The British Journal of Radiology, 79 (2006), 5–8 © 2006 The British Institute of Radiology
DOI: 10.1259/bjr/29444122

President's conference paper

CT scanning the early days

E C BECKMANN, BSc(Eng)

Lanmark, Beaconsfield, Bucks, UK

Abstract. CT scanning has become an established diagnostic tool within the radiology department. This article covers some of the history of the development and early days of CT scanning. It is based upon the lecture given on the Memorial Day for Sir Godfrey Hounsfield during the British Institute of Radiology President's Conference 2005.

It is less than 34 years ago, on 20th April 1972, that an unknown engineer from EMI Ltd, the company better known at the time for publishing the Beatles records, gave a presentation at the 32nd Congress of the British Institute of Radiology. The Engineer, Godfrey Hounsfield, was lecturing with Dr James Ambrose from Atkinson Morley's Hospital on "Computerised Axial Tomography (A new means of demonstrating some of the soft tissue structures of the brain without the use of contrast media)" [1, 2]. Many people attending that BIR congress will never forget the experience of hearing a presentation on CT scanning for the first time. In fact Hounsfield had presented the results of some of his animal experiments the previous year at the 2nd congress of the European Association of Radiology, in Amsterdam, but they had not excited much interest. The same might have happened in the USA because at a Neuro Postgraduate Course at the Albert Einstein College of Medicine, New York, on Monday 15th May 1972, only about a dozen people stayed to hear an extra lunchtime lecture by Hounsfield and Dr Bull, where they showed the first clinical images. However these people realised the significance of what they had seen and the news spread rapidly.

The beginning

In the mid 1960s Hounsfield was working on the pattern recognition of letters when he began to consider whether he could reconstruct a three-dimensional representation of the contents of a box from a set of readings taken through the box at randomly selected directions. He found that by considering the three-dimensional object within the box as a series of slices, reconstruction was easier than treating the content as a volume.

He tested the theoretical principal by working with a matrix of numbers set to zero with a square in the middle where each number was set at 1000. He entered these data into a computer programme to get simulated absorption values and then reconstructed the picture using another programme. Hounsfield recalled his surprise at how accurate the result was.

The project proposal

Once Hounsfield had proved the theoretical principle he went on to generate the original project proposal in 1968. Here he stated "The purpose of the study was to investigate the employment of a computer to make better use of the information obtained when an object is examined by gamma rays or X-rays". In this proposal Hounsfield compared the classic conventional X-ray technique producing a confused and fuzzy picture to the clear outline produced by the proposed system. Hounsfield proposed a system as shown in Figure 1 based upon reconstructing pictures of slices through an object and in detailing the expected benefits he indicated a theoretical accuracy of detection better than 1%.

The lathe bed model

The initial test rig was built on the bed of an old lathe which Hounsfield had been using in a previous project working on computer stores. Hence the early test unit became referred to as the "Lathe bed model". The initial rig utilized a gamma source, Americium 95, with a photon counter as the detector. On this rig, the source made 160 traverses of the object, which was rotated 1° at the end of each traverse for a total of 180°. It took 9 days to collect sufficient information, and 2.5 h to reconstruct the image on an ICL 1905 mainframe computer. However, the resultant images proved the feasibility of the technique and with the replacement of the gamma source by an X-ray source as shown in Figure 2, the scanning time was reduced to 9 h.

Initial images were of inert objects, then specimens from an abattoir, including bullocks brains and pigs bodies as shown in Figure 3. Due to the long scan times, particularly with the gamma source, many of these specimens decayed while the

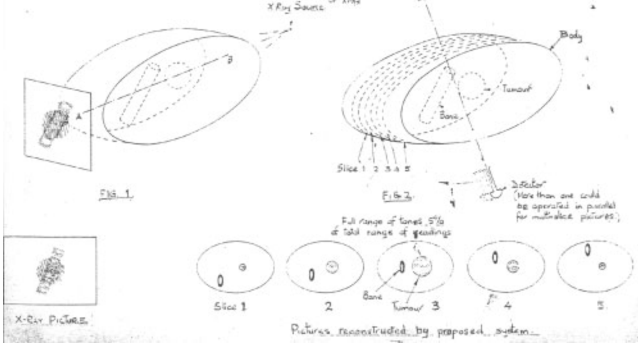

Figure 1. Extract of the original 1968 project proposal.

Received 12 September 2005 and accepted 16 September 2005.

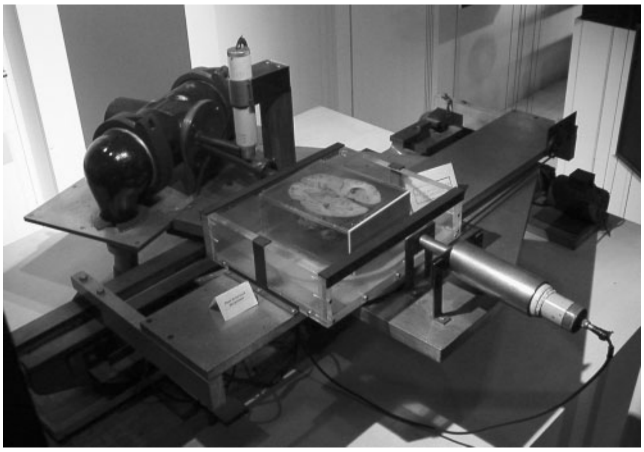

Figure 2. The original lathe bed model (copyright EMI Ltd).

pictures were acquired producing gas bubbles which caused artefacts in the images. This initial work was done by a very small team comprising Hounsfield, Stephen Bates (programming), Peter Langstone (electronics) and Mel King (mechanics) working on a very low budget of £25 000.

Dr James Ambrose recalls that, in about 1969, he received a call from an old acquaintance, Dr Evan Lennon then principal medical officer in Radiology at the Department of Health, asking if he would see a man called "Godfrey Hounsfield" and listen to him. Lennon had found him confusing but was reluctant to dismiss him as a crank (Ambrose later learnt that other eminent radiologists had already dismissed him as a crank!). Ambrose recalls that when he and his senior physicist Dr John Perry met Hounsfield, the conversation was difficult. Hounsfield would only say that the method was fundamentally different from other methods of X-ray imaging, more efficient in photon usage and likely to be more sensitive to small density variations. In order to demonstrate a clinically relevant image, Ambrose arranged for a bottled specimen of a brain to be borrowed from a museum and was amazed at the image Hounsfield showed him 5 weeks later. An image of the first brain scanned is shown in Figure 4.

Building the prototype

Having shown some clinically interesting images the project was then ready to move to the next stage of building a full prototype. However funding was an issue. It was Gordon Higson at the Department of Health who had the foresight to place an order for a machine with a theoretical specification which included a 4–5 min scan time and an 0.5% pixel accuracy, and this enabled the project to continue. This order was for a prototype and three clinical machines that would generate sufficient income to fund a fifth machine for Hounsfield and his team to keep and work on. The Department of Health order would also fund half the remaining research costs and in exchange they would receive a small royalty on sales. At the time it was calculated that it would cost £69 000 to build a complete working system and so it was agreed that the Department of Health would pay £150 000 for each of the four systems.

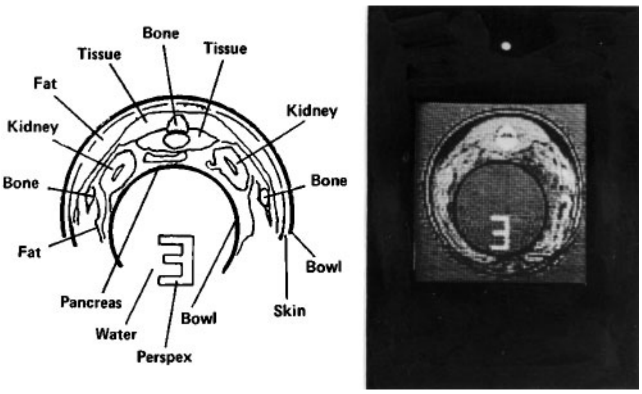

Figure 3. Early scan of a pig.

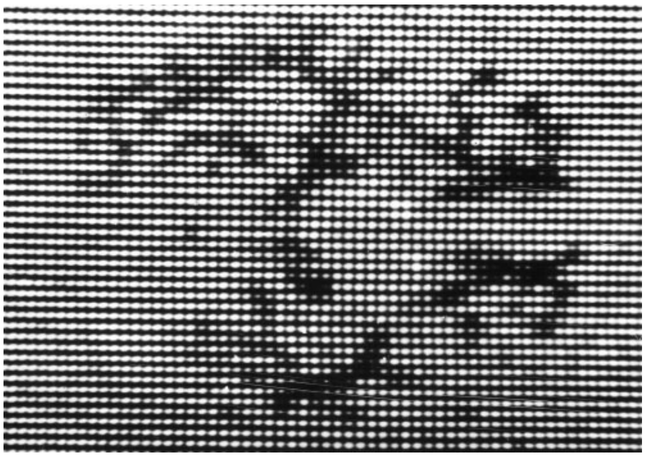

Figure 4. First image of a brain specimen.

The first clinical patient

The prototype was installed at Atkinson Morley's Hospital in South London where the first patient, a middle aged lady with a suspected frontal lobe tumour, was scanned on 1st October 1971. The surgeon who operated on her shortly afterwards reported that "it looks exactly like the picture" shown in Figure 5.

Hounsfield remained cautious. He recalled "I've had this before, first time is always lucky and then everything else goes wrong after that. So I thought, the next ones are not going to be any good, but they did another ten more patients and every one of them came out as being obvious diseases of the brain showing up in various forms. Dr Ambrose found that, by injecting iodine-based contrast agent that would localize the particular spot where the tumour was and it showed up even better". Hounsfield took some of the contrast enhanced images and subtracted without contrast images to compare the blood flow on either side of the brain.

In the original system the patient's head was placed in a rubber cap surrounded by water. This water bag was used to reduce the dynamic range of the detected X-rays and improve the absolute values of the attenuation figures.

Using one sodium iodide (NaI) crystal and photomultiplier tube detector per slice, plus one as a reference detector with a scan time of 4.5–20 min per 180° scan, the system acquired two contiguous slices per scan each with a 80×80 matrix of $3\ mm \times 3\ mm \times 13\ mm$ voxels. Early images showed the ability to meet the pixel density accuracy of 0.5% in the absorption coefficient as defined in the theoretical specification.

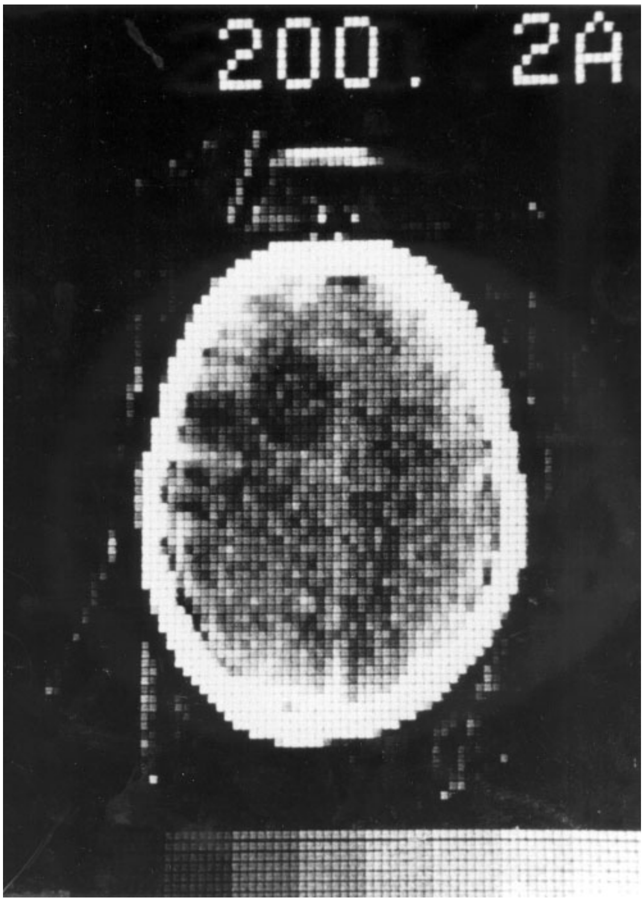

Figure 5. First patient image scanned on the prototype EMI scanner at Atkinson Morley's Hospital on 1st October 1971.

The three systems ordered by the Department of Health were installed at the National Hospital for Neurology and Neurosurgery in London, Manchester and Glasgow. After this, the first CT scanners were installed in the USA at the Massachusetts General Hospital and the Mayo Clinic, where the first scan in the USA was done on 19th June 1973.

Reconstructing the picture

Early scan data were actually taken back to EMI on tape for processing overnight which took 20 min per image on an ICL 1905 computer. In production this was done on a mini-computer which fortuitously had emerged at the right time. Images were taken back the next day on tape to Atkinson Morley's Hospital to be displayed. The early images were displayed in three ways; paper printout, cathode ray tube (CRT) display or as a Polaroid picture of the CRT display.

The early images were generated using iterative algebraic reconstruction implemented by Steve Bates on the ICL 1905 mainframe. Subsequently reconstruction used the filtered back projection or convolution method invented and patented by Chris Lemay, one of the many patents filed and held by Hounsfield and his team. On the original EMI Mk1 scanner an 80×80 image took 7 min to process, with filtered back projection on the same computer a 160×160 image could be processed in 30 s after the end of the scan.

It had been thought that image reconstruction and processing was so complicated that it would have to be done at a central processing unit on a suitable large and fast main frame machine.

But the introduction of the mini computer and the implementation of the new improved reconstruction algorithms were to change this.

CT1010 scanner

A challenge with the original EMI Mk1 scanner was the water bag, both as regards the ease of use with patients and also due to the occasional water leak! Replacement of the water bag with shaped carbon fibre wedges and bean bags was a significant improvement. This was further enhanced by the increase to eight detectors per slice in the CT1010 which was still a two contiguous slice scanner offering 160×160 and 320×320 matrix sizes over a 210 mm scan diameter and with the minimum scan time improved to 1 min. The prototype of this system was installed in 1975 at Atkinson Morley's Hospital and showed significant improvement in clinical image quality.

Body scanning

The feasibility of body scanning was proved when a slim member of the EMI team, Tony Williams, was scanned in a head scanner.

The first body images taken in the body prototype machine were of Hounsfield himself on 20th December 1974. The first body images were shown to a meeting at the first International Conference on CT Scanning in Bermuda on Friday 14th March 1975, one of these images is shown in Figure 6.

All the research machines were named after stones: Opal, Pearl, Garnet and the body prototype was Emerald. This Emerald system was first installed clinically at Northwick Park Hospital in March 1975. The first body scan carried out in the USA was in October 1975 at the Mallinkrodt Institute St Louis. Dr Ron Evans recalled that this was a jaundiced patient, in whom it had been difficult to differentiate between medical and surgical jaundice. The CT scans showed that it was surgical jaundice which was subsequently clinically confirmed.

Initially known as the CT5000, the body scanner was developed into the commercial production machine, the CT5005. These body scanners were single slice machines using a gantry with 30 detectors plus a reference detector to reduce scan time to 20 s. The matrix had been increased to 320×320 over a selectable 240 mm, 320 mm or 400 mm scan field.

The generation game

All these early scanners were the so called 1st or 2nd generation utilizing the translate/rotate technology where the gantry scanned across the patient before indexing by one degree and scanning back.

An early problem in CT scanner design was detector stabilization and the need for calibration. The EMI scanners were using NaI crystal photon detectors and photo multiplier tubes, and the translate/rotate technology enabled detector calibration by taking air readings at the end of each translate movement. This gave high accuracy but limited the speed of the scan. By 1976 there were 17 companies offering CT scanners with 3rd generation rotate/rotate scanners having

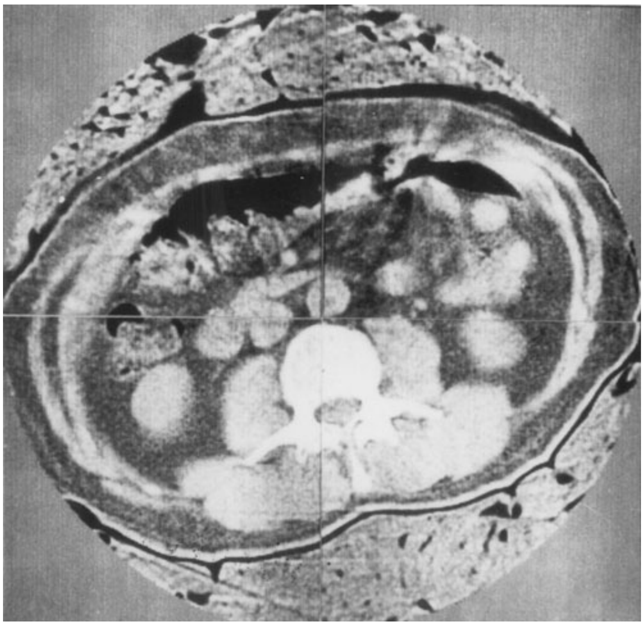

Figure 6. Body scan of Hounsfield taken on the prototype scanner in the laboratories and shown at Bermuda conference on 14th March 1975.

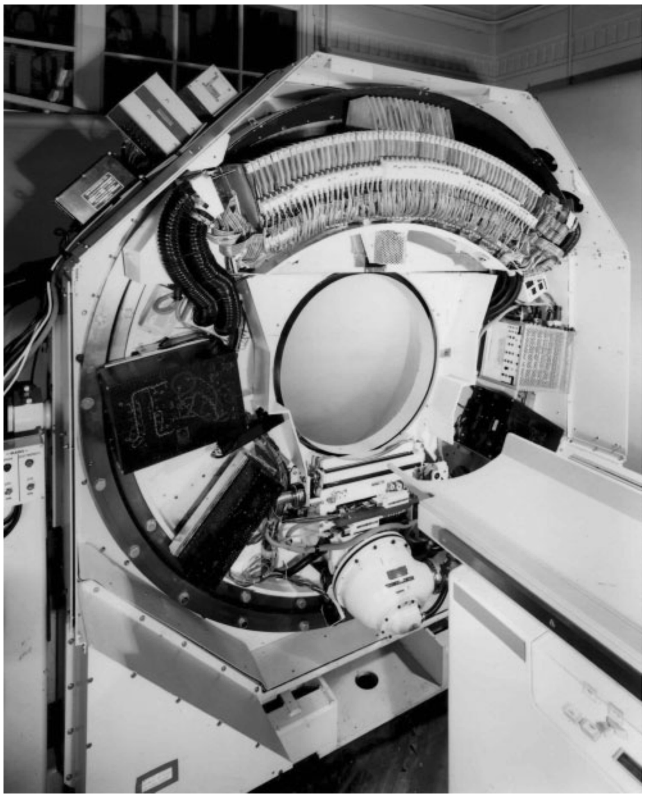

Figure 7. Topaz 3rd generation flying focal spot scanner.

been introduced, to offer fast scan times, most based upon xenon gas detectors arranged in an arc [3].

Hounsfield realised the need for a system that was faster than translate/rotate and that could overcome the calibration and artefact issues of rotate/rotate systems.

Topaz

The patent for a scanning focus system to produce a true volume scanner was filed on 19th October 1976. The Topaz research system, also named after a stone and shown in Figure 7, was a 3rd generation system with a flying X-ray spot. The X-ray flying spot scanned in a direction opposite to the direction of rotation of the machine which meant that the body could be scanned with arcs of detector readings which overlapped in such a way that they could be compared and continuously calibrated. Built with 612 detectors including a central zoom region, Topaz had a resolution in the *x*-*y* plane of 0.65 mm. Volume scans taken in June 1980 were displayed in three dimensions in real time as $1200 \times 1200 \times 270$ pixels.

Recognition

Initially the scale for describing the attenuation coefficients was referred to as EMI numbers. This was then expanded by a factor of two and became known as Hounsfield units (H) where

$$H = \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000$$

and μ is the linear attenuation coefficient. Each Hounsfield unit is equivalent to 0.1% of the attenuation of water [3].

In addition to giving his name to the unit of attenuation, Hounsfield received many awards including the BJR Barclay prize jointly with Ambrose in 1974, the Nobel Prize for Physiology or Medicine in 1979 [4] and a Knighthood in 1981.

Hounsfield and his team created the CT scanner, which has had an explosive impact on diagnostic radiology, with little money and few resources. By the end of the 1970s they already had plans for many of the technologies which were to develop the CT scanner over the next 30 years, including helical multislice scanners and high power continuously rated scanned beam X-ray tubes.

They developed many of the techniques which formed the foundation of modern imaging including image subtraction. By 1976 the reconstruction techniques used in CT were already being applied to other areas including ultrasound and nuclear magnetic resonance.

Acknowledgments

The author is indebted to many people especially those members of the original EMI team who worked with Sir Godfrey Hounsfield for their input to the original lecture and material used in this article.

References

1. Hounsfield GN. Computerised transverse axial scanning (tomography): Part 1. Description of system. Br J Radiol 1973;46:1016–22.
2. Ambrose J. Computerised transverse axial scanning (tomography): Part 2. Clinical application. Br J Radiol 1973;46:1023–47.
3. Brooks RA, Di Chiro G. Principles of computer assisted tomography (CAT) in radiographic and radioisotropic imaging. Phys Med Biol 1976;21:689–732.
4. Computed medical imaging. Nobel lectures in physiology or medicine 1971–1980; 568–86.