The Invisible Light

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Celebrating 50 years since the First Clinical CT Scan

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Editorial.

We are celebrating 50 years since the first clinical CT scan which was performed in 1971. Medicine was transformed and there are few still working who remember clinical practice before the EMI/CT/CAT scanner. There are three papers in this issue. Liz Beckmann has written about the first CT scan, and I have written about the late Frank Doyle whom I nearly met. There is also an interesting paper by Wai Lup Wong and Arpan Banerjee on a significant development of CT scanning – that is hybrid imaging with the combination of CT and PET scanning.

To mark the 50th Anniversary of the first CT scan at Atkinson Morley's Hospital on 1 October 1971, I was interviewed as the Honorary Historian of the British Institute of Radiology by Jeremy Vine on BBC Radio 2 (https://www.bbc.co.uk/sounds/play/m00102g7). I was pleased to have been asked to do it, and it was good to have an entirely positive image of radiology presented on prime time radio.

This Virtual Museum was produced and is maintained by the History Committee of the American Association of Physicists in Medicine, and is to be found at: https://museum.aapm.org . There are galleries on Röntgen, aspects of diagnosis and therapy, and a series of recorded interviews which have been conducted since 1990 by the AAPM History Committee. There is a recently added CT gallery to commemorate the 50th Anniversary. There are good images of the EMI head scanner and of Godfrey Hounsfield and James Ambrose. The primacy for the body scanner is given by them to Robert S Ledley and to his filing of a patent for the ACTA (Automatic Computerized Transaxial) scanner on 15th February 1974. They state that the first full-body CAT scanner developed by Robert Ledley was installed at Georgetown University Medical Center. The 0100 ACTA scanner is described as using a second-generation geometry and was the first to employ gantry angulation, laser positioning , and Fourier reconstruction [1]. The first reference that the virtual museum gives to the EMI body scanner is to an AJR paper from 1976, which does not really tell the whole story. The first body scan was actually performed at EMI on the Mk.1 brain scanner on 19 November 1973. In 1974 EMI was working on the body scanner prototype (Emerald scanner), and this was the scanner that was installed at Northwick Park Hospital. It was images of Godfrey Hounsfield's abdomen that were

[1] Robert S. Ledley, physicist who invented first full-body CT scanner, dies at 86 https://www.washingtonpost.com/local/obituaries/robert-s-ledley-physicist-who-invented-first-full-body-ct-scanner-dies-at-86/2012/07/26/gJQA0TxaCX_story.html

taken on the Emerald body scanner that were shown at the Computed Cranial Tomography International Symposium and Course held in Bermuda in 1975. Godfrey gave a talk on the progress in body scanning ay 8 AM on the 14th of March and it is recorded that the audience gasped and broke into applause [2].

The next issue of The Invisible Light is number 50. It seems astonishing that so many have been produced. I would love to receive an article about any topic in the radiological sciences.

Adrian

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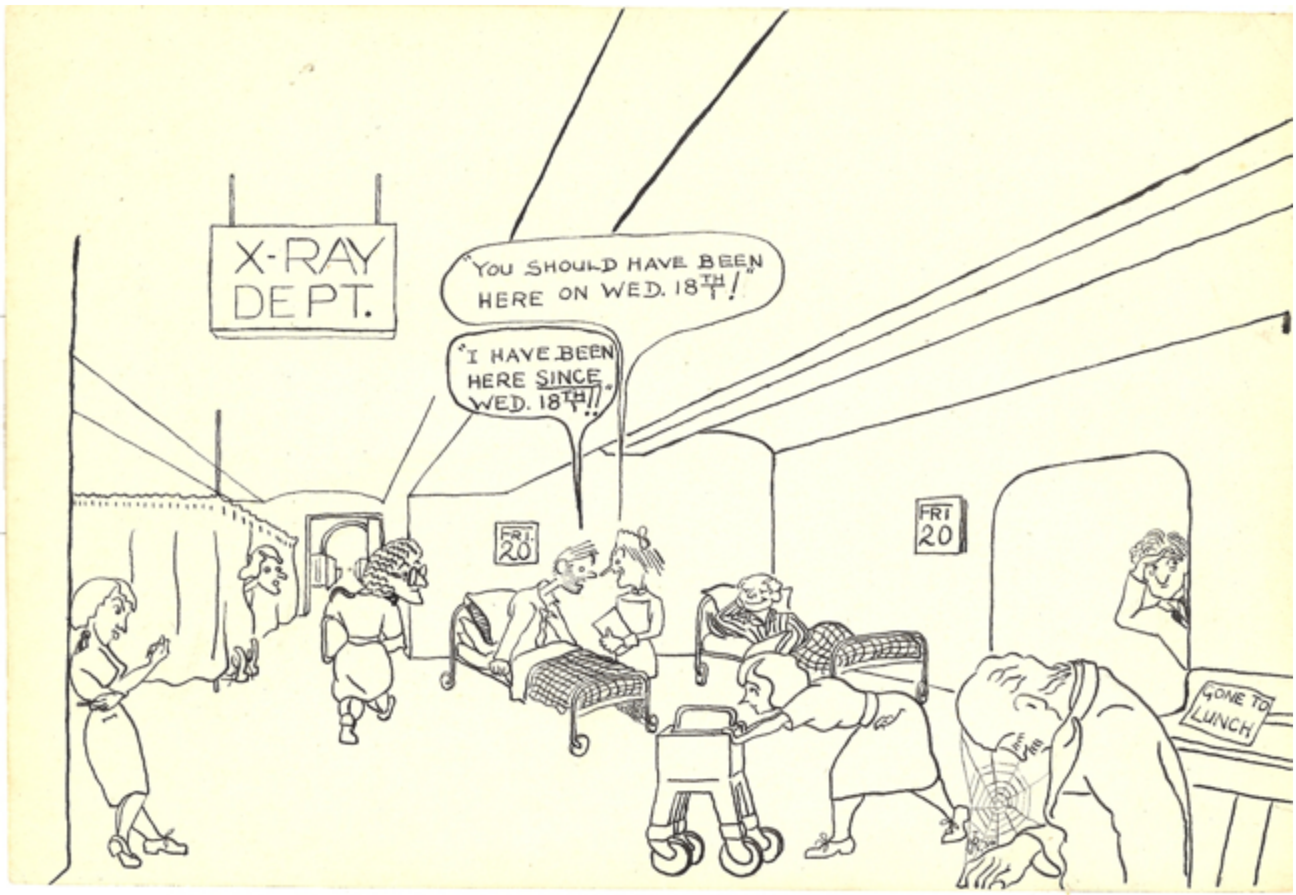

Michael Reilly: 1930s department (nothing changes!)(collection of Adrian Thomas).

Michael Reilly was born in 1898 and studied at the Central School of Arts and Crafts in Birmingham between 1923 and 1926. He lived in Birmingham in the 1930s and was living in Sutton Coldfield by 1946. He was a commercial artist, and received commissions from several railway companies, including Great Western Railway, Southern Railway and also the London Underground.

[2] Bates S, Beckmann E, Thomas AMK, Waltham R. Godfrey Hounsfield: Intuitive Genius of CT. The British Institute of Radiology, 2012.

A brief history of PET
and Positron Emission Tomography-CT [PET/CT] services in the UK.

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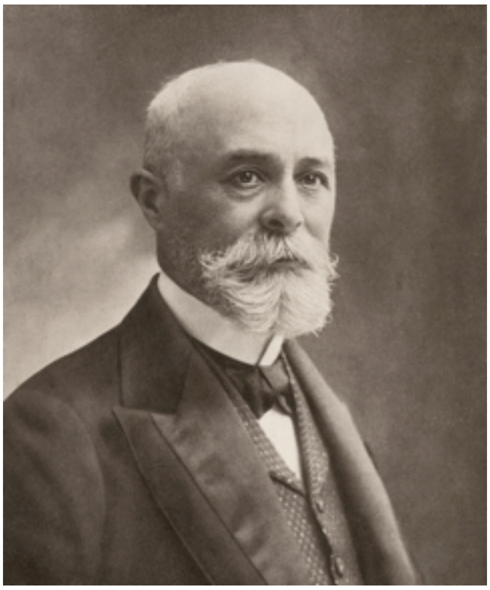
At the time of the formation of the NHS in 1948 most medical imaging investigations in hospitals were limited to taking plain films and simple contrast examinations.
Röntgen's discovery of X-rays in 1895 had revolutionised medical practice in the first half of the twentieth century and perhaps equally important but not as well publicised was Becquerel's (Fig.1) discovery of radioactivity which laid the foundations of the future discipline of nuclear medicine[1].

Fig. 1: Antoine Becquerel.



The second half of the 20th century saw a rapid development of diagnostic imaging; the clinical applications of diagnostic ultrasound took off with a landmark paper by Ian Donald, John MacVicar and Tom Brown from Glasgow on 'The investigation of abdominal masses by ultrasound' published in the Lancet in 1958[2].

In the same year, the first commercially made radio-isotope scanner to be installed in the United Kingdom was purchased by the Royal Marsden Hospital in Surrey.

The early 1970's saw the invention of Computed Tomography CT by Godfrey Hounsfield at the EMI laboratories in Hayes who with Alan Cormack of Tufts University Massachusetts shared the Nobel Prize in medicine in 1979 for their work which transformed the way medicine would be practised in the future[3,4]. This was followed by the development of a Magnetic Resonance Imaging [MRI] scanner by a number of researchers including Paul Lauterbauer, Raymond Damadian, John Mallard from Aberdeen and others including the Nobel Prize winner Sir Peter Mansfield from Nottingham[1].

Positron Emission Tomography [PET] and more recently Positron Emission Tomography/ Computed Tomography [PET/CT] are the two most recent diagnostic modalities to be introduced into clinical practice. It was Paul Dirac (Fig. 2) who first postulated the existence of the particle in 1928 [5] and Carl D Anderson (Fig. 3) in 1932 introduced the term positron. David Kuhl (Fig. 4) and others introduced the concept of emission tomography in the late 1950's in

Pennsylvania [6] and work by Phelps and others in Washington led to further developments with Phelps credited with inventing the first PET camera.

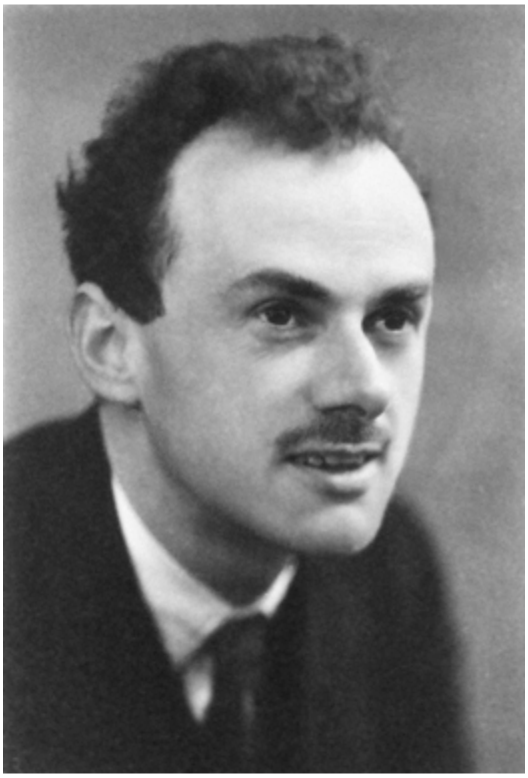


Fig. 2: Paul Dirac.

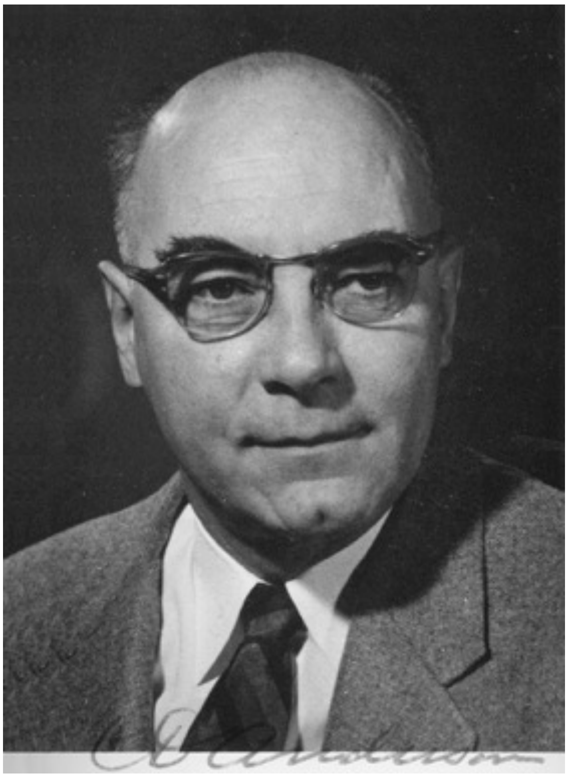


Fig.3: Carl Anderson.

Fig. 4: David Kuhl.

Early scanners were confined to imaging the brain. The first whole body PET scanner became available in 1977. The production of isotopes for scanning became available due to the work of Ernest Lawrence on the cyclotron in the 1930's at Berkley, California. The Massachusetts General Hospital in Boston (G Brownell and colleagues) also played a major role in advances in PET scanning[9,10]. Tatsuo Ido in the 1970's synthesised ^{18}F-FDG AT the Brookhaven National Lab[11] and Abass Alavi administered this to two patients for the first time in 1976 in Pennsylvania.

PET/CT was initially proposed by David Townsend (at the University of Geneva at the time), Ronald Nutt (at CPS Innovations in Knoxville, Tennessee, USA) and their colleagues. An early prototype system was installed in 1998 in Pennsylvania, USA[1].

PET-CT hybrids came into use from about 2000 onwards and improved image resolution. PET computed tomography (CT) is a unique combination of the cross-sectional anatomic information provided by CT and the metabolic information provided by PET, which are acquired during a single examination and fused. FDG PET-CT offers several advantages over PET alone; the most important is the ability to accurately localize increased FDG activity to specific normal or abnormal anatomic locations, which may be difficult or even impossible with PET alone.

UK History

The Hammersmith Hospital, London, and the Clatterbridge Hospital in the Wirral, Liverpool were the site of the earliest cyclotrons in England in the 1960's. Mary Catterall, the director of the Hammersmith unit was a pioneer in the use of neutron therapy in advanced cancer a treatment which sadly caused the patients to suffer considerable side-effects and the treatment became discredited.

In the 1980's the first commercial PET scanner in the UK was installed at the MRC's Cyclotron Unit at the Hammersmith Hospital, London. Researchers from that Unit demonstrated the basis for clinical PET and PET/CT imaging. Building on the seminal research of Otto Warburg[12] who demonstrated that tumours prefer using glucose to oxygen to provide energy, the group showed that gliomas in the brain preferred to metabolize glucose to oxygen and demonstrated that lung and breast cancers also have high uptake of the glucose analogue, 18F-fluro-deoxy-glucose (FDG) the tracer used in PET scanning. This set the scene for the introduction of clinical PET world-wide for the evaluation of people with cancer[13]. The first clinical PET centre in England was established at St Thomas' and Guys Hospital in 1991 under the leadership of Professor Michael Maisey, Professor of Imaging Sciences, and Dr Desmond Croft, a consultant physician at St Thomas's Hospital. At this time there were less than 100 operational clinical PET centres worldwide. This was followed in 1999 by a second PET clinical service, the brain child of Paul Strickland at the Strickland scanner centre, an independent medical charity at Mount Vernon Hospital, Northwood, London.

In 2000 PET and CT scanners were merged together. This was hailed the investigation of the year by Time magazine and the superiority of PET/CT over PET on its own quickly became apparent[14]. The Institute of Nuclear Medicine London introduced PET/CT to the UK and the first patient was scanned on 17 January 2002. However, by 2005, there were still less than 10 PET/CT machines in England. For many patients having a PET/CT involved travelling very long distances to be scanned. Following recommendations from the UK PET/CT Advisory Board and National Cancer Action Team, the Department of Health commissioned the National PET/CT Development Programme.

The Department of Health set aside £20M to expand PET/CT services across England. Since starting in 2005, the NHS England National PET/CT programme delivered by the independent sector working alongside the established leading UK NHS and University clinical and research centres has now developed into one of the most comprehensive and innovative PET/CT services in the world. Initially expanding the services rapidly by using mobile units to visit hospitals on a weekly basis to provide local access to examinations, this has now been consolidated with the introduction of fixed site permanent units[15]. The growth of the PET/CT service was made possible by a well-designed and successful programme of training and audit for imaging teams and in particular doctors reporting PET[16,17]. This was led by PET/CT Guardians appointed by the Secretary of Health; Thomas Nunan a physician from Guy's and St Thomas's PET Centre and Wai Lup Wong a radiologist from the Paul Strickland Scanner Centre.

NHS England commissioned services have been a major contributor to internationally recognised practice changing research[16,17]. Pioneering work by the United Medical and Dental Schools group in the 1990s demonstrated the clinical advantages of combining PET to CT paving the way for modern PET/CT scanning[18,19]

In 2016, over 100,000 PET/CT scans were delivered across England to both adults and children. PET/CT services are wholly commissioned by NHS England for the NHS patients in England, and delivered by NHS England Trusts, University departments, charities as well as the Independent sector. As with other specialised services, NHS England ensures that all people using the NHS receive the high standards of PET/CT service through the NHS England PET/CT Service Specification which clearly defines the standards of care expected from organisations funded by NHS England to provide the service. In addition, the NHS England PET/CT commissioning policy statement ensures that there is equitable access to PET/CT [20].

Research is a key part of the NHS services. Ground breaking PET-CT research by Professors Sally Barrington[21,22,23] and Michael O'Doherty and colleagues at St Thomas's Hospital and King's College London has led PET/CT guided treatment for people with lymphoma which is more effective and can result in fewer side effects.

The PETNECK study a collaborative multicentre NHS trial led by Professor Hisham Mehanna and Wai Lup Wong showed that using PET/CT could reduce the number of people requiring debilitating operations after treatment with chemotherapy for head and neck cancer[24] . Findings from the PETPANC study another NHS collaborative multicentre trial led by Professor Paula Ghaneh about the important role of PET/CT for the assessment of people with suspected or diagnosed pancreatic cancer has contributed directly to the NICE recommendation that PET/CT should be offered to people for the initial assessment of pancreatic cancer[25].

In the next ten years the use of PET/CT will increase with new clinical indications and new novel PET tracers which will contribute to its upward trajectory of usage especially in the field of personalised cancer medicine.[26] Emerging roles for PET/CT include the identification of people who respond early to cancer treatment, and also complementing non-imaging diagnostics, specifically genomics and the 'liquid biopsy' to ensure people have the most appropriate and individualised therapy whilst at the same time avoiding unnecessary treatment. New tracers that image other aspects of cancer behaviour are being developed and likely to have an important role in the future.[27] The role of PET-CT in also expanding in inflammatory, neurological and vascular diseases and may well play a greater clinical role in the diagnosis and management of dementia in the future[27].

The demand for PET scanning is likely to continue to grow in the future not only in the UK [28] but also worldwide and PET scanning will probably have an important role in the advancing field of molecular imaging as well as in oncology and radiotherapy planning. The increasing availability of scanners worldwide and new tracers and a reduction in unit costs are likely to help drive the use of this technology forward for the benefits of future patients.

Figures 6 to 8 illustrate PET scans and scanner.

Mini biographical sketches:

Antoine Becquerel 1852-1908
The French physicist made an important contribution by being the first to demonstrate radioactivity. Becquerel was interested in phosphorescence and by serendipity showed uranium salts emitted radioactivity. He shared the 1903 Physics Prize with the Curies who also made important contributions to the field of radioactivity. Becquerel was also honoured by having the SI unit of radioactivity named after him. Without his pioneering discovery radioisotope tracers used in PET scanning would not have been possible.

Otto Warburg 1883-1970
Warburg was born on October 8, 1883, in Freiburg, Germany. He initially did a doctorate in chemistry before qualifying in medicine. He became a professor in Berlin and was a prolific researcher in the field of cell biology and tumours. He and his colleagues discovered the Warburg effect; the cellular phenomenon that in normoxic conditions tumour cells primarily use glycolysis for energy production. This breakthrough forms the basis for PET CT scanning. The PET scan uses radioactive isotopes and the fact that cancer cells exhibit higher rates of glycolysis to pinpoint tumours with advanced imaging tools. He was the sole recipient of the Nobel Prize in Medicine in 1931[12].

The Cyclotron
In 1931, Ernest Lawrence (Fig. 5)a brilliant Physics Professor (appointed full professor aged 29 years) developed the cyclotron at the University of California Radiation Laboratory, Berkeley, USA and this was patented in 1932. The cyclotron facilitated the production of artificially created radioactive isotopes of some important biologically relevant elements. These enabled the production of isotopes for PET scanning. Lawrence was awarded the Nobel Prize in Physics for this in 1939. He also worked on the Manhattan Project.

Fig. 5: Ernest Lawrence.

FDG (Fluorodeoxyglucose)
In 1968, Dr. Josef Pacak, Zdenek Tocik and Miloslav Cerny at the Department of Organic Chemistry, Charles University, Prague, Czechoslovakia were the first to describe the synthesis of FDG[29]. In the 1970s, Tatsuo Ido and Al Wolf [11] at the Brookhaven National Laboratory, USA were the first to describe the synthesis of FDG labelled with ^{18}F. The compound was first administered to two normal human volunteers by Abbass Alavi in August 1976 at the University of Pennsylvania.

Fig.6: First full body PET scan (1976).

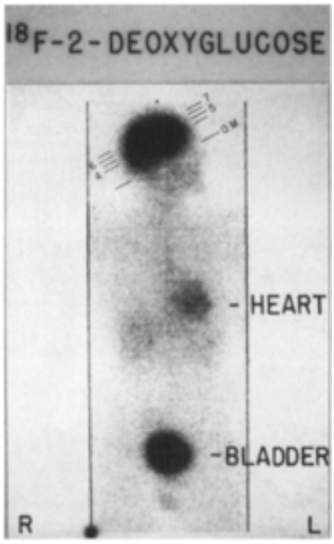


Fig.7: PET/CT scanner from 2009.

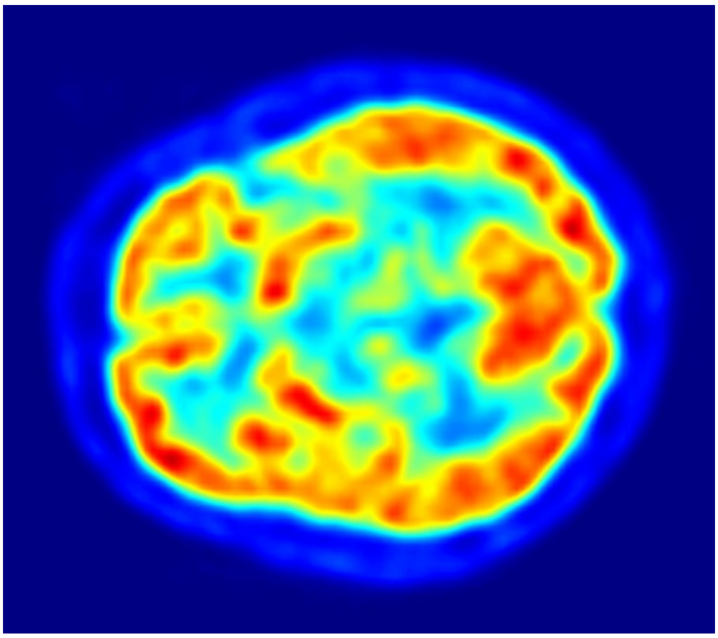


Fig. 8: PET scan brain.

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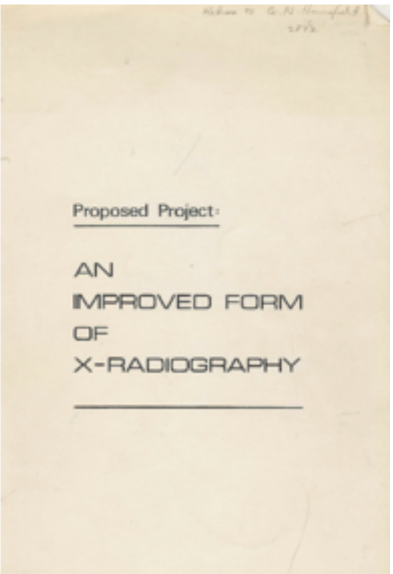
Celebrating 50 years since the First Clinical CT Scan.

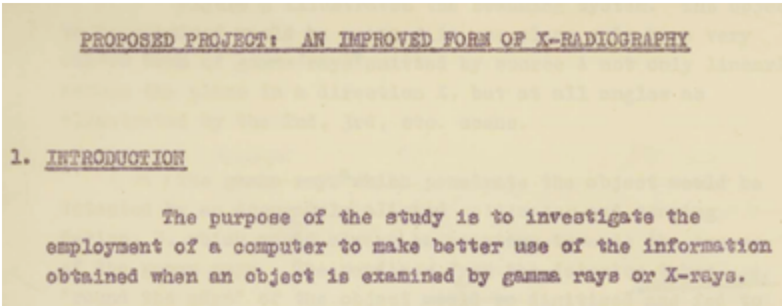
Liz Beckmann B.Sc.(Eng.) FBIR
Chair – British Society for the History of Radiology
Past President British Institute of Radiology
ISHRAD Advisory Board Member

It is difficult for anyone today to realise what imaging and diagnosis was like 50 years ago. In the 1960s imaging was largely x-ray film based and diagnosis depended largely upon the skill and interpretation of the radiologist. Surgeons and other clinicians had to be able to interpret from plain film x-rays into the 3 D space of the actual patient.

Neuro surgery was often guess work based upon the clinical symptoms of the patient as one of the few guides on where to operate. The only Neuro imaging techniques available in the 1960s such as Pneumoencephalography were invasive, traumatic and of limited efficacy.
Relatively little had really changed since the original discovery of X-rays by Roentgen in 1895.
In 1967 Godfrey Hounsfield was working in the Central Research Laboratories (CRL) at EMI Ltd in Hayes Middlesex and when his project on computer stores ended he was asked to give some thought to ideas on Pattern Recognition.


Proposed Project:

AN
IMPROVED FORM
OF
X-RADIOGRAPHY


PROPOSED PROJECT: AN IMPROVED FORM OF X-RADIOGRAPHY

1. INTRODUCTION

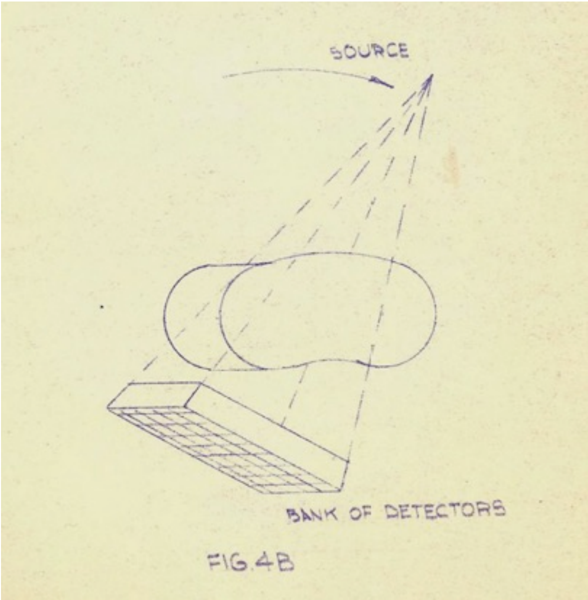
The purpose of the study is to investigate the employment of a computer to make better use of the information obtained when an object is examined by gamma rays or X-rays.

Godfrey decided not just to try to work on how to recognise characters and patterns on a page, but he wondered if he could recognise the contents of a 3D box or object by taking a large number of readings from all around the object. In October 1968 Godfrey submitted a proposal to his superiors at EMI for " An Improved Form of X-Radiography."

In this Early proposal- before he had done any experimentation Godfrey stated that he would achieve higher accuracy in measurement of absorption and discrimination of density differences across the structure being imaged. But he recognised that the system would give much poorer spatial resolution -ability to see finer structures- than was being achieved by conventional X-ray Systems at the time and he realised that this would be an issue since everyone at the time was looking for improved spatial resolution.

Interestingly in his early diagrams Godfrey was showing the " object" as the Body, but early on he was told that the Head greatest challenge -so he focused on imaging the Head.

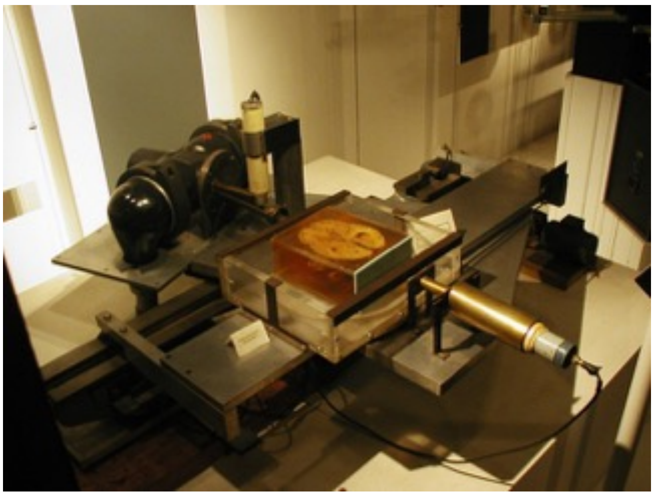
At this stage Hounsfield already forecast that after the concept was proved using the technology and components available at the time, new components would be developed that would improve and speed up scanning. An example of this is the drawing he included in this proposal of a complete bank of detectors , which is of course what is in use in modern day spiral CT scanners, compared to the single or small row of detectors used in early CT Scanners.



In fact so very many of the developments and enhancements that have been incorporated into CT scanners over the last 50 years were actually predicted by Godfrey Hounsfield either in this first proposal or in his very early laboratory notebooks.
From this first idea and after some initial computer experiments he developed a laboratory prototype built upon the base of an old lathe and other discarded components which were lying around the laboratory.
Godfrey initially imaged an arrangement of Perspex blocks of different density, and these early experiments enabled him to prove the concept of being able to reconstruct an image of a specimen through which a large number of x-ray readings had been taken by thinking of imaging the object as a series of slices.

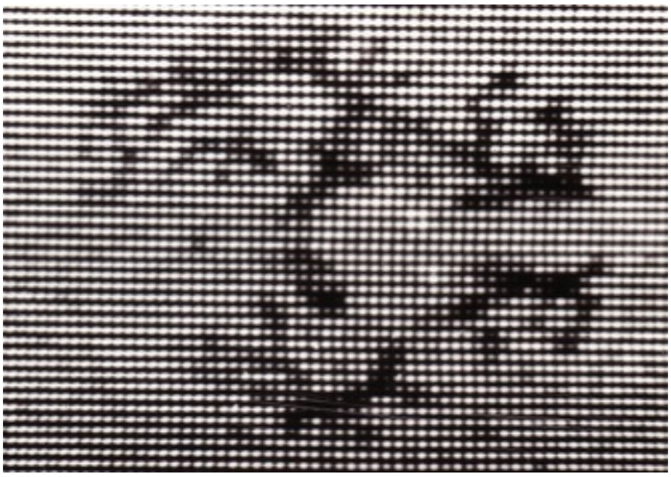
One morning in 1969 Dr James (Jamie) Ambrose, Consultant Radiologist at Atkinson Moley, received a call from an old acquaintance Dr Evan Lennon who was a Principal Medical officer at the Department of Health asking him to see a man called Godfrey Hounsfield and listen to what he had to say.

A meeting was arranged and Hounsfield duly arrived to meet Ambrose at Atkinson Morley Hospital. Ambrose later recalled that " conversation was difficult and tedious mainly because Hounsfield was not particularly forthcoming other than to reiterate that the method he had devised was fundamentally different to that currently in use in X-ray imaging. It was he claimed more efficient in photon usage and likely to be much more sensitive to small density variations in tissues." At the end of a tour of the department Hounsfield simply said " I can do much better than that".



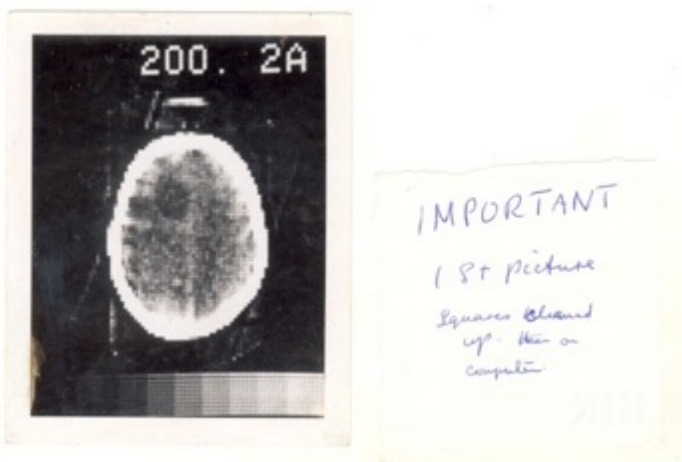
LATHE BED LABORATORY UNIT with the boxed specimen of a Brain in Formalin on it.

Ambrose responded " you can produce better images but by using X-rays in a more efficient and fundamentally different way ?" " Yes " was Hounsfield's reply . Ambrose then said " You sound very confident and I think we had better get you to show us!" So Ambrose arranged for a boxed specimen of a brain in formalin to be borrowed from a local museum for Godfrey.



5 weeks later Hounsfield came back with the now famous Polaroid picture of the transverse axial plane brain cut. Ambrose recalled thinking that by later standards the image was crude, but the potential was electrifying and he said to Hounsfield " do you realise what you have done?" " Yes " was Hounsfield's answer.
From late 1969 Ambrose was key in the team that collaborated with Hounsfield in creating a practical CT scanner. Testing and modifying mock up models of the scanning gantry, patient table, head box and other systems in the CT Scanner design. By August 1970 they had produced the design and specification of the first prototype scanner.

It later became clear to Ambrose that Hounsfield had previously seen and talked to other distinguished senior radiologists who had said that Hounsfield was just another crank and should be dismissed as such – thank goodness that Ambrose did not dismiss him as well.
In 1971 the prototype scanner was installed in Atkinson Morley Hospital, in Wimbledon, South London, and On 1st Oct 1971 Jamie Ambrose with Godfrey Hounsfield made medical history by carrying out the first CT scan on a live patient
Jamie Ambrose recalled that he and Hounsfield on seeing the pictures of the scan were jumping up and down like footballers who had just scored the winning goal.



The first image scan 200.2A showed a circular cystic tumour in the frontal lobe of the female patient.

The surgeon who subsequently operated on this patient reported that the tumour was exactly where it was shown on the first scan.

By the end of September 1973 there were 10 EMI CT scanners installed in hospitals around the world 4 in the UK, 4 in the USA, 1 in Canada and 1 in Sweden.

With the subsequent introduction of whole body CT scanners and evolution into modern day multislice spiral CT scanners   a vast range of patient diagnoses and treatments have been revolutionised.

The impact of CT scanning over the 50 years since its initial announcement has influenced nearly every branch of medicine and surgery, becoming a major tool in diagnosis and the monitoring of disease progression as well as treatment and surgical planning.. It is difficult to think where Radiology, Medicine and Surgery would be today without Godfrey Hounsfield and his invention of CT scanning.

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I nearly met Frank Doyle.

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I arrived at Hammersmith Hospital as a Trainee Registrar in Radiology in 1981 where I found a department in a state of shock following the sudden illness of Frank Doyle who was no longer working in the department following his first stroke. I often walked past his empty office, and I was determined to know more about this remarkable man.

Fig. 1. Frank Doyle in 1970 (collection of Adrian Thomas).

Frank Doyle (1926-1999)(Fig. 1) was a Scot from Clackmannanshire, born on April 10, 1926. He went to school at Sunnyside School in Alloa and in 1938 started at Alloa Academy [i]. He was an excellent student and was said to have excelled in every subject apart from art! He was an accomplished musician and the surviving school records recount a meeting of the Secondary Club recording that "The highlight of the evening was (his) rendering of the Warsaw Concerto and Chopin's Polonaise." There were war-time logging camps for the senior boys, and the local Polish troops were very excited when Doyle played the Polonaise, their unofficial wartime anthem, at Kenmore Church [ii].

Despite his talent, Doyle turned down a chance of a scholarship at the Royal College of Music. He read natural philosophy at St Andrews University. Doyle was awarded a joint first in his final examinations, and as a result was awarded a research post with John Randall (1905-1984) who had made major improvements to the cavity magnetron. In 1943 Randall had taken up the chair in Natural Philosophy at St Andrews. Whilst the magnetron was a secret, it was presumably known that Randall had invented something important. Randall invigorated the department at St Andrews and became particularly interested in applying physics to biological problems [iii].

The cavity magnetron was an essential component for the centimetric wavelength radar which was of a major importance in the Second World War [iv]. This is an interesting association since Doyle was later to work with Godfrey Hounsfield (1919-2004) the inventor of the CT scanner and who himself worked on radar with the RAF and with EMI. Doyle's work with Randall was instead of his National Service (which was obligatory at that time), and it was funded by the Admiralty and security classified. Hounsfield also did work for the Admiralty, and EMI produced the Type 922 radar in 1957 which was fitted to several warships including HMS Antelope. This was the largest radar unit ever produced by EMI and Godfrey designed the signal processing element.

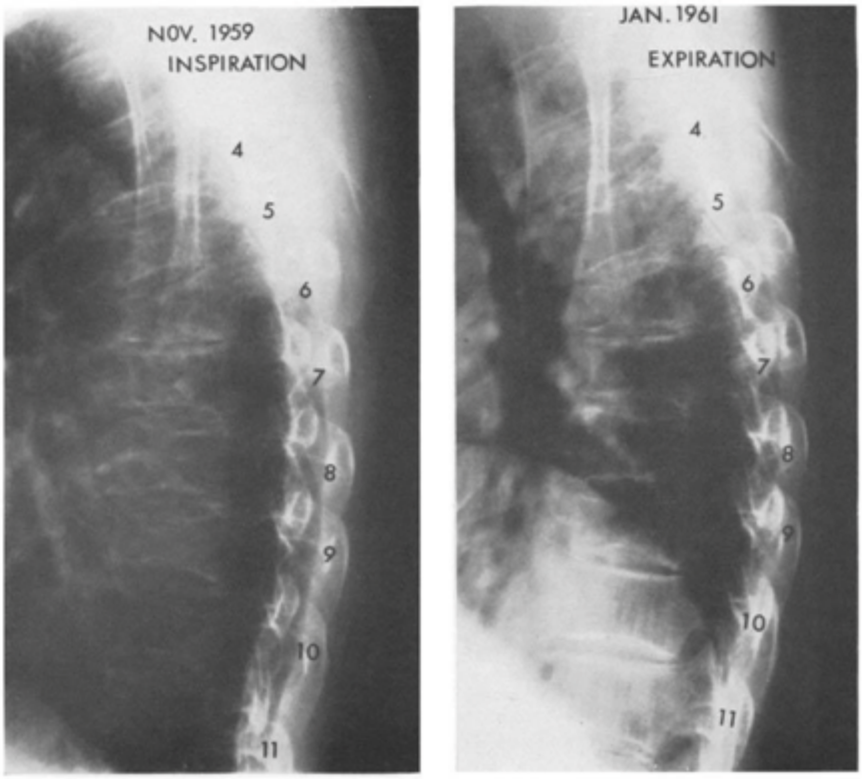
Doyle enrolled as a medical student at St Andrews University in 1947 undertaking his clinical training at University College Dundee. He decided to become a radiologist and in 1955 obtained a lectureship at Bristol University. From Bristol Doyle moved to the Hammersmith Hospital in 1957 as a full-time NHS appointment and Assistant Lecturer. In 1975 he was appointed to a personal chair as Professor of Radiological Science at the Royal Postgraduate Medical School[v]. Doyle was prolific in his publications and wrote about 150 papers. Many of his papers appeared in the British Journal of Radiology and in 1968 he was awarded the Barclay Medal (Fig. 2).

Fig. 2. Frank Doyle's Barclay Medal (collection of Adrian Thomas).

Frank Doyle's interests were many including metabolic bone disease [vi], studies of calcitonin and bone disease, Paget's disease, renal disease, and computed tomography. His contributions to metabolic bone disease were significant including his studies of ulnar bone density [vii], and spinal osteoporosis [viii]. The paper on spinal osteoporosis is important because it demonstrated the difficulties in diagnosing osteoporosis of the spine on plain films in the absence of structural failure (Fig. 3).

A number of his papers reflect the times that he was writing, such as his jointly written paper on the intravenous urogram in acute renal failure [ix] which was written before the ready availability of ultrasound and the modern understandings of contrast media toxicity. He wrote two papers on the bladder and devised a double-contrast technique of cystography to diagnose and assess bladder tumours [x]. The contrast media used was Steripaque, a sterilised suspension of barium sulphate, and carbon dioxide. The paper shows number of cystograms, and he assessed the place of cystography compared to the other diagnostic procedures commonly in use. This was long before the days of outpatient flexible cystoscopy. Again, his chapter from 1979 on radiology of the pituitary in a book on recent advances is solely based on conventional radiography and tomography with additional use of pneumoencephalography [xi]. There was also a discussion of the use of carotid arteriography and cavernous sinus venography. We are left with a realisation as to how difficult imaging was before the use of ultrasound, CT scanning and MRI. However 1979 is now 42 years ago and radiology has made major advances.

Fig.3. Taken from reference 7 (with permission). The image shows one of the problems of plain radiography, with the bone density seeming to vary with patient respiration.



In the 1960s Godfrey Hounsfield and his team at EMI was developing the CT scanner. The Department of Health became aware of the possibility of CT scanning in 1968 when Cliff Gregory was visited by Godfrey Hounsfield [xii]. Hounsfield met both Cliff Gregory and Gordon Higson, who were scientific advisers. Hounsfield was then introduced to Evan Lennon, a radiological adviser on the staff of the Department of Health. In January 1969 Gregory, Higson and Lennon visited EMI at Hayes to see Hounsfield's apparatus. Hounsfield was making proposals in 1968/69 for the development of the scanner. On 7 October 1969 Hounsfield made detailed proposals, and these were remarkable in that Hounsfield foresaw the potentials of CT for the next few decades. Lennon knew that Frank Doyle from the Hammersmith Hospital was looking at bone density measurements. Doyle was measuring ulnar bone density by immersing the forearm in a water bath and using conventional radiography. In order to evaluate the proposal there would be a need to expand the group beyond the Scientific and Technical Branch and so Frank Doyle was added to the circulation list [xiii]. At this period the scanning time was between three and four minutes and therefore it was necessary to scan organs that had no respiratory movement. Lennon thought that scanning would involve scanning the brain and measuring the bone density of the spine. Lennon introduced Godfrey to Doyle, and Doyle was asked to provide samples of bone for scanning.

Doyle had some concerns about Hounsfield's methods, and later recounted them in a letter to James Bull, Professor of Neuroradiology at the National Hospital for Nervous Diseases in London's Queen Square (now The National Hospital for Neurology and Neurosurgery) [xiv]. Doyle was concerned about the use of heterogenous X-rays and that this might introduce a variation in the absorption coefficients, that collimation could not produce a completely parallel beam of X-rays, and that scatter would be a problem. Doyle acknowledged that Hounsfield was a knight's move ahead of him at every turn. Every objection that Doyle raised had already been considered and Hounsfield's calculations had demonstrated that there was not a serious problem. Doyle concluded that Hounsfield's idea of computed tomography was worth supporting.

Frank Doyle gave Hounsfield two lumbar vertebrae of different densities. Hounsfield examined the vertebrae and returned to Doyle with computer printouts of numbers in the coronal plane of the vertebral body (Fig. 4a). Hounsfield had already worked out a scale of numbers and Doyle was impressed with the result. Hounsfield drew a histogram (Fig. 4b), and at the top wrote "air = -630". It was a recurring theme with Hounsfield that even after the development of the EMI scanner that he preferred the computer printout of numbers to a pictorial presentation of the data. Doyle and Hounsfield compared the histogram with radiographs taken in different projections and also with microdensitometer tracings of the radiographs. There was a meaningful correlation between the techniques, and in time Doyle realised the superiority of CT to his own methods of measuring bone mineral density.

Lennon also made contact with two other radiologists. These were James Ambrose and Louis Kreel. James Ambrose was a neuroradiologist from Atkinson Morley's Hospital in South London, and Louis Kreel was from the Royal Free Hospital, moving to Northwick Park Hospital in Harrow when the body scanner was installed. It became apparent that EMI would not spend any more money on developing the new technique without the support of, and a contribution from, the Department of Health. Lennon and Higson reported to the Department of Health, who agreed to give the necessary support. The department agreed to share the costs with EMI on a 50-50 basis. The three radiologists then worked more closely with EMI. Frank Doyle supplied bone specimens, James Ambrose supplied brain specimens and Louis Kreel supplied abdominal specimens. The collaboration was to prove fruitful.

The meeting on 14 January 1970 concluded that a prototype machine should be built. In February 1970 the provisional specifications for such a clinical prototype was submitted by Godfrey Hounsfield and was worked into its final form over the next 3 months. This was decided to be a head scanner and was to be installed at Atkinson Morley's Hospital. Hounsfield made the astonishing jump from the lathe-bed scanner to the prototype scanner in one jump. Hounsfield's genius was the invention of a scanner that would scan patients with an acceptable cost and acceptable level of radiation exposure. It needs to be realised that there was no thought at that time of having a computer integral with the scanner, and this was only to happen following improvements in computer technology.

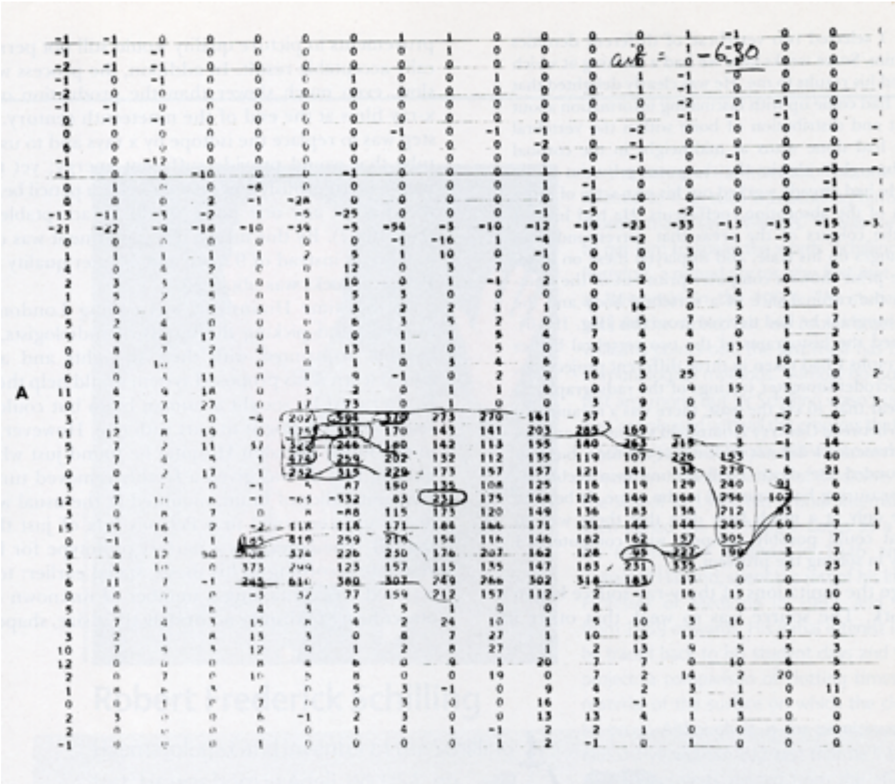


Fig 4a. A print-out of a coronal scan of a third lumbar vertebra. The Hounsfield numbers (as they became called) are shown. The lines were drawn by Hounsfield to show the location of the bone marrow space (from reference 12/public domain).

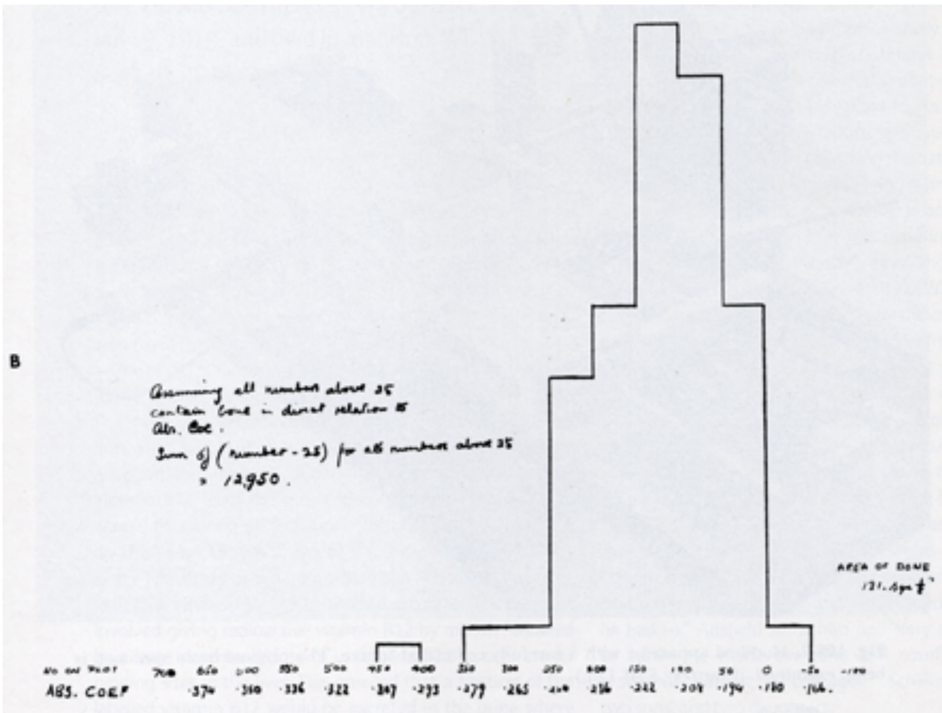


Fig 4b. Hounsfield's histogram showing the areas of bone marrow. Along the abscissa are given the number and the corresponding absorption coefficients. Hounsfield's writing reads:" Assuming all numbers above 25 contain bone in direct relation to Abs.Coe. Sum of (number minus 25) for all numbers above 25 = 12,950. (from reference 12/public domain).

In 1976 after the success of the EMI CT scanner, and again with the assistance of the Department of Health and Social Security, an NMR research team was established by Thorn-EMI [xv]. By late 1978 the Department decided to support EMI in the development of a clinical prototype and to contribute on a cost-sharing basis. The Royal Postgraduate Medical School was nominated as a clinical collaborator. The group initially used a resistive magnet and following further research a super-conducting cryomagnet, made by Oxford Instruments, was installed at Hammersmith Hospital in March 1981. Doyle was actively involved with the research and development, with the team working on the MRI appearances of the liver and brain. Doyle and his co-workers' paper on MRI of the brain was published in *The Lancet* in 1981, and the use of an inversion recovery technique resulted in a remarkable differentiation between grey and white matter. The basal ganglia were seen clearly and better than on CT, as was the posterior fossa and the basal ganglia [xvi]. Sadly Doyle's illness ended his work with NMR and his colleague Robert Steiner (1918-2013) took the lead of the project at the Hammersmith MRI centre that bears his name.

Sadly Frank Doyle was forced into early retirement by his ill health. He returned to Scotland, spending most of his time in Edinburgh. He retained his interest in music and kept in touch with many former students.

In 1984, Frank Doyle endowed an award at the Royal College of Radiologists in the form of a medal [xvii]. The Faculty of Clinical Radiology awarded the medal to outstanding candidates in the First FRCR Examination until the examination format was changed in 2002. From 2004 the medal has been awarded on the basis of performance in the Final FRCR Part A Examination. The Medal is awarded by the Specialty Training Board based on the recommendation of the Final FRCR examiners. In 2019 Richard Chaytor from the Peninsular Radiology Academy was awarded the Frank Doyle Medal (Fig. 5).

In 1994 a bronze bust of Frank Doyle was unveiled at the Royal Postgraduate Medical School, and many old colleagues and students attended. He died at the age of 73 on September 25, 1999. Frank Doyle made many significant contributions, and in the words of the Alloa Advertiser, he was a "local boy who made good" and who reached the heights in the field that he chose. He never married.

Fig. 5. Richard Chaytor's 2019 Frank Doyle Medal (with permission).

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[i] https://sites.google.com/cl.glow.scot/alloaacademy-01259214979/home (accessed 12 May 2021)
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[xvii] https://www.rcr.ac.uk/clinical-radiology/awards-and-prizes/frank-doyle-medal (accessed 12 May 2021).