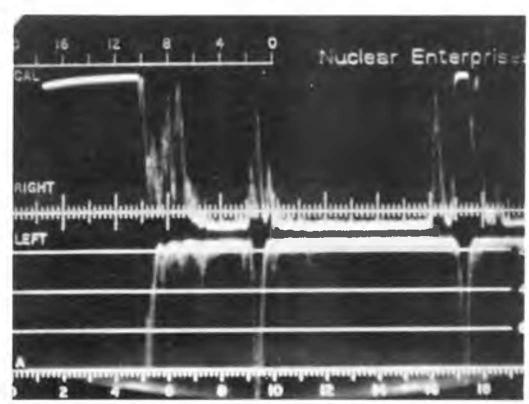

Figure 5: An echoencephalogram. An amplitude modulated oscilloscope trace (repeated and inverted below) which shows 'spikes' demonstrating the squamous temporal echoes and a midline 'spike'.

generated from the lateral walls of the third ventricle and any mass lesion in either hemisphere causing displacement of the third ventricle will cause displacement of the echo and therefore may be detected.

Bone does not conduct sound well and it is only the thin squamous temporal bone that allows an 'acoustic window' in the skull vault in the adult. In the neonate however the fontanelles give an acoustic window which allows more complicated ultrasound imaging techniques to be used.

The use of ultrasound to detect midline shift has been largely superseded by computerised tomography, except possibly in the situation of acute head trauma, because it is possible to monitor the patient in situations where the patient is being resuscitated and because the apparatus used for echo-encephalography is readily portable.

Computerised Tomography

In retrospect, it is difficult to realise the impact that the demonstrations of cerebral anatomy made by computerised tomography had on the medical profession when first demonstrated in 1971. It is important to remember that all the imaging methods described so far do not demonstrate normal cerebral tissue and the presence of mass lesions can only be inferred from the displacement of the normal anatomical structures displayed. Additionally, the most specific methods, air encephalography and arteriography, both carry a significant risk of morbidity and are very unpleasant procedures for the patient. The importance of the development of computerised tomography has been recognised by the award of the Nobel Prize for Medicine in 1979 jointly to G.N. Hounsfield and A.M. Cormack for their work in this development. In retrospect, it may be seen that there were several contributors to the concept of computed tomography and the background to the development still shrouded in some secrecy, but the final break-through to a useable diagnostic tool was made by Godfrey Hounsfield, an electronics engineer employed by E.M.I. (Electro Musical Industries), a company famous for records but not involved in the manufacture of X-ray apparatus. The first prototype, a brain scanner, was installed at the Atkinson Morely Hospital in October 1971, and the first scan carried out on a 41-year old female patient with a suspected left frontal lobe tumour, the tumour was clearly demonstrated.

Computerised tomography uses X-rays and the physical principles involved in the generation of the image are identical to those used in conventional radiography and therefore it may be thought of as taking radiographs of thin slices of a patient cut in the transverse plane. An X-ray tube provides a source of X-rays which are directed in a thin beam through the patient which are detected not by radiographic film but by scintillation or ionisation detectors. This system allows very accurate measurement of the transmitted X-ray energies. The X-ray tube and detecting system are rotated round the patient on a gantry and many measurements of the amount of X-rays passed through the patient's body are made. With the use of a computer, these measurements are used to calculate a pattern of X-ray absorption throughout the slice of the body through whcih the X-rays have passed. The original scanner was designed to scan the brain only and each scan took several minutes. Modern scanners can scan any part of a patient in a time which may be as short as two seconds. The numerical values representing the X-ray absorption pattern are converted to a grey-scale picture which is displayed on a television monitor and which may be photographed (Fig. 6).

Figure 6: A computed tomography scan, the transverse section demonstrating the frontal horns of both lateral ventricles and the cerebral tissue.

Many concepts of neurological disease have changed by virtue of computerised tomography scanning. The ability to detect disease now means that virtually all brain tumours may be detected and localised by computerised tomography during life. The impact on neuroradiological practice has been very great, investigations mentioned in this article which before the advent of computerised tomography were the tools which allowed the morphology of neurological disease to be demonstrated have had their pattern of use significantly changed. Pneumo-encephalography is now infrequently performed, even in specialised neuroradiological centres. Radioisotope brain scans are now infrequently performed in centres with access to computerised tomography. Arteriography is still performed but the reason for its use has changed with emphasis turning from the demonstration of gross anatomy towards the demonstration of vascular abnormalities.

Computerised tomography scanning has become such a crucial part of diagnostic neurology and neurosurgery that it has assumed the same role that conventional radiography has for the orthopaedic surgeon. It is impossible to conceive of a practice of modern neurology without access to computerised tomography.

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