SEEING WITH SOUNDS : FROM BATS TO MEDICAL ULTRASONOGRAPHY

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From the time of Hippocratus (Greece -460 -377) practitioners relied on the patient's external aspect as well as on faecal, urinary, pus, and expectorations studies; the patient's inside remaining a frustrating mystery.

This explains the efforts to build some appropriate equipment to investigate the hidden parts of the body. In the 19th century there appeared the ophthalmoscope (1851, H.L. Helmhotz, Germany 1821-1894), the laryngoscope (1854, M.Garcia, Spain , 1805-1906), the cystoscope (1879, M. Nitze, Austria, 1848-1906) and, at turn of the century, ... radiography (1895, W.C. Röntgen, Germany, 1845-1923).

As far as sounds were concerned, thoracic percussion was defined in 1761 (L. Auenbrugger , Austria, 1722-1809); direct auscultation and the stethoscope were discovered by R. Laennec (France, 1781-1826) in 1819.

Introduction : the bio(logical) sonar.

In the animal world, whales, dolphins and bats have been moving around for thousands of years using ultrasound. It was not until 1794 that man discovered the existence of this phenomenon. The Italian naturalist L. Spallanzani (1729-1799) carefully studied bats and discovered that they did not use their visual capacity to move around but rather their acoustic capacity. This capability enables them to avoid obstacles in absolute darkness (1). Spallanzani concluded that bats definitely used a "sixth sense" but he was uncertain what that sense was or how it worked.

A Swiss zoologist L. Jurine (Switzerland 1751-1819) found that bats could "see" with their ears possibly using sound (2); however, his ideas were rejected by his colleagues.

In 1795, Baron G. Cuvier (France 1769-1832) decided that bats detected obstacles with the wing membranes (3), and this theory was widely accepted ... but it was not true!

Before World War I, Sir Hiram Maxim St., (USA 1840-1916) thought that bats somehow sensed the compression of the atmosphere caused by their ongoing flight with their inner ear. He believed that bats used "sonar", but mistakenly thought they used low-frequency sounds generated by wing movements. (4)

G.W. Pierce (USA 1872-1956) and D.R. Griffin (USA 1915-) first found in 1938 that bats emit a high-frequency sound. (5) The work by Pierce and Griffin made the auditory theory more plausible. The auditory theory states that bats make a sound with their mouths, bounce it off obstacles and prey, and sense it with their ears.
D.R. Griffin and R. Galambos (USA 1914-) decided in 1941 that they wanted to test this theory; it was true! They discovered that bats used sounds and the echoes of these ultrasonic frequencies to locate objects – hence the term "echolocation" **(fig.1)** (6). Echolocation is "sonar sight" for bats. It is similar to the sonar used by the military, and later by the civilian.

The piezoelectricity of quartz.

The word « piezoelectricity » is derived from the Greek « piezin », which means « to press ». It is electricity that is generated by the pressure on crystals. Quartz, or silicon dioxide (SiO_2), has proved to be the preferred material.

The "Abbé" R.-J. Haüy's (France, 1743-1822) experiments in 1817 suggested that any charges which were produced by compression might have been caused by simple «friction or contact electricity ». (8)

A.C. Becquerel (France, 1788-1878) did suggest already in 1819 that such charge potential production could occur by stretching rubber. By correlation, he suggested in 1833 that experiments using crystalline minerals might also show similar effects. (9)

The discoverers of the « piezoelectric phenomenon » were in 1880 P. Curie (France, 1859-1906) and J. Curie (1855-1941). They had a good idea of what they were looking for, plus the experimental background and facilities to carry on the search to its conclusion.
The Curie brothers' work involved slices of various crystals to which tinfoil electrodes were glued. The outer surfaces of these electrodes were then insulated by applying sheets of hard rubber. The electrodes, in turn, were connected to a « Thompson electrometer ». Alternately, one electrode was connected to the ground and the other to the electrometer, after which pressure was exerted on the insulated electrodes, thereby distorting the lattice structure of the material under test. Any surface charges generated were easily measured by the electrometer.
At the April, 1880 **(fig.2)** meeting of the Société Minéralogique de France, a report on the brothers' findings was read by Pierre Curie. During discussions following the reading of that report, the word «piezoelectricity» was suggested and adopted as a name for the phenomenon. (10)

In 1881,G. Lippmann (France, 1845-1921) suggested that the reverse effect, that is the reimposition of surface charges would induce mechanical deformation, should also exist. A year later, the Curie brothers (1882), experimentally verified this assumption by showing that the coefficients for both the direct and reverse effects were identical. (11)

The dearth of applications for piezoelectricity caused the study of the phenomena to be largely confined to demonstrations in laboratory conditions.

From bell to sonar !

Sonar (an acronym for Sound, Navigation and Ranging), an American term dating from World War II, is a system for underwater detection and location of objects by acoustic echo.The first "Sonar", invented during World War I by American, British and French scientists, were used to located submarines and icebergs and were called ASDICS (for Anti-Submarine Detection Investigation Committee).

J.-D. Colladon (1802-1893) a Swiss physicist and Ch.-F. Sturm (1803-1855) a French mathematician, used an underwater bell in an attempt to calculate the speed of sound in the waters of the Lake of Geneva, Switzerland. In his experiment in 1826 an underwater bell was struck; the sound from the bell underwater was heard through a trumpet-like device in the water ! Despite these crude instruments, they managed to determine that the speed of sound under water was 1435 metres/second, a figure not too different from what is known today ! (12)

J.W. Strutt (Lord Rayleigh) (1842-1919) published in 1877 the famous "Treatise on the theory of sound" in which the fundamental physics of sound vibrations (waves), transmission and refraction were clearly delineated. (13)

A English meteorologist, L. F. Richardson (1881-1953), attempted to detect in 1912 underwater objects with audible echo sounding, some weeks after the Titanic sank . The first patent for an under-water echo ranging "sonar" was filed at the British Patent Office, one month after the sinking of the Titanic ! (14) (15) For reasons unknown, he never fully developed those devices.

In 1914, another system (Fathometer) with sonic perceptible waves was designed and built in the United States by the Canadian R. A. Fessenden (1866-1932), the father of Radio Broadcasting, (Patent was introduced in April 2, 1914), (16). The Fessenden sonar (a submerged microphone) could also detect icebergs up to some miles away.

P. Langevin (1872-1946), a French physicist and a student of P. Curie, and C. Chilowsky (?-1958) a Russian electrical engineer in Switzerland turned the investigations in the direction of ultrasounds. They applied in 1916 for patents in the matter of : "Procédés et appareils pour la production de signaux sous-marins dirigés et pour la localisation à distance d'obstacles sous-marins." and were granted a French Patent (502,913) on March 4, 1920 (application date: May 29, 1916). (17). The electrostatic transducer was not a great success in this application, and was soon replaced by a piezoelectric device **(fig.3)**, in around 1916 (shortly after the original application for patent was filed). (18)

The war ended before Langevin's project was successful, but he continued his work after the war and was at last successful in his efforts. All modern sonar applications are a direct result of Langevin's efforts.

From flaws detection in metal...
to medical ultrasonography.

An important development in ultrasonics which had started was the construction of pulsed-echo ultrasonic metal flaw detectors. Particularly relevant at that time was the checking of the integrity of the metal hulls of large ships and the armour plates of battle tanks ... . The concept of ultrasonic metal flaw detection was first suggested by the Soviet scientist S. Y. Sokolov (1897-1971) in 1928 at the Electro technical Institute of Leningrad. (19)

During World War II, the industrial use of ultrasonic testing started simultaneously in three countries : UK, Germany and USA. The key-persons, D. O. Sproule (1903-), A. Trost and Fl. A. Firestone (1896-1986) had no knowledge of each other as they worked strictly in secret. Sproule made the first receiving / transmitting ultrasonic probe on the same side of the work piece (20). Firestone was the first to realize at the university of Michigan the reflection technique (Reflectoscope). He modified a radar instrument and developed for non-military use a transmitter with short pulses and an amplifier with short dead-zone (first ultrasonic oscilloscope) (US-Patent 2 280 226 "Flaw Detecting Device and Measuring Instrument" April 21, 1942). (21)

The same period one saw further developments of naval and military radar equipment (using electromagnetic waves rather than ultrasound), and faster electronics, which facilitated enormously the design of the SONAR and ultrasonic detector devices.

In 1937, the Austrian psychiatrist K. Th. Dussik (1908-) **(fig. 4)** together with his brother Friederich who was a physicist, used a continuous transmission ultrasonic equipment for medical diagnosis in order to visualize the intracranial structures. (22) This application (called "hyperphonography) was highly controversed, because of the numerous artefacts generated by the bones.

In 1949, internist G. Ludwig (1914-) **(fig.5)** together with engineer F. Struthers from the Naval Medical Research Institute at Bethesda (USA) was able to develop A-mode echography by using discarded military equipment; he experimentally demonstrated gallstones and foreign bodies embedded in animal tissue. (23) The A-mode presentation was just a curve and so could not produce images.

At the World Chamberlain Naval Air Station, J. Wild (1914-), an English surgeon who had emigrated to the United States, and a Navy Radar operator, J. Neal, used a 15 MHz transducer and demonstrated in 1951 that A-mode echoes could, in vivo, discriminate normal tissues from diseased ones **(fig.6)**. (24)

Thereafter, researches blossomed all over the world and we shall mention only the major ones.

Also in 1951, in Sweden L. Leksell (University of Lund) still using the ultrasonic A-mode achieved, only in 1955, the first crania-encephalograph **(fig.7)** which became essential in cases of cranial trauma. (25)

In 1952, an American radiologist, Dr. D. Howry (1920-1969) **(fig.8)** and the engineer W. R. Bliss, used spare parts from surplus Navy sonar and of Air Force radar equipment at a frequency of around 2,5 MHz in combination with a rotating ring from a Bomber gun turret. All of it was immersed in a degassed water tank and generated the first two-dimensional B-mode pulse echo scan. (26) The problems inherent in this kind of water-bath coupling system for ill patients were obvious. It is suggested by some that the B-mode denomination took its origin from the name of the B29 bomber !

A different technique, called at that time "transducer in a can", which happened to be the first hand-held contact real-time B-mode scanner (fig), was again designed in 1952 by J. Wild in collaboration with the engineer J. Reid (1926-). They named the method "echography" and also developed a whole range of ultrasonic transducers (transrectal and transvaginal). **(fig.9)** (27)

Doppler's (1803-1853) phenomenon was discovered in 1842. (28) The Swedish doctor I. Elder (1911-2001) and German physicist C. H. Hertz (1910-1990) (29), simultaneously with a Japanese team led by Sh. Satomura (1919-1960) (working on Doppler echocardiography), developed in 1954 a pulse echo motion mode echocardiograph with presentation of the first commercial equipment in 1959 **(fig.10)**. (30) Its radiological applications were mainly used by very active Japanese teams and at present almost all this line of equipment is made in Japan !

A later gynaecologist, I. Donald (1910-1987) served in the RAF during WW2 and learned the technology of sonar and radar ! After a meeting with J. Wild, I. Donald **(fig.11)** and the engineer T. Brown (1933-) (Glasgow) produced in 1958 a prototype of the first manually and automatic compound B-mode contact sector-scanner. Its impact on medicine, particularly in gynaecology, was instant; the technology was finally accepted. The instrument employed a scanning carriage suspended from an overhead framework. The transducer, mounted within the scanning head was capable of continuous contact with the patient's body surface and could pivot at any point within the cross-sectional plane of the scan. (31)

The first commercially produced medical equipment appeared in 1963 with the Diasonograph (Kelvin Hughes Co, later Smiths) by D. Cameron (1939-) then in 1965 by Siemens with the first commercial famous real-time Vidoson by R. Soldner.

The beginning of 3D appeared in 1958. After 10 years of research, T. Brown of Glasgow developed in 1967 the world's first 3D ultrasound scanner **(fig.12)**. (32) It was not a commercial success ... it changed later !

Finally, the linear array transducers was designed in 1971 by a Dutch team under the direction of N. Bom **(fig.13)**. (33) With the Dutch company Organon Technika they produced in 1972 the Multiscan system, probably the first commercial linear array.

Conclusion

The old dream of visualizing medical ultrasounds and their echoes was finally realized. So this young method used in medical imaging appears to be the peaceful development of a military technique. Sounds which were provided by auscultation and percussion could only be detected ... in the listening physician's brain. It is only in the last half century or so that medical doctors are finally able to visualize ultrasounds used in medicine.

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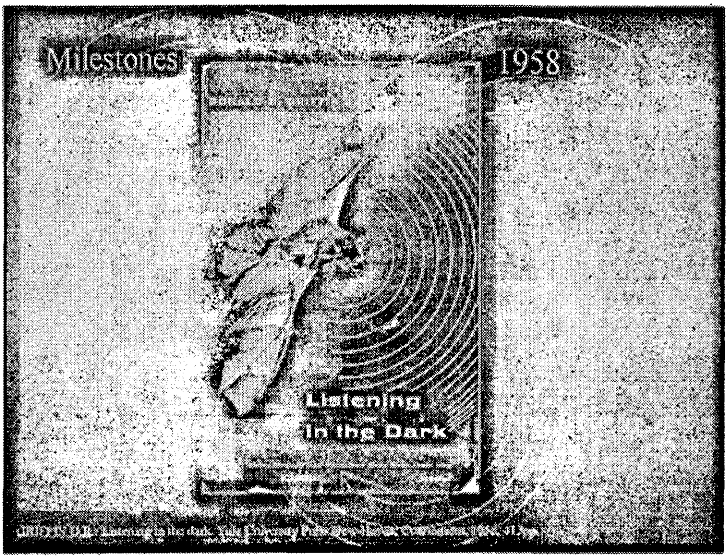


Fig. 1

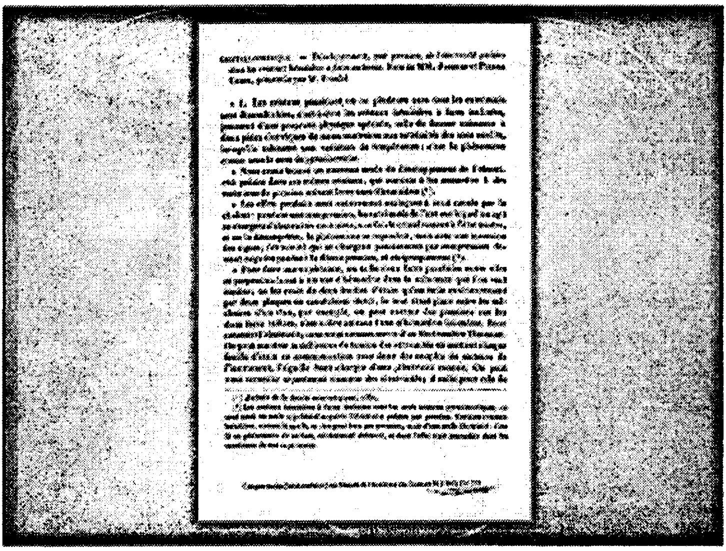


Fig. 2

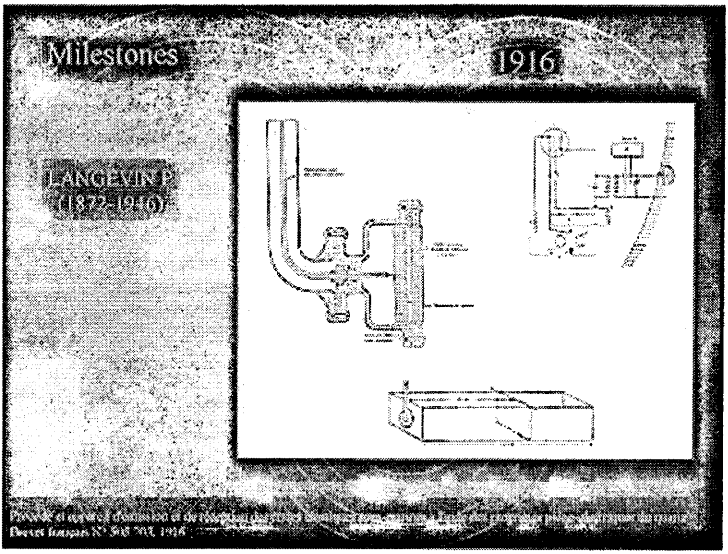
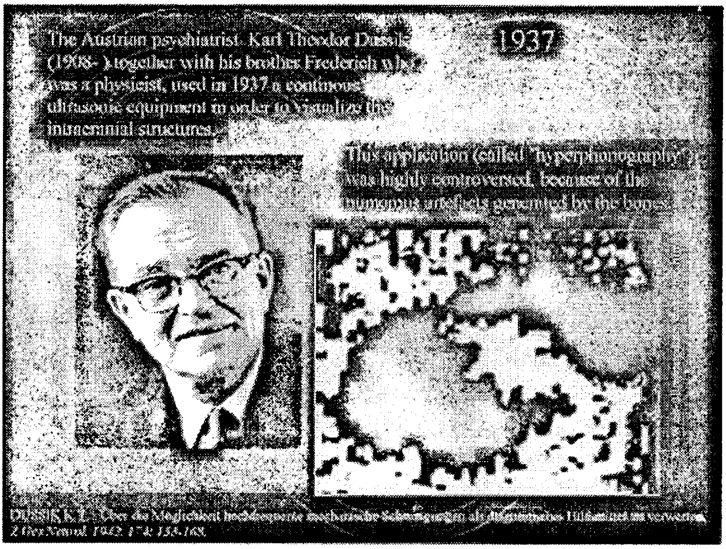

Milestones
1916
LANGEVIN P.
(1872-1946)
Brevet français N° 505 703, 1916

Fig. 3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1937
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DUSSIK K.T.
Z Ges Neurol. 1942; 174: 153-168.

Fig. 4

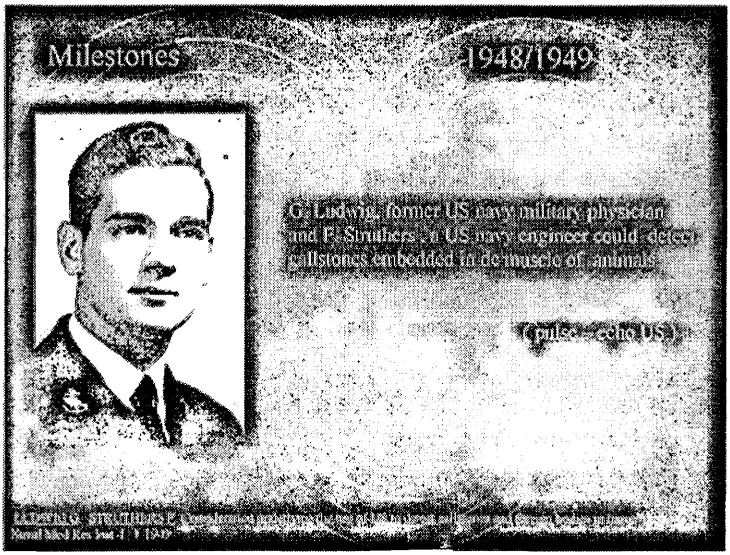
Milestones
1948/1949
G. Ludwig, former US navy military physician and F. Struthers , a US navy engineer could detect gallstones embedded in de muscle of animals
(pulse – echo US)

Fig. 5

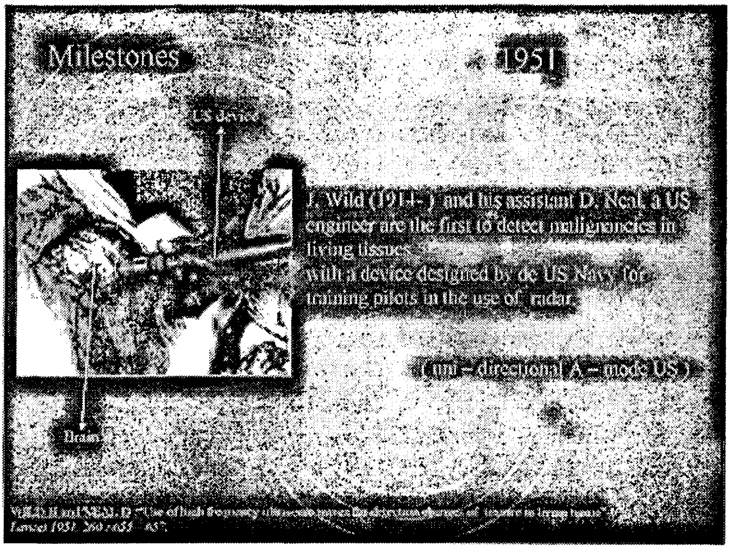
Milestones
1951
US device
Brain
J. Wild (1914-) and his assistant D. Neal, a US engineer are the first to detect malignancies in living tissue
with a device designed by de US Navy for training pilots in the use of radar
(uni – directional A – mode US)

Fig. 6

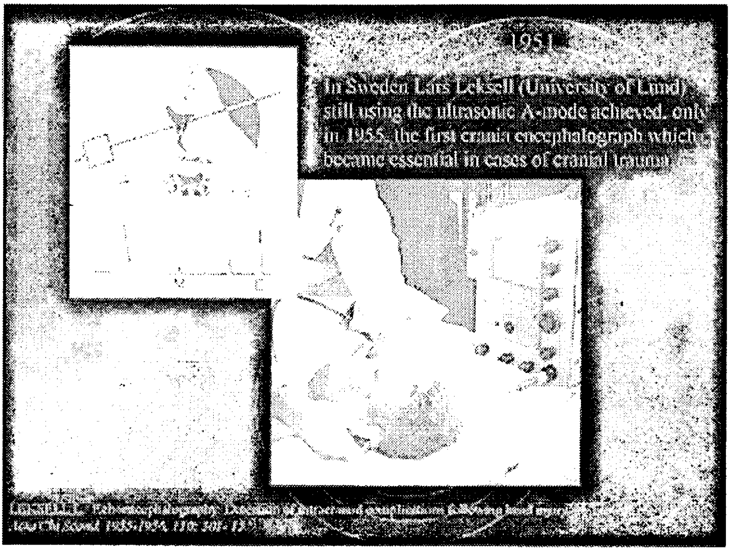
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Fig. 7

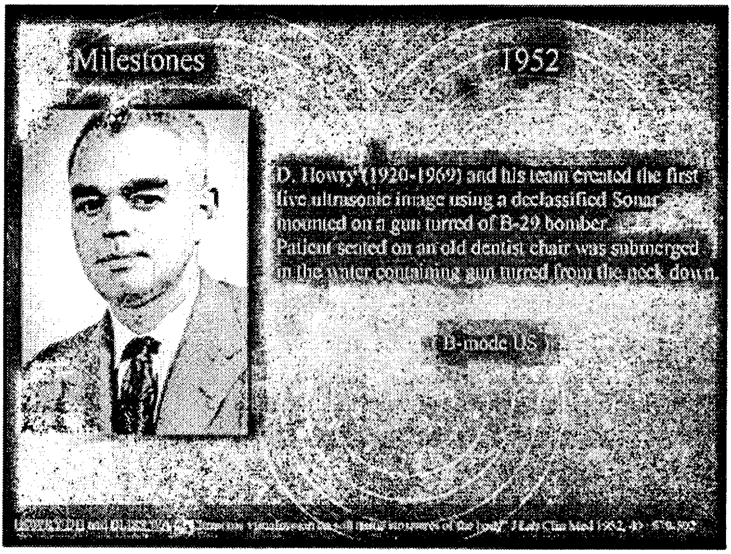

Milestones
1952
D. Howry (1920-1969) and his team created the first live ultrasonic image using a declassified Sonar mounted on a gun turred of B-29 bomber.
Patient seated on an old dentist chair was submerged in the water containing gun turred from the neck down.
B-mode US

Fig. 8

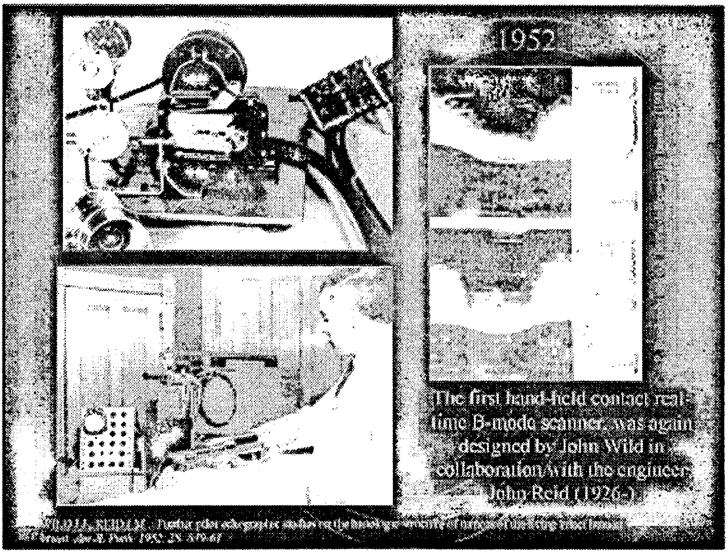

1952
The first hand-held contact real-time B-mode scanner, was again designed by John Wild in collaboration with the engineer John Reid (1926-)

Fig. 9


+/- 1954

Fig. 10

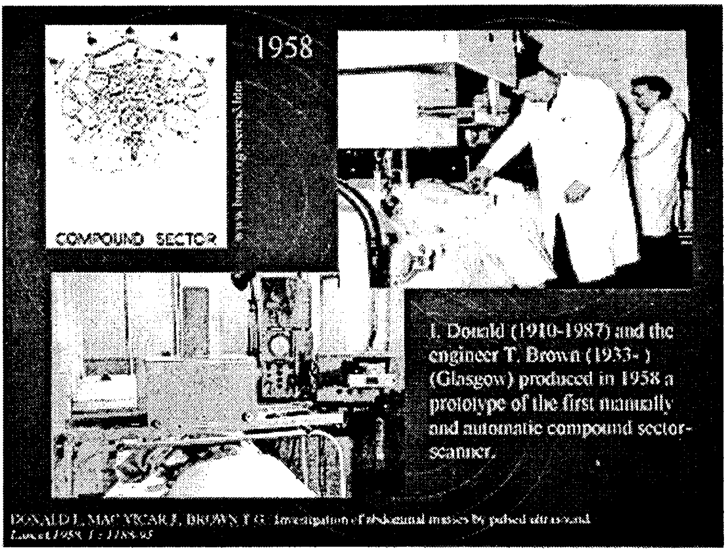
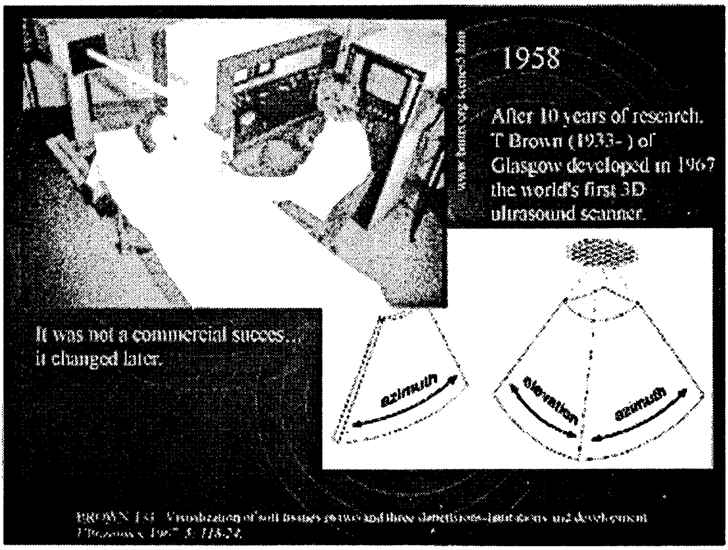

1958
COMPOUND SECTOR
I. Donald (1910-1987) and the engineer T. Brown (1933-) (Glasgow) produced in 1958 a prototype of the first manually and automatic compound sector-scanner.

Fig. 11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It was not a commercial succes... it changed later.
azimuth
elevation
azimuth

Fig. 12

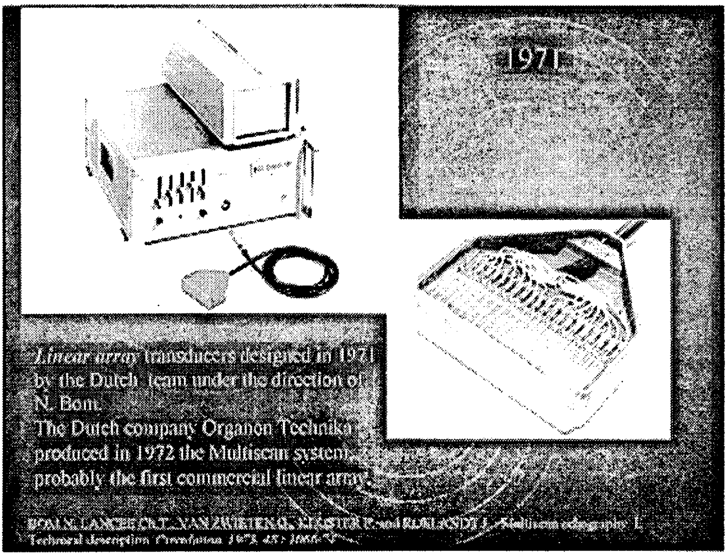
1971
Linear array transducers designed in 1971
by the Dutch team under the direction of
N. Bom.
The Dutch company Organon Technika
produced in 1972 the Multiscan system,
probably the first commercial linear array.

Fig. 13