CHAPTER 1

Pioneers in Radiology

INTRODUCTION

Over the last century, radiology has made giant strides to become an investigating modality of great importance. From the times long ago when Hippocrates (460 BC–370 BC) was known to make diagnoses by tasting his patient's urine and smelling their sweat, medical diagnostics and therapeutics have grown with the field of radiology. Sushruta, the father of Indian surgery in his compilation *Sushruta Samhita* mentioned about the importance of clinical observation and examination and he also stated that surgery prolongs human existence on earth. Great minds have been at work to better radiology—many well-known all over the world, many lost in the pages of history.

1.1 DISCOVERY OF X-RAYS AND DEVELOPMENT OF RADIOGRAPHY

Wilhem Conrad Roentgen (Figs 1.1 and 1.2) (1845–1923), a physics Professor at Würzburg University, Germany, was awarded the first Nobel Prize for Physics in 1901, for his discovery of X-rays. He heralded the age of modern physics and revolutionized diagnostic medicine while studying the phenomena accompanying the passage of an electric current through gas at extremely low pressures in 1895. Previous work in this arena had already been carried out by **J Plucker**, **JW Hittorf**, **CF Varley**, **E Goldstein**, **Sir William Crookes**, **H Hertz**, **Ph von Lenard**, and by the work of these scientists the properties of cathode rays had become well established. Roentgen incidentally observed a fluorescence of crystals on a table near his tube during one of his experiments. The cathode ray tube comprises a glass envelope with positive and negative electrodes within it. The air in the tube was evacuated and when a high voltage was applied, the tube produced a fluorescent glow. Roentgen then covered the tube with a heavy black paper, and discovered a green colored fluorescent light generated by

Fig. 1.1: Wilhem Conrad Roentgen

Fig. 1.2: Roentgen in his laboratory in 1895

the material (barium platinocyanide) located a few feet away from the tube in a dark room (Fig. 1.3).

He concluded that a new type of ray was being emitted from the tube. This ray was capable of passing through the black paper covering and exciting the phosphorescent materials in the room. He found that the new ray could pass through most substances casting shadows of solid objects and named these unknown rays as **X-rays**. Roentgen also discovered that X-rays could pass through the soft tissues of humans, but not bones and metal objects.[1]

About two weeks after his discovery, he took the very first 'roentgenogram' using X-rays of his wife **Anna Bertha Ludwig's** hand (Fig. 1.4). When she saw her skeleton, she exclaimed "I have seen my death!" A month later, a German doctor used an X-ray to diagnose sarcoma of the tibia in the right leg of a young boy. The military then used X-rays in Naples in May of 1896 to locate bullets in the forearms of two soldiers who had been wounded in Italy's Ethiopian campaign.

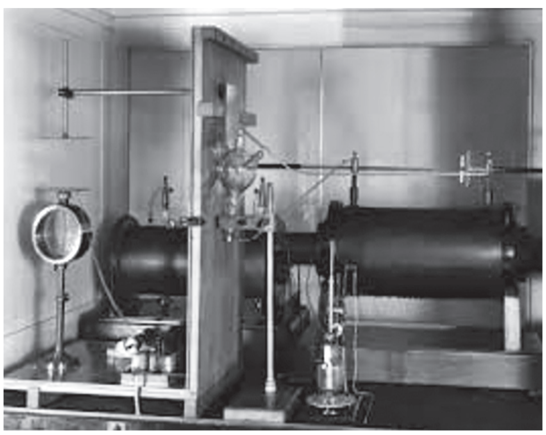


Fig.1.3: Roentgen's apparatus for studying the ionization of air in 1906

Fig.1.4: Print of the first X-ray—Anna Bertha Ludwig's hand taken in 1895

The popularity of this revolutionary discovery spread around the world with exhibitions and shows organized, where people could have a look at their own skeleton for entertainment—Roentgen shows were called and made more so popular in the United States by Thomas Edison. The so-called 'shoe fluoroscope', which has shown the outline of the foot inside the shoe, lured customers into stores. The shows stopped in 1904 when Edison's assistant, Clarence Dally died due to burns caused by X-rays. Several physicists like **Charles Barkla, Rutherford, Henry Moseley** and **William Bragg** contributed to studying the nature, characteristics and physics of X-rays among other electromagnetic radiation after its phenomenal discovery.

Humble beginnings and rise to fame: Born to a German father and Dutch mother, Roentgen attended high school in Utrecht in the Netherlands. He was expelled from school, when one of his teachers intercepted a caricature. Without a high school diploma, Roentgen could only attend university in the Netherlands as a visitor. He did not have the necessary credentials to attend Utrecht University. Upon hearing that he could enter the Federal Polytechnic Institute in Zurich, he passed its examinations, and began studies thereafter as a student of mechanical engineering. He soon graduated with a PhD from the University of Zurich.

In succession, he was appointed to the chair of Physics at the University of Giessen and the University of Würzburg, and in 1900 at the University of Munich, by special request of the Bavarian Government.

Roentgen's original paper '**On a New Kind of Rays**' was published on 28 December, 1895. Roentgen was awarded an honorary Doctor of Medicine degree from the University of Würzburg after his discovery. He published a total of three papers on X-rays between 1895 and 1897.

Honors and awards: In 1901, Roentgen was awarded the **First Nobel Prize in Physics**. The award was officially "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him". Roentgen donated the monetary reward from his Nobel Prize to his university. The International Union of Pure and Applied Chemistry (**IUPAC**) named element 111 as **Roentgenium**, a radioactive element with multiple unstable isotopes, after him. Today, Roentgen is considered as the **Father of Radiology** and the **International Day of Radiology** is celebrated on **8th November** every year. A collection of his papers is held at the National Library of Medicine in Bethesda, Maryland.

His honors include Rumford Medal (1896), Matteucci Medal (1896), Elliott Cresson Medal (1897), Nobel Prize for Physics (1901). Four years after his wife's death, Roentgen died in Munich on 10 February 1923, from carcinoma of the intestine.

Until the First World War the term "radiologist" was applied to anyone who could operate an X-ray set and produce X-rays. Most of the battlefield radiographs were made by untrained persons. In 1916, the Liverpool radiologist **Thurstan Holland** protested at this unsatisfactory situation, and declared that a radiologist must be "a doctor trained to interpret X-rays". In 1919, Cambridge University offered a training course and a **Diploma in Medical Radiology** (**DMR**), which immediately established the radiologist as a qualified medical specialist. **Charles Thurston Holland** is now considered as the **Father of British Radiology**.

Nikola Tesla

The pioneer of alternating current, that powers all machinery from the early days to modern day radiological equipments—**Nikola Tesla** (Fig. 1.5) ought to be remembered as one of the greatest minds of the last century, especially among the radiological fraternity. The **700 patents** held by Tesla are a legacy to American technology and radiologists worldwide.

Tesla's brief experiments with "shadowgrams," (Fig. 1.6) an attempt to produce radiographs of the human body were in their final stages **when much of his work was lost when his laboratory in New York caught fire and burnt down on March 13, 1895**. He heard the news of Roentgen's 1895 discovery of the X-ray and its remarkable utility and promptly

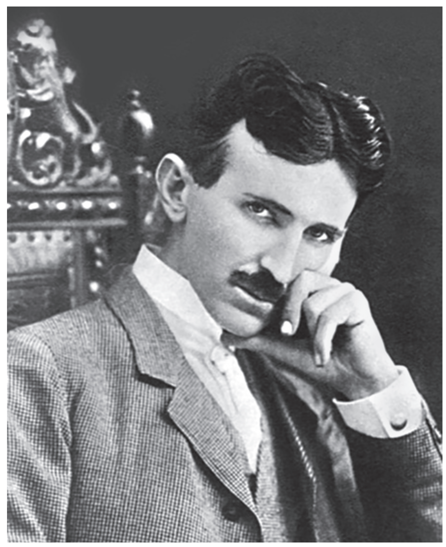


Fig. 1.5: Nikola Tesla

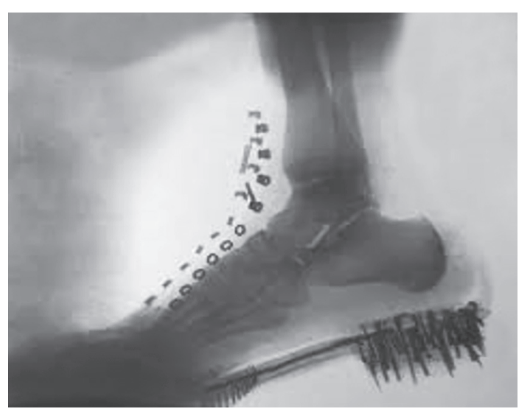


Fig. 1.6: Shadowgraph of a foot in a shoe, obtained by Tesla

cabled his congratulations to the German physicist.

Tesla sent his images to Wilhelm Conrad Roentgen, shortly after Roentgen published his discovery on November 8, 1895. Although Tesla gave Roentgen full credit for the finding, **Roentgen congratulated Tesla on his images, wondering how he had achieved such impressive results**. Tesla soon began work on efficient generators for X-ray machines. The **Tesla-Knott** generator became the most purchased generator for X-ray equipment between 1900 and 1920. Moreover, Tesla described some more clinical benefits of X-rays; for example, determination of foreign body position and detection of lung diseases as denser bodies were more opaque to the rays. **Tesla was also among the first to quote on the biologic hazards of working with X-ray tubes**. However, he attributed the harmful effects on the skin to the ozone and the nitrous acid generated by the rays, rather than to the ionizing effects of the radiation. He described acute skin changes like redness, pain, and swelling, as well as late consequences such as hair loss and new nail growth. Tesla also understood the three main elements of radiation protection: distance, time, and shielding.

Tesla also described the **rotating magnetic field way back in 1882, which forms the basis of most alternating current machinery**. In 1956, in honour of Nikola Tesla, the "Tesla Unit" was proclaimed in Munich by the International Electro-technical Commission–Committee of Action. **All MRI machines are calibrated in "Tesla units"**. The strength of a magnetic field is measured worldwide in Tesla or Gauss units.

In 1896, Tesla demonstrated the **first wireless radio-controlled device**, a toy boat, in a pond at Madison Square Garden. However, the device was so revolutionary that even the patent examiner found it hard to believe its existence. His other most notable discoveries include **wireless power transmission** and **the Tesla coil**. He was also instrumental in the construction of the **first hydroelectric power plant at the Niagara Falls**. In doing so, Tesla has shown that the falls were not just a thing of scenic beauty to admire but also a powerful tool that had immense potential to help humanity.

Even in retirement, Tesla continued writing, lecturing, and encouraging other young inventors until his death on January 7, 1943, at the age of 86. After Tesla passed away, Edwin A Armstrong, inventor of frequency modulation (commonly known as FM) radio, said of him, "**The world will wait a long time for Tesla's equal in achievement and imagination**".[2]

1.2 INVENTIONS IN CONVENTIONAL RADIOLOGY

In 1913, **William D Coolidge** (Fig. 1.7) (1873–1975), the American scientist invented the coolidge tube (Fig. 1.8), which had a cathode filament made of tungsten. This was an improvement on the Crookes tube (Fig. 1.9) that allowed more intense visualization of deep-seated anatomy and tumors and its basic design is still in use. He invented the first **rotating anode X-ray tube**.

In 1913, discovery of the anti-scatter **Grid and Bucky** by **Gustav Peter Bucky** (Fig. 1.10) helped to reduce harmful radiation doses. The radiographs were initially made onto glass photographic plates and in 1918, **George**

Fig. 1.7: William D Coolidge

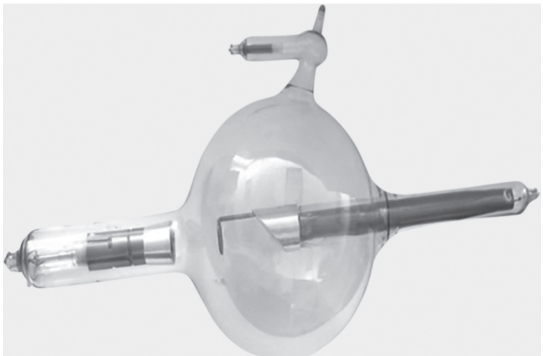


Fig. 1.8: Coolidge tube

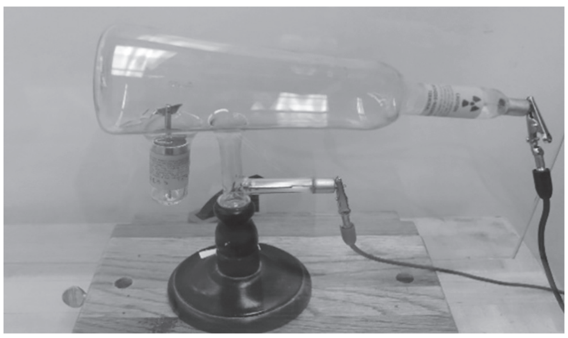


Fig. 1.9: Crookes X-ray tube in 1895

Fig. 1.10: Gustav Peter Bucky

Eastman introduced the **X-ray film—a transparent film of cellulose nitrate coated with silver bromide**.

Throughout the 1920s and 1930s, there was a steady significant improvement in the intensifying screen and radiograph films which contributed to better chest imaging. In 1929, **Philips** began production of the first rotating anode tube, called the **Rotalix**. Pioneering strides in this field were made by the American radiologist **Dr Henry K Pancoast**. He was in fact the first professor of radiology in the United States, being appointed in 1912 at the University of Pennsylvania. In the same year, he was elected President of the American Roentgen Ray Society. He published widely on pneumoconiosis, but he is probably best remembered today for his description of Pancoast syndrome. **Kodak** in 1956, introduced the first roller transport film processor. **3M™ introduced the first dry processor laser imaging system in 1994** (Fig. 1.11).

1.3 EVOLUTION OF CONTRAST MEDIA

Scientists realized that it was difficult to adequately assess the vascular system, gastrointestinal system and urinary system using X-rays alone. This led to the invention and application of various contrast media.

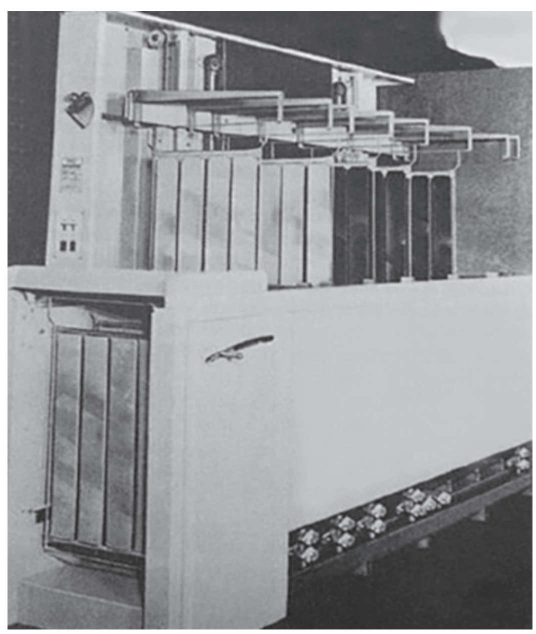


Fig. 1.11: First automatic processor in 1942—great developments since then with the latest being dry processor laser imaging systems

1.4 GASTROINTESTINAL CONTRAST MEDIA

For the GI system, the first contrast media contained **lead acetate**, which was soon replaced by **bismuth. George E Pfahler** noted in 1897, that a photographic plate of a patient's abdomen showed bismuth in the stomach. Bismuth used to be a remedy for gastric ulcers at the turn of the century. Although **Walter Cannon,** described the use of bismuth subnitrate in 1898, a search was made for other substances, in view of the toxicity of the nitrate component (which via its conversion to nitrite, gave rise to methaemoglobin in the body), and later due to the scarcity of bismuth. **Schule** first described a contrast investigation of the large bowel using bismuth and oil enema to image the colon in 1904.

The development of **barium sulphate** as a contrast medium evolved from the prior use of bismuth preparations. Barium sulphate was introduced into medical practice largely through the work of **Krause**, Director of the University Medical Clinic at Muinster in Westphalia. It was in Manchester that **Alfred Barclay** developed techniques for X-rays of the alimentary tracts using barium meals.

Initial studies were all single contrast studies. The value of double contrast studies for studying mucosal detail however had been recognised by **Holzknecht** (Fig. 1.12) who used an effervescent agent for studying the stomach. The first double contrast enema was described by **Laurell** of Uppsala in 1921.[3]

Fig. 1.12: Guido Holzknecht

1.5 INTRAVASCULAR CONTRAST AGENTS

The development of intravascular contrast agents was another important milestone in the development of radiology. In 1907, **Burkhardt** and **Polano** injected oxygen into the renal pelvis as a negative contrast agent, but the radiographic shadow was difficult to differentiate from bowel gas.

The discovery of iodine as a safe radio contrast agent was accidental. In the early 1920s, when iodine-containing compounds were used to treat syphilis, **Osborne *et al*** observed that the urine of patients treated with iodine was radiopaque. Later, they went on to perform the first successful clinical pyelogram in **1923** at the Mayo Clinic. In the same year, **Berberich** and **Hirsch** successfully employed **strontium bromide** to perform a femoral angiogram. In 1924, **sodium iodide** was used by **Brooks** to perform an angiogram. **Moniz** in 1927, first performed a carotid angiogram by using sodium iodide. He then used colloid **thorium dioxide** (**Thorotrast**), which became widely employed. However, it has non-biodegradable property and its association with the later development of malignancy limited the usefulness of Thorotrast.

In 1929, Uroselectan (derivative of Iodo-pyridone) was tested by **Dr Moses Swick**, an American urologist for the purpose of intravenous urography. In 1953, scientists working at different institutions realized that a fully substituted tri-iodobenzoic acid was superior to acetrizoate, thus they produced diatrizoic acid, which is widely used as the sodium or meglumine salt.

In 1968, **Dr Torsten Almen** (Fig. 1.13) began his research on the development of lower osmolar compounds, focusing on the ionicity and osmolality of the agent as key toxic property.

Fig. 1.13: Torsten Almen

Fig. 1.14: Hanns Joachim Weinmann

1.6 ULTRASOUND CONTRAST AGENTS

The concept of ultrasound contrast agents is widely acknowledged to have emerged in 1968, when **Gramiak** and **Shah** observed a "cloud" of echoes from the aortic root after injecting saline through an intra-aortic catheter. Since then, many contrast agents have been used to enhance echocardiography. It took more than 20 years to develop the first stable, commercially available and FDA approved USCA (**Feinstein**,1990) **Albunex®**, an albumin-coated and air-filled microsphere. In 1991, **Echovist** was used which has galactose microparticle as shell material but later it was withdrawn. In 1995, **Levovist** was introduced. In **1998, Optison (GE)** was approved for clinical use which uses cross linked serum albumin shell material and octofluoropropane as gas. In **2002, Imagent/Imavist** with phospholipid shell material was introduced. Later in 2014, **Lumason/Sonovue** was produced with sulphur hexafluoride by Bracco diagnostics, Italy.[4]

1.7 MRI CONTRAST AGENTS

In April 1978, **Paul C Lauterbur** at the State University, New York, administered **manganese** (Mn)-II **chloride** solution at a dose of 0.1 mmol/kg body weight into the left ventricle of a Mongrel dog, which was the first MR contrast agent ever used. Gadolinium compound was subsequently introduced. **Heinz Gries** and **Douwy Rosenberg** chose to prepare first well-known salts of Mn-(II)-EDTA, Gd-EDTA, and Mn-(II) citrate, which they passed to **Weinmann** (Fig. 1.14) for initial imaging studies. Mn-(II)-EDTA disodium was well tolerated. The first imaging studies of compound solutions in glass containers were performed under the watchful eye of Weinmann on **May 19, 1981**, at Siemens AG in Erlangen.

In early **August 1981**, the tolerability of **Gd-DTPA** salt was studied by routine methods in the Schering Laboratories. Simultaneously, **Weinmann** performed systematic studies of the effects of paramagnetic chelates at various concentrations on relaxation times, using the facilities of the Physics Department, Berlin. It turned out that Gd-DTPA salt was not only extremely well tolerated by animals and was highly soluble, it also preserved good relaxation properties. Imaging studies at a suitable dose of Gd-DTPA salt confirmed its identification as a **realistic MRI contrast agent**. On May 5, 1982, Weinmann for the first time observed Gd-DTPA dependent enhancement of tumor signal intensity in a live animal model.

Beginning in early 1988, the pharmaceutical product Gd-DTPA dimeglumine 0.5 M for injection, now named Magnevist appeared in various markets, where it was very well received. Within a short time, contrast-enhanced MRI became a routine modality.[5]

1.8 FLUOROSCOPY

In the late 1890s, **Thomas Alva Edison** (Fig. 1.15) began investigating materials for ability to fluoresce when X-rayed and by **1896**, he had invented a fluoroscope with sufficient image intensity to be commercialized. Edison had quickly discovered that **calcium tungstate** screens produced brighter images.[6] Edison, however, abandoned his researches in 1903 because of the health hazards that accompanied use of these early devices. A glass blower (Clarence Dally) of lab equipment and tubes at Edison's laboratory was repeatedly exposed, suffering radiation poisoning.

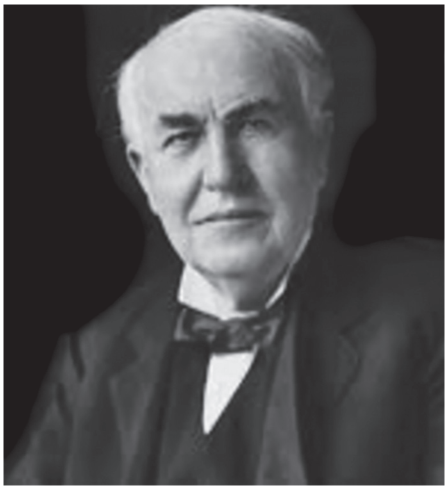
Edison himself damaged an eye in testing these early fluoroscopes. He stopped all experimentation with fluoroscopy and X-rays following the death of Dally.

1.9 RADIATION PROTECTION

Unshielded X-ray tubes and unshielded operators were the rule in 1896, with predictable results. Early reports described a burn like dermatitis, with ulceration. Scientists learned that radiation was not only a source of energy and medicine, it could also be a potential threat to human health if not handled properly. In fact, pioneers in radiation research died from radiation-induced illnesses.

The first case appeared as skin burn in the United States just after several months from November 1895 when Roentgen discovered X-rays. In addition to Dally, Percy Brown lists 26 Americans who died as a result of their pioneering work with X-rays. After this event, radiation damages to the hands and fingers have been reported from several countries such as the UK and Germany.

X-ray protection pioneer **William Herbert Rollins** (Fig. 1.16) was a Boston dentist who, during the period 1896–1904, made numerous original contributions to the emerging science of radiology. He was a true pioneer of radiation protection. Among his contributions, several were pertaining to radiation protection which includes leaded tube housings, collimators and other techniques (including the development of high voltage tubes) to limit patient dose. Rollins also performed a series of experiments that showed X-rays could kill Guinea pigs. His experiments included exposure of a pregnant Guinea pig which resulted in killing of the fetus. Thus, Rollins expressed concern about the use of X-rays in pelvic exams of pregnant women. For a period of several years, Rollins was the quintessential promulgator of radiation protection techniques.



1.15: Thomas Alva Edison

1.16: William Herbert Rollins

1.10 MAMMOGRAPHY

Albert Salomon (Fig. 1.17A) was a German surgeon who is best known for his study of early **mastectomies** that considered the beginning of mammography in 1913.[7] He compared X-ray of the breasts to the actual removed tissue, observing specifically-microcalcifications.

In 1949, Raul Leborgne introduced the **compression technique** (Fig. 1.17B). The widespread adoption of mammography is primarily attributable to the **work of Egan** and his coworkers.

Fig. 1.17A: Albert Salomon

Fig. 1.17B: Leborgne compression technique

In 1960, Egan described a reproducible high milliamperage–low kilovoltage technique that used industrial film and he reported excellent results in imaging the breasts of his first 1000 patients. In 1965, **Charles Gross** from France developed the first unit dedicated to mammography. Ingeniously such an apparatus presented a molybdenum X-ray tube with a 0.7 mm focal spot. In 1999, **GE full filed digital mammography** equipment is introduced. Later **Stafford Warren** reported a stereoscopic technique for mammography. In the year 2011, contrast mammogram came into practice.[8]

1.11 ULTRASONOGRAPHY

Ultrasound consists of mechanical waves with frequencies above the upper limit of auditory sound, i.e. 20 kHz. Echo generation results from the interaction of the incident ultrasound pulse with structures in the tissue medium. In 1794, physiologist **Lazzaro Spallanzani** (Fig. 1.18) was the first to says that bats do not use their eyes for navigation in total darkness, but some other sense (echo location), which forms the basis of USG.

In 1877, **Pierre and Jacques Curie** (Figs 1.19A and B) discovered the **piezoelectric** effect. **In 1942, Karl Theodore Dussik** (Fig. 1.19C), **neurologist and psychiatrist at the University of Vienna, was regarded as the first physician to use ultrasound for medical diagnosis (of brain tumors)**. In 1948, **George D Ludwig** (Fig. 1.20A), an internist at the Naval

Fig. 1.18: Lazzaro Spallanzani

Fig. 1.19: (A) Pierre Curie (B) Jacques Curie (C) Karl Theodore Dussik

Medical Research Institute, developed A-mode ultrasound equipment to detect gallstones.

In 1949–1951, **Douglas Howry** and **Joseph Holmes**, from the University of Colorado pioneered the B-mode ultrasound equipment, including the 2D B-mode linear compound scanner. **John Reid** and **John Wild** invented a handheld B-mode device to detect breast tumors. In 1952, the American Institute of Ultrasound in Medicine (**AIUM**) is founded. In 1953, Physician **Inge Edler** and Engineer **C Hellmuth Hertz** performed the first successful echocardiogram by employing an echo test control device from a Siemens shipyard.[9]

Ian Donald (Fig. 1.20B) (1910–1987), introduced the ultrasound in diagnostic and medicine in 1956, when he used the one-dimensional A mode (amplitude mode) device in order to measure the parietal diameter of the fetal head. He was the **Pioneer of obstetric ultrasound** and Regius, Professor of obstetrics and gynaecology from 1954 to 1976. He was awarded an honorary DSc in 1983.

John Julian Cuttance Wild (Fig. 1.21) (1914–2009) was an English born American physician who was part of the first group to use ultrasound for body imaging. **He is the Father of Medical Ultrasound**.

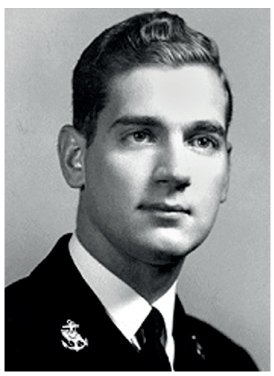


Fig. 1.20A: Ludwig

Fig. 1.20B: Ian Donald

Fig. 1.21: John Jullian Cuttance Wild

Modern ultrasonic diagnostic medical scans are descendants of the equipment, what Wild and his colleagues developed in the **1950s**.

Using A-mode equipment, he studied the lumps, cysts and fibroids to differentiate them from the solid masses in the body. Ian Donald published his results in 1958 in the *Lancet*. Together with Tom Brown, he developed a portable apparatus called **prototype scanner** (Fig. 1.22) which is used to visualize the density of the tissue, which is a turning point in ultrasound application.

Real-time ultrasound machines were introduced in the late 1970s and ultrasound is now the most used technique. **Kazunori Baba** of the University of Tokyo, developed 3D ultrasound technology and captured three-dimensional images of a fetus in 1986. **1994—Olaf von Ramm and Stephen William Smith** of Duke University produced an improved scanner that provides high resolution down to 20 centimetres. The duo and their developed state-of-the-art "Medical Ultrasound imaging integrated circuits" (**MUIC**) are capable of processing signals from multiple real-time phased-array images. In 1996, **Thomas Nelson** and his team published independent studies on **4D** (motion 3D) fetal echocardiography, using sonographic cardiac gating methods to remove artefacts, which are commonly present with static 3D.

1.12 DOPPLER SONOGRAPHY

The **Doppler effect** (or the **Doppler shift**) is the change in frequency of a wave in relation to an observer who is moving relative to the wave source. The phenomenon of Doppler effect was discovered on 25 May 1842. This phenomenon bears the name of its discoverer, **Christian Andreas Doppler** (Fig. 1.23), an Austrian mathematician and physicist, born on November 29, 1803 in Salzburg, Austria.

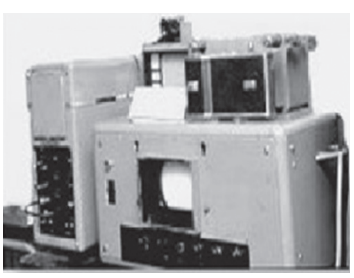


Fig. 1.22: Prototype scanner

Fig. 1.23: Christian Doppler

The first medical applications of Doppler sonography were initiated during the late 1950s, and impressive technologic innovations have been continuing ever since. **Shigeo Satomura** from the Institute of Scientific and Industrial Research of Osaka University reported the record of various cardiac vascular movements. Based on their experience, Satomura suggested the potential use of Doppler sonography for percutaneous measurement of blood flow. **In 1960, Satomura and Kaneko were the first to report construction of ultrasonic flowmeter**.[10]

In 1959, Dean Franklin initiated the development of prototype continuous wave Doppler device. **Donald Baker, Dennis Watkins** and **John Reid** began working on this in 1966 and produced one of the first pulsed Doppler device. During 1970s, many new developments came into ultrasound including spectral wave Doppler, continuous wave Doppler and color Doppler. This Seattle team also pioneered the construction of Duplex Doppler. In 1997, **harmonic imaging** was introduced accidently in the USA, when scientists were working on the development of microbubbles for contrast in echocardiography. They found that a tissue image was still created when the receiver was tuned to receive at twice the transmitted frequency.

1.13 CT SCAN

On **October 1, 1972**, CT scanning was first introduced by **Sir Godfrey Hounsfield** (Fig. 1.24) into medical practice with a successful scan on a patient at the Atkinson Morley Hospital in Wimbledon, London using a prototype scanner (Fig. 1.25). Godfrey Hounsfield was an unassuming British scientist who was born and raised near Newark in England. Prior to joining EMI in 1949, he worked on aircraft maintenance and radar for the RAF during the Second World War. At EMI, he continued his work on radar and then made some major advances in the field of computers.

Godfrey Hounsfield was working in the central research laboratory of EMI (Electric and Musical Industries Ltd) in UK. Hounsfield conceived the idea of a tomographic X-ray scanner in 1967 and EMI was able to fund Hounsfield to do his research.

Hounsfield, together with Dr Jamie Ambrose, a radiologist presented a paper entitled '**Computerized Axial Tomography**' at the 32nd Annual Congress of the British Institute of Radiology. **Dual energy CT** was also introduced by **Hounsfield in 1973**. Two pictures were taken of the same slice with one at 100 kV and another at 140 kV. Dual energy methods were further subsequently investigated by **Alvarez** and **Makowski in 1976**.

Willi A Kalender (Fig. 1.26), the German physicist, developed and introduced the helical CT scan in 1989.

Fig. 1.25A: EMI scanner

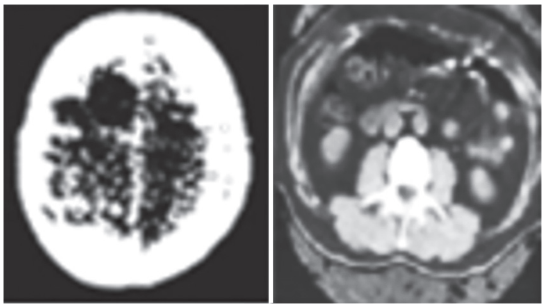


Fig. 1.25B: The first CT image of the brain and Godfrey Hounsfield's own abdomen

Fig. 1.24: Godfrey Hounsfield

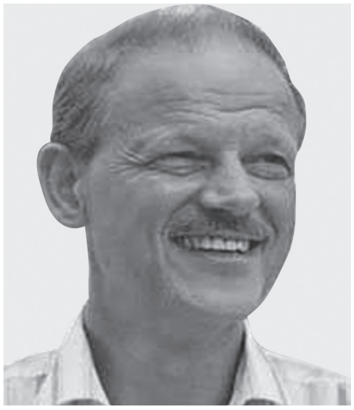


Fig. 1.26: Willi A Kalender

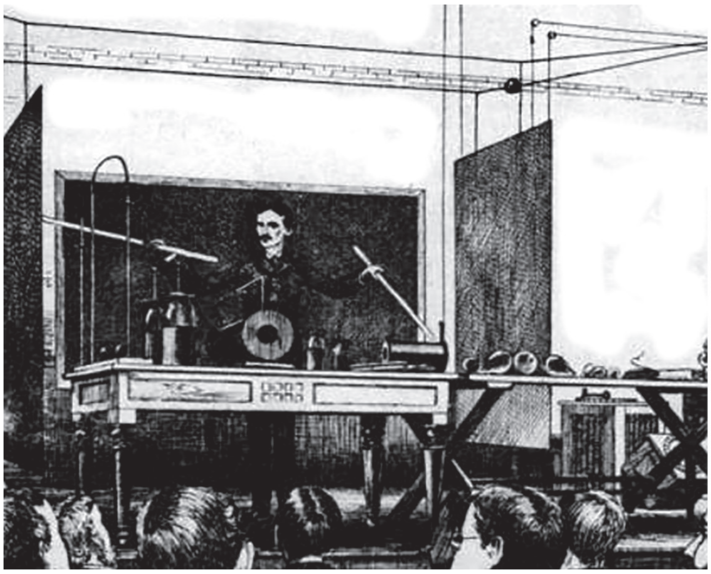



Fig. 1.27: (A) Nikola Tesla demonstrating the interventions in the society meeting (B) Isidor Isaac Rabi

1.14 MAGNETIC RESONANCE IMAGING (MRI)

Nikola Tesla (1.27A), the Serbian-American engineer and physicist, described the **rotating magnetic field in 1882** and made the operation of alternating current (AC) possible which is instrumental in MRI. The **discovery of NMR** goes to **Isidor Isaac Rabi** (Fig. 1.27B), working at New York City's Columbia University in the 1937, Rabi and his team were attempting to measure the magnetic properties of various nuclei including hydrogen, deuterium, and lithium. Using a modification of Otto Stern's apparatus, Rabi described how nuclei could be induced to flip their principal magnetic orientation by an oscillating magnetic field and he was awarded Nobel prize in physics in 1944. This idea was originally proposed by Dutch physicist **Cornelius J Gorter** in 1936 (one year before Rabi's successful demonstration), but Gorter was unable to validate this phenomenon due to limitations of his experimental setup. Gorter is known as "**the man who *almost* discovered NMR**."[11]

The first truly successful NMR phenomenon were reported in early 1946, by two independent teams. One of these teams was led by **Felix Bloch** at Stanford University. Bloch obtained PhD from the University of Leipzig in 1928.

The other team was led by **Edward M Purcell** at MIT. Purcell obtained a PhD from Harvard in 1938. **Bloch** and **Purcell** (Fig. 1.28) were awarded the Physics Nobel prize in 1952 for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith.[12]

Interest in the medical diagnostic possibilities of NMR began in 1971 with the study by **Raymond Vahan Damadian** (Fig. 1.29).

Fig. 1.28: Bloch (left) and Purcell (right)

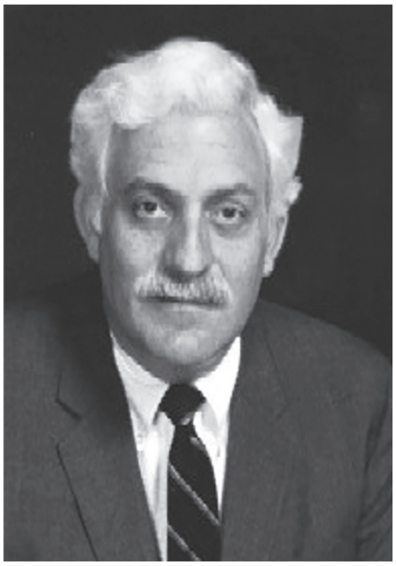


Fig.1.29: Raymond Vahan Damadian

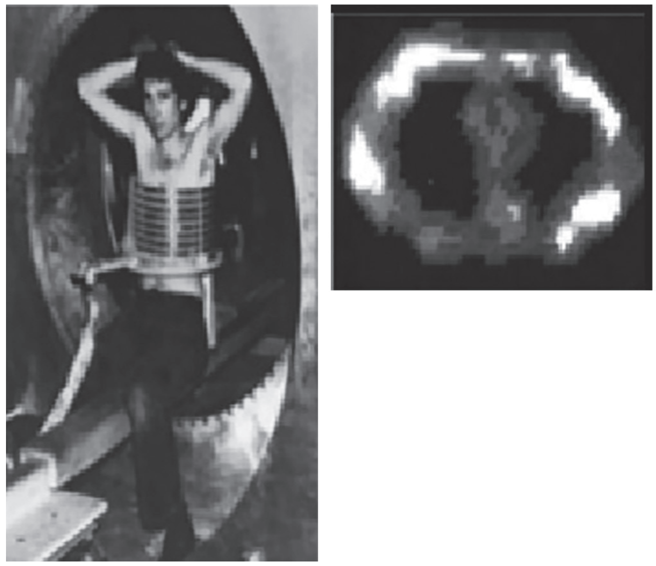


Fig.1.30A: The first MRI image

Raymond is an American physician, medical practitioner, and **inventor of the first MR (magnetic resonance) Scanning Machine**.[13,14] He studied the differences in relaxation times T1 and T2 between different tissues and between normal and cancerous tissue. His research into sodium and potassium in living cells led him to his first experiments with nuclear magnetic resonance (NMR) which caused him to perform a full body scan of a human being in 1977 to diagnose cancer. He invented an apparatus and method to use NMR safely and accurately to scan the human body, a method now well known as **magnetic resonance imaging**. In 1977, first ever MRI image (Fig. 1.30A) of human body with **field strength of 0.05T** was taken and it tooks 4 hours to collect a single slice.This huge amount of time for a single slice was unacceptable. Meanwhile, **Lauterbeur** and **Mansfield** started work on this new principle trying to make the process faster.

In 1952, **Herman Carr** created a one- dimensional MR image and the use of magnetic gradients for spatial localization. **Lauterbeur** discovered that two-dimensional images could be produced by introduction of **gradients in a magnetic field**. In 1973, he described how the addition of gradient magnets to the main magnet made it possible to visualize a cross-section of tubes with ordinary water surrounded by heavy water—a feat not possible with any other imaging method. **Mansfield** discovered that the use of gradients in the magnetic field could rapidly and effectively be analyzed and transformed to an image. He has also shown how extremely **rapid imaging** could be achieved by **very fast gradient variations**. This approach became possible in clinical practice a decade later." **Paul C Lauterbr** and **Sir Peter Mansfield** (Fig. 1.30B) were then **jointly awarded the 2003 Nobel Prize in Physiology or Medicine for their discoveries concerning magnetic resonance imaging**.[15]

In 1974, **Hinshaw** introduced the "sensitive point" technique, another sequential point scanning technique using three alternating gradients fields. In 1977, Hinshaw published a surprisingly detailed cross-sectional image of the human wrist using this technique.

Another early and essential contribution to MRI was made by **Richard Ernst** (Fig. 1.31). During the 1960s, he had introduced **Fourier transform** NMR spectroscopy. In 1975, he realized that one should be able to generate 2- or 3D NMR images by applying switched

Fig. 1.30B: Paul C Lauterbeur (left) and Peter Mansfield (right)

Fig. 1.31: Richard Ernst

magnetic field gradients and then employing the Fourier transform methods that are now a mainstay of modern MR image reconstruction.[16] He was awarded the **Nobel Prize in Chemistry in 1991** for contributions to the development of the methodology of high resolution nuclear magnetic resonance (NMR) spectroscopy.[17]

Paul Lauterbeur appeared at the 1979 annual meeting of the Radiological Society of North America in Atlanta to announce the development of what would later be called magnetic resonance imaging. His presentation referred to the field strength of the magnet used to produce the images in a way that anticipated now-familiar designations such as 1 T, 1.5 T, and 3 T.

1.15 INTERVENTIONAL RADIOLOGY

In **1967, Sven Ivar Seldinger** (Fig. 1.32) introduced the idea of how to administer a catheter that would be able to reach every human artery. He was born on 19th April 1921 in Dalarna, Sweden. He first began his medical training in 1940 at the Karolinska Institute. He was qualified with the title of Docent in Radiology in 1967 after successfully defending his thesis on percutaneous transhepatic cholangiography. He was later able to demonstrate, using "phantom experiments" on how one could insert a catheter into the femoral artery and reach both the parathyroid and renal arteries.[4]

Fig. 1.32: Sven Ivar Seldinger

In **1964, Charles Theodore Dotter** (Fig. 1.33), the vascular and interventional radiologist was the first to describe flow-directed balloon catheterization, the double-lumen balloon catheter, the safety guidewire, and the "J" tipped guidewire. He was then known as the "**Father of Interventional Radiology**".[17] He was also a leading force in Machlett's development of an X-ray tube capable of obtaining millisecond exposures. Percutaneous transluminal angioplasty was his landmark contribution. Dotter (along with Marcia K Bilbao) invented the "loop-snare catheter" for retrieving intravascular foreign bodies. **Julio Palmaz**, an intervention radiologist, introduced the balloon-expandable stent in 1985.

Dotter was the 1st to describe flow-directed balloon catheterization, the double-lumen balloon catheter, the safety guidewire, percutaneous arterial stenting, and more. This practical mastermind dedicated his entire energy to the belief that there is always a better way to treat a disease. His personal contributions to clinical medicine, research, and teaching have saved millions of limbs and lives all over the world.

A Second Source of Radiation: Radioactivity

Shortly after the discovery of X-rays, another form of penetrating rays was discovered. In **1896**, French scientist **Henri Becquerel** (Fig. 1.34) discovered natural **radioactivity**. He was born in Paris into a family which produced four generations of scientist. He won the Nobel Prize for Physics in 1903. Becquerel demonstrated that the radiation emitted by uranium certain characteristics like X-rays but, unlike X-rays, it could be deflected by a magnetic field and therefore must consist of charged particles.

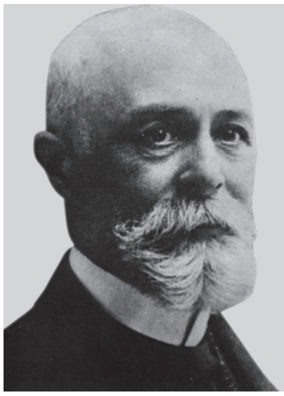


Fig. 1.34: Henri Becquerel

Pierre Curie (*see* Fig. 1.19A) was a French physicist, a pioneer in crystallography, magnetism, piezoelectricity and radioactivity. In 1903, he received Nobel Prize in Physics.

Marie Skłodowska Curie (Fig. 1.35) was a Polish and naturalized French physicist and chemist who conducted pioneering research on radioactivity. She was the **first woman** to win a **Nobel prize, the only woman** to win in **two fields**, and the only person to win **in multiple** sciences. Under her direction, the world's first studies were conducted into the treatment of neoplasms, using radioactive isotopes. She founded the **Curie Institutes in Paris** and in **Warsaw**, which remain major

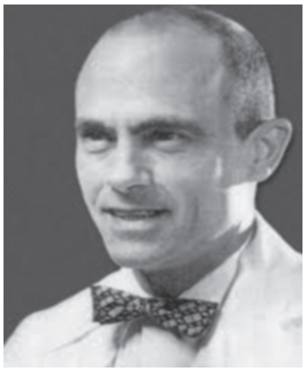


Fig. 1.33: Charles Theodore Dotter

Fig. 1.35: Marie Sklodowska Curie

centres of medical research today. During World War I, she established the first military field radiological centre.[18]

1.16 NUCLEAR MEDICINE

Nuclear medicine is a radiology "done inside out" or "endo-radiology", because it records radiation emitting from the body rather than radiation that is generated by external sources. **Gamma camera** also called **scintillation camera or Anger camera**, is a device used to image gamma radiation emitting radioisotopes. The origin of this medical idea date back as far as the mid-1920s in Freiburg, Germany, when **George de Hevesy** made experiments with radionuclides administered to rats, thus displaying metabolic pathways of these substances and establishing the tracer principle.

Possibly, the genesis of this medical field took place in 1936, when **John H Lawrence** (Fig. 1.36A), known as "**The Father of Nuclear Medicine**" took a leave of absence from his faculty position at Yale Medical School to visit his brother Ernest Lawrence at his new radiation laboratory in Berkeley, California.[19]

The highly efficient method of detecting gamma rays was discovered in 1944 by **Sir Samuel Curran**. He is the **inventor of the scintillation counter, the proportional counter, and the proximity fuse.** Nuclear medicine first became recognized as a potential medical specialty in 1946 when it was described by **Sam Seidlin** in the Journal of the American Medical Association. In 1949, **Benedict Cassen** developed the **first rectilinear scanner** which was further developed into the first useful **scintillation camera (Anger camera) by Hal O Anger in 1957.** The concept of emission and transmission tomography was introduced by **David E Kuhl, Luke Chapman** and **Roy Edwards** in the late 1950s.

Work by **Gordon Brownell, Charles Burnham** and their associates at the Massachusetts General Hospital beginning in the 1950s contributed significantly to the development of **Positron Emission Tomography-PET** technology and included the first demonstration of annihilation radiation for medical imaging. In 1961, **James Robertson** and his associates at Brookhaven National Laboratory built the first single-plane PET scan, nicknamed the "head-shrinker'. The **first PET camera** was built for human studies by **Edward Hoffman, Michael M Ter-Pogossian, and Michael E Phelps in 1973.**

1.17 DISCOVERY OF RADIO PHARMACEUTICALS

In 1932, **Ernest O Lawrence** (Fig. 1.36B) and **M Stanley Livingston** published the first article on "the production of high speed light ions without the use of high voltages." It was a milestone in the production of usable quantities of radionuclides. In 1936, **John H Lawrence** made the first clinical

Fig. 1.36A: John H Lawrence

Fig. 1.36B: Ernest O Lawrence

therapeutic application of an artificial radionuclide when he used phosphorus-32 to treat leukemia. In 1938, **Emilio Segre** and **Glenn Seaborg** discovered technetium-99m. In 1940, **Saul Hertz** gave a patient the first therapeutic dose of iodine-130.[19]

In 1946, **Allen Reid** and **Albert Keston** discovered iodine-125, which became important in the field of radioimmunoassay. In 1947, **Benedict Cassen** used radioiodine to determine whether a thyroid nodule accumulates iodine, helping to differentiate benign from malignant nodules.

1.18 ARTIFICIAL INTELLIGENCE IN RADIOLOGY

The term artificial intelligence is credited to **John McCarthy**, a mathematician (and the creator of the LISP programming language). **Computer aided diagnosis (CAD)** is the use of a computer-generated output as an assisting tool for a clinician to make a diagnosis. It is different from automated computer diagnosis, in which the end diagnosis is based on a computer algorithm only. The breakthrough paper, "**Reducibility among Combinatorial Problems**" by **Richard M Karp** made it clear that there were limitations but also potential opportunities when one develops algorithms to solve groups of important computational problems. **In 1998, the first commercial CAD system for mammography, the ImageChecker system**, was approved by the US Food and Drug Administration (FDA). In the following years, several commercial CAD systems for analyzing mammography, breast MRI, medical imagining of lung, colon, and heart also received FAD approvals. Currently, CAD systems are used as a diagnostic aid to provide physicians for better medical decision-making.[20] In 2008, molecular imaging saw widespread fusion of images with PET CT scans, which permits a functional understanding of the underlying causes of disease in the body by joining functional and anatomical information in the same image.

1.19 3D-PRINTING IN RADIOLOGY

While use of advanced visualization in radiology is highly important in diagnosis and communication with referring clinicians, there is a huge need to render digital imaging and communications in medicine (DICOM) images as three-dimensional (3D) printed models (Fig. 1.37)[21] capable of providing both tactile feedback and depth information about anatomic and pathologic states. The earliest record of 3D printing through the additive

Fig. 1.37: Three-dimensional printed models used for surgical planning in two patients with facial trauma. Surgeons can use these models for charting out the optimal plan for reconstruction in case of extensive injuries

process is of the Japanese inventor **Hideo Kodama in 1981**. He created a product that used ultraviolet lights to harden polymers and create solid objects. **Charles Hull** developed the technique of stereolithography.

Courtesy: WikiMedia Commons

MILESTONES IN THE FIELD OF RADIOLOGY

Pre-Roentgen era

1794 Physiologist Lazzaro Spallanzani described the concept of echo location

1842 Doppler effect described by Christian Andreas Doppler

1877 Pierre and Jacques Curie discovered the piezoelectric effect

1882 Nikola Tesla—described the rotating magnetic field and made the operation of alternating current (AC) possible

1895 Wilhelm Roentgen detected X-rays

Post-Roentgen era

1896 Antoine Henri Becquerel discovered radioactivity

1896 Thomas Edison invented the first commercially available fluoroscope

1898 Marie Curie published her paper "Rays Emitted by Uranium and Thorium Compounds"

1913 Albert Salomon commenced research leading to mammography

1927 Egas Moniz developed cerebral angiography

1934 Frederic and Irene Joliot-Curie artificially produced radioisotopes

1936 John Lawrence used phosphorus-32 to treat leukemia

1939 Kitty Clark published Clark's Positioning in Radiography

1950 David Kuhl invented Positron Emission Tomography (PET) and John Julian Cuttance Wild became the first person to use ultrasound for body imaging, most notably for diagnosing cancer.

1951 Benedict Cassen, Lawrence Curtis, Clifton Reed and Raymond Libby automated a scintillation detector to "scan" the distribution of radioiodine within the thyroid gland.

1953 Gordon Brownell and HH Sweet built a positron detector based on the detection of annihilation photons by means of coincidence counting.

1953 Sven-Ivar Seldinger developed his famous technique of vascular access

1957 Ian Donald invented fetal ultrasound

1964 Charles Dotter introduced image-guided intervention

1972 Godfrey Hounsfield introduced the CT scanner (co-developed with Allan Cormack)

1976 Ronald Jaszczak developed the first dedicated head SPECT camera.

1977 Ray Damadian built the first commercial MRI scanner

1987 The Center for Emerging Cardiovascular Technologies at Duke University headed by Olaf von Ramm developed a real-time 3D volume scanner for imaging the cardiac structures.

1989 Daniel Lichtenstein, a French professor, pioneered general ultrasound in intensive care. Lichtenstein called ultrasound 'the real stethoscope'.

1995 ADAC Laboratories shipped the first SPECT camera to offer coincidence detection capable of FDG/PET imaging.

2008 The first hybrid PET/MRI system for humans, created by Siemens, was installed.

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