A short History of the development of Ultrasound in Obstetrics and Gynecology

Dr. Joseph Woo

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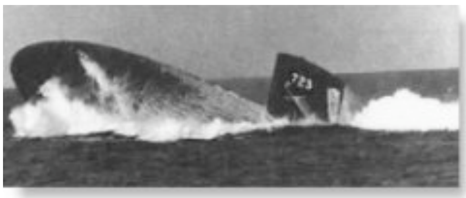
read this first

The story of the development of ultrasound applications in medicine should probably start with the history of measuring distance under water using sound waves. The term **SONAR** refers to **Sound Navigation and Ranging**. Ultrasound scanners can be regarded as a form of 'medical' Sonar.

As early as **1826**, **Jean-Daniel Colladon**, a Swiss physicist, had successfully used an **underwater bell** to determine the speed of sound in the waters of Lake Geneva. In the later part of the 1800s, physicists were working towards defining the fundamental physics of sound vibrations (waves), transmission, propagation and refraction. One of them was **Lord Rayleigh** in England whose famous treatise "the Theory of Sound" published in **1877** first described sound wave as a mathematical equation, forming the basis of future practical work in acoustics. As for high frequency 'ultrasound', **Lazzaro Spallanzani**, an Italian biologist, could be credited for it's discovery when he demonstrated in **1794** the ability of bats navigating accurately in the dark was through echo reflection from high frequency inaudible sound. Very high frequency sound waves above the limit of human hearing were generated by English scientist **Francis Galton** in **1876**, through his invention, the **Galton whistle**.

Pierre Curie
1859 - 1906

The real breakthrough in the evolution of high frequency echo-sounding techniques came when the **piezo-electric effect** in certain crystals was discovered by **Pierre Curie** and his brother Jacques Curie in Paris, France in **1880**. They observed that an electric potential would be produced when mechanical pressure was exerted on a **quartz crystal** such as the Rochelle salt (sodium potassium tartrate tetrahydrate). The reciprocal behavior of achieving a mechanical stress in response to a voltage difference was mathematically deduced from thermodynamic principles by physicist **Gabriel Lippman** in 1881, and which was quickly verified by the Curie brothers. It was then possible for the **generation** and **reception** of '**ultrasound**' that are in the frequency range of millions of cycles per second (megahertz) which could be employed in echo sounding devices. Further **research and development** in piezo-electricity soon followed.

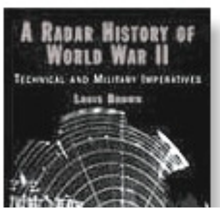


Underwater sonar detection systems were developed for the purpose of underwater navigation by submarines in World war I and in particular after the **Titanic** sank in **1912**. **Alexander Belm** in Vienna, described an underwater echo-sounding device in the same year. The first patent for an underwater echo ranging sonar was filed at the British Patent Office by English metereologist **Lewis Richardson**, one month after the sinking of the Titanic. The first working sonar system was designed and built in the United States by Canadian **Reginald Fessenden** in **1914**. The Fessenden sonar was an electromagnetic moving-coil oscillator that emitted a low-frequency noise and then switched to a receiver to listen for echoes. It was able to detect an iceberg underwater from 2 miles away, although with the low frequency, it could not precisely resolve its direction.

Paul Langevin
1872 - 1946

The turn of the century also saw the invention of the **Diode** and the **Triode**, allowing powerful electronic amplifications necessary for developments in ultrasonic instruments. Powerful high frequency **ultrasonic** echo-sounding device was developed by emminent French physicist **Paul Langévin** and Russian scientist **Constantin Chilowsky**, then residing in France. Patents were filed in France and the United States. They called their device the '**hydrophone**'. The **transducer** of the hydrophone consisted of a mosaic of thin quartz crystals glued between two steel plates with a resonant frequency of 150 KHz. Between 1915 and 1918 the hydrophone was further improved in classified research activities and was deployed extensively in the surveillance of German U-boats and submarines. The first known sinking of a submarine detected by hydrophone occurred in the Atlantic during World War I in April,1916.

Langevin's hydrophones had formed the basis of the development of naval pulse-echo sonar in the following years. By the mid 1930s, many ocean liners were equipped with some form of underwater echo-sounding range display systems.



In another development, the first successful **radio** range-finding experiment occurred in **1924**, when British physicist **Edward Appleton** used radio echoes to determine the height of the ionosphere. The first practical **RADAR** system (Radio Detection and Ranging, and using electromagnetic waves rather than ultrasonics) was produced in **1935** by another British physicist **Robert Watson-Watt**, and by **1939** England had established a chain of radar stations along its south and east coasts to detect aggressors in the air or on the sea. **World war II** saw **rapid developments** and refinements in the naval and military radar by researchers in the United States.

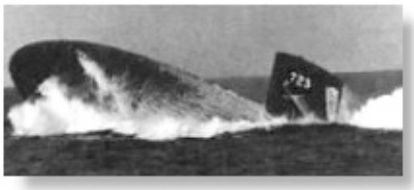
Such radar display systems had been the direct precursors of subsequent 2-dimensional sonars and **medical ultrasonic systems** that appeared in the late 1940s. Books such as the "**Principles of Radar**" published by the **Massachusetts Institute of Technology** (M I T) Radar school staff in **1944** detailed the techniques of oscilloscopic data presentation which were employed in medical ultrasonic research later on (see below). Two other engineering advances probably had also influenced significantly the development of the sonar, in terms of the much needed data aqusition capabilities: the **first digital computer** (the Electronic Numerical Integrator and Computer -- the **ENIAC**) constructed at the University of Pennsylvania in **1945**, and the invention of the point-contact **transister** in **1947** at AT & T's Bell Laboratories.

Yet another **parallel and equally important** development in ultrasonics which had started in the **1930's** was the construction of pulse-echo **ultrasonic metal flaw detectors**, particularly relevant at that time was the check on the integrity of metal hulls of large ships and the armour plates of battle tanks.

Metal flaw detector in use **
(Kretztechnik, Austria)

The concept of ultrasonic metal flaw detection was first suggested by Soviet scientist **Sergei Y Sokolov** in **1928** at the Electrotechnical Institute of Leningrad. He showed that a transmission technique could be used to detect metal flaws by the variations in ultrasionic energy transmitted across the metal. The resolution was however poor. He suggested subsequently at a later date that a **reflection method** may be practical.

The equipment suggested by **Sokolov** which could generate very short pulses necessary to measure the brief propagation time of their returning echoes was not available until the 1940s. **Early pioneers** of such reflective **metal flaw detecting devices** were **Floyd A Firestone** at the University of Michigan, and **Donald Sproule** in England. Firestone produced his patented "**supersonic reflectoscope**" in **1941** (US-Patent 2 280 226 "Flaw Detecting Device and Measuring Instrument", April 21, 1942). Because of the war, the reflectoscope was not formally published until **1945**. **Messrs. Kelvin and Hughes**® in England, where Sproule was working, had also produced one of the earliest pulse-echo metal flaw detectors, the **M1**. **Josef** and **Herbert Krautkrämer** produced their first **German version** in **Köln** in 1949 followed by equipment from **Karl Deutsch** in Wuppertal. These were followed by other versions from **Siemens**® in Erlangen, **KretzTechnik AG** in Austria, **Ultrasonique** in France and **Mitsubishi** in Japan. In **1949**, **Benson Carlin** at **M I T**, and later at **Sperry Products**, published "**Ultrasonics**", the first book on the subject in the English language.



The underwater **SONAR**, the **RADAR** and the ultrasonic **Metal Flaw Detector** were each, in their unique ways, a precursor of medical ultrasonic equipments. The modern ultrasound scanner embraces the concepts and science of all these modalities.

- The **early development of ultrasonics** is summarised **here**.

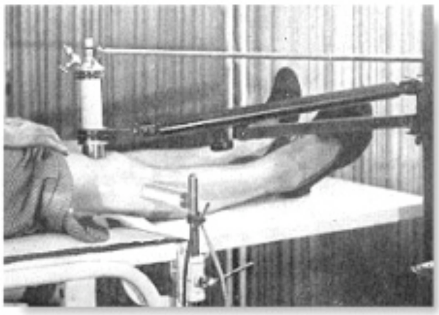
- Readers are also referred to **an article** by **Dr William O'Brien Jr.**, which also looks at the early history of the developments of ultrasonics.^

The use of **Ultrasonics** in the field of medicine had nonetheless started initially with it's applications in **therapy** rather than diagnosis, utilising it's heating and disruptive effects on animal tissues. The destructive ability of high intensity ultrasound had been recognised in the **1920**s from the time of **Langévin** when he noted destruction of school of fishes in the sea and pain induced in the hand when placed in a water tank insonated with high intensity ultrasound; and from the seminal work in the **1930**s from **Robert Wood**, **Newton Harvey** and **Alfred Loomis** in New York and **R Pohlman** in Erlangen, Germany.

Ultrasound used in therapy

High intensity ultrasound progressively evolved to become a neuro-surgical tool. **William Fry** at the University of Illinois and **Russell Meyers** at the University of Iowa performed **craniotomies** and used ultrasound to destroy parts of the basal ganglia in patients with **Parkinsonism**. **Peter Lindstrom** in San Francisco reported ablation of frontal lobe tissue in moribound patients to alleviate their pain from carcinomatosis. **Fry** in particular had worked towards improving research and dosimetry standards, which was much needed at the time.

Ultrasonic energy was also extensively used in physical and rehabilitation medicine. **Jerome Gersten** at the University of Colorado reported in **1953** the use of ultrasound in the treatment of patients with **rheumatic arthritis**. Other reseachers such as **Peter Wells** in Bristol, England, **Douglas Gordon** in London and **Mischele Arslan** in Padua, Italy employed ultrasonic energy in the treatment of **Meniere's disease**.



Uses of ultrasonic energy in the 1940s. Left, in gastric ulcers. Right, in arthritis

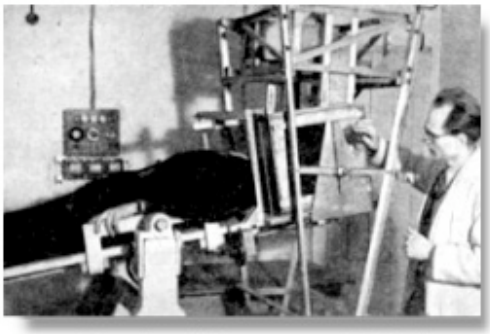
The **1940**s saw exuberant claims made in some sectors on the effectiveness of ultrasound as an almost "cure-all" remedy, abeit the lack of much scientific evidence. This included conditons such as arthritic pains, gastric ulcers, eczema, asthma, thyrotoxicosis, haemorrhoids, urinary incontinence, elephanthiasis and even angina pectoris! Cynicism and concern over harmful tissue damaging effects of ultrasound were also mounting, which had curtailing consequences on the development of diagnostic ultrasound in the years that followed.

Karl Theodore Dussik

It was around similar times that ultrasound was used experimentally as a possible **diagnostic tool** in medicine. **H Gohr** and **Th. Wedekind** at the Medical University of Koln in Germany in **1940** presented in their paper "**Der Ultraschall in der Medizin**" the possibility of ultrasonic diagnosis basing on echo-reflection methods similar to that used in metal flaw detection. They suggested that the method would be able to detect tumours, exudates or abscesses. However they were unable to publish convincing results from their experiments. **Karl Theo Dussik**, a neurologist/ psychiatrist at the University of Vienna, **Austria**, who had begun experiments in the late 1930s, was generallly regarded as the **first** physician to have employed ultrasound in medical diagnosis.

Dussik, together with his brother Friederich, a physicist, attempted to locate brain tumors and the cerebral ventricles by measuring the transmission of ultrasound beam through the skull. Dussik presented his initial experiments in a **paper in 1942** and further results after the end of the second world war in **1947**. They called their procedure "**hyperphonography**".

They used a **through-transmission technique** with two transducers placed on either side of the head, and producing what they called "**ventriculograms**", or echo images of the ventricles of the brain. Pulses of 1/10th scond were produced at 1.2 MHz. Coupling was obtained by immersing the upper part of the patient's head and both transducers in a water bath and the variations in the amount of ultrasonic power passing between the transducers was recorded photographically on heat-sensitive paper as light spots (not on a cathode-ray screen). It was an earliest attempt at the concept of '**scanning**' a human organ. Although their apparatus appeared elaborate with the transducers mounted on poles and railings, the images produced were very rudimentary 2-dimensional rows of mosaic **light intensity points**. They had also reasoned that if imaging the ventricles was possible, then the technique was also feasible for detecting brain tumors and low-intensity ultrasonic waves could be used to visualize the interior of the human body.

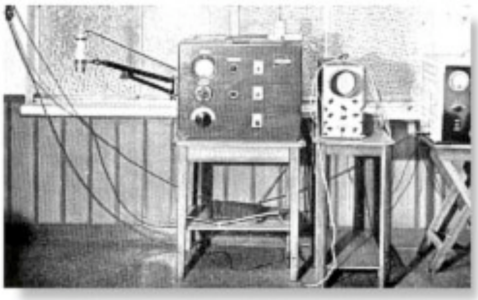


Dussik and his apparatus in 1946

Nevertheless, the images that Dussik produced were later thought to be **artifactual** by **W Güttner** and others at the Siemens Laboratory, Erlangen, Germany in 1952 and **researchers at the M.I.T.** (see below), as it had become apparent from further experiments that the reflections within the skull and attenuation patterns produced by the skull were contributing to the attenuation pattern which Dussik had originally thought represented changes in acoustic transmissions through the cerebral ventricles in the brain. Research basing on a similar transmission technique was not further pursued, both by Dussik, or at the M. I. T.. For more information read **Dussik**.

In nearby **Germany**, **Heinrich Netheler**, a physician at the Luebeck-South Hospital in **Hamburg**, was operating in **1945** a small repair facility for medical equipments at the Hamburg university hospital at Eppendorf and had a mission of developing inventive medical products. **Professor Hansen**, his superior, suggested to him in that year to develop an ultrasonic tomographic equipment for medical use basing on the concept of the RADAR. Important pioneering **reseach work** started at the Eppendorf University Hospital. Nevertheless, due to a lack of funds right after the war, the equipment designs had not reached the stage of actual fabrication. In the mid 1940s, German physician **Wolf-Dieter Keidel** at the Physikalisch-Medizinischen Laboratorium at the **University of Erlangen**, Germany, also studied the possibility of using ultrasound as a medical diagnostic tool, mainly on cardiac and thoracic measurements. Having discussed with researchers at **Siemens**, he conducted his experiments using the transmission technique with ultrasound at 60 KHz, and rejected the pulse-reflection method. He was only able to make satisfactory recordings of intensity variations in relation to cardiac pulsations. He envisaged much more difficulties would be encounterd with the reflection method. In the **First Congress of**

Ultrasound in Medicine held in Erlangen, Germany in May, **1948**, **Dussik** and **Keidel** presented their papers on ultrasound employed in medical **diagnosis**. These were the only two papers that discussed ultrasound as a **diagnostic tool**. The other papers were all on its therapeutic use.



Denier's ultrasonic apparatus in 1946

In **France**, French scientists who were in the study of ultrasonics, namely **André Dognon** and **André Dénier** and several others at the research center in **Salpêtrière** in **Paris** also embarked on ultrasound insonation experiments before the 1950s. **Dénier** published his theoretically work on ultrasound transmission in **1946**, among many other works on ultrasound used in therapy, and suggested the possibiity of "**Ultrasonoscopie**". This was a transmission technique and recordings made on a micro-ampere meter and oscilloscope. Equipments were fabricated from 'therapy' counterparts and various electrical current values were determined on different body tissues. Attempts to display voltages as Lissajous figures on the oscilloscope were made. However the work was unsuccessful in producing useful structural images and related instruments were not constructed. **André Dénier** published in 1951 his book, *"Les Ultras-sons -- Appliques a la Medecin"*. Nearly the entire book was devoted to ultrasonics used in the treatment of various diseases and only a small portion of the text was on ultrasound diagnostics.

George D. Ludwig

Systematic investigations into using ultrasound as a **diagnostic tool** finally took off in the United States in the **late 1940s**. The time was apparently ripe for this to happen. The concept of applying ultrasonics to medicine had progressively matured, so were the available equipments and electronics after the war. **George Ludwig**, a graduate from the University of Pennsylvania in 1946 was on active duty as junior Lieutenant at the **Naval Medical Research Institute** in Bethseda, Maryland. There, he **began experiments on animal tissues** using A-mode industrial flaw-detector equipment. Ludwig designed experiments to detect the presence and position of foreign bodies in animal tissues and in particular to localise gallstones, using reflective **pulse-echo** ultrasound methodology similar to that of the **radar** and **sonar** in the detection of foreign boats and flying objects. A substantial portion of Ludwig's work was considered classified information by the Navy and was not published in medical journals. Although Ludwig's work had started at a considerably earlier date, notice of his work was not released to the public domain until October **1949** by the United States Department of Defence. The **June '49 report** is considered the **first report** of its kind on the diagnostic use of ultrasound from the United States.

Ludwig systematically explored physical characteristics of ultrasound in various tissues, including beef and organs from dogs and hogs. To address the issue of detecting gallstones in the human body, he studied the acoustic impedance of various types of gallstones and of other tissues such as muscle and fat in the human body, employing different ultrasonic methodologies and frequencies. His collaborators included **Francis Struthers** and **Horace Trent**, physicists at the Naval Research Laboratory, and **Ivan Greenwood**, engineer from the **General Precision Laboratories**, New York, and the Department of Research Surgery, University of Pennsylvania. **Ludwig** also investigated the **detection of gallstones** (outside of the human body) using ultrasound, the stones being first embedded in pieces of animal muscle. Very short pulses of ultrasound at a repetition rate of 60 times per second were employed using a combined transmitter/ receiver transducer. Echo signals from the reflected soundwaves were recorded on the **oscilloscope screen**. Ludwig was able to detect distinct ultrasonic signals corresponding to the gallstones. He reported that echo patterns could sometimes be confusing, and multiple reflections from soft tissues could make test results difficult to interpret. Ludwig also studied transmission through living human extremities, to measure acoustic impedance in muscle. These investigations also explored issues of attenuation of ultrasound energy in tissues, impedance mismatch between various tissues and related reflection coefficients, and the optimal sound wave frequency for a diagnostic instrument to achieve adequate penetration of tissues and resolution, without incurring tissue damage. These studies had helped to build the scientific foundation for the clinical use of ultrasound.

Ludwig's A-mode apparatus in his gallstone experiments

In the following year, **Greenwood** and **General Precision Laboratories** made available commercially the "**Ultrasonic Locator**" which Ludwig used for "use in Medicine and Biology". Suggested usage indicated in the sales information leaflet already included detection of heart motion, blood vessels, kidney stones and glass particles in the body. Ludwig's pulse-reflection methodology and equipment in his later experiments on **sound transmission in animal tissues** were after **earlier designs** from the work of **John Pellam** and **John Galt** in **1946** at the Electronics and Acoustics research laboratories of the **Massachusetts Institute of Technology** (M. I. T.), which was on the measurement of ultrasonic transmission through liquids. The M. I. T. was then very much at the forefront of electronics and ultrasonics research. A significant amount of physical data and instrumentation electronics were already in place in the second half of the 1940s, on the characteristics of ultrasound propagation in solids and liquids.

Among other important original findings, Ludwig reported the **velocity of sound transmission** in **animal soft tissues** was determined to be between 1490 and 1610 meters per second, with a mean value of **1540 m/sec**. This is a value that is still in use today. He also determined that the optimal scanning frequency of the ultrasound transducer was between **1 and 2.5 MHz**. His team also showed that the speed of ultrasound and acoustic impedance values of high water-content tissues do not differ greatly from those of water, and that measurements from different directions did not contribute greatly to these parameters.

Ludwig went on to collaborate with the Bioacoustics laboratory at the M. I. T.. His work with physicist **Richard Bolt** (who, at the age of 34 was appointed Director of a newly conceived Acoustics Laboratory at M. I. T.), neurosurgeon **H Thomas**

Ballantine Jr. and research physicist **Theodor Hueter** from Siemens, Germany were considered very important seminal work on ultrasound propagation characteristics in mammalian tissues.

Theodore Hueter

M I T's project reported in "The Tech", 1950

Prior to 1949, **Hueter** had already been involved at **Siemens**, Erlangen, Germany, in **ultrasonic propagation experiments** in animal tissues using ultrasound at frequencies of about 1 MHz, and in ultrasonic dosimetry measurements. These were started in the early 1940s by Ultrasonics pioneer **Reimar Pohlman** in the same laboratory. In 1948, **Hueter** met **Bolt** and **Ballantine** at an ultrasonic trade show in New York and agreed to join them for new research into the application of ultrasonics in human diagnosis. After a visit to **Dussik's** department in Austria with Bolt and Ballantine, the group launched a **formal project** at M. I. T. to perform experiments in through transmission similar to that of **Dussik**'s. Their initial experiments produced results similar to that of Dussik's, and their conclusions were published in their papers in **1950** and **1951** in the Journal of the Acoustical Society of America, and Science. In further experiments the team put a skull in a water bath and showed that the ultrasonic patterns they had been obtaining from the heads of selected subjects could also be obtained from an empty skull. They noted that ultrasonic mapping of the brain tissues within the human skull was prone to great error due to the large bone mass encountered. Efforts were made to compensate for the bone effects by using different frequencies and circuitries, but were only marginally successful at that stage of computational technology.

The M. I. T. research project was subsequently terminated in 1954. They wrote in their paper: "It is concluded that though compensated ultrasonograms (sound shadow pictures) may contain some information on brain structure, their are too sharply "noise" limited to be of unqualified clinical value". The findings had prompted the United States Atomic Energy Commission to conclude that ultrasound will not be useful in the diagnosis of brain pathologies. Medical research in this area was somewhat curtailed for the several years that followed, and enthusiasm was dampened at the Siemens laboratories in Germany to carry out further developments in imaging with ultrasound. At M .I. T. nevertheless, in the course of these pursuits, much basic data essential for **tissue characterization** and **dosimetry** were assembled and proved useful for later diagnostic work on other body regions. They had also demonstrated very importantly that interpretable **2-dimensional images** was not impossible to obtain. These efforts had paved the way for the subsequent development of 2-D ultrasonic image formation. M. I. T.'s research had also benefited from interactions between the various groups at **Champaign-Urbana**, **Minnesota** and **Denver**.

By the **mid 1950s**, bibliographic listing of work on ultrasonic physics and engineering applications had totalled more than 6,000. Ultrasonics was already extensively deployed in non-destructive testing, spot welding, drilling, gas analysis, aerosol agglomeration, shear processing, clothes washing, laundering, degreasing, sterilization and, to a lesser extent, medical therapy. **Hueter** and **Bolt**'s book "*SONICS - techniques for the use of sound and ultrasound in engineering and science*" published in 1954 became, for example, one of the important treatises in ultrasonic engineering.

In **1956**, **D Goldman** and **Hueter** pulled together all the then available data on ultrasonic propagation in mammalian tissues for publication in the Journal of the Acoustical Society of America. The earliest journal devoted entirely to the application of ultrasonics in medicine was "***Der Ultraschall in der Medizin***" published in Germany. Articles prior to 1952 were entirely on aspects of ultrasound used in therapy. Much of the academic activity at M. I. T. were published in the *M. I. T. quarterly progress reports* and the *Journal of the Acoustic Society of America*. After the mid-1950s, due to its ineffectiveness, the transmission technique in ultrasonic diagnosis was abandoned from medical ultrasound research worldwide except for some centers in Japan, being replaced by the **reflection technique** which had received much attention in a number of pioneering centers throughout Europe, Japan and the United States.

Smaller and better **transducers** were being assembled from the **newer piezoceramics barium titanate** after the mid 1940s. They were replaced by **lead zirconate-titanate** (PZT) when it was discovered in 1954. PZT had a high electro-mechanical coupling factor and more superior frequency-temperature characteristics. The newer transducers had better overall sensitivity, frequency handling, coupling efficiency and output. The availability of very high input impedance amplifiers built from improved quality **electrometer tubes** in the early 1950s had also enabled engineers to greatly amplify their signals to improve sensitivity and stability.

Inge Edler

The 'newer' uni-directional pulse-echo A-mode devices developed from the reflectoscope/ metal flaw detectors were soon employed in experiments on medical diagnosis by bold and visionary pioneers around the world. Such were the cases with **Douglas Gordon**, **JC Turner** and **Val Mayneord** in London, **Lars Leksell** (in 1950), **Stigg Jeppson** and **Brita Lithander** in Sweden, **Marinus de Vlieger** in Rotterdam and **Kenji Tanaka** and **Toshio Wagai** in Japan for their pioneering work in the examination of brain lesions. These devices were also employed by **Inge Edler** and **Carl Hellmuth Hertz** in Lund in cardiac investigations in 1953, and followed on by **Sven Effert** in Germany in 1956, **Claude Joyner** and **John Reid** at the University of Pennsylvania in 1957 and **Chih-Chang Hsu** in China, designing their own A- and later on M-mode equipment. Similarly A-mode devices were used in ophthalmologic investigations by **Henry Mundt Jr** and **William Hughes** at the University of Illinois in **1956**, **Arvo Oksala** in Finland in **1957** and **Gilbert Baum** and **Ivan Greenwood** in **1955**. These uses were all in the **1950s** and largely predated clinical applications in the abdomen and pelvis. **Researchers in Japan** were also actively investigating and producing similar ultrasonic devices and their diagnostic use in neurology, but their findings have only been sparsely documented in the English literature (see below).

John Julian Wild, an English surgeon and graduate of the **Cambridge** University in England, immigrated to the United States after World War II ended in 1945. He took up a position at the **Medico Technological Research Institute of Minnesota** and

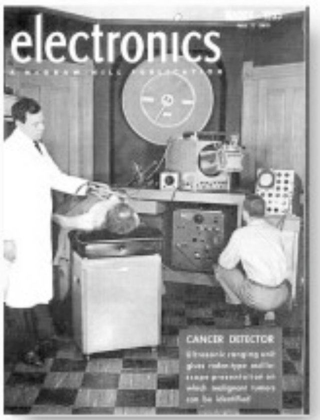
John Wild c. 1953

started his investigations with ultrasound waves on the thickness of the bowel wall in various surgical conditions, such as paralytic ileus and obstruction. Working with **Donald Neal**, an engineer, Wild published their work in **1950** on uni-directional **A-mode** ultrasound investigations into the thickness of surgical intestinal material and later on the properties of gastric malignancies. They noted that **malignant tissue** was more **echogenic** than benign tissue and the former could be diagnosed from their density and failure to contract and relax. **Wild's** original vision of the application of ultrasound in medical diagnosis was more of a method of **tissue diagnosis** from the intensity and characteristics of different returning echos rather than as an imaging technique. Between 1950 and 51, he also collaborated with **Lyle French** at the department of Neurosugery in making diagnosis of brain tumors using ultrasound, although they had not found the method to be very helpful.

John M Reid c.1970s

Donald Neal was soon deployed to regular naval services at the naval air base after the Korean war. **John Reid**, a newly graduating electrical engineer, was engaged through a grant from the **National Cancer Institute** as the sole engineer to build and operate Wild's ultrasonic apparatus. The device which they first used was an ultrasonic instrument which had been designed by the U.S. Navy for training pilots in the use of the radar, with which it was possible to practise 'flying' over a tank of water covering a small scale map of enemy territory. " We have a **tissue radar machine** scaled to inches instead of miles by the use of ultrasound". **Wild** and **Reid** soon built a linear hand-held B-mode instrument, a formidable technical task In those days, and were able to visualise tumours by sweeping from side to side through breast lumps. The instrument operated at a frequency of 15 megahertz. In 1952 they published the Landmark paper: "*Application of Echo-Ranging Techniques to the Determination of Structure of Biological Tissues*". In another paper **Reid** wrote about their first scanning equipment:

> ' The first scanning machine was put together, mechanically largely by John with parts obtained through a variety of friends in Minneapolis. I was able to modify a standard test oscilloscope plug-in board. We were able to make our system work, make the first scanning records in the clinic, and mail a paper off to Science Magazine within the lapsed time of perhaps ten days. This contribution was accepted in early 1952 and became the first publication (to my knowledge) on intensity-modulated **cross-section ultrasound imaging**. It appeared even before **Douglass Howry**'s paper from his considerably more elaborate system at the end of the same year.'



Wild and Reid's setup reported in Electronics in 1955

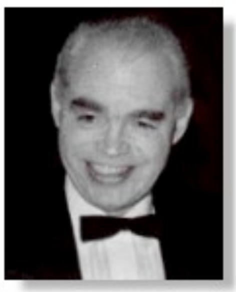
In **May 1953** they produced real-time images at 15 megahertz of cancerous growths of the breast. They had also coined their method **'echography'** and **'echometry'**, suggesting the quantitative nature of the investigation. By **1956**, Wild and Reid had examined 117 cases of breast pathology with their linear real-time B-mode instrument and had started work on colon tumour diagnosis and detection. Analysis of the breast series showed promising results for pre-operative diagnosis. Malignant infiltration of tissues surrounding breast tumours could also be resolved.

Wild and **Reid** had also invented and described the use of A-mode **trans-vaginal** and **trans-rectal scanning transducers** in **1955**. Despite these, Wild was not commended for his unconventional research methods at the time. His results were considered difficult to interpret and lacked overall stability. Intellectual and financial support for Wild's research dwindled, and legal disputes and politics also hampered further governmental grants. His work was eventually supported only by private funds which ran scarce and his data apparently received much less recognition than they deserved.

John Reid completed his MS thesis in 1957 on focusing radiators. In addition he had importantly verified that dynamic focusing was practical. After leaving Wild's laboratory he pursued his doctoral degree at the University of Pennsylvania. From 1957-1965 he worked on echocardiography, producing and using the first such system in the United States, with cardiologist **Claude Joyner**.

- Visit **John Wild's own site** on his discoveries and current activities.

- Read also: "**The scientific discovery of sonic reflection of soft tissue and application of ultrasound to diagnostic medicine and tumor screening**" by **John J Wild** (Press Release at the Third Meeting of the World Federation for Ultrasound In Medicine and Biology, 1982).



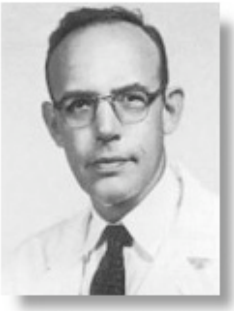
Douglass Howry c.1967

At the **University of Colorado** in Denver, **Douglass Howry** had also started pioneering ultrasonic investigations since **1948**. Howry, a radiologist working at the **Veteran's Administration Hospital**, had concentrated more of his work on the development of B-mode equipment, displaying body structures in a 2-dimensional and sectional manner "comparable to the actual gross sectioning of structures in the pathology laboratory". Published works from the **M I T** Radar school staff served as initial reference material on techniques in data presentation.

He was able to demonstrate an ultrasonic echo interface between structures or tissues, such as that between fat and muscle, so that the individual structures could be outlined. Supported by his nephrologist friend and colleague **Joseph Homles**, who was

Howry's somascope reported in the LIFE magazine in 1954

then the acting director of the hospital's Medical Research Laboratories, Howry produced in **1951** with **William Roderic Bliss** and **Gerald J Posakony**, both engineers, the **'Immersion tank ultrasound system'** *, the first 2-dimensional **B-mode** (or **PPI**, plan position indication mode) linear compound scanner. Two dimensional **cross-sectional images** were published in **1952** and **1953**, which convincingly demonstrated that interpretable 2-D images of internal organ structures and pathologies could be obtained with ultrasound. The team produed the formal motorized **' Somascope'**, a compound circumferential scanner, in **1954**. The transducer of the somascope was mounted around the rim of a large metal immersion tank filled with water . The machine was able to make compound scans of an intra-abdominal organ from different angles to produce a more readable picture. The sonographic images were referred to as **'somagrams'**. The discovery and apparatus were **reported in the Medicine section** of the **LIFE Magazine**® in **1954**.



Joseph H Holmes
1902 - 1982

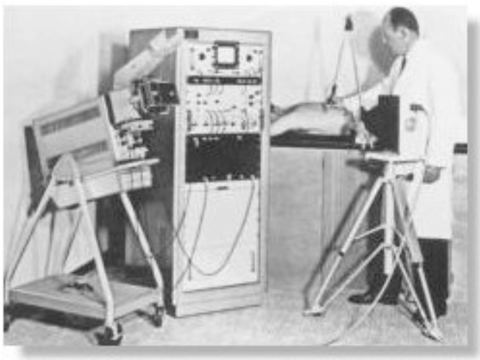
The **'Pan-scanner'** *, where the transducer rotated in a semicircular arc around the patient, was developed in **1957**. The patient sat on a modified dental chair strapped against a plastic window of a semicircular pan filled with saline solution, while the transducer rotated through the solution in a semicircular arc. The achievement was commended by the **American Medical Association** in **1958** at its scientific meeting in San Francisco, and the team's exhibit was awarded a **Certificate of Merit** by the association.

The pan-scanner in 1957

The work of **Douglass Howry**, **Joseph Holmes** and his team is necessarily the most important pioneering work in B-mode ultrasound imaging and contact scanning in the United States that had been the direct precursor of the kind of ultrasound imaging we have today. Pioneering designs in **electronic circuitries** were also made in conjunction with the development of the B-scan, these included the pulse-echo generator circuitry, the limiter and log amplification circuitry and the demodulator and time gain compensation circuitries.

The Howry/ Holmes systems, although capable of producing 2-D, accurate, reproducible images of the body organs, required the patient to be totally or partially immersed in water, and remained motionless for a length of time. Migration to lighter and more mobile versions of these systems, particularly with smaller water-bag devices or transducers directly in contact and movable on the body surface of patients were imminently necessary.

Read notes and see more pictures from **Gerald Posakony** on the early **Howry scanners** **here**.



The articulated arm scanner that Wright and Meyerdirk built in 1962, the earliest of such design in the U.S.

Homles, together with consultant engineers **William Wright** and **Ralph (Edward) Meyerdirk**, and support from the U. S. Public Health Services and the University of Colorado, continued to fabricate a new prototype **compound contact scanner**, which had the transducer in direct contact with the patient's body and suspended on moving railings above the patient. The apparatus and the usage of ultrasound scanning were reported in the **May 22 issue** of the **TIME Magazine** in 1964.

Time Magazine article
May, 1964

After working on the project for about 2 years, the team finally came up with an innovative **multi-joint articulated-arm** compound contact scanner with wire mechanisms and electronic position transducing potentiometers. The transducer could be positioned by hand and moved over the scanning area in various directions by the operator. In **1962**, with blessing from Holmes, Wright and Meyerdirk left the University to form the **Physionics Engineering® Inc.** at Longmont, Colorado, to **produce and market** their scanner.

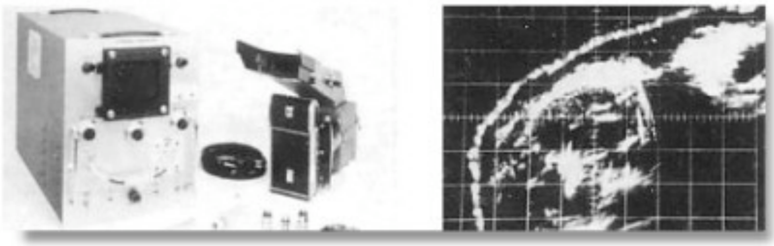
In **1963**, the first hand-held **articulated arm** **compound contact B-mode scanner** (pictured on the left) was commercially launched in the United States. The launch was reported in the Longmont "***Daily Times-Call***" in 1963. This was the start of the most popular design in the history of static ultrasound scanners, that of the articulated-arm scanning mechanism.

Electronic Doctor Being Made
By Longmont Engineering Firm

The Daily Times-Call
Report, 1963

Physionics® was acquired by the **Picker Corporation** in **1967**. Picker continued to produced **improved versions** of the design right into the 1980s.

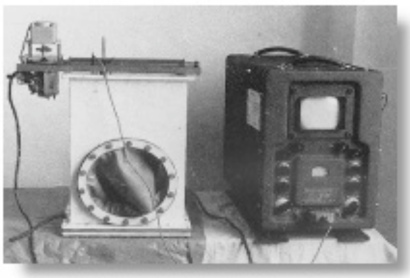
Much of the later work in clinical ultrasound was followed up by Homles and his colleagues, **Stewart Taylor**, **Horace Thompson** and **Kenneth Gottesfeld** in Denver. The group published some of the earliest papers in obstetrical and gynecological ultrasound from North America. Douglass Howry had moved to Boston in 1962 where he worked at the Massachussetts General Hospital until he passed away in 1969.



Earliest Wright-Meyerdirk scanner console with one of the first images from a practical commercial articulated-arm scanner. Portability was also emphasized.

Toshio Wagai c.1979

In **Japan**, at about the same time as Wild and Howry's development, **Kenji Tanaka** and **Toshio Wagai**, surgeons at the Juntendo University, Tokyo, together with **Shigeru Nakajima**, director of the Japan Radio Company, **Rokuro Uchida**, physicist and chief engineer, had also started looking into the use of ultrasound in the diagnosis of intracranial disease in collaboration with the Nihon Musen Radiation and Medical Electronics Laboratory which had later become the **ALOKA**® Company in **1950**, headed by **Uchida**. Nakajima and Uchida built Japan's first ultrasonic scanner operating in the A-mode in **1949**, modified from a metal-flaw detector. **Yoshimitsu Kikuchi**, professor in ultrasonics from the **Tohoku University** in Sendai also assisted in their research. Together, the team started their formal ultrasound research in **1952**.

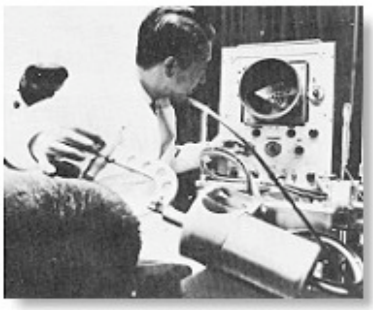


B-mode experiments at Juntendo, 1955

They published 5 papers on **ultrasonic diagnosis in brain diseases** in that year and many other papers in the ensuing few years. In **1954**, Tanaka published an important review entitled "Application of ultrasound to diagnostic field", and investigations had started with other body organs. By **1955**, experiments and fabrication with **B-mode scanning** had started using a similar scope modified from the original A-mode machine coupled with a **linear moving transducer gantry**. This was shortly developed into the **water-bag scanners**.

Also read the **Preface and introduction (history)** to Tanaka's book "Diagnosis of Brain Disease by Ultrasound" published in 1969 for a short history of his pioneering work in the 1950s.

The **M I T** hosted a historical conference in Bioacoustics in **1956** and those who attended included **Wagai, Kikuchi, Dussik, Bolt, Ballantine, Hueter, Wild, Fry** and **Howry**. Many of them met each other for the first time and important views concerning methods and instrumentations were exchanged at the meeting.



Kikuchi's one-point contact sector tomograph in 1957

Kikuchi was very active in equipment designs, and by **1957** he was able to demonstrate the "**one-point contact-sector scanning tomography**" using the plan-position indication (PPI) B-mode format, which had a resemblance to a '**radar display**'. This development, which was at around a similar time as the pioneering work of **Howry** in Denver and **Ian Donald** in Glasgow (see below), had a similar concept of "position-referenced contact scanning".

Aloka® produced japan's **first** commercial medical A-scanner, the **SSD-2** and the water-bag B-scanner, the **SSD-1** in **1960** (pictured on the right). The application of ultrasound in Obstetrical and Gynaecological diagnosis started around 1956 with the A-scan basing on a **vaginal approach** and later B-scans at around **1962** basing on the use of the "**one-point contact-sector scanner**" in the PPI format. Early commercial water-bag scanners were being produced by Aloka® and Toshiba® in the early 1960s.

The water-bag B-mode scanning system, the SSD-1, from Aloka in 1960

Masao Ide at the Musashi Institute of Technology in Toyko, working with **Wagai** and others launched important pioneering research on the bioeffects of ultrasound. **William Fry** hosted another conference on ultrasonics in **1962** at the University of Illinois which served as a very important meeting point for researchers from the United States, Europe and Japan.

Michio Ishihara at the National Sanatorium Kiyose Hospital in Tokyo and **Hajime Murooka** at the department of obstetrics and gynecology, Oomiya Red Cross Hospital, Saitama, delivered the first paper on ultrasound diagnosis of gynecological masses in the Japanese language at the 19th Kanto District Meeting of the Japanese Obstetrical and Gynecological Society in **1958**, basing on the A-scan. Murooka had earlier in 1957 received instructions from **Wagai** on the A-scan methods at the Juntendo University. They described A-scan echoes in cancer of the cervix and also in the presence of different causes of uterine enlargement. **Wagai** published a review article in the use of ultrasound in Obstetrics and Gynecology in **1959**. The Murooka's group apparently did not continue their work after the first two papers presented at scientific meetings.

Also read a **short History of the development of Medical Ultrasonics in Japan**.

John Wild was back in **England** in **1954** to give a lecture on his new discovery and this was attended by **Val Mayneord**, Professor of medical physics at the Royal Cancer Hospital (now the Royal Marsden) who had also been experimenting with the Kelvin & Hughes® MK IIB metal flaw-detector in neurological diagnosis. Among the audience was **Ian Donald** who was then Reader in Obstetrics and Gynaecology at the St. Thomas Hospital Medical School in London and was about to take up the appointment of Regius Chair of Midwifery at Glasgow University. **Donald** was quick to realize what ultrasound had to offer.# Wild, while returning to Minnesota, had mainly concentrated his investigations on the diagnosis of tumors of the breast and colon using 15 MHz probes which had tissue penetrations of only up to 2 cm. In **1956**, Wild published his landmark paper on the study of 117 breast nodules, reporting an accuracy of diagnosis of over 90 percent. Despite that, the ultrasonic method of tissue diagnosis which he so popularised did not reach the point of wide acceptance. Pioneering work in ultrasonic diagnosis in the field of **Obstetrics and Gynaecology** however, soon took off in **Glasgow**, **Scotland**.

The following is an excerpt from an **article** in the University of Glasgow publication **'Avenue'** No. 19: January 1996 entitled **' Medical Ultrasound ---- A Glasgow Development which Swept the World '**, by **Dr. James Willocks MD**, who had best described the circumstances of **Donald**'s early work :

' Ultrasound scanning is a household word. Every mother knows it and many have pictures to prove it. It is painless, safe and reliable. Its success since its beginnings 40 years ago is truly astonishing. It started in Glasgow in the University Department of Midwifery under **Professor Ian Donald** and seemed a rather crazy experiment at the time. But Ian Donald was no backroom boffin, but a full-blown flamboyant consultant at the sharp edge of one of medicine's most acute specialities - a colourful character of Johnsonian richness for whom I am a very inadequate Boswell.

Professor Ian Donald
1910 - 1987

He was born in Cornwall in December 1910, the son and grandson of Scottish doctors. His school education began in Scotland and finished in South Africa. He returned to England in 1931 and graduated in medicine at St Thomas's Hospital Medical School in 1937. In 1939 he joined the RAF where his service was distinguished. He was decorated for gallantry for entering a burning bomber with the bombs still in it, to rescue injured airmen. Service in the RAF stimulated his interest in gadgetry of all kinds and he became familiar with radar and sonar, a technique which had been devised by the French physicist, Paul Langevin in the First World War as a possible method of submarine detection.

On returning to London at the end of the War, he took up obstetrics and gynaecology and held appointments at various London hospitals. His first research work was directed towards respiratory problems in the newborn, and he devised apparatus to help babies breathe when respiration did not get off to a flying start. Because of his interest in machines, Ian was known as 'Mad Donald' by some of his London colleagues, who caricatured him as a crazy inventor, but his talent was spotted by that great university statesman, Sir Hector Hetherington, and he was appointed to the Regius Chair of Midwifery at the University of Glasgow in 1954 ....

The prototype scanner made from 2 flaw detectors

His interest soon turned to the idea that **sonar** could be used for medical diagnosis and the idea was first put into practice on **21 July 1955**, when he visited the Research Department of the boilermakers Babcock & Wilcox at Renfrew on the invitation of one of the directors, who was the husband of a grateful patient. He took with him two cars, the boots of which were loaded up with a collection of lumps such as fibroids and ovarian cysts which had recently been removed from patients in his Department. He carried out some experiments with an industrial **ultrasonic metal flaw detector** on these tumours, and on a large lump of steak which the company had kindly provided as control material. (No one had the appetite for the steak afterwards!) Later he formed a link with the **Kelvin & Hughes Scientific Instrument Company**, and particularly with a young technician called **Tom Brown**. Quite by accident, Tom Brown had heard the strange tale of a professor who was attempting to use a metal flaw detector to detect flaws in women. He telephoned Professor Donald and suggested a meeting, and it was not long before Donald and Brown together with **Dr John MacVicar**, later Professor of Obstetrics & Gynaecology in the University of Leicester, plunged into an intensive investigation into the value of ultrasound in differentiating between cysts, fibroids and any other intra abdominal tumours that came their way.


pages from the 1958 paper

Early results were disappointing and the enterprise was greeted with a mixture of scepticism and ridicule. However, a dramatic case where ultrasound saved a patient's life by diagnosing a huge, easily removable, ovarian cyst in a woman who had been diagnosed as having inoperable cancer of the stomach, made people take the technique seriously. 'From this point', Ian Donald wrote, 'there could be no turning back'. Results eventually appeared in print in **The Lancet** of **7 June 1958** under the arid title **'Investigation of Abdominal Masses by Pulsed Ultrasound'**. This was probably the most important paper on medical diagnostic ultrasound ever published. Ten years later all doubt had been cast away and Ian Donald was able to review the early history of ultrasound in a characteristic , forthright manner. 'As soon as we got rid of the backroom attitude and brought our apparatus fully into the Department with an inexhaustible supply of living patients with fascinating clinical problems, we were able to get ahead really fast. Any new technique becomes more attractive if its clinical usefulness can be demonstrated without harm, indignity or discomfort to the patient .... Anyone who is satisfied with his diagnostic ability and with his surgical results is unlikely to contribute much to the launching of a new medical science. He should first be consumed with a divine discontent with things as they are. It greatly helps, of course, to have the right idea at the right time, and quite good ideas may come, Archimedes fashion, in one's bath.'


James Willocks

In **1959** Ian Donald noted that clear echoes could be obtained from the **fetal head** and began to apply this information. **I** became involved shortly afterwards, and indeed was given the project to play with on my own. At the Royal Maternity Hospital, Rottenrow, there was no separate room to examine the patients and not even a cupboard in which to keep the apparatus, so my colleague, the physicist **Tom Duggan**, and I pushed it about on a trolley and approached patients in the wards for permission to examine them at the bedside. Glasgow women are wonderful and they accepted all this without demur .... We applied the method of fetal head measurement to assess the size and growth of the foetus. When the Queen Mother's Hospital opened in 1964 it became possible to refine the technique greatly. My colleague **Dr. Stuart Campbell** (now Professor at King's College Hospital, London) did this and **fetal cephalometry** became the standard method for the study of fetal growth for many years.

Within the next few years it became possible to study pregnancy from beginning to end and diagnosis of complications like multiple pregnancy, fetal abnormality and placenta praevia (which causes life threatening haemorrhage) became possible. Professor Donald had gathered around him a team of talented young doctors and technologists, including the research engineers **John Fleming** and **Angus Hall**, who were engaged by the University when the Kelvin Hughes company was closed in 1966.

John Fleming has continued at the Queen Mother's Hospital as the technical genius behind all developments, and is also in charge of the valuable historical collection about diagnostic ultrasound. Practically all apparatus is now Japanese in origin, but the contribution of Scottish engineering to the development of medical ultrasound should never be forgotten. **'**

Ian Donald was also aware of the work of **Howry** in the United States and **Kikuchi** in Japan in the early 1950s, and had referenced these pioneers alongside with the work of **Wild** and **Reid** in his **Lancet paper** in **1958**. **Donald** had felt that it was his fortune to have started with these historical A-mode and B-mode instruments instead of the apparatus that **Wild** and **Howry** had used, as these involved **high frequency transducers** (and hence associated with poor penetration into tissues) or a **water-bath arrangement** which could both become deterrants to further development in a medical setting ##. Aside from this, **Donald** had on many occasions remarked that a lot of his developments in ultrasound was from a stroke of

Tom Brown
c. 1956

accident, coincidence and luck. The '**full bladder**' was one, which he only discovered in 1963. That the fetal head, being a symmetrical skull bone could be easily demonstrable and measured accurately by a beam of ultrasound in an A-scan was another, as was the opportunity of meeting up with a number of important **administrators** on the way and working with the very bright engineer **Tom Brown** from Kelvin & Hughes®.

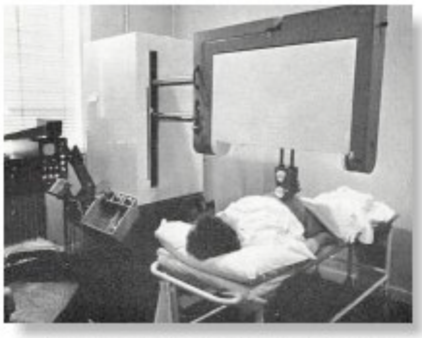
Brown, at the age of 24, invented and constructed with Ian Donald the prototype of the world's first **Compound B-mode** (plan-position indication, PPI) contact scanner in **1957**. The transducer operated at 2.5 MHz. The prototype was progressively improved to become the **Diasonograph**® manufactured commercially by **Smith Industrials of England** which had taken control of the **Kevin and Hughes Scientific Instrument Company** in 1961.

The prototype scanner that Donald and Brown built in 1957

For a detailed account of the pioneering development of the prototypes, read an important unpublished paper by **Tom Brown** entitled **Development of ultrasonic scanning techniques in Scotland 1956-1979**.

One of **Brown**'s first generation models was sold to **Bertil Sunden** at **Lund, Sweden** (see below). The console design of the **Diasonograph**® came from **Dugald Cameron** who was then an industrial design student at the Glasgow school of Art. Brown also invented and patented an elaborate and expensive **automated compound contact scanner** in **1958** and it was at the machine's exhibition in London in 1960 that Ian Donald met for the first time **Douglass Howry** from the United States who had been using the much larger size water-tank circumferential scanner for several years (see above). **Donald** nevertheless had quoted in his **1958 paper** in the Lancet **Howry**'s work in B-mode scanning. The meeting had also influenced **Howry** and his team into producing a **similar compound contact scanner** like the Donald's although this had rapidly evolved into the multi-joint articulated arm version.

A brief description of the working of the prototype compound contact scanner (which eventually developed into the **Diasonograph**®) was given by Donald and Brown in **1958**, the same concept and design were extended into the later commercial models:



The Diasonograph produced in 1963

" ..... A probe containing both transmitting, and receiving transducers is mounted on a measuring jig, which is placed above the patient's bed. The probe is free to move vertically and horizontally and, as it does so, operates two linear potentiometers, which give voltage outputs proportional to its horizontal and vertical displacements from some reference point. The probe is also free to rotate in the plane of its horizontal and vertical freedom, and transmits its rotation via a linkage to a sine-cosine potentiometer. The voltage outputs from this system of potentiometers control an electrostatic cathode-ray tube, so that the direction of the linear time-base sweep corresponds to the inclination of the probe, and the point of origin of the sweep represents the instantaneous position of the probe. The apparatus is so calibrated that the same reflecting point will repeat itself in exactly the same position on the cathode-ray tube screen from whatsoever angle it is scanned, and likewise a planar interface comes to be represented as a consistent line.

The echoes picked up by the probe are displayed on three oscilloscope screens: an A-scope display, a combined B-scope and PPI display on a long-persistence screen for monitoring: and a similar screen and display of short persistence with a camera mounted in front of it. The probe is moved slowly from one flank, across the abdomen to the other flank being rocked to and fro on its spindle the whole time to scan the deeper tissues from as many angles as possible. ....."

The **automated scanner** which Brown originally designed to overcome the effects of motion variables did not catch on well, while the **Diasonograph**® was sold to many other parts of Britain and Europe including Sweden, London and Bristol, the place where another ultrasound pioneer, **Peter NT Wells**, a medical physicist, had been developing a different version of the multi-joint articulated arm scanner (basing on the **Diasonograph electronics**), independently from his American counterpart.

The NE 4102

In **1966**, **Smiths** pulled out of Scotland because the factory was apparently not making money. At the same time the US Supreme Court ruled against Smiths in favour of **Automation Industries** (formerly the **Sperry Company**) of Denver on the question of the so-called "**Firestone patents**" (Floyd Firestone's patent on flaw-detection devices in 1942, see above). As part of the settlement, Smiths undertook to withdraw both from the industrial and medical applications of ultrasound, and Automation acquired title to the collection of Smiths' patents on these subjects. This included the **Brown** patents on 2-D contact scanning. Smiths sold the medical business to **Nuclear Enterprises (G.B.) Ltd**. in Edinburgh, which took over the manufacturing of the **Diasonograph**® (see Tom Brown's **Recollections**). Ian Donald had to set up his own Department of Ultrasonic Technology

NE 4102 scanning gantry

at the Queen Mother's Hospital. He had **John Fleming** and **Angus Hall** back to help him. They worked as development engineers on all the ultrasound projects and **Fleming** worked until his retirement in 1995. He is co-ordinator of the **BMUS historical collection** and oversees the ultrasonic equipments at the Hunterian Museum, University of Glasgow. By 1968, **Brian Fraser** and **Alan Cole** at **Nuclear Enterprises** revamped the mechanical and valve design and redeveloped a new electronic system using semiconductor technology. The resulting "**NE 4102**" became a very popular instrument, and was used in most British hospitals and many European ones.

Donald in front of the NE 4102

For a detailed account of the pioneering development of medical ultrasonics in Glasgow, Scotland, read the biography of **Tom Brown** and an important unpublished paper by **Brown** on the **Development of ultrasonic scanning techniques in Scotland 1956-1979**.

Visit the pictorial presentation: **Scenes from the History of Ultrasound** from the **British Medical Ultrasound Society** (BMUS) Historical Collection. Co-ordinator: **Mr. John Fleming**.

Read also **Peter Well**'s article on the **History of the development of ultrasonography**.

Donald, Takeuchi and others, Pittsburg, 1965

Joseph Holmes and **Ian Donald** had subsequently become good friends across the Atlantic and Ian Donald and **John Fleming** were invited to speak on their experiences at the **International Conference** at Pittsburg hosted by Homles and others in **1965**. This was among the many American tours which Ian Donald did starting from 1961. He spoke about Homles in a speech he gave in 1967 to the **World Federation for Ultrasound in Medicine and Biology (WFUMB)**, '*I think Joe Holmes has done more than anyone to pull us all together from our several pathways*'. **Holmes** became the founding editor of the ***Journal of Clinical Ultrasound*** in **1973**.

Over in continental **Europe**, **Bertil Sunden** in **Lund, Sweden**, had started investigations in **1958** with **Alf Sjovall**, his professor in Obstetrics and Gynecology, on early pregnancies using an A-mode echoscope (a Krautkramer® reflectoscope USIP 9). The study on the application of ultrasound in Lund had already started formally in **1953** in **cardiology** and **neurology** (see above). **Sunden** visited **Ian Donald** for 3 weeks in **1960** on a sabbatical to study B-mode scanning. His work at Donald's department had resulted in the shipment of the **first generation Diasonograph®** to Lund, with which he produced his doctoral thesis on the use of ultrasound in Obstetrics and Gynecology, and reported his experience on **400 cases** of pelvic pathologies. He also studied the possible harmful effects of ultrasound on pregnant rats, and did not find any. **Sunden's thesis** published in the *Acta Obstet Gynaecol Scand* in **1964** represented the **earliest** and the **most comprehensive** publication in Obstetrical and Gynecological ultrasonography at that time.

Bertil Sunden C. 1972

Read also: **A short history of the development of ultrasonography in Lund, Sweden**.

At around the same time, **N D Selezneva**, a disciple of the famous Soviet scientist, **S Y Sokolov**, published his work in **ultrasonography in Gynecology** in the former **USSR** in the early 1960s. **R A Khentov**, **R A Khestova** and **I A Skorunskii** from the Central Institute of Advanced Training in Medicine, Moscow followed on with a large number of Russian publications in Obstetrics and Gynecology from **1965** onwards, using A-mode and later on B-mode equipments made at the USSR Scientific Research Institute of Medical instruments and Equipment. Almost ninety-nine percent of these publications were nevertheless in the Russian language.

Read **further notes on early developments in Obsterical and Gynecological ultrasonography in the Soviet Union**

The Ultrasonic Boom

Alfred Kratochwil c. 1966

The increase in the research and application of ultrasound in Obstetrics and Gynecology appeared to **boom from 1966** onwards (see chart below) when there was an upsurge of centers and people in Europe, the United States and Japan that had begun to embark on studies in the application of ultrasound diagnosis in this specialty. **A-** and **B- mode equipment** were both in use including the first 'fast B-scanner', the **Vidoson**® from **Siemens**® (see **part 2**) used by **D Hofmann** and **Hans Holländer** at the Wilhelm University in **Münster, Germany**.

Dr. Alfred Kratochwil working with the A-scan on a pregnant patient in the mid 1960s**

Alfred Kratochwil at the Second University Frauenklinik, **Vienna, Austria** started working on placental localisation with the A-mode scanner he acquired from **Paul Kretz**, founder of **KretzTechnik AG** in Zipf, Austria. He soon learned of **Ian Donald**'s work with the **B-scan** and quickly collaborated the company to develop a similar device. The model 4100 originally designed for ophthalmologic use was adapted to carry an articulated-arm gantry (pictured below) for the abdominal B-scan mode. The articulated-arm design he found, was easier to manipulate than the Glasgow counterpart. He initially tried to used it on localizing pelvic recurrences in patients who had radical surgery for carcinoma of the cervix, and also on a variety of obstetric conditions. As early as 1972, **Kratochwil** had, among other endeavours, successfully demonstrated the visualisation of **ovarian follicles** with static B-mode ultrasound.

An early articulated-arm compound static scanner from KretzTechnik, Austria**
A vaginal scanning device is seen on the left

Kratochwil soon became one of the most prolific users of the instrument and worked on areas such as the breasts and other surgical conditions, where he also published a number of important early papers. Since **1968** he developed training courses in ultrasound in **Vienna** and his department was visited by many hundreds of radiologists and obstetricians to learn about the applications of ultrasonography. **Kratochwil** was probably the most productive of all the investigators in Europe and was instrumental to the constantly **improving designs** at **KretzTechnik AG**.

Read a **Short history of Kretztechnik AG**, **Austria**.

Hans Henrik Holm, a urologist, started the ultrasound laboratory at the **Gentofte Hospital** in **Copenhagen**, **Denmark** in **1964**, and with **Jorgen Kristensen**, **Allen Northeved**, **Jan Pedersen**, **Jens Bang** among others had established a strong research team. Holm also designed their version of an **articulated-arm scanner** which subsequently was taken up for commercial production at **Smith Kline Instrument**® in the United States. The Copenhagen center had in time become a leading center in **Interventional ultrasound**, even up to this day.

Read a **short history of the early development of ultrasonography in Copenhagen, Denmark**.

And so it was that the early pioneers in diagnostic ultrasound from the **United States**, **Japan**, **United Kingdom**, **Austria**, **Germany**, **Sweden**, **Switzerland**, **Denmark**, **France**, **Poland**, **Holland**, **USSR** and **China** have all started with the A-scan basing on the **metal flaw detector** or a modification of the instrument. Many had first started their investigations in **neurology**, **cardiology** and **ophthalmology**, and only later on did they apply ultrasonic techniques to the abdomen and pelvis.

In **Germany**, at around 1950 both **Siemens**® and **Krautkrämer**® had started to make flaw-detecting equipment. Located close to the steel industry **Krautkrämer**® provided better service than **Siemens**® and soon dominated the market. After W Güttner and others had shown the impracticality of the transmission technique in 1952, Siemens had lost interest in diagnostic ultrasound. Around the end of 1956 the company decided to stop producing flaw-detection equipment completely. It was **Inge Edler** and **Carl Hertz** in Lund who adapted three of the Siemens® flaw detectors for cardiac investigations in 1957 (see above), and these were introduced back into hospitals in Germany. After a lapse of almost 10 years, the company developed the first fast B-scanner, the **Vidoson** in 1967, suitable for gynecological and abdominal examination (see **Part 2**). Germany was nevertheless one of the more 'prolific' of the European countries in terms of centers in early ultrasonic applications and research, with publications coming from Muchen, Erlangen, Bonn, Heidelberg, Berlin, Frankfurt, Freiburg and Bochum.

Read a **history of the development of ultrasonography at Siemens, Germany**.

Vienna in Austria, as noted above was 'historically' important because of the company **Kretztechnik AG** which produced some of the best and most advanced machines in the world at that time. The **B-scan**, basing on more sophisticated instrumentation emanating from radar sciences quickly evolved and replaced the A-scans. Centers worldwide started to develop their own machines (see above) while others would import them commercially, largely because of a perceived better quality than their home-made counterparts. For example, in the late 1960s some Finnish centers used **Physionics**/**Picker**® machines from the United States and French and Italian centers used scanners from **Nuclear Enterprise**® and **KretzTechnik AG**. **Smith Kline Instruments**® scanners were used in Spain, **Aloka**® models in Brussels and the **Siemens**® Vidoson was employed by a number of centers outside of Germany.

Read a **short history of the development of ultrasound in Obstetrics and Gynecology in France**.

Manfred Hansmann

The "**First World Congress on Ultrasonic Diagnostics in Medicine**" was held in Vienna in **1969** and the second in Rotterdam in 1972 where an increasing number of papers in this specialty was presented. These meetings identified and brought together an international group of clinicians and scientists who started to contribute heavily towards the developments of ultrasonic instrumentation and methodology. In **Europe**, **Alfred Kratochwil** (1966), (**Austria**), **D Hofmann** (1966), **Hans Hollander** (1966), **Manfred Hansmann** (1966), (**Germany**), **Malte Hinselmann** (1968) (**Switzerland**), **Salvator Levi** (1967) (**Brussels**), **Hans Henrik Holm** (1967), **Jens Bang** (1967) (**Denmark**), **Georges Boog** (1969), **Francis Weill** (1969) (**France**), **I**

Manfred Hansmann

Salvator Levi

Roszkowski I (1968), Jerzy Groniowski (1968), (**Poland**), **Paavo Pystynen** (1966), **Pekka Ylöstalo** (1971), **Pentti Jarvinen** (1968), Pentti Jouppila (1970) (**Finland**), **J Hernandez** (1970), **R Montero** (1970), **Fernando Bonilla-Musoles** (1971) (**Spain**), **Bruno Damascelli** (1967), **L Roncoroni** (1967), **Alberto Zacutti** (1968), **C Brugnoli** (1968), **Achille Ianniruberto** (1970) (**Italy**), **E Kalamara** (1972), **M Bulic** (1972), Asim Kurjak (1973) (**Yugoslavia, now Croatia**), Juriy Wladimiroff (1974) (**Netherlands**), **M Falus** (1969), **M Sobel** (1969), **L Kun** (1973), **P Bosze** (1973) (**Hungary**), among many others, soon followed up with their many publications in obstetrical and gynecological sonography, although much of what was published was not in the English language. [The year in parenthesis denoted the year in which publications in Obstetrics and Gynecology from the particular author first appeared in the literature]. The delegates of 13 European ultrasound societies met in Basel, Switzerland in **1972** to form the **European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB)**.

Read a **brief history of the development of medical ultrasonics in Poland**.

Peter NT Wells

Stuart Campbell

In the **United Kingdom**, **Ellis Barnett**, **Patricia Morley**, **Hugh Robinson**, **Usama Abdulla** in Glasgow, **Peter Wells** in Bristol, **A C Christie** in Aberdeen, **E I Kohorn**, **Stuart Campbell** in London (see **Part 2**), **Hyton Meire** and **Pat Farrant** in Middlesex, and **Christopher Hill** at the Royal Marsden continued to make very important contributions in many areas.

Barnett and Morley's book in **1974**: "*Clinical Diagnostic Ultrasound*" was the first book (including publications from the United States) devoted to abdominal B-mode ultrasonography. **Peter Wells** in particular, was the single most important contributor to the advancement of ultrasound technology in Britain. **Stuart Campbell** eventually became one of the world's most well-known researcher and teacher in the field of Obstetrical and Gynecological ultrasound. The **British Medical Ultrasound group** was formed in **1969** by members of the Hospital Physicists Association and the British Institute of Radiology. The group later changed its name and became officially the **British Medical Ultrasound Society (BMUS)** in **1977**.

Read the **early history of Obstetrical and Gynecological ultrasound in Finland**.

Barry Goldberg

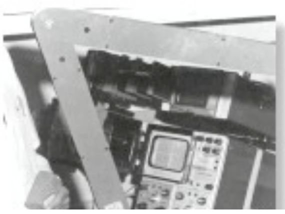
Back in the **United States**, **J Stauffer Lehman**, in Hahnemann, Philadelphia was instrumental in the early 1960's to the continuing development of ultrasound technology in the **United States**. His association with **Smith Kline Instruments**® had been catalytic to the company's production of water-bag and contact B-mode scanners on top of their existing line of A- and M- mode equipments for echocardiography. The **LIFE® magazine** made an introduction to Ultrasound scanning at **Lehman's laboratory** in their January and September issues in **1965**. The **Family Circle® magazine** also reported on the medical use of ultrasound in their October 1966 issue.

Lehman's equipment was nevertheless cumbersome and expensive to fabricate and later on a smaller company, **Hoffrel** took up the production of his machine. After the expiration of SKI's contract, Lehmann turned to use the **articulated arm** scanner originally invented and produced by the **Physionics Inc** in Longmont, Colorado (later on acquired by the **Picker Corporation** and further expanding its development).

Barry Goldberg joined Lehman in 1968 and expanded the research. He published extensively on a variety of subjects including echocardiography and interventional ultrasonography and was on record the first to describe **fetal cephalometry** in **1965** outside of Britain and Europe. **George Evans**, then a young Radiologist, was responsible for organizing the service and several important research projects. With his team was **Marvin Ziskin**. Together they have introduced ultrasound to the Radiological community in the United States and convincing them of the technique's clinical value. **Lajos von Micsky**, working at the St. Luke's Medical Center in New York, was also one of the important pioneers of **abdominal as well as endoscopic sonographic equipment**. He established a bioacoustical laboratory at the center in 1963 and devised many **innovative** abdominal, trans-vesical, rectal and trans-vaginal scanners.

Also read an article "**Obstetric US imaging: the First 40 Years**" by **Dr. Barry Golberg**.

Articulated arm scanners such as the **PortaScan** from **Physionics Inc**® produced in the mid-1960s had become the most popular format in compound contact B-scanners in the United States and throughout the world. Other earliest manufacturers of similar devices included the **UniRad Corporation**®. Newer machines soon followed from manufacturers in the United States and worldwide. These included the **Picker**® Laminograph 102, the **KretzTechnik AG** Combison 1 and 2, the **Nuclear Enterprise**® Diasonograph 4102 (pictured above), the **Aloka**® SSD-10 compound contact scanner (pictured below) and the **Toshiba**® TSL systems. **Jan C Somer** and **Nicolaas Bom** in the Netherlands introduced the **phased-array** and **linear-array transducers** respectively in **1968** and **1971** (see **Part 2**).



Louis M Hellman, **Mitsunao Kobayashi**, **Ross Brown**, **George Leopold**, **Roy Filly**, **Roger Sanders**, **Arthur Fleischer**, **Kenneth Taylor**, **Fred Winsberg**, **John Hobbins** and **William Cochrane** were among those who produced a substantial amount of work from the early 1970s on the application of ultrasound relating to **Obstetrics and Gynecology** and had contributed much to moving the modality forward. Winsberg had a particular interest in real-time scanners and he was the first to use the German

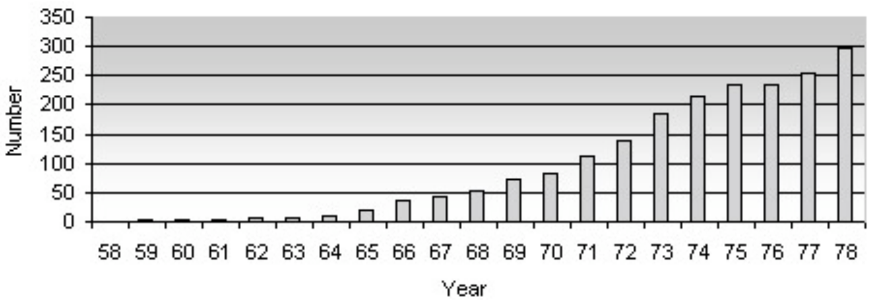
The Picker Laminograph in the mid-70s, evolved from the Physionics Porta-scan

George Leopold

Vidoson® real-time scanner (see part 2) in North America (at the **McGill University** in Montreal, Canada) in **1970**. One of the very earliest textbooks in sonography in the English language aside from **Bertil Sunden**'s thesis was from **Kobayashi**, **Hellmen** and **Cromb**: "**Atlas of Ultrasonography in Obstetrics and Gynaecology**" published in **1972**.

The **American Institute of Ultrasound in Medicine (AIUM)** which was founded in **1952** by a group of physicians engaged primarily in the use of ultrasound in physical medicine only started to accept members in the diagnostic arena in **1964**. **Diagnostic ultrasound** has since then become the mainstream application in the organization. The **"First International Conference on Diagnostic Ultrasound"** was held in **Pittsburgh, Pensylvannia** in **1965** and was well attended by most of the ultrasound pioneers.

The ***Journal of Ultrasound in Medicine***, the official journal of the **AIUM**, was inaugurated in **1982** replacing the **Journal of Clinical Ultrasound** as the association's main vehicle of communication with it's members. **George Leopold** was its founding editor. By the mid-1970s important producers of articulated compound B-scanners in the United States included the **Picker Corp**®, **Smith Kline Instruments**®, the **UniRad Corporation**®, **Searle Ultrasound**®, **Rohe Scientific**®, **Litton Medical Systems**® and **Metrix Inc**®. A list of manufacturers of **static compound contact scanners** as at **1975** can be found **here**.



The number of publications in the world literature each year on the application of ultrasound in Obstetrics and Gynecology rose from 1(Ian Donald's paper) in **1958** to 296 in **1978**. In the first 10 years, most publications were of a general descriptive nature and had similar titles to the effect of "The use of ultrasonography in Obstetrics and Gynecology".[ref]

Hisaya Takeuchi

In Japan, **Shigemitsu Mizuno**, **Hisaya Takeuchi**, **Koh Nakano** and **Masao Arima** followed up the ultrasound work at the Juntendo University in Tokyo, and experimented with new versions of the **A-mode transvaginal scanner**. The first ultrasound scan of a 6-week gestational sac by vaginal A-scan was reported in the Japanese language in 1963. From 1962, the group worked extensively with the **water-bag** B-scanner, the Aloka **SSD-1** and was very active in many areas and producing a huge number of research publications, ranging from early pregnancy diagnosis to cephalometry to placentography. They also reported on a large series of pelvic tumors in 1965, and in the following 2 years switched from the water-bag contact scanner to the articulated-arm compound contact scanner, the **SSD-10**. Another group consisting of **T Tanaka**, **I Suda** and **S Miyahara** started researches into the different stages of pregnancy in 1964.

Articulated-arm compound contact scanner the SSD-10 from Aloka used at the Juntendo University in late 1960's. The same model was used by Salvator Levi in Brussels in 1968

Shigemitsu Mizuno, **Hisaya Takeuchi** and their team also demonstrated in **1965** an **endovaginal scanner** for pelvic examination using the plan-position indication (PPI) B-mode format. The device was mannually rotated and the resulting display was very similar to a circular military 'radar" display. Used either transrectally or transvaginally, It was capable of producing some meaningful pictures of the pelvic organs. See **Hisaya Takeuchi** for a list of early work from the group.

The **Japan Society of Ultrasonics in Medicine** was officially formed in **1962**. In the **1970s** important work started at the **Tottori Uinversity**, Toyko under **Kazuo Maeda**, particularly on doppler **fetal cardiotocography** and at the **University of Toyko** under **Shoichi Sakamoto**. Toshiba® produced their first **A-mode scanner**, the **SSA-01A** and the **compound contact B-scanner**, the TSL system in **1967**. **Hitachi**® produced their first A-mode (the **EUA-1**) and B-mode scanner (**EUB-1**) in 1971 and 72 respectively.

- Also read a **short history of the development of Medical Ultrasonics in Japan**.

In the **Republic of China**, **Shih An** founded in **1958** the **Shanghai Ultrasonic Medical Research group** at the Sixth People's Hospital of Shanghai and his team included Tao-Hsin Wang and Shih-Yuan An. In the same year they started ultrasonic investigations using a modified


B-mode scanner produced at Wuhan, China in the early 1960s

metal flaw detector (the **Chiang Nan Type I**) manufactured at the chiang Nan Ship Building Plant. The group collaborated with investigators from the Shanghai First and Second Medical Colleges, namely Shih-Liang Chu, Hsiang-Huei Wu, Chih-Chang Hsu (Zhi-Zhang Xu) and Kuo-Juei Yu. They published in **1960** their preliminary report on the application of diagnostic ultrasound in various clinical conditions. This article which was published in Chinese in the '**Chinese Medical Journal**' was not known to the west until two years later when their follow-up publication **"The use of pulsed ultrasound in clinical diagnosis"** appeared in the foreign language edition of the same journal. In these articles the diagnosis of **hydatidiform mole** with A-mode ultrasound was described, supposedly the first time in world literature, where they demonstrated a significant increase in the number of small echo spikes between the proximal and distal uterine walls.

Further work in Obstetrics and Gynecology came from **Xin-Fang Wang** and **Ji-Peng Xiao** at the Wuhan Medical College (now Tongji Medical University) in **Wuhan, China**. In **1963**, the group reported on the sonographic findings in 261 abnormal pregnancies and in **1964** described fetal M-mode echocardiography which was probably the earliest of such reports in the medical literature°°. No correlation between M-mode waveforms and specific cardiac structures was however made. **Yong-Chang Chou** who had also been pioneering A-mode ultrasound diagnosis since the late 1950s at the **Shanghai Sixth People's Hospital** published a similar report in the next issue of the same journal (May, 1964).

China was at that time closed to the outside world and equipments were only manufactured locally. Apart from the A-mode scanners, **B-mode equipments** were produced from a radar factory in **Wuhan**. One of the more important designs came from **Zhi-Zhang Xu** of the Shanghai Research group working at the ZhongShan Hospital. Regrettably progress was completely brought to a halt by the Cultural Revolution in 1966 and did not resume until the late 1970's.

In **Taiwan**, Republic of China, ultrasonic investigations started at the **National Taiwan University** in 1966, where J P Hung and Y C Chen used the Aloka® SSD-2C in the detection of mid-line shifts in head injuries and brain tumors. In the following year, their department and Obsteticians Hsi-Yao Chen and S M Wu had switched to the use of the B-mode **SSD-10** from **Aloka**® and published papers on B-mode cephalometry in **1971** in the chinese language. The Society of Ultrasound in Medicine, Republic of China (SUMROC) was founded in **1984**.

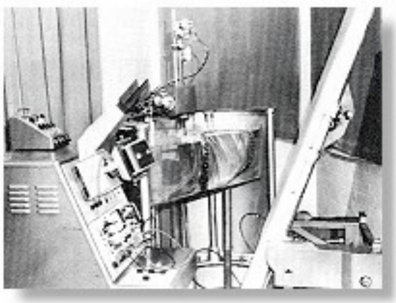
- Also read a history of the **Early development of ultrasonography in China**. (partly in chinese).


George Kossoff c. 1975


William Garrett

Down under in **Australia**, the **Ultrasonic Research Section** at the **National** (formerly **Commonwealth**) **Acoustic Laboratory** in **Sydney** was established in **1959**, with the objective of creating a center of technical expertise in the field of medical ultrasound. The section was headed by it's chief physicist **George Kossoff**. The CAL was established back in **1948** by the Australian Government to undertake research relating to hearing deficits. An **ultrasonics committee** was set up in **1955** under the chairmanship of **Norman Murray**. Murray visited **Joseph Holmes'** laboratory in 1958 and was impressed with the use of ultrasound as a diagnostic tool.

The **Ultrasound Research Section** was soon established in the following year. Working in conjunction with **William Garrett**, a gynecologist from the Royal Hospital for Women in Sydney, who was eager to have a new diagnostic method for placental localization, Kossoff introduced the water-coupling **CAL echoscope** in **1959** and perfected it in **1962**, which was also modified for breast scanning. His team also included **David Robinson**, who joined the Institute in 1961. They published their first obstetric scans at the Ultrasonics symposium in Illinois in the following year.


The CAL echoscope (MK I)

In 1968, **Garrett**, **Robinson** and **Kossoff** published one of the earliest papers in fetal anatomy "Fetal anatomy displayed by ultrasound" using the water-bath **CAL echoscope** that had brought out the role ultrasound would play in the diagnosis of **fetal malformations**. In **1970** they published **one of the ealiest papers** on the diagnosis of fetal malformation, reporting a case of fetal **polycystic kidneys** at 31 weeks of gestation.


The UI Octoson

The original echoscope was replaced with a **Mark II** version in **1969**, which had already incoporated basic **gray scaling** in the images, before the invention of the 'scan-converter'.

The group reported **gray-scale obstetric scans** in **1971** at the International Biological Engineering meeting in Melbourne and then at the World Congress of Ultrasonic Diagnosis in Medicine in Rotterdam in **1973**. **David Carpenter** joined the Section in 1968, and headed the Engineering Research subsection. **Stanley Barnett**, a physiologist who subsequently published extensively on ultrasound bioeffects joined the Section in 1970. Kossoff and his team developed sophisticated **annular dynamic phased-arrays** in **1974** which was installed in the mark II water-coupling echoscope.

In **1975**, they constructed the **UI Octoson**, a rapid multi-transducer water-bath scanner which had then incoporated the new **scan-converter**, improved annular array transducers and more powerful computing electronics that had allowed for superior compound scans to be completed in less than 1 second. The scanning mechanism of the **Octoson** is completely immersed in the coupling tank and the patient, lying prone, is examined from below. (see also **Part 2**)

Also read **An historical look at ultrasound as an Australian innovation** by **Kaye A Griffiths**.

Interestingly about **terminologies** in the early days: At the "**First International Conference on Diagnostic Ultrasound**" in Pittsburgh, Pensylvannia in **1965**, **Charles Grossman**, editor of the proceedings made the following comments:

> " ..... The terminology of diagnostic ultrasonics, like that of any new science, is still in the formative stage ...... The first term to describe the diagnostic medical procedure involving the application of ultrasound appears to be ***ultrasonoscopie*** and was suggested by Denier in 1946. Dussik in 1947 used ***hyperphonography*** for the transmission technic and Ballantine, Bolt, Hueter and Ludwig in 1950 ***ultrasonic ventriculography***........ Wild and Reid in 1952 tried to simplify the terminology and changed the term ultrasonoscope to ***echoscope***, in their words 'to correspond with the word stethoscope.' They further suggested the terms '***echograph***' for the equipment and '***echograms***' for the records as well as ***unidimensional echography*** for A-scope and ***two- dimensional echography*** for B-scan presentations. In the same year (1952) Howry and Bliss referred to their instrument as the '***somascope***' and to the B-Scan recordings as '***somagrams***'. Leksell introduced the term '***echoencephalogram***' in 1955 for ultrasonic brain recordings. In my own publications the medical procedure of ultrasonic diagnostic examination of the brain is termed '***sonoencephalography***', whereas the graph is called '***sonoencephalogram***'...... . In Japan, they call it ***'ultrasono-tomogram'*** and in Australia '***echograms***' .... ".

Most have quickly settled with calling this "diagnostic medical procedure involving the application of ultrasound" '**ultrasonography**' and the images recorded '**ultrasonograms**'. In North America, the terms '**sonography**' and '**sonogram**' soon became more fashionable, and technical staff performing the procedure became known as '**sonographers**'. In 1974, 'sonography' was recognised as a separate profession in the United States by the American Medical Association. On the other hand, "**Ultrasonography**" is now used as the sole **MeSH keyword** in Medline indexes to delineate the subject.

Go to **[Part 2]** and **[Part 3]**

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Acknowledgements:

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Image of Dr. John Wild courtesy of Dr. Wild.
^ Dr. William O'Brien Jr., Professor, Bioaccoustic Research Laboratory, Department of Electrical and Computer Engineering, University of Illinois.
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Pictures of Professors Bertil Sunden and Salvator Levi courtesy of Professor Levi.
^^ Courtesy of the Department of Ultrasonics, Polish Academy of Science.
ref raw data from "Ultrasound in Biomedicine - Cumulative Bibliography of the World Literature to 1978" by Drs. Denis White, Geraldine Clark, Joan Carson and Elizabeth White. Pergamon Press 1982.
¥ The story of the early development of sonar in Glasgow was vividly narrated in the article "Sonar -- the Story of an Experiment" by Professor Ian Donald which appeared in Ultrasound in Medicine and Biology, vol 1 pp109-117, 1974.
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- Every effort has been made to ensure accuracy in dates, persons and events.
- It is not possible to include all the names who have contributed significantly to the advancement of Obstetrical and Gynecological sonography, some who may have been less well-known than the others and some who may not have published so extensively in the English language. Apologies are extended to those whose contribution has not been fully credited in this article.

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Go to **[Part 2]** and **[Part 3]**

A short History of the development of Ultrasound in Obstetrics and Gynecology

Dr. Joseph Woo

[Part 1] [Part 2] [Part 3] [Site Index]

Search

Pushing ahead, new technology and new techniques

The A-mode scan had been used for early pregnancy assessment (detection of fetal heart beat), **cephalometry** and **placental localization** in Europe, Britain, United States, Japan, China, USSR, Poland and Australia in the early 1960s, the measurement of the **biparietal diameter** (BPD) having been invented by **Ian Donald** in **1961** and further expanded in his department by **James Willocks**, basing on improvements in the 'bright-up' markers and the electronic caliper system. The measurements were done 'blindly' without actually seeing the structures under study. Visualising the **gestational sac** by **B-mode** ultrasound was first described by the **Donald** and **MacVicar** team in **1963**. In 1965, they were able to demonstrate a 5-weeks gestational sac. The **Gestational sac diameters** in the assessment of fetal maturity was described by **Lou M Hellman** and **M Kobayashi** in **1969** and by **Pentti Joupilla** (Finland), **Salvator Levi** (Brussels) and **E Reinold** (Vienna) in **1971** in relation to early pregnancy complications. **Kobayashi** also described the ultrasonic appearance of **extra-uterine pregnancy** using bi-stable B-mode ultrasound in **1969**. **Kenneth Gottesfeld** in **Denver** reported in **1970** a large series of patients where fetal death in utero was diagnosed solely on bistable ultrasound scan.

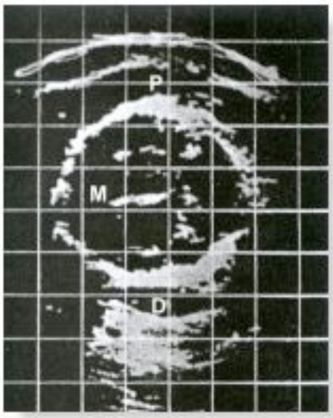
Stuart Campbell

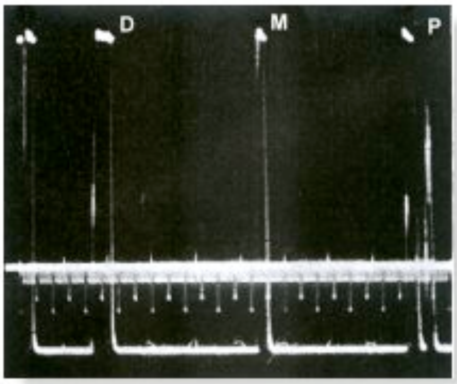
The ability to recognise and confirm the presence of fetal cardiac action in early pregnancy was considered to be one of the **most indispensible** use of ultrasonography (and still is). Although detection of fetal hreartbeat by the **A-scan** and audio doppler ultrasound (the first "**Doptone**" was invented in **1965**, see section below on doppler) had been variously reported by early groups such as **Wang** (1964, M-mode from 10 weeks), **Kratochwil** (1967, vaginal A-scan from 7 weeks), **Bang and Holm** (1968, A- and M-mode from 10 weeks), it was not until **1972** that **Hugh Robinson** in Glasgow, basing on improved instrumentation reported a practically useful 100% detection of fetal cardiac action from **7 weeks onwards**. The fetus was first located with B- scan ultrasound and the heartbeat obseved with a directed beam in A- and M-mode (also see below). This breakthrough has profound implication in the management of **early pregnacy bleeding** and **threatened miscarriages**.

B-mode **placentography** was successfully reported in **1966** by the **Denver group** in the United States and the **Donald group** in **1967** (**Usama Abdulla**). Ultrasonic diagnosis of **molar pregnancies** was described as early as **1963** by the same group.

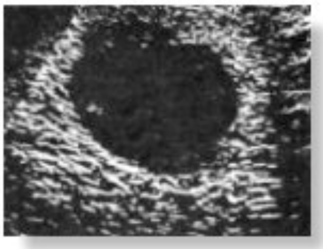
Localisation of the placenta another indispensible use of ultrasonography

Stuart Campbell's landmark publication in **1968** "An improved method of fetal cephalometry by ultrasound" described the use of both the A- and B-mode scan to measure the fetal biparietal diameter. This elegant and practical 'maneuver' had quickly become standard practice in an ultrasound examination of the fetus for the next 10 years. Operating the static scanner skillfully and effectively has also become a crafted art. In **1971**, with improvements in the caliper system, Campbell and Newman published normograms for the biparietal diameter from the 13th weeks of gestation and has made cephalometry a standard tool for the assessment of fetal growth and maturity. Many early paper in cephalometry followed in the late 1960s such as those from **Boog** in France, **Khentov** in the USSR, **Zacutti** and **Brugnoli** in Italy, **Kratochwil** in Austria and **Pystynen** and **Ylostalo** in Finland.





The early bistable oscilloscopic B-scan image at the level of the BPD and the A-scan tracing showing cephalic (P and D) and midline echoes (M). The distance between the 2 cephalic echoes is the BPD. Without scan converters on-screen (oscilloscope) measurements on the B-mode image are not possible. Very accurate measurements can however be made using the A-scan calipers.



The concept of blighted ovum started with advent of the B-scan

Two years later in **1973**, measurement of the fetal **crown-rump length** was described by **Hugh Robinson** in Glasgow who was then a research registrar. Life size magnification of the images had become possible with the newer machines which enabled accurate measurements to be made on early embryos. In **1972**, the Scottish group, basing on the ultrasonic findings, expounded the concept of **'blighted ovum'** in Obstetrics, first described by **Ian Donald** in 1967, which had changed considerably the concept and management of pregnancies with vaginal bleeding in the first trimester.

Horace Thompson

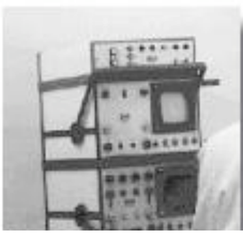
Horace Thompson in **Denver** has described in **1965** measurement of the **thoracic circumference** (**TC**) as a method for studying fetal growth. The measurement had an accuracy of within 3cm in 90% of the patients. Thompson also introduced the idea of **fetal weight estimation** basing on the TC and estimates were found to be accurate to within 300 grams in 52% of patients. The resolution of images at that time however, did not in general allow for very accurate measurement of the fetal trunk. **Manfred Hansmann** in **Bonn**, **Germany** re-introduced the **thoracic circumference** in **1972** and similarily correlated it with the birth weight of the fetus. In the same year he also described **intrauterine transfusion** under ultrasonic guidance. **William Garrett** and **David Robinson** in **Sydney** had also reported on measurement of the fetal trunk area as a means to assess fetal size. The group used a water-bath Echoscope which by 1970 had already incorporated some degree of gray scale capabilitiy allowing for better visualization of the fetal trunk.

With the static B-scan, **Campbell** reported the diagnosis of an anencephalic fetus at 17 weeks in **1972** and the diagnosis of spina bifida in **1975**. Both had appeared as landmark papers in the Lancet. They were the first cases of these conditions in which a correct diagnosis by ultrasound had effectively led to a termination of pregnancy. In **1975**, the **Campbell** group introduced the measurement of the **abdominal circumference** which has since then remained the most important single parameter to assess fetal weight and nutrition. Circumference measurements of the fetal trunk is considered superior to diameter measuements as the former is less affected by the change in shape of the fetal body. It was not until **1979** that **Margi Mantoni** and **Jan Fog Pederson** in **Copenhagen** first described the visualization of the **yolk sac**, using the static B-scan.

- Also read a brief discussion on the historical aspects of the **fetal trunk circumference measurements**.

It was round about this time in the *History of Ultrasonography* (the mid-70s) that several important developments in ultrasound instrumentation took place.

Gray scale and the Scan Converter

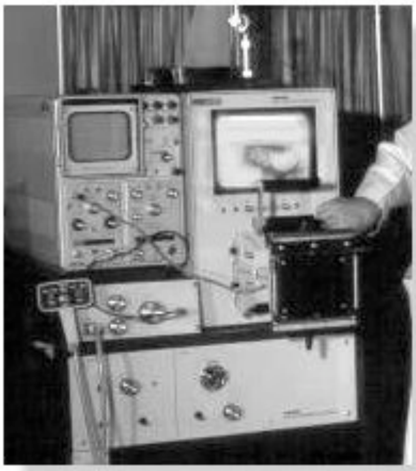


Pioneering designs in **electronic circuitries** were made in conjunction with the development of the B-scan, these included the pulse-echo generator circuitry, the limiter and log amplification circuitry and the demodulator and time gain compensation circuitries. Early B-scanners employed threshold detection which registered echoes on a phorsphorous coated oscilloscope screen as dots of light. A '**storage**' or '**bi-stable**' cathode-ray tube was used. Echoes above a certain amplitude are displayed as dots of **constant** intensity and echoes of a lesser amplitude below the threshold were not depicted. The images were often recorded unsatisfactorily on ordinary 35mm photographic film. The situation was improved with the advent of the black and white "peel-apart" **polaroid® instant** film which had become

The early B-scan with the bistable oscilloscope **

available from **1959** onwards in both England, Europe and the United States. Although there was good representation of size, shape and position, the images did not depict differences in echo amplitude. It was apparent that some sort of **gray-scaling** was imminently necessary to expand the diagnostic capability and accuracy of a B-scan.

The most **important innovation** in ultrasound imaging subsequent to the invention of the compound contact scanner was the advent of the **scan converter**. The cathode ray tube had a low dynamic range of about 16 decibels. Early attempts at creating a **'gray scale'** was through the use of a short-persistence oscilloscope and varying the time of shutter exposure in the photography. This could manage roughly 4 shades of gray in the final picture but the process was difficult to control and results unpredictable. In later developments prior to the appearance of the scan converter, echoes were compressed using sophisticated **logarithmic compression amplifiers** to accomodate the maximum amount of information into the range and a useful degree of grey-scaling could be managed with this principle.



Scan converter incoporated in early American model. Image is being displayed on the TV monitor on the right Note the black-on-white display format

Machines such as that developed in Glasgow in the mid-1950's were actually grey-scale ready from the outset. The function of the signal processor was to provide a degree of time-domain pulse shaping, in an attempt to separate echoes arriving closely-spaced in time and secondly to enable the display to record the very large dynamic range of signals (at least 60 dB, a range of signal amplitudes of more than 1000 to 1) which were received, without going into 'hard limiting' at the top end, or suppression of small echoes at the bottom end. The focus at that time was rather more on "spatial noise" reduction by signal integration as it was on accommodating the large dynamic range of the received signals.

Videotaping became possible with the advent of the scan converter

The analog **scan converter** which was hailed as a profound "invention" in the field of image processing and reproduction, used a silicon oxide/silicon target that acted as a capacitance matrix and was then raster-scanned by an electron beam that 'read' it and displayed the information on a standard television monitor unit. By doing so, computer-processor technology, which was just up and coming at about the same time, could be applied to process the signal. **Images could then be scaled**, **calipers moved and applied on-screen** (something that had changed entirely the way measurements are made), **gray-scaling** applied to the images and the resultant image recorded on a variety of media including **videotape**, **emulsion films** and **thermal printer devices**.

The application of true gray scaling had evloved from the work of the **Kossoff** group at the **Ultrasonic Institute in Sydney** (formerly the National Acoustic Laboratories), **Australia**.

George Kossoff c. 1975

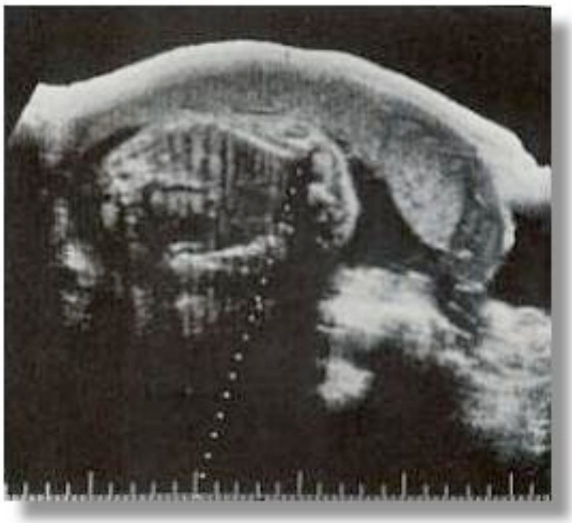
George Kossoff, chief physicist and director of the Ultrasonic Research Section, had been inventing and refining ultrasound apparatus for a variety of purposes including ophthalmic applications since 1959. Together with **William Garrett**, a gynecologist, **George Radovanovitch** and **David Carpenter**, two brilliant engineers, they published their new scan converter with **gray scale** capabilities in **1973**, basing on work which they had already started in **1969**. They demonstrated that the clinically relevant echoes that affected the magnitude of reflected echoes were those that came from the internal texture of soft tissues, and in gray-scale imaging they optimised the signal processing to display this textural information. By about ' 73-' 74 other centers in Britain and Europe have also published on their version of gray-scale equipments. In 1975 the **Kossoff** group constructed and demonstrated the **UI Octoson®**, a rapid water-bath scanner employing 8 annular dynamic phased-array transducers which achieved it's scans by a combination of mechanical rocking and sequential pulsed-echo operations. The machine produced very impressive images at that time compared with the European counterparts.

A similar mechanism was evaluated at the **Royal Marsden Hospital** in England at the same time under **Kenneth Taylor** and **David Carpenter**, who was visiting engineer from the Kossoff group. Together with **Christopher Hill** and **VR McCready** the group published their experience with gray scale imaging in **1973** and demonstrated their version of the compound gray-scale contact scanner. (Taylor moved to Yale University in 1975). Gray scale equipments had soon become widely available commercially by 1976. Gray scale sonography, as **Kossoff** had put it "*had the shortest transition phase between development and acceptance*" because improvements in the quality and 'interpretability' of the images were truely dramatic. The addition of gray scale had been instrumental at that point in time to the evolvement of the measurement of the fetal **abdominal circumference**, first discribed by the **Campbell group** at King's College Hospital; and to the assessment of fetal malformations and gynecological pathologies.

A bistable b-scan image of the maternal abdomen showing abdominal circumference and placenta using a compound contact scanner (Diasonograph®) *without* gray-scale in the late 1960s.

B-scan image with **gray scale** of a similar section of the maternal abdomen showing abdominal circumference and placenta using the Nuclear Enterprise® NE 4102 in the late 1970s

A **gray scale** Octoson® image of the abdominal circumference and placenta in the late 1970s. The Octoson® produced superior images as compared to articulated arm scanners but loosed out on mobility and flexibility.



A **gray scale** longitudinal scan of a section of the fetal trunk and placenta made with the very popular Picker® 80L static scanner in the early 1980s. Despite the very good images that could be obtained with these machines, they were soon replaced by the new real-time scanners.

The DEC (Digital) PDP-11

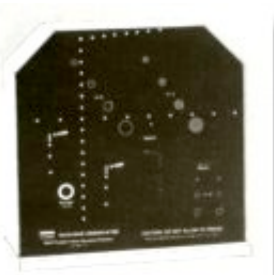
With advancement in computer electronics, the analog scan converter was soon being replaced by **digital scan converters (DSC)**. **Albert Waxman** and others at **Searle Ultrasound** produced one of the earliest DSCs in **1976** with a 256 by 240 pixels memory. Position and velocity data were fed through a PDP-11 mini-computer (Digital Equipment Corporation) and logic circuits sampled the data from the analog front end and wrote it to the correct place in DRAM, and at the same time reading out the data continuously for display on a grayscale video monitor.

The digital scan converter provided for enhancement in peak detection operation for larger pulse echo amplitudes, and the integration-normalization analysis for smaller amplitudes, resulting in great improvements in the grey scale quality and resolution of the ultimate diagnostic image. Non-uniformities and distortions, both of linearity and of gray scale that were associate with analog converters could be avoided. Small echo amplitudes emanating from interfaces between similar tissues bearing useful image information could be preserved. Multiple image storage capability was improved, and write and erase speed were also much enhanced to permit real time imaging (see below).

In the late 70s' DRAM memory boards (mainly from Intel®) and analog-digital converter electronics were expensive necessitating new and more targeted designs. New general-purpose microprocessors (see below) were starting to appear which gradually replaced the large **PDP-11** (picture). The early Searle design also incorporated digital differential analyzer, rate multiplier and peak value detector circuits. Image clarity was very substantially improved from the analog counterparts. The bulky size (kitchen cabinet) of the static machines with more advanced digital conversions seen at that time was partly contributed to by the computer electronics housed inside. A number of designs even up to the first few years of the 1980s still incorporated the entire PDP-11 inside the console. By this time new and advanced microprocessors such as the **8086** from **Intel**® and the **6800** from **Motorola**® were coming into the market (see below).

Hitachi in Japan produced their scanner, the EUB-20Z in **1978** incorporating what they claimed to be the world's first DSC in an array ultrasound scanner. **David Robinson** and **George Kossoff** in Australia also described one of the earlier DSCs in **1978**, employing a 512 by 512 pixels digital memory. The images were stable and the simultaneous read and write capabilities allowed for versatility in processing the image. 4 bit (16 shades of gray) and 5 bit (32 shades) machines had become available. **Aloka**® in Japan produced a similar digital device in the same year and was incoporated into their production models.

Subsequent developments in pulse-echo imaging and scan conversion was based on the recognition that ultrasonic echoes originate not only from major interfaces but also from the smallest mechanical structures of the human body. The advancements were therefore directed towards the detection of small echoes in the presence of noise and to display the subsequent information in the fullest dynamic range of **spatial details** and **echo amplitudes** and calling for **smaller spot size** and wider range of **brightness levels** in the display.



With early scanners made of vacumn tubes there was often problem of **drifts** and **numeric instability** which required **periodic re-calibration**. Another important consideration in the early days was the assumed velocity of ultrasounds in human tissues. Different centers adopted different values, ranging from 1540 m/s, 1580 m/s and 1600 m/s, and this had to be stated in their reports and papers. By about the early 1980s and after several meeting of the experts, the ultrasound community throughout the world settled for **1540 m/s**. This universal acceptance is important because with different velocity calibrations measurements like the biparietal diameter will end up with different normals.

Attenuation charcteristics, axial and lateral resolution, fluid enhancement characteristics

Tissue phantom

etc. were also periodically tested with "**tissue phantoms**" to determine the imaging quality and accuracy of the scanner. Hospital physicists are often pre-occupied with such calibrations. With the later advent of array real-time scanners these tissue phantoms progressively became obsolete and by about the late-80s they have completely disappeared from the scene and few are bordered by the figure of 1540 m/s.

The black-on-white display

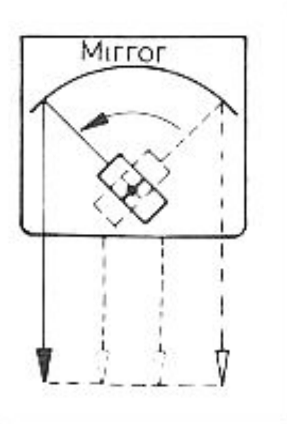
Also of interest to mention here is the **black-on-white** (b-o-w) display format that was commonly used in the United States prior to the mid-1980s. British, European and most other parts of the world had started with a **white-on-black** (w-o-b) display and had stuck to it since. It was initially thought that the b-o-w display format might visually allow the operator to appreciate more detail on the screen. However, there were a number of reports in the early '80s which indicated excessive **eye-strain** to the operator who needed to look continously at the brighter b-o-w monitor screen in a dimmly lit examination room ^^. Eventually, there was a complete switch in the United States to the w-o-b display format , which was supposed to produce less eye-strain on the operator.

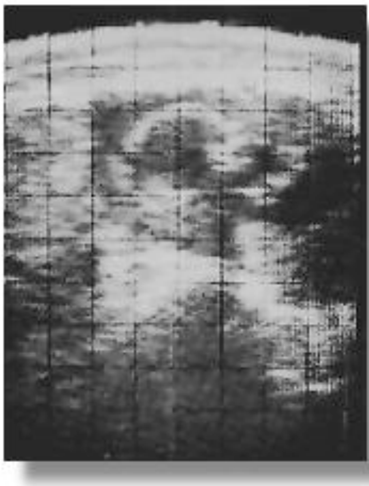
Real-time, the real revolution

Richard Soldner

The innovation which had soon **completely changed the practice of ultrasound scanning** was the advent of the **Real-time scanners**. The first real-time scanner, better known as fast B-scanners at that time, was developed by **Walter Krause and** **Richard Soldner** (with **J Paetzold** and **and Otto Kresse**) and manufactured as the **Vidoson**® by **Siemens Medical Systems** of Germany in **1965**. **D Hofmann**, **H Holländer** and **P Weiser** published it's first use in Obstetrics and Gynecology in **1966** in the German language. **Hofmann** and **Holländer**'s paper in 1968 on "**Intrauterine diagnosis of hydrops fetus universalis using ultrasound**" also in German, is probably the first paper in the medical literature describing formally the diagnosis of a fetal malformation using ultrasound.

The **Vidoson** used 3 rotating transducers housed in front of a parabolic mirror in a water coupling system and produced 15 images per second. The image was made up of 120 lines and basic gray-scaling was present. The use of fixed focus large face transducers produced a narrow beam to ensure good resolutions and image. Fetal life and motions could clearly be demonstrated.





The Vidoson*, its working mechanism and the resultant image of a fetal face and hand.
The transducer housing is mounted on a mobile gantry and rigidly connected to the main console.
The scanning frequency was 2.25 MHz. Scaling and caliper functions were not present.

Hans Holländer, in his paper in **1968** demonstrated the usefulness of a 'real-time' scanner in the diagnosis of ovarian tumors which were not spotted on pelvic examination. **Malte Hinselmann**, using the **Vidoson**, demonstrated in **1969** the universal visualization of fetal cardiac action from 12 weeks onwards. The **Vidoson** was popular in the ensuing 10 years or so and were used in many scientific work published from centers in Germany, France, Switzerland, Austria, Belgium, Italy and other European countries. The initial popularity was not based on its image resolution but rather its ability to allow the operator to **display and study movements**, such as fetal cardiac motion, gross body movements and fetal breathing movements (see also **Part 3**). In the *International Symposium on Real-time ultrasound in Perinatal Medicine* held in Charleroi, Belgium in **1978**, most of the presentations were based on results from the **Vidoson**.

> " .... For almost ten years, real-time ultrasound has been used in many obstetrics departments. By means of an apparatus which has since become technologically outdated many doctors, technicians and expectant mothers had, at the time, the moving experience of being able to observe the living fetus. This seems to me to have been a psychological break-through. For the first time, the human eye pierced the 'black box' of the womb...... Those who were present in obstetrics departments when this technique was first used soon realized how indispensable it was proving to be in providing a valid means of observation of the fetus and its health, in ascertaining its age and studying its morphology and growth........ . Over the last three years, the appearance of the multitransducer scanner has brought about substantial technical progress. At the same time, but quite independently of this, numerous studies on fetal breathing movements, fetal behavior and neonatal cardiology were published ...."
> --- **R. Chef**, Maternité Reine-Astrid, Charleroi (Belgium), in the foreword to the Proceedings of the International Symposium on Real-time Ultrasound in Perinatal Medicine held in **1978** at **Charleroi**.

- Read a **history of the development of ultrasonography at Siemens, Germany**.
- Read also an article **40 Years of Realtime-Ultrasound Diagnostics** by Hans Hollander.

Carl Kretz

James Griffith and **Walter Henry** at the National Institute of Health produced a **mechanical oscillating real-time scanning apparatus** in **1973** which was capable of producing clear 30 degree sectoral real-time images of good resolution. The scanner was essentially a motor-driven oscillating transducer coupled with a commercially available one-dimensional echocardiograph (the SmithKline Eckoline 20). The 2-D scanning device was hailed as one of the most significant milestones in the development of echocardiography, and indeed in the development of sonography in general. Other mechanical systems published included an oscillating design with membrane-oil coupling from **W N McDicken** in Edinburgh (1974, produced commercially as the EMI® Emisonic 4260), a continuously rotating wheel with radially-mounted transducers from **Hans Hendrik Holm** and **Allen Northeved** in Denmark (1975), and a single transducer direct-contact design from **Reginald Eggleton** in Indiana (1975). The design, which was supposed to have been modified from the mechanisms of an "electric toothbrush", was a commercial success. **Toshiba**®, in Japan produced their first prototype real-time mechanical sector scanner in 1975, the **SSL-51H**. A number of others were available commercially soon afterwards and sold well such as the circular rotating system **Combison 100** from **Kretztechnik**® of Austria (1977), produced under the ingenuity of **Carl Kretz**.

Although these have relatively heavy probes they produced outstanding real time resolution in the near and far field (because of highly focused beams resulting from the relatively large curvatured transducers and the lens apparatus) and with much less image-degrading electronic noise that was associated with electronic scanners that soon became available at around the same time.

The large hand-held circular rotating transducer (Combison 100) from KretzTechnik® and the resultant sector image. The transducer is connected to the main console by a flexible cable.

Nicolaas Bom

The concept of the multi-element **linear electronic arrays** was first described by **Werner Buschmann** in an **ophthalmologic application** in **1964** in East Berlin. His probe, fabricated in collaboration with **Kretztechnik AG** consisted of 10 small transducers mounted on an arc-shaped appartus to fit over the eye. Buschmann's transducer however, never became very functional in a clinical setting and did not go into serial production. A number of similar designs followed on the same concept. **Jean Perilhou** and her group in France, working under the auspices of the Philips® Company, described a multi-element scanning array in **1967**, although they do not produce images in a real-time fashion. The real-time array concept was further expanded by **Nicolaas Bom** at the Thoraxcenter, University Hospital, Erasmus University in Rotterdam, the Netherlands. His initial design in **1971**, which was described in his application for a Dutch patent, consisted of only **20 crystals** (each 4mm x 10mm). The probe face was 66 mm long and 10 mm wide and produced 20 scan lines. It operated at a frequency of 3.0 MHz sweeping at a frame rate of 150 frames/sec. The axial resolution was 1.25 mm while the beam width at 6 cm was 10 mm. This abeit simple and inadequate design at that time has evolved into the very sophisticated real-time scanners that are widely available today.

Multiscan system from Organon Teknika, 1972

In collaboration with cardiologist **Paul Hugenholtz** and local Dutch company **Organon Teknika**, they produced in **1972** the "**Multiscan system**", notably the **earliest** commercial linear array scanner in the world, mainly aimed at cardiac investigations.

The transducers operated at either 2.25 or 4.5 MHz, again with 20 crystals producing 20 scan lines. The lateral resolution of this improved version at a dynamic range of 10dB was 3.7 mm at 6 cm and 6 mm at 10 cm depth. It did not sell very well though because of its relatively primitive resolution and its inability to image abdominal structures adequately.

Aloka's first linear array scanner, 1976

In Japan, **Rokuro Uchida** at **Aloka®** (see also **Part 1**) had similar research on the array technology in the late 1960s predating their European counterpart. In **1971** they published in Japanese (and presented at the Japan Society of Ultrasonics in Medicine) a system based on 200 closely interspaced transducers. Electronic switching and use of overlapping groups of 20 small elements yielded 2-D images with a field depth of 20 cm at a rate of 17/frames per second. The company produced their **first prototype linear array scanner** in the same year. The model however, was not produced commercially or given a model number. The **first commercial linear array scanner** from **Aloka®** only debuted in **1976**. **Toshiba®** produced their first commercial real-time linear array counterpart in the same year, the **SSL-53H**, aimed at abdominal applications. Like the Aloka® this was a huge machine considering present day fabrication standards.

Subsequent to **Bom**'s work and the research in Rotterdam, **Leandre Pourcelot** and **Therese Planiol** in Tours, France was experimenting with more advanced segmented sequence transducer-array scanning possibilities in **1972**, in order to

Pourcelot's prototype real time scanner, 1972

enhance the lateral resolution of the devices. **Donald L King** at the **Columbia University** in New York described a 24-elements segmented sequence linear-array cardiac scanner in **1973**, in collaboration with the **Hoffrel Instruments Inc.**®, at Norwalk, Connecticut. In his design 3 crystal elements were fired simultaneously to produce a single pulse of ultrasound. The echoes returned from the 3 reflections were written into a single line on the scan. The crystals were stepped in a "1,2,3,... 2,3,4,... 3,4,5... " manner. There was however no delay lines for the implementation of 'focusing' techniques.

Also concurrent to **King**'s work was the work in from the **Tony Whittingham** group at Newcastle-upon-tyne in England, where crystal stepping techniques were also being investigated.

Tony Whittingham

"...... I tried various ideas, but the one that worked was to make an array of very narrow rectangular elements and to use a group of these to form a square aperture. This group of elements defining a composite transducer would scan the line in front of itself. Then you drop one element off from one end, put another element on at the other end, infront of the group, and advance the active group along the array in this way. When I was doing this I was totally unaware that it would work. I hope it would work, but I was worried that there would be cross-coupling from the end elements of the group into what should have been passive elements, so that you might not be able to get a well-defined active aperture. But it did work, and that proved to be the way forward, because you could make finer and finer elements and get more lines into the array ...." -- **Tony Whittingham**, describing his work in real-time imaging in the mid 1970s. ^

Images of the earlier models were nevertheless hampered by the problems of small crystal size, lobe artifacts, unwanted specular reflections, low dynamic range, unsatisfactory lateral resolution and image noise from electronic processing. There was an overwhelming need for the refinement of beam characteristics. **Fredrick (Fritz) Thurstone**, **Olaf von Ramm** and **H Melton Jr** at the **Duke University** published some of the earliest and most important work on electronic focusing using annular arrays ('71-'74), both on transmit and receive. Similar techniques were subsequently employed in the design of linear arrays transducers. Basing on these designs, a number of centers and private laboratories were starting to embark on making machines geared to examination of the abdomen. **Albert Macovski** at the **Standford University** filed a patent in 1974 for a circular array where the elements generate dynamically focused beams that could also be swept through space by adjusting the delays to the array. This was one of the more advanced designs in dynamic focusing techniques. Another important design - "signal processor for ultrasonic imaging" was described by the **William Beaver** group of the **Varian Associates**® in Palo Alto in California in **1975** where selection of scan angles and focusing distances were effected. **George Kossoff** in Australia also filed a patent in **1973** on a linear array system incoporating phased-focusing electronics. A summary of the advances in design can be found with **M Maginness**'s article (at Stanford) "*State-of-the-art in two-dimensional ultrasonic transducer array technology*" in 1976.

The ADR realtime scanner ****

It was **Martin H Wilcox**, founder and engineer at the **Advanced Diagnostic Research Corporation** (**ADR**®, a company founded in 1972 in Tempe, Arizona), who designed and produced one of the earliest commercially available models of a linear-array real-time scanner in **1973** and very much set the standard for subsequent designs to follow. The array contained **64 crystals** in a row (3 times the number in the earlier cardiac counterparts and 3 times as long and wide), fabricated with the best material available and in the best accoustic configurations and using 'stepping' crystals techniques. This was the first 'good-resolution' **abdominal linear-array scanner** that was in the commercial market.

Their second model **the 2130** marketed in **1975** had brought the linear-array principle and the application of 'focusing techniques' to commercial fruition. It was a big hit in the United States and had sold over 5000 units worldwide, including Germany and other European countries. The machine was marketed in Europe under the **Kranzbuehler** label. In 1980 a new 3.0 MHz variable focus transducer was added on to the 2130. The new transducer contained **506 crystal elements**, boasted both mechanical and phased focusing, improved gain and reduced noise, much quieter transducer operation, and switchable focal zones. The image had twice the number of data lines and probably the best real-time resolution in the industry at that time.

Marty Wilcox c.70s

" .... In Dallas, Texas, Ian was shown the first real-time scanning machine brought from Phoenix, Arizona, by some talented young men. Ian was of course, *wildly* excited. They wanted to carry him off to Phoenix to show him more, but sadly Ian couldn't change his next commitments. However, it wasn't too long before he had one of his own. ...."
--- **Alix Donald**, wife of the late **Ian Donald**, speaking in 1998 about their first encounter with the **ADR** real-time scanner in the early 1970s. [ref.]

ADR® merged with **ATL**® (Advanced Technology laboratories®, see below) in 1984. **ADR**® produced the **2150** in 1980 and the last model under the ADR label, the **ADR 4000** in 1982.

Toshiba SAL-20A
marketed in 1978

Linear array and annular array technology had also been heavily investigated by the **Japanese** since the early 1970's. The country had been moving ahead very successfully with innovative electronic engineering in many domestic, commercial and professional sectors. Commercial linear array models from companies like **Hitachi**®, **Toshiba**®, and **Aloka**® soon began to dominate the world market. **Hitachi**® also produced their first linear array scanner the **EUB-10** in **1976**, followed by the **EUB-20** in **1977** and the **EUB-22** in **1979**. The **EUB-20Z** produced in **1978** already incorporated the world's first **digital scan converter**.

Kazuhiro Iinuma

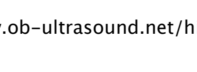
The **Toshiba**® **SAL-10A** and the more portable **SAL-20A** (pictured on the left) and **SAL-30A**, which were marketed in **1977**, **1978** and **1979** respectively, and the **Aloka**® **SSD-202** (1979), **SSD-203** (1980), **SSD-240** (1981) and **SSD-256** (1982) were popular and had found their way into notable Institutions outside of Japan such as the **King's College Hospital** in London (Campbell), the **Herlev (Gentofte) Hospital** in Copenhagen (Holm), the **Hospital Universitaire Brugman** in Belgium (Levi) and were employed in many important early studies. The **SAL-10A** which was designed by acclaimed Japanese engineer **Kazuhiro Iinuma**, received many commendations. Other popular early choices included the **Axiscan 5** (1976) and **Abdoscan 5** (1979) from **Roche Kontron**®, the **Sono R** from **Philips**® (1978), the **RA-1** (1980) and the **Imager 2300** (1981) from **Siemens**®, and the **LS 1500** (1981) from **Picker/ Hitachi**®. **Aloka**® scanners were marketed in the United States under the brand **Narco Air-Shield**®. **Diagnostic Sonar® Ltd**, a company founded in 1975 in Edinburgh, Scotland produced the first electronic real-time scanner, the **System 85** in the **United Kingdom** in **1976**.

Early scanner probe was bulky to fit on the abdomen ***
Images from early real-time scanners
had obstrusive scan lines, low dynamic range and resolution.

Many of the early models typically had **very large probes** housing an array of some 64 transducer (crystal) elements arranged in a linear row, and operating with **sequential electronic switching** or **dynamic focusing**. It was not until the early 1980s that probe size had gotten smaller and image resolution significantly improved.

Read the **short History of the development of Medical Ultrasonics in Japan** for a chronology of Japanese contributions to the development of ultrasound scanners.

At around the same time, **steered-beam phased array transducers** and **annular array transducers** with more complicated electronic circuitry were described, and had found their way into echocardiographic examinations because of the relatively small contact surface.



The **phased-array** scanning mechanism was first described by **Jan C Somer** at the **University of Limberg** in the Netherlands and in use from **1968**, way


Jan C Somer


Frederick Thurstone

ahead of its time and several years before the appearance of linear-arrays systems. The principle of phased-arrays had probably been known much earlier where the technique was engaged in underwater submarine warfare and hence the technology was kept confidential. **Fredrick (Fritz) Thurstone** and **Olaf von Ramm** at the **Duke University** published one of the earliest and most significant phased-array designs in **1974**, which was incorporated into a number of commercial sector-array scanners. Very sharp focusing over an extended range was obtained from annular arrays using focusing methods on both transmit and receive. Other early significant contributors to the **beam-former techniques** included **Albert Macovski** at Standford University and **Samuel Maslak** at Hewlett Packard®. **Maslak** later founded the **Acuson Corporation** (see also **Part 3**).

The **Kossoff** group in **Australia** had also made significant progress in the **annular phased array** transducer designs as early as **1973** and the technology was incoporated into their water-bath scanner, the **UI Octoson**. In England, **EMI**® produced the **Emisonic 4500**, a phased-array sector scanner which was nevertheless expensive, electronically noisy and had inferior resolution in the near fields. Early phased-arrays in the late 70s were all used in cardiac applications. Important manufacturers included **Varian**® and **Irex**®. In the first half of the 1980s, image quality in phased-arrays had continued to improve and some outstanding designs had come from **Irex**® and later on **Elscint**® (**Dynex**) and **Hewlett Packard**®. Despite the small probe size, phased-array sector scanners had never been popular with Obstetrical and Gynecological examinations.


The Digital Imager II from Picker, one of the newer static scanners in the early 1980s

Compound static scanners continued it's tradition of being very huge bulky machines, probably influenced by the design norms of other imaging modalities such as tomographic x-ray machines and the bulky digital electronics housed in the console (see above on scan converters) before the impact of the micro-processors. **New static scanners** which were in great demand and produced excellent images were still on the drawing board and production line in the early 1980s. It was believed that real-time scanners would play only a **complimentary role** to static scanners in the assessment of moving structures. These static machines however were **starting to be replaced** or phased out at a rate that was **faster than expected**. There was apparently little practical, economical or clinical advantage of these costly machines over the more mobile and flexible electronic real-time scanners.

There were initially many who were so used to and skillful at operating the static machines that they were unhappy to switch over entirely to the real-time counterparts. They were also anxious about the latter's limited field of view, poorer resolution and allegedly 'less accurate' on-screen measuring system that they have only started to get used to not too long ago. Static scanners were not completely out of the scene until about **1985-86**. The switch-over had serious financial implications to some companies who had a large inventory of static scanners.

Read a **commentary** by **Royal J Bartrum**, Dartmouth Medical School, in the book "Real-time ultrasonography" in 1982, on the switch-over to the real-time scanner.

From **Digital's PDP-11** to **Intel's 8080** and beyond

The rapid reduction in the physical size of the machine console in the later half of the 1970s (See Aloka® and Toshiba®'s early products above) was the direct result of the invention of the microprocessor and the evolution of the **minicomputer** into the **microcomputer**.


The DEC (Digital) PDP-11

By the late 1960's, computers built from discrete transistors and simple **integrated circuits** (IC) already existed. The first practical IC was fabricated in 1959 at Fairchild and Texas Instruments and Fairchild began its commercial manufacture in 1961. As manufacturing technology evolved, more and more transistors were put onto a single silicon chip with the maximum number of transistors per chip doubling every year between 1961 and 1971. They progressively became a device containing many circuits and was called a LSI (Large Scale Integration). The **PDP-11 minicomputer** from **DEC**® containing many ICs and LSIs, was used in many scanner consoles up to the late 1970s. The UNIBUS architecture used by the CPU in the PDP-11 was particularly suited to communicating with memory and peripherals.

Towards the end of **1969** the structure of the smaller programmable calculator had emerged. **Intel**®, under contract from Japanese company Busicom for the design of a small desktop **programmable calculator**, produced the world's first microprocessor chip the **4004** in **1971**. In order to create a chip of such complexity, new semiconductor design technologies had to be developed. The 4004 is considered the first general-purpose programmable microprocessor, even though it was only a 4-bit device. The original 4004 measured 1/8th of an inch long by 1/16th of an inch wide and contained 2,300 transistors. It ran at 108 KHz and executing 60,000 operations in a single second. It had about the same amount of computing power as the original **ENIAC** which weighed 30 tons, occupied 3,000 cubic feet of space and used 18,000 vacuum tubes. Today's 64-bit microprocessors are still based on similar designs, with more than 8.5 million transistors performing hundreds of millions of calculations each second.

The **4004** was followed quickly by the 8-bit **8008** microprocessor. The **8008**, which contained 3300 transistors, was originally intended for a CRT application and was developed concurrently with the 4004. By using some of the production techniques developed for the 4004, **Intel**® was able to manufacture the 8008 as early as March 1972. The 8-bit era between about 1975 and 1980 had a major impact on household computing and industry because the first few microprocessors were available at very affordable prices.

The Intel 8080 chip

The 8008 microprocessor from **Intel**® was however relatively crude and unsophisticated. It had a poorly implemented interrupt mechanism and multiplexed address and data buses. The first really popular general-purpose 8-bit microprocessor was Intel's **8080**, in production in early **1974**. This had a separate 8-bit data bus and 16-bit address bus. It ran at 2 MHz with 6000 transistors. It has essentially ten times the performance of the 8008.

Shortly after the **8080** went into production, **Motorola**® created its own competitor, the 8-bit **6800**, containing 4000 transistors and destined for use in automotive and industrial applications . Although the 8080 and 6800 were broadly similar in terms of performance, they had rather different architectures. The 6800 was, to some extent, modeled on the PDP-11 and had much a cleaner architecture than the 8080. Other **newer processors** followed and found their way into industrial operations including medical scanners and equipments.

Scanner engineering itself was soon in the hands of commercial companies rather than clinical personnel as advanced computer technologies were fiercely incoporated into each design to manipulate beam characteristics and signal processing to produce the best possible scan images. Apart from those mentioned above, other important early manufacturers of real-time equipments included **Shimadsu®** from **Japan**; **EMI®, KretzTechnik AG, Bruel and Kjaer®, GEC® and Rohe®** from **Europe** and **Diasonics®, Dynex®, Ecoscan®, Elscint®, Hewlett-Packard®, Irex®, SKI®, Phosonic Searle®, Technicare®** (acquired **Unirad®**) and **Xonics®** from the **United States**. The application of **ultrasound in Obstetrics and Gynecology** had since then undergone an explosive proliferation all over the world. By the early 1980s there were over 45 large and small ultrasonic scanner manufacturers worldwide.

Further Improvement in performance aside from focusing the ultrasound beam was acheived largely through an increase in the number of transducer crystals (or channels, from 64 to 128), improvements in transducer crystal technology (going into broad-band and high dynamic range), increasing array aperture (more crystals firing in a single time-frame), faster computational capabilities, improving technical agorithms for focusing on receive (increasing the number of focal zones along the beam), incoporating automatic time-gain controls and progressively replacing analog portions of the signal path to digital. It was perhaps regretable to see that **British manufacturers** have failed to keep up with developments made by other leaders in array technology, notably those from the **United States** and **Japan**. This was probably reflection of a similar trend in other arenas of electronic and micro-processor development in these countries. It is also of interest to note that the **Siemens Vidoson**® and the **Octoson**®from Australia both did not sell in North America at all. Both had the disadvantage of being **cumbersome** when scanners from other manufacturers were rapidly getting better in resolution and manuevability.



In the early 1980s (around 1980-1985), many agreed that mechanical sector scanners (be it rotating, oscillating or wobbling designs) which employed relatively large area transducers produced better and less noisy images than electronic linear-array scanners. Shown here are very good images from **SKI**® (left), **Diasonics**® (middle) and **ATL**® (right) taken in 1981. The market in Obstetrics and Gynecology was divided between the mechanical sector scanners and the linear-arrays until the second half of the 1980s where both were replaced by **convex** sector-arrays.

Hitachi's convex array in 1984

Because of its smaller convex contact surface, the **curvilinear** or **convex sector-array** fits much better on the abdomen and allows for a wider field of view than does the linear-array configuration. Work on the fabrication of an electronic **convex** array had started in the **late 1970s** in the larger Japanese companies such as **Hitachi**® (publishing their convex attachment to their **EUB-10A** scanner in 1978); **Aloka**® (filing their **patent** on the convex scanner in 1980), as well as in U. S. companies notably the **North American Philips**® and the **Picker Corporation**®, who had filed their **patents** for convex arrays and processors in **1979** and **1980** respectively. The first commercially available **convex array transducer** apparently only debuted in 1983 in a scanner from **Kontron Instruments**® in Europe, the **Sigma 20**, which was designed especially for use in Obstetrics and Gynecology. **Hitachi**® in Japan marketed their model **EUB-40** with their new convex array later on in the same year.

Toshiba® introduced a similar array in **1985**, in their new scanner model **SAL-77A**. Interestingly, the design actually replaced an earlier model (by only about 9 months) the **SAL-90A** which boasted a new "trapezoid" linear array in which the face of the transducer was flat but a trapezoid-shaped image was produced from the 128 transducer elements using phased electronics. American machines were apparently still using linear arrays by 1985, although very shortly they were quickly replaced by the new convex configuration. By about 1987, convex arrays are standard on every new scanner, whether or not it is configured for use in Obstetrics and Gynecology.

Model number of some of the scanners made after 1980 from important manufacturers are listed **here** with the year in which they were marketed. Also **view pictures of some of the early scanners**.

Skin Coupling material for ultrasonic transmission has also switched from oil to a water-soluble (non cloth-staining) gel medium. One of the more well-known manufacturers was the **Parker Laboratories**® at New Jersey. Images are commonly recorded on "peel-apart" **Polaroid® films** (the **Type 611** was most commonly used). **Multi-format** radiographic films (6-9 images on one film) using dedicated video imagers soon became mainstream with institutional users and **thermal paper printers** in the private practice market.

Polaroid type 611
"peel-apart" B&W film


The MiniVisor ****

Worthy of mention here was the attempt in the late 70s and early 80's to miniaturize scanners so that they could be portable and be used at the bedside. Four such examples were the all-in-one **MiniVisor**® from Organon Teknika® in the Netherlands, the **Bion PSI-4000** from Bion Coporation® in Denver, the **Shimasonic SDL-30** from Shimadzu Corporation®, Japan, and the **210DX** from Aloka®.

The **Minivisor**® (available from 1979) was a spin-off from **Bom**'s laboratory. It was battery operated, shaped like a mushroom, had no wires and used a 2-inches display with an on-screen caliper system and digital readout. The transducer is fused to the bottom of the device similar to a 'large' fetal pulse detector. **Juiry Wladimiroff** suggested in **1980** the device would be useful for routine BPD screening. Nevertheless the popularity of these machines were short-lived for several important reasons pertaining at that time: The resolution was unsatisfactory because of the available electronics. The images of the 'standard' and larger devices, as well as their overall 'portability' have seen rapid improvements round about the same time; and thirdly, real-time ultrasound has very rapidly established itself as a definitive diagnostic entity and the concern for good image information appeared to overide that of the extra portability.

The invention of the real-time scanner had enabled much more effective diagnosis of many **fetal malformations** and in particular cardiac anomalies which hitherto was impossible to diagnose accurately. (see **Part 3**). **Fetal sonography** and **prenatal diagnosis** (a term which was only coined in the 1970s) had emerged as the 'new' science in Obstetrics and fetal medicine.

John C. Hobbins

John C. Hobbins at the **Yale University**, Connecticut and **Stuart Campbell** at the **King's College Hospital** in London were among others, the two most important forerunners on either side of the Atlantic. Their centers have also become two of the most important teaching centers in fetal sonography. Many of the research fellows and staff members that had come through **Hobbins**' department for example, have in time become celebrated names in the field of **fetal sonography** and **prenatal diagnosis**.

femur length measurements only became possible with the advent of real-time scanners

Other important early North American workers in **fetal biometry** included **Peter Cooperberg**, **David Graham**, **Charles Hohler**, **Alfred Kurtz**, **Rudy Sabbagha** and **Roger Sanders**. Their early work on the biparietal diameter was particularly notable, establishing charts for different populations, standardizing measuring methods and errors and comparing differences that may be present between measurements made on static and real-time equipments. (see also **Part 3**). The real-time scanner had soon enabled the accurate measurement of fetal limb bones that lead to the introduction of the important measurement of the fetal **femur length** by John Hobbins in **1979** for the evaluation of skeletal dysplasia followed by **Gregory O'Brien** and **John Queenan** who described it's use in fetal growth assessment. **Phillipe Jeanty** at Yale provided in **1984** measurement charts for all the fetal long bones.

Ultrasound guidance was started to be employed in procedures such as **amniocentesis** (**Jens Bang** and **Allen Northeved 1972**, Copenhagen), **fetoscopy** (**John Hobbins** and **Maurice Mahoney**, **1974**) and transabdominal **chorionic villus sampling** (**Steen Smidt-Jensen** and **N Hahnemann**, **1984**, Copenhagen).

Read here **a short history of Amniocentesis, fetoscopy and chorionic villus sampling**.

Transvaginal scanners

Vaginal A-scan from KretzTechnik circa 1968

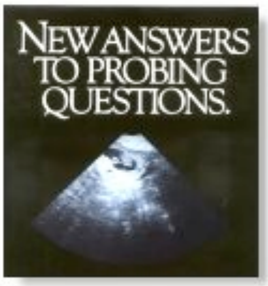
Wild and **Reid** had invented and described the use of A-mode **trans-vaginal** and **trans-rectal** scanning transducers as early as **1955** (see Part 1). Using a proprietary **A-mode** vaginal scanner from **KretzTechnik** in the early 60s, **Alfred Kratochwil** in Austria had reported on fetal heart pulsation at slightly over 6 weeks menstrual age. He also developed a **thimble attachment** transducer to facilitate vaginal sonography with pelvic examination. Trans-vaginal sonograms were also reported by **Lajos von Micsky** in New York around the same time, using innovative prototype equipment that he devised. Other A-mode vaginal transducers were deviced by Japanese researchers. With the advent of B-mode equipments, A-mode vaginal scanners had slowly disappeared from the market.

The first commercially available transvaginal transducer from KretzTechnik in 1985

Shigemitsu Mizuno in Japan demonstrated in **1965** an **endovaginal scanner** for pelvic examination using a plan-position indication (PPI) B-mode format (the same format as an abdominal compound contact scanner). The device was mannually rotated and the resulting display was very similar to a circular military 'Radar" display. Used either transrectally or transvaginally, It was capable of producing some meaningful pictures of the pelvic organs. **Salvator Levi** at Brussels was one of the early advocates of **Aloka**® equipments and published on their transvaginal scanner as early as **1970**. **R A Khentov** in the USSR and **von Micsky** in the United States also demonstrated vaginal and rectal scanning devices in the late 1960s.

Despite the advantages of transvaginal scans, its use had waited almost 20 years to become practical and popular in gynecological scanning. Athough the need and technology were there, the really practical real-time **transvaginal scanning probe** was not "invented" until **1985** when **KretzTechnik**® of Austria produced their first **real-time mechanical vaginal sector scanner**. The transducer had a scan angle of 240 degrees and was designed with the use for transvaginal ovum retrieval in mind, in collaborations with IVF pioneers **Wilfried Feichtinger** and **Peter Kemeter** in **Austria**. The coming of such mechanical devices was also in part the outcome of advances in microprocessor controller circuitry and ferro-magnetics resulting in much smaller and more efficient motors.

from KretzTechnik in 1985



advertisement of the vaginal probe from Philips

Dutch manufacturer **Philips**® followed on with [one of the earliest] mechanical vaginal scanners in the second half of **1986**. The probe was in the shape of a microphone with a roundish elongated head housing a 5MHz 13mm wobbler transducer. It could be retro-fitted onto their real-time scanner [SDR 1550] which first debuted in 1985. Although they produced excellent images compared to their abdominal counterpart, mechanical endovaginal designs were not favored by many ultrasound manufacturers, partly because of the vibration that was generated.

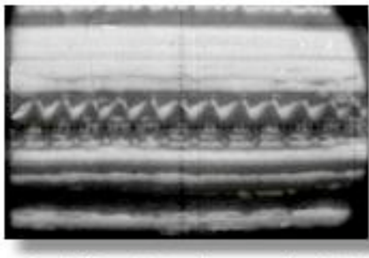
Mechanical designs were rapidly followed by **electronic array versions** which are rather like a reduced-size abdominal **convex sector transducer** that has appeared around the same time from other manufacturers in Japan. **ALOKA**® produced an electronic sector version which could be retofitted onto their older model the [SSD-256]. **GE Medical Systems**® produced their first endovaginal probe to fit their [RT3200] in **mid 1987**. By **1988** most manufacturers had endovaginal options installed in their scanners.


B-Joachim Hackeloer

The advent of tranvaginal scanning (at higher frequencies of 5 - 8 MHz and resulting in much finer resolution) had a significant impact on the diagnosis of **gynecological** and **early pregnancy** pathologies. In particular the accurate recognition of fetal cardiac pulsations in **missed abortions** was facilitated at an early gestational age of 6 weeks.

Non-palpable ovarian masses were often picked up by a vaginal scan. Transvaginal scanning has also progressively become standard practice in the management of **infertility** patients, in assessing follicular development and endometrial growth, as well as being an indispensible aid in the retrieval of oozytes from the ovaries. The assessment of **ovarian follicular development** had before that been based on static and real-time abdominal ultrasound, first popularised by [B-Joachim Hackelöer] and his group in Germany since 1977. (See also **Part 3**). And before that time, most clinicians did not envisage that cyclical changes in morphology and size of ovarian follicles can be so closely followed with ultrasonography.

M-mode and Doppler

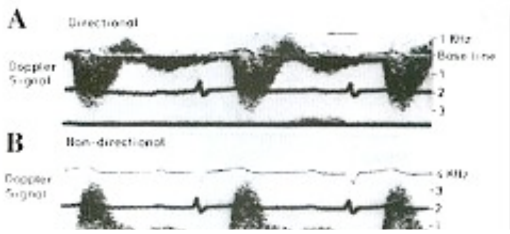

Early M-mode tracings are depicted on oscilloscope screens

The **M-mode (time-motion) display** was first described by [Inge Edler] and [Hellmuth Hertz] in **Lund**, **Sweden** in 1954 using a modified metal-flaw detector from Siemens® of Germany. They demonstrated the feasibility of recording cardiac valvular motion ultrasonically. **Sven Effert** in Germany, who had been collaborating with Hertz in some of his work, futher demonstrated the usefulness of **M-mode echocardiography**, which had subsequently caught on as a mainstay investigation in cardiology. [Xin-Fang Wang] first described in China in **1964** the use of M-mode ultrasound in the study of [fetal] cardiac movements. **Jens Bang** and [Hans Henrik Holm] demonstrated fetal cardiac motion using M-mode from 10 weeks onward in **1968**. In the same year [Alfred Kratochwil] described similar usefulness of detecting fetal cardiac motion by M-mode in patients with threatened abortion. These were nevetheless 'blind' procedures. [Hugh Robinson] in Glasgow described with great success in **1972** the detection of fetal cardiac motion at 7 weeks by A- and M-mode after locating the fetus with on B-mode ultrasound. In the same year **Fred Winsberg** in Canada described **M-mode diagnosis** of fetal cardiac anomaly.

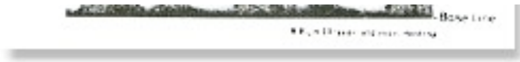

Shigeo Satomura *^*

The [Doppler principle] was first described over 100 years ago by [Christian Andreas Doppler] in Austria in **1842**. Medical applications of the [Ultrasonic doppler techniques] were first implemented by [Shigeo Satomura] and **Yasuhara Nimura** at the **Institute of Scientific and Industrial Research** in Osaka, Japan in **1955** for the study of cardiac valvular motion and pulsations of peripheral blood vessels.

The **Satomura** team which also included [Ziro Kaneko], pioneered [transcutaneous doppler flow measurements] in **1959**, several years ahead of the work at the **University of Washington** in Seattle.



It has also become known from the work of [Ziro kaneko] and **Kanemasa Kato** in Satomura's laboratory in **1962** that **blood flow** can be detected by the ultrasonic doppler method largely because blood itself consists of a suspension of "**uncorrelated point back-scatterers**" (the red cells) with varying density and compressibility, and not because of turbulence in the flow stream as was previously thought. In **1966**, **Kato** and **T Izumi** pioneered the [directional flow-meter] using the local oscillation method where **flow directions** were detected and



Spectral and bi-directional flow demonstrated by Kato and Izumi in 1966. A: directional flow. B: non-directional

displayed. This was a breakthrough in doppler instrumentation as **reverse flow** in blood vessels could then be documented.

Compared to the western world, throughout the history of doppler ultrasound, **Japanese** research had played a leading and major role in its development. Much of the ground-breaking research were presented in national engineering journals and at the *annual scientific meeting of the Japan Society of Ultrasonics in Medicine* (in japanese) and were thus unknown to the west until a later date.

A brief history of the pioneering work in **Doppler applications** in **Japan** is described **here**.

Donald Baker

Donald Baker infront of an early doppler device ****

In the United States, ground breaking work in Doppler instrumentation **started at the University of Washington** in Seattle from **1958** onwards led by **Robert Rushmer**, a pediatrician and physiologist, who was determined to characterise cardiovascular functions in intact un-anaesthetised animals. He was soon joined by **Dean Franklin**, **Dick Ellis** and **Donald Baker**, engineers who were recruited into Rushmer's cardiovascular instrumentation development program. The team pioneered **transcutaneous continuous-wave** flow measurements and **spectral analysis** in 1963 and as a clinical application, surgeon **D Eugene Strandness** undertook the clinical testing. He published the first transcutaneous vascular spectral flow signals in the following year.

Although continuous wave doppler instruments were quite in place by the mid 1960s, for the next 10 years or so it's use in **Obstetrics and Gynecology** was largely confined to that of a fetal pulse detector and continuous fetal heart rate monitoring (see below). Gynecologist **Wayne Johnson** working with **Rushmer** reported the detection of fetal life at 12 weeks gestation (from LMP) with **Strandness'** continuous wave instruments in **1965** (see also below). The continuous wave technology was transferred to **Smith Kline Instruments**® from the University of Washington and the company manufactured the first **Doptone** in 1965. Other early commercial suppliers of continuous wave doppler devices in vascular applications included **Parks® Electronics Inc.**, **Kay® Electric company** (the SonaGraph), and **Medasonics® Inc** (the Versatone). An audio transcript of "*Typical Doppler Sounds from peripheral arteries and veins*" prepared by D Eugene Strandness in the late 1970s can be heard **here**.

Third version of the duplex scanhead 1976. The plunger on the right moves in and out to adjust the range-gating

The continuous wave Doppler method did not provide explicit information about the distance between the ultrasonic transducer and the moving target. Further development led to the introduction of **pulsed-doppler** system by **Baker** in **1970**, a concept based on the repetitive propagation of short ultrasound bursts and analysis of the signal received at a preselected time delay with respect to emission (the sample volume). **Baker** also outlined a technique for determining the volume blood flow from Doppler velocity measurements. The team also recruited **John Reid** from **Pennsylvania** who complemented the flow designs with 2D and M-mode technology. New instruments basing on the ultrasound doppler principles were developed. The first **duplex pulsed-doppler** scanner, a milestone development in ultrasound instrumentations was designed and developed by **Frank Barber**, **Baker**, **Reid** and other colleagues in **1974**. The duplex scanner finally enabled 2D gray scale imaging to be used to guide the placement of the ultrasonic beam for doppler signal acquisition.

> " .... The program was instrument and hardware orientated, because in those days, medical research was carried out in little the same way as wars are fought. Wars are fought according to the weapons you have, and the rules of the game will be according to the weapons you have. I think a lot of researches are in the same way. If you have the tools that nobody else has you can create a new game that nobody else can play........ People saw this as an opportunity. ...... They saw an opportunity to get ahead of their colleagues and publish ...." --- **Donald Baker**, speaking on his early work in doppler instrumentations and his efforts in popularising them at ATL.

ATL® (Advanced Technology Laboratories) was founded in 1969 near Seattle, Washington, by a small group of engineers developing marine electronic systems. Starting form 1973, technology developed at the University of Washington Center for Bioengineering were transferred to ATL in the development of systems for diagnostic sonography. The first duplex pulsed-doppler scanner, the **Mark1** (with pulsed-doppler module model 400) was released in **1974** for cardiac investigation. The later version **400B** became part of the well-known **ATL Mark V** duplex scanner which debuted in **1978**. **Squibb Coporation**® acquired **ATL** in 1980 and **ADR** in 1982. **ADR** was merged into **ATL** in **1984**.

In England, pioneering work from **Peter Wells** in **Bristol** also demonstrated in **1969** that pulsed-doppler information may be obtained through the combination of range-gating methodogy and continuous wave and 2D techniques. In the late 1960s the **Okujima** and **Ohtsuki** group and the **Ziro Kaneko** group in **Japan** (after the death of **Shigeo Satomura**), and the **Pierre Peronneau** group in **Paris** were equally active

Early doppler device from England

in pioneering pulsed-doppler devices. The development of **[pulsed-doppler instruments]** by these groups enabled, for the first time, non-invasive localised measurements of blood velocity. In addition, their instrument could acquire velocity information at several positions along a vessel's diameter, thus enabling the velocity profile of the blood to be visualised. On the clinical side, various waveform **indices** were devised in doppler investigations to reflect flow inadequacies. **Leandre Pourcelot** introduced the '**resistance index**' in Tours, France in 1974. In the same year **R Gosling** and **D King** introduced the '**pulsatility index**'. The **J Drumm** group in Dublin, Ireland described the use of the **A/ B ratio** in 1980.

In the late 1970s, aside from the Seattle group, early duplex doppler devices were also researched and fabricated by the **T Ogawa** group in **Japan** (phased-array duplex sector, 1977), the **James Griffith** and **Walter Henry** group in the United States (phased-array duplex sector, 1978) and the **Bjørn A. Angelsen** group at **Trondheim**, Norway (combination duplex linear arrays, 1981).

Doppler development in Obstetrics and Gynecology

The Doptone from SKI

The use of spectral flow analysis on the **fetus and placenta** was a remarkable *late-comer*. The detection of fetal pulsations using doppler ultrasound was first reported in **1964** by **D A Callagan** who was working with ultrasonic devices at the United States Naval medical Research Institute at Bethesda, Maryland. In the following year (1965), Gynecologist **Wayne Johnson** working with the **Rushmer** team at the University of Washington (see above) reported 100% accuracy in the detection of fetal life in 25 patients at **12 weeks** (from LMP). **Smith Kline Instruments**® manufactured the first **Doptone** in the same year basing on their technology.

Edward Bishop at the University of Pennsylvania, using the SKI® Doptone, reported positive doppler signals from **11 weeks** (LMP) pregnancies in **1966** and 65% success in locating the **site of the placenta** basing on audio doppler signals in the third trimester. The **Callagan** group in the same year reported doppler interrogation of the **fetal heart** and described "*the sound of horse's hoofs when running*' and oscilloscopic 'beats' of the **cardiac** doppler signals. **John Barton** at the Northwestern University in Chicago further reported in 1967 positive audio doppler signals at **10 weeks**. In 1968, the **Johnson** group in Seattle expanded on the usefulness of the doppler flowmeter (audio signals) to the **localization of the placenta**, demonstrating the characteristic '*whirlwind*' and '*rushing wind*' sound of placental blood flow.

In **1967**, the **Rushmer** group outlined the use of **doppler ultrasound in Obstetrics** in an article in **JAMA**, "*Clinical applications of a Transcutaneous Ultrasonic Flow Detector*", which was confined basicaly to the detection of fetal life, placental location, blood flow through the uterine vasculature and fetal movements. Aside from the **SKI**® **Doptone**, other similar devices marketed at that time included the **Ames**® **Ultradop** and the **Magnaflux**® **MD 500**. Other companies producing doppler fetal pulse detectors included Parks Medical Electronics, Imex, Medasonics, Sonicaid and Life Sciences. The **Doptone** was considered as one of the most important instruments that was ever invented in Obstetrics. Before that great difficulty was often encountered in detecting fetal life in both early and late gestations. This now seemingly trivial instrument has quite considerably changed the practice of Obstetrics since the 1960s.

While the use of vascular '**spectral flowmetry**' was quite in place by the mid-1960s (see above), the use of **doppler flowmetry** in **pregnancy assessment** was not followed up in the

Umbilical aterial doppler described by Takemura et al in 1968

American or European literature until about **1977** when **3 separate groups** of investigators were making important pioneering contributions.

The study of **flow velocity waveforms** in *fetal and placental blood vessels* have nevertheless been reported by Japanese reseachers as early as **1968**. In that year **H Takemura** and **Y Ashitaka** described **umbilical arterial** and **placental doppler spectral velocity waveforms** at the *14th meeting of the Japan Society of Ultrasonics and Medicine*. Although the clinical significance of these signals were not quite known, their devices had allowed them to publish very clear and remarkable signal traces resembling those produced on recent equipment (see above right).

In **1977**, **J E Drumm**, a gynecologist and **D E FitzGerald**, then director of the Angiology Research Group of the Irish Foundation for Human Development in **Dublin**, **Ireland**, reported in the **British Medical Journal** the combined use of **continuous-wave doppler** and 2-D static B-mode ultrasound in the study of flow velocity waveforms in the **fetal umbilical artery**, and described probably the **first umbilical arterial velocity waveforms** in the western literature. The shape and applications of these waveforms were not discussed, although they suggested that "... *the shape of the blood-velocity waveforms will change with conditions affecting the efficiency of blood-supply, and the method should be useful in assessing conditons such as pre-eclampsia and intrauterine growth retardation* .... ". The same group reported in **1980** in a much longer paper umbilical waveforms in relation to **gestational age**, their analysis in terms of systolic and diastolic components, and the use of various **waveform ratios**.

W D McCallum

Another pioneering group consisting of researchers from **Stanford University**, the **University of Washington** and the **Varian associates**®, described in **1978** fetal flow velocity waveforms basing on pulsed-wave (range-gated) doppler instruments to overcome the short-coming of the continuous wave counterpart. **William McCallum**, a gynecologist at Stanford (who immigrated from Belfast, Ireland in 1975) together with his co-workers devised sophisticated computer-based techniques to process the doppler signals through a series of **fast Fourier transformations** instead of the older and more primitive method of 'time-interval histogram'. Although they commented that no general conclusions could be reached on the clinical significance of these waveforms from the small study, the group had firmly established the basic groundwork for further investigations.

Sturla Eik-Nes

Robert Gill, together with the **Kossoff group** in **Sydney, Australia** made quantitative measurements of human blood flow velocities since **1977** with the **Octoson®**. He determined that the flow in the **fetal umbilical vein** increased with gestational age but remains constant at around *103* ml per min per kg fetal weight. Accurate measurement of **flow volumes** and **flow velocities** in the fetal blood vessels was however affected by a diversity of factors such as operator skill, fetal position, blood vessel diameter and angle of insonation which made it an **impractical investigation** in the fetus. **Sturla Eik-Nes**, working with **Karel Marsal** in **Norway**, devised the **first** hand-held linear-array real-time apparatus coupled with range-gated doppler in **1980**. The group in that year documented blood flow velocities in the **fetal aorta** and reported in **1983** volume flow through the umbilical vein using the new apparatus.

Pentti Joupilla

Early doppler work also came from the **Pentti Jouppila** and **Pertti Kirkinen** group at **Oulu, Finland** who also worked with **quantitative blood flow velocities** in the umbilical vein and found **significant reduction in flow** in growth-retarded fetuses. Their work importantly demonstrated (in **1981**) that quantitative umbilical venous flow became unrecordable in fetuses with severe growth-retardation and (in **1984**) a significant negative correlation existed between umbilical venous flow and the cord haemoglobin.

Although a relationship could be established between low flow volumes and fetal compromise, such measurements were difficult to be made accurately and thus had not become practical and popular as a fetal investigation. Measurement of volume and velocity flow in fetal blood vessels were **not further pursued** as a research and clinical tool after the mid-1980s.

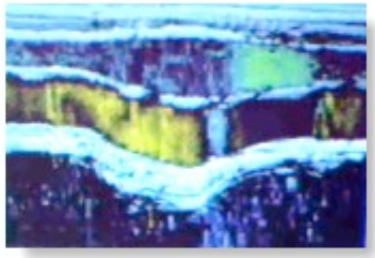
Stuart Campbell and **David Griffin** at the King's College

Hospital in London suggested in **1983** that the shape of the arterial flow velocity waveforms would be more useful in fetal assessment. In the same year **Campbell** also reported on the usefullness of uterine and placental arcuate arterial waveforms, particularly in conditions such as pre-eclampsia.


Brian Trudinger

With the efforts of **WB Giles** and **Brian J Trudinger**, the Australian group made significant contributions to the study of **velocity waveforms** and had made popular the measurement of **waveform ratios** in the assessment of fetal well-being. Such ratios soon became standard in the assessment of fetal circulation in utero. The **Trudinger** group demonstrated in **1986** that abnormal doppler waveform tended to preceed abnormal fetal heart traces. The mid 1980s saw many other centers starting their investigations into doppler velocimetry, often on shared equipment with their cardiology collegues. The significance of a diminishing diastolic flow in the face of fetal compromise was most certainly established. It wasn't until the **late 1980s** that clinical applications of doppler arterial blood flow started to become an important and integral part in fetal assessment. (To continue in **Part 3**)

Further development led to **2D color flow imaging**. **Marco Brandestini** and his team at the University of Washington in **1975** obtained blood-flow images using a 128-point multi-gated pulsed doppler system, where velocity waveforms and flow images were encoded in color and superimposed on M-mode and gray scale 2-D anatomical images. The team included physician **Geoffrey Stevenson** and engineers **Mark Eyer** and **David Philips**, who brought in new technology on **scan-converters** from the **Thurstone** group at **Duke University**. They were able to demonstrate the value of color flow imaging in the diagnosis of various **cardiac defects**. **Leandre Pourcelot** in Tours, France also described their first color-coded doppler images in **1977**. Color doppler systems in the late 1970s and early 80s were however limited by the processing power of the equipment, the lack of good duplex arrays (as contrasted to the mechanical rotor systems) and the agorithm and technique with which doppler frequency estimation was performed.


2-D color flow image of the carotid and jugular vein (top) from the Brandestini group in 1975


The first real time color flow Doppler machine from Aloka, Japan (SSD-880)

It was not until the work of **Chihiro Kasai**, **Koroku Namekawa**, **Ryozo Omoto** and co-workers in **Tokyo, Japan**, which was published in the English language in **1985**, that led to the widespread realization that **real-time color flow imaging** could be a practical possibility. The group had already reported on the technical details and clinical (cardiac) applications in the Japanese language in **1983**. **Namekawa** and **Kasai** were bio-engineers working for **Aloka**® and **Omoto** was cardiologist at the **Saitama Medical School** in Tokyo which had a long history of collaboration with **Aloka**®. What is 'required' to produce a **flow image** of blood vessels is that the **amplitude**, **phase** and **frequency** contents of the returned echoes from a single linear array probe are captured and very rapidly analysed. The Japanese group used a phase detector based on an **autocorrelation technique** in which the changing phase of the received signal gave information about changing velocity along the ultrasonic beam. This provided a rapid means of frequency estimation to be performed in real-time. This approach to **color flow mapping** is still in use today.

Continuing advances in electronics have permitted the development of faster color Doppler instruments, which displayed two-dimensional blood velocity measurements at many frames per second. The successful introduction of color Doppler required fast and stable positioning of the ultrasound beam, which was provided by the development of the linear array and phased-array scanheads. A breakthrough filtering mechanism was also deployed in which the high amplitude/ low velocity clutter signals generated by the movements of tissue structures and vessel wall are removed. Such filters were described by **Bjørn A. Angelsen** and **K Kristofferson** at the **Department of Physiology and Biomedical engineering** at **Trondheim**, Norway in 1979 on the analysis of moving targets in radar systems. In the early 80's the Trondheim group published important work on annular array color flow imaging technology. Color flow mapping not only allowed elucidation of blood flow but had also helped in the determination of pathology in tissues.


Bjorn Angelson

The Company **Vingmed Sound AS**® which manufactured some of the earliest doppler applications was formed in 1974 with technology transfers from **Angelsen**'s Department. The company's doppler equipments performed very well and had a sizeable market in the United States, teaming up with companies like **Irex**®, **Ausonics**® and **Interspec**® in cardiac applications. **Vingmed**® was later acquired by **GE Medical Systems**®.

Advertisements of the first machine with real-time Color flow mapping capabilities from **Aloka®** (the **SSD-880CW**) made it's debut in medical journals in the middle of **1985** (It was produced in Japan in 1984). **Toshiba®** followed up with their

SSH-65A later on in the same year. **Asim Kurjak** in Croatia, using the Aloka® machine was the earliest pioneer to introduce the application of color flow doppler in **fetal assessment**, publishing his work in **1987**. (See also **Part 3**).

Quantum's first ad in 1986

Quantum Medical Systems®, Issaquah, Washington, a new company formed by a group of engineers who left **ATL**, had started introducing the concept of real-time **color doppler imaging** at the **AIUM meeting** in the fall of **1983**. The **first color images** were shown at the **RSNA** (Radiological Society of North America) meeting in **December 1984**. The prototype machine was tried out at several centers and one of the first papers was reported in the **October 1985** meeting of the RSNA by **Christopher Merritt**'s group at Tulane University, New Orleans. **Quantum**® marketed their first machine, the **QAD-1** in **1986** which produced some very impressive real-time color flow images of the carotid and other arteries basing on the newer array technology. They called it "**AngioDynography**" although the term had not subsequently become popular. The transducer design and signal processing were described by **Alfred Persson** and **Raymond Powis**, one of **Quantum**'s founders in their article "*Recent advances in imaging and evaluation of blood flow using ultrasound*" in 1986.

Color flow imaging made it's real impact in the United States in **1987** and in Europe in the following year. **ATL**® after some re-organization, marketed its first color doppler machine, the **UltraMark 9** in **1988**. **Irex**® did not make its own color doppler but marketed **Aloka**®'s SSD-880 in the united States instead. **Irex**®, being acquired by the **Johnson & Johnson Co**®., and sold later to **GE**®, discontinued its line of duplex scanners. **Quantum Medical Systems**® was later acquired by **Siemens**® of Germany, who moved their main operations to Issaquah, Washington.

It was not until the **early 1990's** that the modality found it's way into the assessment of **Gynecological** and **early pregnancy** abnormalities.

"**Power doppler**" or "**Color power imaging**" continued to develop in the 1990s. "**Tissue doppler imaging**" developed further from a revived concept with the arrival of better computational electronics. These developments had important clinical impact on the diagnosis of malignant conditions where tissue vascularity is increased and on moving structures other then blood flow (see **Part 3**).

Tissue Characterization

The ability to develop methods for signal processing of ultrasonic echoes from tissues which allow correlation of acoustic parameters with tissue constituents had always been on the minds of early ultrasound inventors and reseachers such as **John Wild**, **Tom Brown** and **Alfred Kratochwil**. However, **tissue characterization** never became a fruitious area in ultrasonic applications and had never caught on particularly in the field of Obstetrics and Gynecology. Texture characterization of human body tissues has never been easy to perform. Quantitative methods used included fractal models, multichannel methods, analysis of first and second-order statistics of texture, Gaussian Markov random fields, mean scatterer spacing and multiresolution analysis. Invented algorithms are complicated and often inefficient.

The success of tissue characterization in medical ultrasound, and particularly in Obstetrics and Gynecolgy, is largely hampered by the presence of the **inhomogeneous soft tissue medium** and inconsistency of position between the tissue of interest and the insonifying ultrasound transducer (ie. abdominal wall etc.). As the acoustic wavefront propagates through the inhomogeneous tissue, it is modified in amplitude and phase which often has a large and unpredictable effect on the output voltage of the receiving transducer. In addition, the tissue introduces attenuation, and multiple transmission paths through the soft tissue may create replicated echoes. Back-scattered signals are also degraded by speckle noise, acoustic shadowing, and system distortions present in all instrumentation. Important early researchers in this area included **Christopher Hill** at Sutton, England; **Frederick Kremkau** at **Yale**, **John Reid** at **Drexel** and the **Kossoff** group in Sydney. Up to this day, no effective technique for tissue characterization is in use in Obstetrics and Gynecology.

sister chromatid exchanges in a normal chromosome spread

The **safety of diagnostic ultrasound** has received rigorous scrutiny since it's inception, particularly when high power ultrasound had been used in the 1940s for destructive and therapeutic purposes. Subsequent to a number of early reports which did not demonstrate any harmful effects of ultrasound insonation on human cells, **Ian Donald**, in co-operation with **Malcolm Ferguson-Smith**, director of the cytogenetic laboratory at the Queen Mother's Hospital conducted extensive experiments in 1967 to delineate possible harmful effects on high intensity ultrasound on interphase and mitotic chromosomes and did not find any. Studies in 1963 at the **Juntendo Ultrasound Reasearch Center** in Japan also did not reveal any harmful effects on pregnant rats exposed at the maximum power of diagnostic equipments for 3 days after fertilization. **Bertil Sunden** in Lund, Sweden found no teratogenic effects in his thesis research in 1964. Other studies conducted in England by **El Kohorn** in 1967 and **John C. Hobbins** in the United States also did not show any appreciable cytological effects.

Important early researchers included **Wesley Nyborg** at the Pennsylvania State University and later at the University of Vermont; **Paul Carson** at the University of Colorado; **Raymond Gramiak** at the University of Rochester; **William** and **Francis Fry**, **Floyd Dunn** and **William O'Brien Jr.** at the University of Illinois; **Christopher Hill** at Sutton, England; **Marvin Ziskin** in Philadelphilia; **Masao Ide** and **Kazuo Maeda** in Toyko; and **Stanley Barnett** and **George Kossoff** in Australia, to name just a few. Much was done on the study of in-vitro effects of ultrasonic insonation at various intensities, their effects on heating, cavitaion and bubbles; their mechanisms of action, standardization of intensity measurements and drawing up various Guidelines on Biological Safety.

Researchers were also looking at immuno-suppresive effects, platelet aggregation, cell phagocytosis, DNA damage, fetal weight alterations and increase in sister chromatid exchanges in the presence of ultrasound insonation. **LM Hellman**'s study in **1970** on 400 newborns insonated before birth also reveal no increase in abnormalities in the infants. Many other studies followed. A **Bioeffects committee** was set up in the **AIUM** which reviews and monitors the world literature on ultrasound bioeffects on a regular basis. Similar watch groups were set up by the **EFSUMB** and the **WFUMB**. A definite harmful effect at diagnostic levels of ultrasound cannot be confirmed. Such findings give further impertus to the rapid development of ultrasonography in Obstetrics, where concerns for bioeffects safety was obvious.

In the 1980s and 90s, **new studies** emerged looking at the long term effects in children exposed prenatally to ultrasound. No definite adverse effects could be determined in the long term. Other activities in the United States are described **here**. The **Bioeffects Committee** of the **AIUM** made the following **statement** in **1982** and again in **1997**:

> *" No confirmed biological effects on patients or instrument operators caused by exposure at intensities typical of present diagnostic ultrasound instruments have ever been reported. Although the possibility exists that such biological effects may be identified in the future, current data indicate that the benefits to patients of the prudent use of diagnostic ultrasound outweigh the risks, if any, that may be present. "*

It was widely held that the clinical use of ultrasound over the years has not established any adverse effect arising from its exposure. While randomized clinical studies are the most rigorous method for assessing potential adverse effects of diagnostic ultrasound, studies using this methodology show no evidence of any effect on birthweight in humans. Other epidemiologic studies have also shown no causal association of diagnostic ultrasound with any of the adverse fetal outcomes studies (AIUM statements). The World Federation, European Federation and the Australasian Society also held similar views. *These activities and statements played an important role in the* ***proliferation of ultrasound use in Obstetrics*** *as any slightest harmful effect would likely have constituted a major deterrant.*

- Read the article: **"Assessing the Risks for Modern Diagnostic Ultrasound Imaging"** by **Dr William O'Brien, Jr.** ^

- An important article on the Historical Development of Bioeffects Assessment can be found **here**.

- Read also the article: "**History of the American Institute of Ultrasound in Medicine's efforts to keep Ultrasound safe**" by **Wesley Nyborg**

.... **Image quality** of real-time ultrasound scanners made steady improvements during the mid 1980's to early 90's secondary to the increasing versatility and affordability in microprocessor technology. Nev ertheless it was not until the early to mid 1990's that more substantial enhancements in image quality were seen (see **Part 3**) ....

.... The use of ultrasonography continued to boom into the 1980s. According to statistics from the **Bureau of Radiological Health Surveys (FDA)**, in the United States, the percentage of hospitals using ultrasound for dating increased from **35% in 1976** to **97% in 1982** ....

.... The World Federation of Ultrasound in Medicine and Biology (**WFUMB**) **1988 Meeting** in Washington was preceeded by a **two day Symposium** on the **History of Ultrasound**. This event was the culmination of the sustained efforts of the **AIUM Archives Committee**, chaired by **Barry Goldberg**. Of the 500 or so delegates about 200 were recognised as pioneers. During the awards ceremony a further 40 pioneers all over the world were recognised In Memorium. The British Medical Association (**BMUS**) held a similar parallel event in **Glasgow** in the same year. In both meetings there were exhibition of many historical ultrasound instruments ....

.... **Stuart Campbell** with his committee of international luminaries soon started the **International Society of Ultrasound in Obstetrics and Gynecology** (**ISUOG**) in **1990** and held it's first world congress in the following year. He also became the founding editor of the Society's official journal: ***Utrasound in Obstetrics and Gynecology*** ....

Go to **[Part 3]**

- A list of the **Landmark** references : (in the order as they appeared in the text)

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Horace Thompson's image courtesy of the AIUM.
George Kossoff's picture courtesy of Professor Salvator Levi.
** Courtesy of KretzTechnik®, Zipf, Austria.
*** Scottish machine, images reproduced with permission from Dr. RG Law, from his book 'Ultrasound in Clinical Obstetrics', John Wright and Sons Ltd, Bristol, 1980.
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A-scope image courtesy of the Department of Ultrasonics, Polish Academy of Science.
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Image of Aloka's 1971 real-time scanner courtesy of Aloka Co.
Dr. Kato and Dr. Takemura's spectral traces are from the article: "Introduction of the Ultrasonic Doppler Technique in medicine: A historical perspective" by Yasuhara Nimura which appeared in the journal of Medical Ultrasound 1998, 6:5-13.
Prefessor Joupilla's image courtesy of Dr. Aydin Tekay at the Oulu University.
- It is not possible to include all the names who have contributed significantly to the advancement of Obstetrical and Gynecological sonography, some who may have been less well-known than the others and some who may not have published so extensively in the English language.
Apologies are extended to those whose contribution has not been fully credited in this article.

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A short History of the development of Ultrasound in Obstetrics and Gynecology

Dr. Joseph Woo

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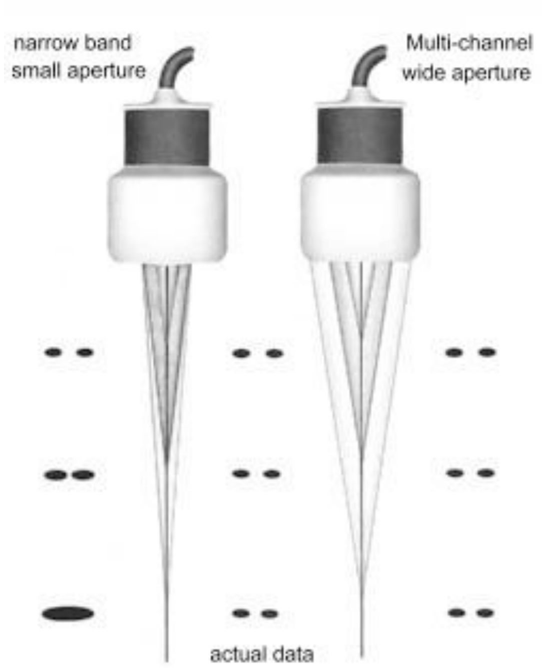
Technology Push and Consumer Pull



Ultrasound scanner technology continued to develop and improve in the 1980s. Real-time scanners had rather standard appearance, sizes and fabrication. They are usually portable on 4 wheels with the monitor on the top of the console and rows of receptacles at the bottom to accomodate a variety of scanner probes. See some of these scanners **here**. By the mid 1980s curvilinear or convex abdominal transducers have come into the market which have a better fit to the Obstetric abdomen and have a wider field of view further from the transducer face. Curvilinear arrays have completely replaced the linear configuration by the late 1980s.

Prior to the 1990s, B-scan ultrasound images made steady progress in resolution and quality, but the improvements were not dramatic and except for a few really top-end brands, most had felt that images in the late 1980s did not have significant improvements over those in the early 80s. During this period, techiques for resolution and overall image enhancement centered around:

the *increase in the number of transducer crystals (or channels, from 64 to 128), improvements in transducer crystal technology (going into broad-band and high dynamic range), increasing array aperture (more crystals firing in a single time-frame), faster computational capabilities, improving technical agorithms for focusing on receive (increasing the number of focal zones along the beam), incoporating automatic time-gain controls and progressively replacing analog portions of the signal path to digital.* See a brief discussion on the linear and phased-array principles.

Acuson Coporation®, a company founded in California in **1979**, marketed their first model **Acuson 128 System** in 1983, employing a 128-channel "Computed Sonography platform" based on a software-controlled image formation process. The machine shook the ultrasound community with its excellent resolution and clarity (and also the price). Many other companies followed on similar system designs. Other innovative breakthroughs were seen in designs from companies such as **ATL**® (Advanced Technology Laboratories), **GE**® (General Electric) and **Toshiba**® . The early to mid- 1980s was the time with the heaviest proliferation of standard-setting good quality machines. By the early 1980s there were over 45 large and small diagnostic ultrasound equipment manufacturers worldwide.

Image quality saw **real improvements in the early 1990s**. It is interesting to note that the availability of new and effective technologies to ultrasound scanners had also progressively stemmed from advances in technology in other areas of science such as **radar navigation**, **telecommunications** and **consumer electronics**. Such included the rapid developments in **cellular telephones**, **micro-computers**, **digital compact and versatile disk players**, and **high definition TVs**. The very high-speed digital electronics required for ultrasound application had become available at an affordable costs. The ultrasound imaging market alone would not have supported the development of these new technologies.

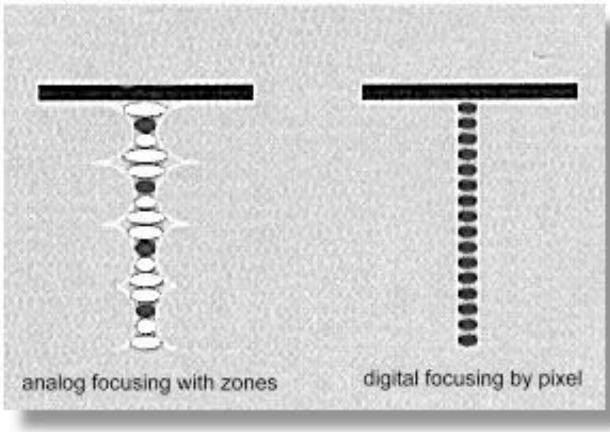
(Model number of scanners made after 1980 from important manufacturers are listed here with the year in which they were marketed).

The new developments in the 1990s which has lead to some real enhancement in image quality and resolution include:

1. **The entire signal processing chain becomes digital**. The entire signal chain which includes:

[the transducer] --> [beamformer] --> [signal processor] --> [scan converter] --> [Monitor]

all operate under digital electronics.



Digital beamformer reduces noise and increase focal points

Previously the **beamformer** (employing analog delay lines) and the signal processing stages are usually analog in their operation. The digital change-over was based on the very **powerful computer platforms** that were only available after the mid 1990s. The processor in the newer highend machines has the power equivalent of roughly **40 Pentium tm processors**, executing some **20 to 30 billion operations per second**. Most of the processing are also programmable software-based rather than hardware-based and allow for much more versatility and finer adjustments in the manipulation of beam signals. Signals from and to the transducer elements are digitized before any signal processing, which is one of the most important advancement in ultrasound technology in the 90s. It opened the venue for dealing with some of more difficult areas in ultrasound physics.
Superfast digital beamformers allow for many times the number of focal points along the beam and produce microfine focal points on receive to the size of a screen pixel. Digital beamforming also reduces noise in the signal processing by several hundred folds producing a much cleaner picture.

2. **Extensive use of refined broad-band wide aperture transducers**, improving both definition of tissue textures and dynamic range. With wide aperture transducers, transmit and receive apodization also allowed for the electronic reduction of the lateral array elements (sidelobes). In the early 1990s there was much improvements in transducer material design and fabrication technology allowing for higher frequency transducers, improved sensitivity and contrast resolution. The number of channels in high-end systems went up to **256** and more recently to **512** and **1024 (2-D arrays)** in several high-end systems allowing for extremely wide aperture on transmission and reception. In ultrasound physics, the lateral resolution is the product of the wavelength and the **f-number**. The f-number equals the depth of the returning echo divided by the **aperture** of the beam. (the aperture of the beam is the width of the number of simultaneous firing transducer elements in the array, that means the larger the aperture the more elements are fired simultaneously). Therefore lateral resolution will be best (smallest) if there is a large aperture and short wavelength (higher frequency).

Too large an aperture will slow the frame rate considerably and requires very fast computation and parallel processing. This has been made possible with the more recent digital electronics and the very powerful super-processors (see above). Many slightly older ultrasound systems are capable of using low f-numbers on reception at an affordable cost. However, they often employed large f-numbers on transmit in order to cover a large area. Significant improvement in lateral resolution requires low f-numbers both on transmit and receive. With the new 'very wide' aperture beamformer (often up to 128 channels), the transmit and receive f-numbers are lowered. The resulting improvements in lateral resolution can be as much as 4 times.

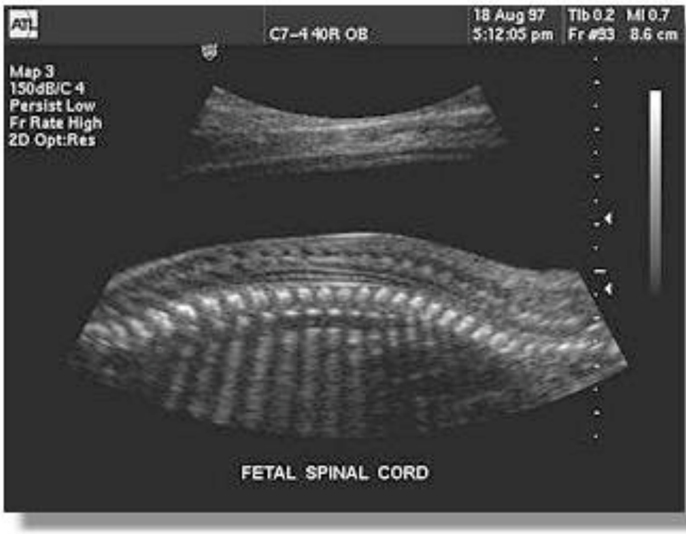
2-D arrays with focusing in two planes

3. **The phase data in returning ultrasound echoes**, in addition to the amplitude data are processed in what is known as coherent image processing. The technique produced twice the amount of data from which to create ultrasound images of high resolution. The frame rate is also increased. The late 1990s has also seen transducer developing into **2D arrays** which is made up of large number of elements arranged in rows and columns across the face of the transducer. Focusing occurs in two directions which produced a finer and clearer definition in both planes eliminating artifacts from adjacent tissue planes which may produce the partial volume effect.

4. **The advent of tissue harmonic imaging**. The technology, which has emerged as a major imaging trend in the last 4 years of the 1990s, made used of the generation of harmonic frequencies as an ultrasound wave propagates through tissue, dramatically reducing near field and side lobe artifacts. In a nutshell, tissue harmonic Imaging made use of lower frequency sound waves to improve penetration, while receiving and processing only the higher frequency echoes produced by the body's inherent harmonic characteristics. This process can reduce clutter and improve image clarity significantly. As ultrasound waves propagate through tissue, there is non-linearities in sound propagation that gradually change the shape of the wave, a shape change that can only result from the development of harmonic frequencies within the wave. There are no harmonic frequencies present at the transducer face. They develop gradually as the wave propagates through tissue, and so in the near field there is very little harmonic energy available for reflection from tissue. Since the near field is a source of much of the artifact in the ultrasound image, selective display of harmonic energy will show dramatically less **near-field artifact**. The strength of the harmonic energy generated is proportional to the square of the energy in the fundamental wave. Most of the harmonic energy results from the strongest part of the beam, and weaker portions of the beam (side lobes, for example) generate relatively little harmonic energy. selective harmonic imaging will yield a **dramatically cleaner contrast** between adjacent tissue structures. It is a sonologist dream come true. The black is black and the white is white. Much of the fuzzy picture noise that have made diagnosis difficult are gone.

The development of harmonic imaging would not have been possible until the late 1990s as there must be excellent beam linearity on transmission and super sensitivity and dynamic range on receive to display the harmonic energy without an unacceptable amount of noise, as the harmonic signals are always much less in amplitude than the original fundamental signal. There must also be a very selective and fast digital filter within the receiver, to exclude the large percentage of the fundamental signal. Harmonic imaging is particularly useful in **obese patients**.

From left to right: Changes in image quality from 1985, 1990 to 1995 respectively.
There were improvements in spatial and contrast resolution, background noise reduction, dynamic range, and near and far field visualization.



More significant improvements came after the mid-1990's.
This image from ATL® * demonstrating fetal spine and cord.

Ultrasound scanners came into **different categories** according to their performance and price. From the early 1980s, scanners have started to move into clinics and private offices and there is a trend to decentralise ultrasound services all over the world. Acceptance and demand from the lay public have also increased exponentially coupled with increased utilization by various medical specialties and sub-specialties. **Standards** and **quality of scans** became an emerging problem not seen in other areas of medical imaging, where Radiogists received the relevant training and underwent apppropriate examinations before running the service. **Obstetricians** were simply using the scanner probe as a torch to "look inside" the uterus. Standards varied and mis-diagnosis was not uncommon. Obstetricians and Gynecologists took on the fact that they are the more suitable persons to do the scans as compared to their radiological colleagues. Special training centers and accreditation boards were gradually set up by the health authorities in the United States, Australia, Europe and other countries.

Joan Baker

In the United States, an impetus for the development of ultrasonography was that medical insurance agencies such as "Blue Cross" had started re-imbursing ultrasonographic examinations since **1966**. Medical sonographers also took up much of the responsibilities of the scans and sonography itself was recognised as a separate profession by the American Medical Association in 1974, the first sonography program being accredited in **1981** by the **Joint Review Committee for Education in Diagnostic Medical Sonography** (the **JRC-DMS**). The **American Registry of Diagnostic Medical Sonographers** was founded in **1974** by the **Society of Diagnostic Medical Sonographers** (**SDMS**). Joan Baker was the first Chairperson. The **AIUM** gradually went beyond developing guidelines and established an ultrasound practice accreditation program. Since 1996, this voluntary program has accredited over several hundred ultrasound practices. To achieve accreditation in obstetrics-gynecology, physicians and sonographers must interpret a minimum of 170 ultrasound scans per year. In **Australia**, the Council of the Australian Society (ASUM) awards the **Diploma of Diagnostic Ultrasound** and the **Diploma of Medical Ultrasound** to medical practitioners and sonographers who sucessfully pass the examination.

And in both a '**Consumer pull**' and **'Technology Push'** situation the diagnostic application of ultrasound in the field of Obstetrics and Gynecology continued to expand into new horizons. In 1975, that is before the advent of real-time equipments, in the United States there were only 5 legitimate indications in obstetric sonography: ◆ measurement of the biparietal diameter (and other dating purposes), ◆ determining amniotic fluid volume, ◆ diagnosis of early pregnancy failure, ◆ evaluation of multiple gestations and ◆ placental localisation. The indications have since the early 80's expanded into at least 2 dozen, including most notably the accurate evaluation of fetal growth and the diagnosis of fetal malformations.

Fetal biometry developed and '**flourished**' in the 1980s as accurate fetal measurements do not require the prerequsite of very high resolution equipments. **At least two dozen measurements** were "invented" to assess gestational age and fetal

size, each claiming their unique usefulness. Nevertheless by the mid 1980s only a few parameters were considered as standard measurements and ones that had "stood the test of time". These include the crown-rump length (**CRL**), the biparietal diameter (**BPD**), the head circumference (**HC**), the femur length (**FL**) and the abdominal circumference (**AC**). Many other measurements were considered useful only in situations where fetal dysmorphology was in question.

(top row) Rudy Sabbagha, John Hobbins, Peter Cooperberg.
(bottom row) Roger Sanders, Alfred Kurtz, Charles Hohler.
producing important work in biometry from the U.S.

Take for example the **BPD**, at least 200 charts are in used in the 1990s in different parts of the world (information supplied by commercial ultrasound scanner venders who set up the charts for their clients). Early workers in the United States who have published extensively on fetal biometry include **Rudy Sabbagha** at the Northwestern University, Chicago, **Alfred Kurtz** at the Thomas Jefferson University, **John Hobbins** at Yale, **Charles Hohler** in Phoenix, Arizona, **Peter Cooperberg** at the University of British Columbia, Canada, **David Graham** and **Roger Sanders** at Johns Hopkins, Baltimore and **Frank Hadlock** and **Russell Deter** at the Baylor College of Medicine, Houston, Texas. There are others from Britain and Europe like **Hansmann**, **Jouppila**, **Kurjak** and **Levi**. Fetal biometry was explored from many different perspectives and in different populations.

The **abdominal circumference** measurement which was described by **Campbell** and **Wilkin** in **1975** remained the mainstay measurement in the evaluation of fetal growth and nutrition. The assessment of **gestational age** and **intrauterine growth retardation** using ultrasonic parameters was the subject of a **huge number** of research papers. Fetal growth analysis and charting were also performed on desktop personal computers (PC) using commercial or home-made proprietory softwares.

◆ Stuart Campbell published the first BPD chart in 1971. Since then, Charts and Tables had become an important and integral part of Obstetric practice, at which Obstetricians and Gynecologists were slowly getting used to. ◆

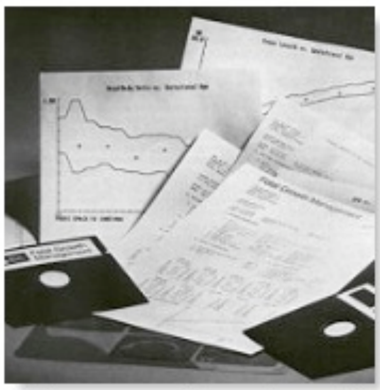
Estimation of in-utero fetal weight basing on the combination of the biparietal diameter and the thoracic circumference was first reported in **1965** by the **Thompson** group in **Denver**, **Colorado**. He reported an accuracy of within 300 grams in 66% of the weight estimates. This was followed by work from **Garrett** in Australia, **Hansmann** in **Germany** and **Campbell** in England. In **1977** the **Hobbins'** group at Yale published one of the most important papers in fetal biometry, **"Estimation of fetal weight by computer-assisted analysis of fetal dimensions"** which had started in the next 10 to 15 years, an almost non-stopping search all over the world for computer-generated models of fetal weight determination basing on multiple fetal parmeters.

$$\text{Log}_{10}\ \text{Weight} = -1.7492 + 0.166\,(\text{BPD}) + 0.046\,(\text{AC}) - 0.002646\,(\text{AC})\,(\text{BPD})$$

One of the several popular weight estimating equations, this one from MA Shepard and co-workers
Normograms and weight estimations have become standard packages built into each ultrasound machine

Frank Hadlock

Similarily the craving to produce normograms for incremental growth of every **'measurable'** part of the fetal body never stopped. One can find **gestational-age normograms** for parameters such as the **Binocular diameter** (Mayden K et al, 1982, Jeanty P et al, 1982), **thigh circumference** (Deter et al, 1983), **clavicular length** (Yarkoni et al, 1985), **fractional spine length** (Li DF et al, 1986), **fetal foot length** (Mercer BM et al, 1987) or **fetal ear length** (Birnholz JC et al, 1988); and charts for parameters such as **cerebral ventricular width**, **cardiac chamber dimensions**, **chest circumference**, **limb lengths**, **renal** and **calyceal sizes** that were of great value in the assessment of specific fetal anomalies. In **1987 E Albert Reece** at Yale demonstrated the usefulness of the **trans-cerebellar diameter** as a growth-independent parameter to assess gestational age.



Software generated growth analysis and charts

Among many others, the comprehensive normograms of **Frank Hadlock** and **Russell Deter** from the Baylor College of Medicine, Houston, Texas were widely used. The group had in particular incorporated the **femur length** measurement into the calculations and popularised the concept of limb length/ trunk circumference ratios in the assessment of fetal growth.

Russell Deter

In the last 40 years or so in the development of ultrasonic **fetal biometry**, there has been much effort among the obstetric and ultrasound community to devise and develop fetal measurements that would be able to distinguish between fetuses that are small because of **nutritional reasons** and those fetuses that are "**by nature**" small. **Head, limb versus abdomen ratios** were once thought of be of promise but as it was noted that the growth-retardation process also affected fetal head and limb growth in varying degrees, the value of these ratios did not stand up to their initial expectations. Up to this day, there is still not one or several size measurement parameter in combination that can **unequivocally diagnose growth retardation** in the fetus when a woman is seen for the first time in the later part of pregnancy.

Visualization of the the **fetal yolk sac** with the real-time scan was first described by **Eric Sauerbrei** and **Peter Cooperberg** in Vancouver, Canada in **1980**. It is interesting to note that perhaps because of its size (and hence the difficulty to visualize with existing equipments at that time) its significance and usefulness in early pregnancy failures was not discussed until much later in the second half of the **1980**s.

The diagnosis of fetal malformations obviously received the enormous attention that was deserved and findings of many abnormalities diagnosable by ultrasound have been described.

Large Exomphalos were considered as "straight forward" diagnosis

Ian Donald included a case of **hydrocephaly** in one of his early "introduction" ultrasound papers in **1961**, which demonstrated "tissue interface within the body by ultrasonic echo sounding". In **Bertil Sunden**'s thesis in **1964** there was description of the diagnosis of anencephaly in the third trimester using on the bi-stable Diasonograph. In **1968 D Hofmann** and **Hans Hollander** in **Germany** reported on **9 cases of 'hydrops fetus universalis'** diagnosed with the **Vidoson** (see **Part 2**) and **William Garrett** in **Sydney** reported the diagnosis by ultrasound of **a fetus with polycystic kidneys** using the **CAL echoscope** in 1970 (see also **Part 1**). These two papers were probably the two earliest papers describing formally the diagnosis of a congenital anomaly using ultrasound. Both reports were about cases in the third trimester and resulted in fetal death.

The diagnosis and management of a 17 weeks **anencephaly** was reported as early as **1972** by **Stuart Campbell** using statc B-mode equipment. This was followed by the diagnosis of **spina bifida** in **1975**. Both reports had appeared as landmark papers in the Lancet. They were the first cases of such conditions in which a correct diagnosis by ultrasound had effectively led to a termination of pregnancy. **Manfred Hansmann** in Bonn, Germany and **John Hobbins** at yale were among others, early pioneers in the ultrasonographic diagnosis of fetal malformations. With the advent of better real-time scanners, many more malformations were diagnosed, abeit in the late second trimester when fetal organs become more discernible on the scans. A review published in **1981** (Stephenson and weaver) reported that around **90 different fetal malformations** had been diagnosed by ultrasound.

Looking at fetal face and lips

Common anomalies that were considered "straight forward" to diagnose at that time included **anencephaly**, **hydrocephaly**, **exomphalos**, **duodenal atresia**, **polycystic kidneys**, **hydrops fetalis** and **limb dysplasias**. More difficult areas for diagnosis of malformations were the **fetal face**, the **fetal extremities** and the **fetal heart**. The diagnostic accuracy progressively improved with more experience and better resolution machines. With the advent of the newer **high-resolution** scanners and the transvaginal transducer the diagnosis of these and other more subtle conditions were achieved, and particularly at an earlier gestation, moving from the third trimester of pregnancy to the second and later on to the **first trimester** in the latter half of the 1990's. **Fetal trisomies**, **spina bifida** and the more subtle **cardiac anomalies** were among the many examples. So-called **soft signs** and **sonographic markers for chromosomal anomalies** (**see below**) were started to be described.

◆ *The ability to recognise and follow up in utero of all these malformations by ultrasound has opened up further the entire avenue of "**Prenatal Diagnosis**" and has markedly enhanced and pushed forward the study of congenital abnormalities among obstetricians, pediatricians, geneticist, pathologist and other allied specialties. All of a sudden, obstetricians started to learn about so many congenital malformations that they have not even heard of.* ◆

The diagnosis of fetal **cardiac malformations** gained foot in the early 1980s. Pioneers included the **Wladimiroff** group in Rotterdam, the Netherlands; the **Hobbins** group (**Charles Kleinman**, **Greggory Devore**, **Joshua Copel**, **Peter Grannum** ....) at **Yale**; **Lindsey Allan** at **Guy's Hospital**, London (now in New York); **L W Lange**, **David Sahn** at **Portland**, **Oregon**; **Kathryn Reed** at **Tucson**, **Arizona** and **Beryl Benacerraf** at **Harvard**.

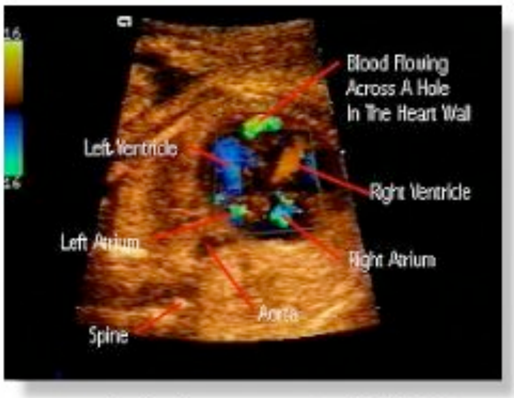
Lindsey Allan

A 4-chamber view from the early 80's

The first real-time fetal heart images and quantitative data were published by the **Lange**, **Sahn** and **Reed** group in Tuscon, Arizona in 1980. **Allan** published her echo/anatomical correlates in the same year. **Allan**, a pediatric cardiologist, described systematically real-time normal and abnormal ultrasonic anatomy of the fetal heart which laid the foundation for subsequent studies. Using ultrasonic equipment available in the early 1980s and much painstaking enthusiasm and skill, she had very importantly shown that real-time **cross-sectional study** and **diagnosis of fetal cardiac anomalies** in utero in the **second trimester** was a distinct possibility and would no doubt develop into a distinctive diagnostic science.

Dev Maulik

The improvements in diagnostic capabilities that came with the 'new technology' scanners in the 90's had tremendous impact on fetal cardiac diagnosis. The usefulness of direct doppler interrogation of **fetal intracardiac flow** was first demonstarted in **1985** by **Dev Maulik** and **Navin Nanda** (Professor of Cardiology) at the University of Alabama. **Allan** and **Reed** followed up with more publications. The **Maulik** group further demonstrated the value of **color doppler** in fetal cardiac studies in **1986**. **Greg Devore** soon popularised the use of **doppler color flow mapping** in the assessment of fetal cardiac malformations and particularly in a **screening situation** in **1987**. The use of color doppler has become indispensible in the diagnosis of more complicated cardiac malformations. By the late 1990s, the diagnostic accuracy of the nature of complex cardiac malformations in utero can be as high as 95 percent.

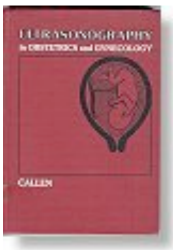


color doppler assessment of a VSD ***

Read also: the **American College of Cardiology Position Statement on Doppler Echocardiography in the Human Fetus** prepared by **Charles Kleinman**, **James Huhta**, and **Norman Silverman** which covers some of the **historical aspects of fetal doppler echocardiography**.

The accuracy of diagnosing fetal malformations in a "**high-risk**" populations have been variously reported in the early 1980s right up to the early 1990s. These included some classic reports from **Kurjak** in Croatia (1980), **Campbell and Pearce** in London (1983), **Gembruch and Hansmann** in Germany (1984), **Sabbagha** in the U.S. (1985) and a good number of other authors. Diagnostic accuracies in "targeted" scans progressively increased with improvement in instrumentations and accumulation of knowledge about the ultrasound characteristics of the various anomalies.

With improved resolution in the new equipment, diagnosis of fetal cardiac anomalies have moved into the late first trimester. All the improvements in machinery and earlier detection of abnormal structures in the fetus have nevertheless brought along with it "**false positives**" and **difficult-to-be-sure-what-will-happen** diagnosis that generate much undue anxiety in patients. Such has far-reaching effects on a woman's perception of child-bearing. Researchers try very hard to determine the course of events for a particularly abnormality or the **implication** and **prognosis** of a certain finding on ultrasound examination so that proper counselling can be done to alleviate anxiety and uncertainty from the diagnosis.



"**Textbooks**" in Obstetrical and Gynecological sonography had emerged out of necessity because of the large amount of information that had become available and as reference materials of those sitting for examinations. Books had gone from being just overviews and atlases to systematic discussions of ultrasound techniques and findings. Notably the books by **Peter Callen** at the University of California, San Francisco (1983) and **Sanders/James** at Johns Hopkins were popular and represented two of the earliest standard textbooks in the field. Multiple authorship contributed to the excellence of these texts. Many other texts followed, some devoted mainly to special topics such as fetal anomalies or doppler ultrasound.

Peter Callen

Karel Marsal

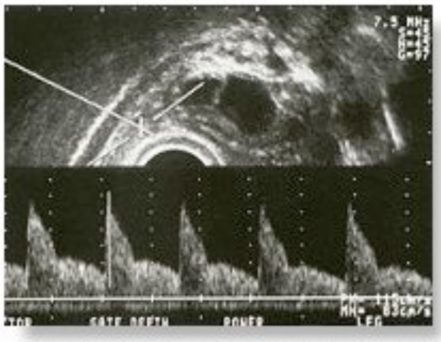
The advent of the real-time scanners also prompted research into **body movements** and **breathing movements** of the fetus The study of fetal breathing movements (FBM) was first suggested by **Geoffrey Dawes** and **K Boddy** at the Nuffield Institute of Medical Research, **Oxford Univeristy, England**, in the early '70s, in that the presence or absence of breathing movements, theiir amplitude and intervals will be indicative of fetal well-being. Much research into these areas came from the **Karel Marsal** group at the University Hospital at Malmo, Sweden, the **Tchobroutsky** group at the Maternite de Port-Royal, paris, the **Wladimiroff** group at Rotterdam, and the **Brian Trudinger** group in Australia. all of them having switched to the use of real-time apparatus in the early to mid '70s. **Wladimiroff** demonstrated in **1977** that maternal hyperventilation decreased fetal breathing. The quantitative documentations of fetal breathing movements however require elaborate equipments, and was very time-consuming, so much so it would be difficult to be incoporated into clinical practice. The results also have wide overlap between positives and negatives. The advent of real-time had also raised hopes of being able to study **physiological responses**, **sensations** and **behavior** in the fetus. Again the assessment were time consuming and results were often equivocal, which made them unsuitable as clinical tests. **Jason Birnholz** at Harvard published several pioneering papers in these areas including the assessment of fetal movement patterns as a possible means of defining neurological **developmental milstones** in-utero and the development of **fetal eye movements** and possible 'dream states' in the feus.

The study of FBM and FM patterns did not gain further popularity although the semi-quantitative counting of FBMs and the documentation of 'adequate" fetal body movements were popularised further in **fetal biophysical profile** scores made popular by **Frank Manning** and **Lawrence Platt** in Winnipeg and Los Angeles, who had started studies into FBMs round about the same time as their European counterparts. In **1980**, **Manning** and **Platt** reported on the important finding that a **reactive cardiotocographic finding** was just as predictive as the presence of **FBMs** or total fetal movements.


juiry Wladimiroff

Spectral doppler or **doppler velocimetry** (the study of doppler waveforms), had evolved to become a standard tool in the late 1980's in the assessment of fetal wellbeing and compromise. (See **Part 2** for more of its early development).

Its advent in Obstetrics in the mid 1980s had fascinated (or perhaps *misguided*) many as *the* new promise in fetal assessment. The **absence** and **reversal** of **end-diastolic flow** in the **umbilical arteries** in severely compromised fetuses were striking demonstration of fetal pathophysiology , so was the finding of clear and unequivocal **increase in diastoic flow** in the **middle cerebral arterial** waveforms in mounting fetal hypoxia. It has also become clear that umbilical doppler velocimetry does not correlate with fetal weight in utero, nor is useful as a screening procedure.



Duplex doppler became standard in the 1990s


Torvid Kiserud

Stuart Campbell's group at the King's College Hospital in London reported in **1983** the evaluation of **utero-placental flow velocity waveforms** in compromised pregnancies with duplex doppler, and described the **'frequency index profile'**. In **1984**, **P Reuwer** in Utrecht, the Netherlands first discussed the ominous significance of **absent end-diastolic flow** in the umbilical artery. Further work from the **Campbell** group, including work from **Gerald Hackett** and **T Cohen-Overbeek** in **1986** and **1987** clearly demonstrated the prognostic significance of absent end-diastolic flow in the fetal **descending aorta**. In **1986**, **Brian Trudinger** in Australia demonstrated that abnormal doppler waveform patterns tended to preceed abnormal cardiotocographic traces. In the same year the **Wladimiroff** group reported the value of **middle cerebral artery** waveforms in the assessment of severely compromised fetuses. **Sanjay Vyas** working at King's College Hospital in England described the use of **renal artery** waveforms in **1989**. The value of fetal **Venous** blood flow in the assessment of fetal compromise was first suggested by **Torvid Kiserud** in **Bergen**, **Norway** in 1991. **Giuseppe Rizzo** at the Universita di Roma Tor Vergata in Italy furthered expounded the usefulness of the **ductal venus velocimetry** in **fetal acidemia** and **cardiac decompensation**. In 1987, **Asim Kurjak** introduced the use of **color flow doppler** in fetal assessment.

Doppler ultrasound became a standard and indispensible tool in the evaluation of progressive **fetal anoxia** (the umbilical artery), **compensation** and **decompensation** (the middle cerebral artery), **acidosis** and progression to **cardiac failure** and **emminent fetal death** (the ductus venosus). It has also been employed in the assessment of women at risk of **pre-eclampsia** and **utero-placental arterial compromise**, leading to early and effective therapeutic intervention. It is of interest to note that historically, these velocimetric parmeters have appeared each a number of years apart with increasing sophistication of the apparatus. By the beginning of the 1990's, most mid- to highend ultrasonic equipments had incoporated **duplex doppler** as standard facility. In the mid 90's, **color flow mapping** had also found its way into most mid- and highend machines. Aside from aiding **cardiac diagnosis** (see above), impressive flow images were often popularly reported such as those found in **Vasa Previa** and the fetal **Circle of Willis**.

◆ *Doppler velocimetry is not only a fascinating demonstration of fetal physiology that provides a vital assessment of fetal well-being, but will likely change the concept of routine antenatal care by picking up placental insufficiency at the earliest stage.* ◆

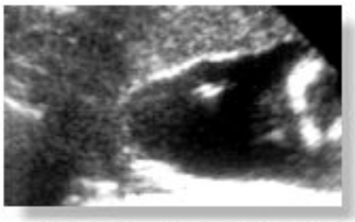

Amniocentesis with the Vidoson

As early as **1967**, and basing on the **Vidoson**, **Hofmann** and **Hollander** in Germany had discussed the importance of placental localization using ultrasound before amniocentesis. **Jens Bang** and **Allen Northeved** in Copenhagen described ultrasound-guided amniocentesis in **1972**. In the mid 1970s to early 80s, **genetic amniocentesis** was largely performed under static B-scan ultrasound guidance. An ultrasound scan was performed to locate a


Puncture adapter on a

feasible pocket of amniotic fluid before a tap, which was done basically without actually seeing the needle tip going into the fluid pocket. With the advent of real-time scanners, a small number of centers had in the late 1970s started to perform amniocentesis by simultaneously visualizing the puncture needle tip on the scanner monitor. One such pioneer was the **Birnholz** group at **Harvard** who used an early **phased array** for the purpose. **Needle-guide adapters** soon became available from ultrasound manufacturers which could be coupled to the linear array or phased array sector probes where the needle passed through a fixed path either parallel or at an angle to the ultrasonic beam. These were **cumbersome** to use however, particularly in a busy setting. They also had serious problem of keeping the equipment **sterile**. The adapters may also increase the risk of traumatisation as it did not allow for the 'desired' and sensitive placement of needles.


Single operator 2-hands technique


Visualization of the needle and tip through the placeta into the fluid

Many centers started to do it **freehand** with an assistent holding onto the transducer probe that was commonly wrapped in a sterile adhesive drape. In 1984, **Wolfgang Holzgreve** in Basel, Switzerland described a large series of over 3000 'freehand' amniocentesis with low complication rate. Similar experience was also reported by **Lawrence Platt** in **Los Angeles**, who emphasised on the need for the transducer probe to be manipulated by the same operator which resulted in better hand-eye co-ordination. In the following year, **Roberto Romero** at **Yale** formally described the single operator two-hands technique in amniocentesis and the reduction in the number of multiple taps and bloody taps associated with the procedure. Most centers soon adopted this single operator technique, which had become popular because of it convenience and effectiveness. **Chorionic Villus sampling** (**CVS**) also relied heavily on sonographic guidance. **Z Kazy** and his group in the USSR reported in **1980 fetal sexing** and **enzyme assay** on chorion biopsies taken at 6 -12 weeks' gestation, using either an endoscopic or ultrasound-guided approach. **RH Ward** in London and **Bruno Brambati** in Milan both reported transcervical CVS under ultrasonic guidance in **1983**. **Brambati** reported the success rate of obtaining chorionic villi rose from 75% without ultrasound to 96% with ultrasound guidance. **Danish** investigators **Steen Smidt-Jensen** and **N Hahnemann** first described the ultrasound-guided transabdominal approach in **1984**. Other adjunctive ultrasonic techniques were reported by the **Brambati** group and the **Golbus** group in **San Francisco** in **1985**.

The **Beryl Benacerraf** group at Harvard (se below) reported the feasibility of **early amniocentesis** (11-14 weeks) in **1988**. In 1990, the same group reported an early fetal loss rate of **over 2.3%**. Several important reviews in the mid-90s confirmed this **high incidence of fetal loss**. The practice has for this reason not gained general acceptance.

Read here **a short history of Amniocentesis, fetoscopy and chorionic villus sampling**.

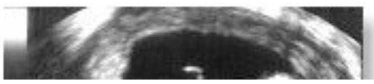

Fernand Daffos


Kypros Nicolaides

Other interventional intra-uterine diagnostic and therapeutic procedures also started to catch on. After fetoscopy, **ultrasound-guided** pure fetal blood **cordocentesis** was pioneered in France in **1983** by **Fernand Daffos**. Pure fetal blood was aspirated in-utero at around 18 weeks from the umbilical vein near the placental insertion of the cord using a twenty gauge needle under ultrasound guidance. Their group reported the first case of Haemophilia A diagnosed in-utero by this method. The procedure was also popularised around the same time in England by the **Stuart Campbell** and **Charles Rodeck** group at King's College Hospital. The **Hobbins** group at **Yale** described their technique in **1985** and called the procedure **percutaneous umbilical blood sampling** (**PUBS**). This replaced blood sampling via **fetoscopy** which the group had pioneered in **1974**. **Kypros Nicolaides** at King's developed the single operator two-hands method and became a leading figure in **cordocentesis** exploring many important aspects of fetal physiology and pathophysiology. With the advent of color flow mapping, the technique has become even more accessible. In **1988**, **Umberto Nicolini**, working with **Charles Rodeck** at the Queen Charlotte's Maternity Hospital in London, first described fetal blood sampling from the **intrahepatic** portion of the **umbilical vein** in the fetus, as an alternative procedure in cases where cord needling was unsuccessful. In the **late 1980s** fetoscopy has mainly been reserved for **tissue** or **organ sampling**, and fetal blood sampling are always done via the ultrasonic-guidance needle procedure. The **commonest indication** of fetal blood sampling has evolved to become one of quick **confirmation of abnormal karyotype** in the 22-24 weeks fetus, when a chromosomal abnorrmality has been suggested on ultrasound scan.

Various in-utero drainage procedures under ultrasound guidance were described in the late 1980s such as the drainage of **Chylothorax** and **hydronephrosis**, and the treating of fetuses by **transfusion** into the umbilcal vessels. **Selective reduction** of the number of fetuses in cases of triplet or quadruplet pregnancies was first described by **Richard Berkowitz** in New York in **1988**, using intra-cardiac potassium chloride injections given under ultrasonic control. **Vesico-amniotic shunt placement** was described by the **Mitchell Golbus** group (with **Michael Harrison**, **Roy Filly**, **Peter Callen** ....) in **San Francisco** in **1982**. The group became one of the most important forerunners in **fetal surgery** and continued to make many new fetal surgical innovations. In that year, they published their multicenter classic paper "**Fetal Surgery 1982**" in the New England Journal of Medicine.

Read here **a short history of Amniocentesis, fetoscopy and chorionic villus sampling**.



With improved resolution from transvaginal sonography, **Mark Cullen** at Yale first reported in **1990** a large series of congenital anomalies detected in the **first trimester**


Ilan E. Timor-Tritsch


Cystic hygroma diagnosed at 12 weeks with vaginal scan

using **transvaginal ultrasound**, and pointed out the importance of a good understanding of normal embryonic development in such diagnosis. Many studies followed around the same time reporting on the usefulness of the first trimester **transvaginal scan** in the evaluation of fetal anomalies. **Moshe Bronshtein**, working in **Haifa, Israel**, described extensively since the early 1990s results of transvaginal sonography in the first trimester. A similar report to Cullen's also appeared in **1990**. **Ilan E. Timor-Tritsch**, working in Israel and later on at New York University, followed on with many reports on fetal anatomy and anomalies systematically studied using high resolution transvaginal transducers in the first trimester, opening up convincingly a new area in fetal ultrasound diagnosis, that of "**sono-embryology**". **Timor-Tritsch** was also credited for organizing the first three **transvaginal ultrasound courses** in the United States.

As ultrasound became a widely available and popular investigation, it contributed heavily to several **population screening programs** that took place between the late 70's and the 90's. The first was the **Maternal serum alpha-feto protein (MSAFP) screening** programs for the detection of neurotube defects (NTD). It started in the United Kingdom in the late 1970s, notably in parts of **Scotland**, where the prevalence of NTDs was high.

In **1972**, **David Brock** and **R Sutcliffe** measured the AFP values in the amniotic fluid of 31 pregnancies with **anencephaly** and 6 pregnancies with **spina bifida**. All of the cases of anencephaly and most of those with spina bifida demonstrated markedly elevated AFP levels. This was a landmark 'discovery' in the history of prenatal diagnosis. In **1974**, **Nick Wald** and co-workers at the University of London reported in **the Lancet** maternal serum AFP levels in 7 pregnancies with open neural tube defects which were significantly higher than that in 14 other controls. This led to the idea of measuring **MSAFP** in **screening for NTDs**. The 19-centers **U.K. Collaborative study** in **1977** subsequently demonstrated the utility of this test for prospective open neural tube defect screening. Similar results were arrived at in large-scale studies in the **United States** in **1979**. By **1984**, **MSAFP screening** had also become part of standard antenatal care in the U.S.

As scanner resolution and sonography skill improved, **ultrasound** gradually replaced **amniocentesis** in the diagnosis of screened-positive cases. By the mid-1990s amniocentesis is often not performed in patients with elevated MSAFP levels. Either a positive or negative diagnosis is made **basing solely on ultrasound findings**.


Salvator Levi

The second was the **routine fetal scan** at 20 weeks which had progressively become an integral part of antenatal care in the early **1990's**.

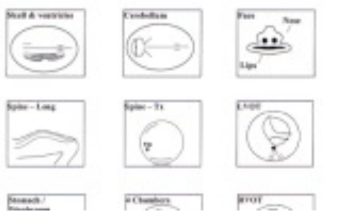
In the late 1970s a number of **large scale population ultrasound screening studies** have been described variously from London, Germany, Brussels, Sweden, Norway, Finland and other countries in Europe and in the United States. At least 20 similar large-scales studies were reported up to the year 1990.

There is apparently a distinct difference in the attitude towards routine ultrasound screening between the Europeans and the Americans. **Routine screening scans** were introduced in **Germany** in 1980, in **Norway** in 1986 and in **Icelend** in 1987. The scans basically try to date the pregnancy, exclude twins and detect any fetal malformations that may be present. In the U.S., routine scans in pregnancy has however been looked upon with much controversy and their **cost-effectiveness** and validity in improving **'quantifiable' perinatal outcome** has not been firmly established. Nevertheless, those who argue for a routine scan would claim that parents have a natural desire to know if any fetal congenital anomaly is present or if there is any health compromise in the fetus. Being able to reassure the parents is a natural part of prenatal care.

Two important large scale studies emerged to address the issue: the **RADIUS study** (Routine Antenatal Diagnostic Imaging with Ultrasound) with a cohort of 15,000 low-risk pregnancies in the United States in **1993** and the **Eurofetus Study** in Europe in **1997** in which 200,000 low-risk pregnant women in 60 hospitals had obstetric ultrasound examinations performed in centers proficient in prenatal diagnosis. **Salvator Levi** was the **Project leader** of the **Eurofetus Study Group** and a strong proponent for routine screening. A **61%** overall detection rate of structural anomalies in the Eurofetus study contrasted sharply with the **35%** overall detection rate in the RADIUS study.

In order to address the conflicting data and conflicting opinions on this topic, a conference was held at The Rockefeller University in **New York City**, in June **1997**, sponsored by the New York Academy of Sciences. Over **150** scientists and clinicians participated in the meeting, with highly informative presentations and discussions.

The following conclusion was made:



> " .... *In summary .... we have tried to put together comprehensive state-of-the-art information on the routine obstetric ultrasound controversy. Our conclusion .... is that routine obstetric ultrasound is warranted for all pregnancies, but only if it is performed in a quality manner. Although there is still scientific and economic controversy about our conclusion, we would argue that, at a minimum, there is an ethical obligation to present the option of an 18-22-week routine obstetric ultrasound examination in*

clinical centers in which quality ultrasound is available. We hope that our efforts will move public policy in this direction and encourage further discourse on this most important topic in contemporary obstetrics." --- Preface, Ann NY Acad Sci 1998 847: 1-ix.

scanning guidelines formulated for 20 weeks screening. Click to enlarge

A discussion on the findings of these two important studies can also be found **here**.

In any case, by the late 1990s and the turn of the century, an **ultrasound examination** for each and every pregnancy at **20 weeks** has become quite standard practice worldwide, as long as facilities are available. As the skill of ultrasonographers and equipment improved the **diagnostic accuracies** of the examinations also improved. This improvement is also brought on by the large number of *ultrasound training courses* throughout the world. Some, like the fetal echocardiography course at Guy's Hospital in London has been shown to effectively improve the pick-up rate of congenital heart defects in certain parts of the United Kingdom. Many other centers in the United States, Europe and the United Kingdom, also run well-attended and effective courses in the prenatal ultrasound diagnosis of congenital anomalies. **Guidelines** formulated by **accreditation bodies** also have a positive effect on ensuring quality of the examinations.

◆ *The standard **20 weeks fetal examination** could have been the single **most important development** in the practice of Obstetric ultrasound in the last 40 years, ever since the day of the biparietal diameter. It was a development that has culminated from developments in skill, training, practice, attitudes, machinery and administration.* ◆

Beryl Benacerraf

The third was the **screening for chromosomal abnormalites**, notably Down syndrome, which became popular in the mid **1990's**. Screening basing on **multiple biochemical parameters** in the low-risk population had started around **1990** in some centers and because of its relative convenience had soon caught on and become standard antenatal care in many parts of the world.

Screening basing on ultrasonic parameters had not become popular until the mid-1990s. Measurement of the **nuchal translucency**, which was first described by **Beryl Benacerraf** and her group at the **Harvard Medical School** in **1985** formed the basis of such screening. Working with fetuses **between 15 and 20 weeks** of gestation her group discovered good correlation between a thickened nuchal skin fold that was above 5mm and the presence of Down syndrome in the fetus. Benacerraf had also earlier on published **biometric parameters** (shorter femurs and humerus, and decreased femur length/ biparietal diameter ratios) as markers for the diagnosis of **Down syndrome** which formed one of the earliest observations and endeavours for an "**indirect**" diagnosis of chromosomal anomalies. Endocardial cushion defect, atrial and ventricular septal defects, omphaloceole, pyelectasis, choroid plexus cyst, echogenic cardiac foci, echogenic bowels, hypoplasia of the middle phalanx of the fifth digit and simian creases were considered as other 'indirect' or 'soft' signs of fetuses with Down syndrome.

Benacerraf had on top of other things brought to the attention of researchers and clinicians the necessity and feasibility of visualising '**small**' **abnomalites** in the fetus and had in so doing pushed scanning skills, machine resolution and operator patience to the limit. Anomalies such as club foot, early hydrocephalus, phalangeal abnormalities, facial clefts .... are some of these examples. In a contribution to a book on prenatal diagnosis **Benacerraf** wrote in 1989^:

> "..... Although many fetal anomalies -- such as anencephaly, hydrocephalus, and anterior abdominal wall abnormalities -- can now be diagnosed sonographically even in the second trimester, more refined diagnosis involve examination of the face and extremities. It is not sufficient, however, to diagnose isolated cleft lip and palate or a clubfoot. Rather, the presence of these lesions should stimulate the ultrasonographer to seek a pattern and fit the pieces of the puzzles together in order to recognize the syndromes associated with chromosomal anomalies ......"

The reason for the seemingly 'late' popularity of 'ultrasonic' screening was probably twofold. Much time was spend initially on making the measurement at 16-19 weeks (following **important work** from **Benacerraf**, **James Crane**, **Hélène Grandjean** and others) and not at 11-14 weeks as practised now (see below). **Measurement of the nuchal fold** at this latter gestation is demanding on operator skill and machine resolution and is also error prone.

measurement of the nuchal skinfold

With improved resolution of ultrasound scanners, better understanding of fetal patho-physiology and more emerging data, ultrasonic screening for nuchal fold thickness has moved from between **16 and 19 weeks** (using a cutoff level of around 6mm) to between **11 and 14 weeks** (using a cutoff of around 3mm) in the first trimester. **Kypros Nicolaides** and his group at King's published the landmark paper in **1992** in the **British Medical Journal**, where the measurement of nuchal translucency between 11 and 14 weeks was used to screen for Down syndrome. He demonstrated the importance of likelihood ratios in the detection. The group later on turned out some of the most important data regarding the appication of **nuchal translucency measurements** including risk estimates and the quantitization of the measurement into gestational-age related multiples of the median (MoM).

Read also: **A discussion on the Nuchal Translucency** from an online book by **Kypros Nicolaides**, **NJ Sebire** and **RJM Snijders**.

Ovarian follicles on vaginal scan
The imaging modality quite dramatically altered the management of infertility patients

In **Gynecology**, ultrasound has started as a diagnostic tool in the differentiation and assessment of solid, cystic or mixed masses in the pelvis. Even in the late 1970s (still very much a static-B era), it has already become a well-established and indispensibe tool in the evaluation of a variety of pelvic pathologies. In **1976**, the **B-J Hackelöer** and **Hansmann** group in Germany, basing on the static B-scan, reported on the successful monitoring of **follicular size** and **number** in patients undergoing ovulation induction. A 'very-full' bladder was a pre-requisite for good visualization of the ovaries. Follicular growth was noted to be linear and is around 1-4mm/day in the pre-ovulatory time period and follicles ovulate when they reach 15 to 28 mm in diameter. Other morphological parameters were also described. Ultrasound monitoring was 'formally' introduced into ovulation induction programs in **1979**. By about 1980-82 there were a number of important reports attesting to the usefulness of abdominal ultrasound in the assessment of follicular development and ovulation. In **1982**, the **Colm O'Herlihy**, **Lachlan de Crespigny** and **Hugh Robinson** group at the **Royal Women's Hospital** in Melbourne, Australia, published on important follicular size criterion and protocols for ovulation inductions. Other important early work had also come from the **Joupilla** group in Finland, the **Lopata** group in Melbourne, the **Queenan** and **O'Brien** group in England and the **Fleischer** group in Tennessee. **Transvaginal scanners** replaced the abdominal counterparts after they became available in the mid 1980's. The addition of **endometrial evaluation** using transvaginal scanning enhanced diagnostic accuracies in the mangement of ovulation induction cycles. Follicular and edometrial sonography, although tremendously useful when used in combination with estrogen assays was unable to ro predict ovulation and avoid multiple pregnancies.

Vaginal sonography had also become indispensible in the evaluation of **non-palpable masses**, **ascites**, **uterine and cervical leisions**, **early pregnancies** and the **localization of IUCDs**. It's value as a tool in the diagnosis of **ectopic pregnancies** and **ovarian and edometrial cancers** was extensively re-evaluated in the late 1980's and later on in the early 90's with addition of **transvaginal color flow imaging** (see below). As mentioned the greatest development of transvaginal imaging in the late 1980s has been in **assisted reproduction**, where all aspects of diagnosis and management are incomplete without a vaginal scan. From initial assessment for pelvic pathologies to surveillance of ovarian follicles and edometrial responses with or without medications, to ovum retrieval in In-vitro fertilization/ embryo transfer cycles, vaginal sonography had become essential and indispensible. The diagnosis of **ectopic pregnancies** continued to be a challenge, despite better machines and the transvaginal approach. A number of authors such as **Roberto Romero** at **Yale** devised diagnostic criterion for making a diagnosis, combining the use of sonography, HCG levels and color doppler assessment, which allowed a vast majority of the diagnosis to be made.

Susan Lenz

Interventional sonography in **gynecology** dated back to the early 1970s when **Hans Henrik Holm** described percutaneous puncture of ovarian tumours in **1972**. They performed over 500 procedures with very few serious complications. It was not until **1982** that **David Graham** and **Roger C Sanders** at the Johns Hopkins Hospital, Baltimore, revisited the idea of transvaginal aspiration of pelvic masses under transabdominal ultrasound guidance. There was a necessity to develop similar techniques for the retrieval of follicles in IVF programmes which has hitherto been achieved only through laparoscopy. **Susan Lenz** and **JG Lauritsen** at the University Hospital Rigshospitalet in **Copenhagen** described percutaneous transabdominal - transvesical aspiration of ovarian follicles in **1981** and **1982** which showed for the first time that ovum retrieval can be performed as an ultrasound-guided and out-patient procedure.

Transvaginal ovum retrieval under abdominal ultrasound guidance was further described by **Norbert Gleicher** in Chicago in **1983** in a letter to the **Lancet** and several months later by the **P Dellenbach** group in Shiltigheim, France in **1984**. They reported for the first time successful pregnancies (5 out of 30 patients) using this technique. They further reported on favorable results in **1985** in more than 100 cases of oozyte retreival using this '**transabdominal scan - transvaginal puncture**' method.

Kretztechnik's mechanical rotary vaginal scanner in 1985 with puncture attachment

W Feichtinger

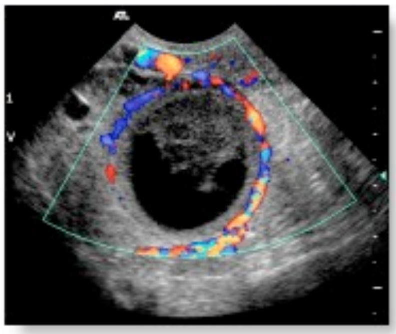
The advantage of this technique is that the ovaries are more accessible and the procedure is safer and relatively pain free. More importantly, the procedure is repeatable on an out-patient basis, and dramatically cuts down the cost of the IVF procedure. The true impact on ovum pickup came with the appearance of the mechanical **transvaginal sector scanner** from **Kretztechnik** in **1985** when **Wilfried Feichtinger** and **Peter Kemeter** in **Austria** described its use in transvaginal aspiration of ovarian follicles for IVF. Since then, ovum retrieval had steadfastly become an outpatient routine compared to just a few years ago when it was done as a laparoscopic procedure under general anaesthesia. The technique has also found its way into many ultrasound-guided interventional procedures in gynaecology (refer to **Part 2**).

◆ *In another consumer-pull and technology-push situation, ovum retrieval has interestingly gone from a transabdominal scan - transabdominal puncture approach to a transabdominal - transvaginal approach and further onto the universally accepted* *transvaginal - transvaginal approach.*◆

Campbell's group at Kings (with **John Parsons**) was among one of the earliest pioneering groups to have set up an out-patient oocyte retrieval service in IVF. In **1989** Campbell's department was the first to publish on a large scale **screening project for ovarian cancer** using abdominal ultrasound over a span of 5 years. Their results showed a low positive predictive value. Subsequent to this **Paul DePriest's** group in Kentucky published in **1993** results in ovarian cancer screening using the vaginal approach which arrived at similarily low postitive predictive values. Morphological scoring systems to improve the diagnosis of ovarian cancer in ultrasound-detected pelvic masses were described by several workers, notably **Ilan E. Timor-Tritsch** and **AM Sassone** in **1991**. Results of studies appeared to indicate that many women would undergo surgical procedures to diagnose relatively few cancers. It has so far not been convincingly demonstrated that **screening** will reduce morbidity or mortality from ovarian cancer or for that matter improve the health status of women. **Bengt Karlsson** and **Seth Granberg** in Helsinki, Finland reported in 1994 the use of **endometrial thickness measurement** (over 5mm) to predict endometrial cancer.


Asim Kurjak

The application of **doppler ultrasound** in **gynecology** did not appear until the mid 1980's when **Kenneth Taylor** at **Yale** described blood flow in the **ovarian and uterine arteries** in **1985** and **Asim Kurjak** in **Croatia** pioneered the use of **transvaginal color doppler** in the assessment of the pelvic circulation in **1989**. **Kurjak** was the founder of the **Ian Donald Inter-University School of Medical Ultrasound** in Dubronik, one of the largest and most important Ultrasound schools in the world. The **Coatian group** continued to contribute heavily to the applications of trans-vaginal color doppler in Obstetrics and Gynecology.


Corpus Luteum cyst diagnosed with the help of color flow doppler *

It should be mentioned here that the use of transvaginal 2-D, doppler and color doppler ultrasound almost started around the same time in the late 1980s, and one finds the introduction of **vaginal doppler studies** almost coincided with the first reports on vaginal sonography. Work also came out from the United States from the **Arthur Fleischer** group in Nashville, Tennessee in the early 1990s on **ovarian tumour vascularity** using transvaginal color doppler. The group had around the same time published other important work on transvaginal ultrasound in gynecology. Color flow imaging of **Intra-follicular blood flow** and **impedance in the uterine arteries** during assisted reproductive cycles further added to the diagnostic capabilities of vaginal doppler ultrasound.


Arthur Fleischer

The work of **Tom Bourne** and the group at Kings also confirmed the usefulness of **color doppler** in refining the prediction of **ovarian cancer** in ovarian masses, and in a screening setting. Their group had also made exhaustive investigations into the use of transvaginal color doppler in the diagnosis of a variety of gynecological conditions. They have also documented the usefullness of **periovulatory blood flow** in ovarian and uterine arteries in the management of **assisted reproductive cycles**.

In **Color power imaging** (**Power doppler**), red or blue luminosity is used to indicate the power or amplitude of the blood flow signal. The process is more sensitive than color velocity imaging. The display of color from image areas with low amplitude echoes can by adjustment be inhibited and only high amplitude echoes are displayed and color coded according to their power or velocity. The process has been called "**Tissue doppler imaging**" by **W N McDicken** in England in **1992**. This was expounded in **1994** by **K Miyatake** and **M Yamagishi** in Japan in the evaluation of left ventricular wall motion. The development had come about with the availability of more powerful electronics. Further developments had also led to the degree of tumor vascularization being quantitatively estimated. The approach has received much attention from the gynecology sector in the investigation of **pelvic malignancies**.

Three-dimensional ultrasound comes of age. Visualization of the fetus in 3-D has always been on the minds of many investigators, including **Tom Brown** in Glasgow in the early 1970s, who had developed an elaborate **Multiplanar scanner** in **1973**, under the **Sonicaid Ltd**®. With improvements in ultrasonic and computer technology, work on **three-dimensional visualization** began to appear in the early 1980's. Some basic computer algorithms came from the group at **Stanford** (**JF Brinkley**, **WD McCallum** and others) and also from the **Holm** group at Gentofte, Denmark. Other work came from the domain of cardiologists where initial efforts were directed to acertaining the volume of cardiac chambers. Real-time scanner probes mounted on articulated arms were often employed where positions of the probe can be accurately determined. The principle has always been to stack successive parallel image sections together with their positional information into a computer.

Kazunori Baba at the Institute of Medical Electronics, University of Tokyo, Japan, first reported on a 3-D ultrasound system in **1984** and succeeded in obtaining 3-D fetal images by processing the raw 2-D images on a mini-computer in **1986**. Their setup was reported in the Acta Obstetrica et Gynaecologica Japonica. **Baba**, with **Kazuo**

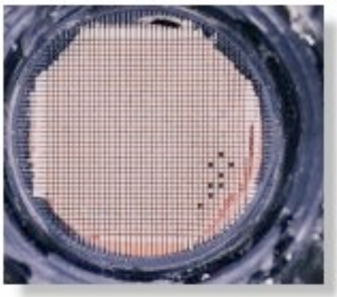
Kazunori Baba

Satoh and **Shoichi Sakamoto** at the **Saitama Medical Center** described the improved equipments in **1989** in which they used a traditional real-time convex array probe from an Aloka SSD280 scanner mounted on the position-sensing arm of a static compound scanner (Aloka M8U-10C). The images obtained were processed on elaborate computer systems (see picture with description below). This approach successfully produced 3-D images of the fetus which were nevertheless inferior to that produced on convenional 2-D scanners. At the same time, to generate each 3-D image it took on an average some 10 minutes for data input and reconstruction making the setup impractical for routine clinical use. **Baba** published in **1992** in the Japanese language the first book on ultrasonography in Obstetrics and Gynecology which contained chapters on 3-D ultrasound. In the mid 1990s, **Baba** collaborated with **ALOKA**® with technology developed at the Biomedical Engineering Department of the **Tokyo University**, and was a driving force in the development of commercial 3-D ultrasound technology in Japan.

Baba's Early 3-D image of a 19 weeks fetus

Kazunori Baba's 3-D setup in the mid 1980s. A linear array probe was mounted on an articulated arm for position sensing. On the right is the computer setup for making the calculations. (click on the picture for larger view and description)

Another group at the **Columbia University** led by **Donald King** described in **1990** other approaches and computer algorithms for 3-D spatial registration and display of position and orientation of real-time ultrasound images. **HC Kuo**, **FM Chang** and **CH Wu** at the National Cheng Kung University Hospital in **Taiwan**, Republic of China, reported in **1992** 3-D visualization of the fetal face, cerebellum, and cervical vertebrate using a the **Combison 330** from **Kretztechnik**®, Zipf, Austria. The **Combison 330** which appeared in **1989**, was the first commercial 3-D scanner in the market. The Taiwanese group were also the first to describe 3-D visualisation of the fetal heart in the same year although at that time they were only able to image static parts in 3-D.



2-D matrix-array at Duke

In **1987**, the Center for Emerging Cardiovascular Technologies at **Duke University** started a project to develop a **real-time volumetric scanner** for imaging the heart. In **1991** they produced a **matrix array scanner** that could image cardiac structures in real-time and 3-D. In **1994**, **Olaf von Ramm**, **Stephen Smith** and their team produced an improved scanner that could provide good resolution down to 20 centimeters. The team developed state-of-the-art "Medical Ultrasound imaging" integrated circuits (**MUsIC**) which were capable of processing signals from multiple real-time phased-array images. The microprocessors were developed in collaboration with the **Volumetric Medical Imaging Inc**. at Durham, North Carolina. The MUsIC 3.2, a 40MHz 1.2μ chip completed in **1994**, was the basis for the beam-former in the world's first **electronically steered** matrix-array 3-D ultrasound imager. This became available commercially from Volumetric Medical Imaging, Inc. in **1997**.

Olaf T. von Ramm

The matrix-array transducer, which steered the ultrasound beam in three dimensions, contained 2,000 elements in which 512 were used for image formation. The beam-former produced **4,096 lines** running at **30 frames per second**. This required as much ultrasound signal processing power as eight top-end 2-D systems, running on microprocessors that execute instructions 30 times the speed of a typical 2 GHz Pentium tm. Due to the relatively small size of the 2-D matrix array probe, it is more suited to **cardiac examination** rather than for the abdomen. The apparatus is also costly to produce and poses problem in manufacturing and in image quality due to the large amount of crystals and interconnections.

Other pioneering investigators included **Ian Kelly** and **John Gardener** at the **Middlessex Hospital** in London and the **Sturla Eik-Nes** group at **Tronheim**, Norway, using equipments from **Vingmed**® which were partly developed at the University's bio-engineering department (see **Part 2**) . They were able to demonstrate early gestational age fetuses with their apparatus. **Wilfried Feichtinger** at the University of Vienna, Austria reported images of 10

Professor Kratochwil from A-scan to 3-D

weeks embryos imaged with **3-D transvaginal transducers** in **1993**. Kretztechnik®. had in this year marketed their 2nd generation 3-D scanner the **Voluson 530D**. **Alfred Kratochwil** had continued his support in the development of 3-D technology at Kretztechnic® and was active in the teaching of 3-D sonography after his retirement. The **Ulrike Hamper** group at **Johns Hopkins** reported images of various **congenital malformations** with a prototype 3-D scanner. Computation was based on a 486 computer together with a RISC processor (860/240 mhz).

Thomas Nelson and **Dolores Pretorius** at the **University of California, San Diego**, approached the carotid arteries with their prototype 3-D system in **1992** and produced very successful images. The signal chain consisted of a transducer-array moving along the patient's neck producing sequentially sampled images which were digitised, acquired and surface-rendered on the connecting workstation. They collaborated with development by **Donal Downey** and **Aaron Fenster** at the **Imaging Research Laboratories** of the John Robarts Research Institute at the **University of Western Ontario**, Canada.

Their group continued to make refinements to the instrumentation and started to publish on **fetal visualization** in the following years and continuing on to become one of the **most important** research teams in the field of 3-D ultrasound in Obstetrics and Gynecology. In 1996, **Nelson's** group and the **Medical Imaging group** at the **university College Hospital in London** published independent researches on **4-D** (motion 3-D) **fetal echocardiography**, using sonographic cardiac gating methods to remove motion artefacts, which are present with conventional (static) 3-D methods. A useful feature of 3-D display is the **cine loop**, in which the rendered 3-D volumes are viewed as they rotate. This capability enhances depth perception and gives a true 3-D perspective of both normal and abnormal structures.

Dolores Pretorius

Eberhard Merz

In **1995**, **Eberhard Merz** at the Center for Diagnostic Ultrasound and Prenatal Therapy, University of Mainz, Germany, demonstrated the usefulness of **multiplanar orthogonal imaging** as well as as **surface views** and **transparent views** in the diagnosis and confirmation of fetal **surface** and **skeletal** anomalies such as cleft lips and complex multiple malformations. He and his co-workers reported a large series of over 600 cases of fetal diagnosis using 3-D ultrasound. In **1997**, his team reported on the diagnosis of facial anomalies using **trans-vaginal** 3-D scans.

In **Obstetrical and Gynecological 3-D imaging**, mechanical designs appeared to be the only popular choice. Two-dimensional arrays are mechanically moved to provide the third dimension by sweeping or rotating, using either **constrained free-hand adapters** or an existing probe alongside with an external **motion-sensing system**. The most sucessfully deployed transducer design is the mechanically-driven arrays that is built-in into the probe housing from the Austrian manufacturer **Kretztechnik**®. Their technique was described in the paper "***3D ultrasound - the Kretztechnik Voluson approach***" in the European Journal of Ultrasound in **1994**.

Hand-held 3-D probe from Kretztechnik

The process of acquisition is microprocessor-controlled and automatic. In the display of the acquired data, the degree of transparency is first chosen which involves applying a mixture of ray-traced, volume-rendered illumination and maximum intensity or summed voxel projection. Perception in 3-D surface is acheived by a combination of depth shading, color-mapping, texture mapping and ray-traced volume rendering. The introduction of **Multiplanar reformatting** has allowed the generation of any arbituary slice within the data aquired. In obstetrics this is valuable for measurement, and for obtaining re-constructed critical views (such as the 4-chamber view) or scans orthogonal to the face and soft palate. All these are heavily dependent of the **software algorithms** and processing power of the computers within the machines.

Volume rendering in medical imaging has in fact much of its roots in **computer graphics engineering**. Volume rendering developed as a separate body of techniques, mainly within the computer graphics literature, before and independent of its application to medical data. One of the earliest pioneers in volume rendering is **Marc Levoy** at the University of North Carolina (now at Stanford). Volumes are rendered directly from sampled data without first creating an intermediate surface representation. This creates images that represent the underlying data very accurately and can reveal fine details that might be obscured with surface methods. Following his initial paper in **1988**: "**Display of Surfaces from Volume Data**" where he described the classic volume ray tracing algorithm and has been the basis (directly or indirectly) for most commercial 3D ultrasound systems, Levoy has published a number of papers that have continued to break new ground. Volume rendering has made a major impact on the many scientific, engineering and medical disciplines that create and display large multi-dimensional datasets.

Many of the volume rendering agorithms and technology had actually originated from computer scientists at the **filmmaking** company **Pixar Animation Studios**, famous for its 3D computer animated films! Initial volume rendering techniques and agorithms weres "invented" by company founders **Robert Drebin**, **Loren Carpenter**, and **Pat Hanrahan**. The algorithm embodied three key ideas: Directional shading based on the gradient in a volume, digital compositing to combine the slices of a volume, and Image warping, also applied to a volume.

Gradient shading of volumes first appeared in a 1986 paper by **Karl-Heinz Hoehne**, hamburg, who called it graylevel gradient shading. Compositing can be traced through **Thomas Porter** and **Tom Duff**'s 1984 paper to **Edwin Catmull** and **Alvy Ray Smith**'s invention of the alpha channel in the mid-70's. Image warping is a special case of texture mapping, which dates back to Edwin Catmull's 1974 PhD thesis at the University of Utah.

Volume rendering approximates the passage of light through a participating media. In this respect, **James Blinn**'s 1982 paper on clouds and dusty surfaces, **Jim Kajiya**'s 1984 paper on volume densities, and **Holly Rushmeier**'s 1987 paper with **Ken Torrance** on zonal radiosity must also be regarded as formative. This relationship between volume rendering and light transport was pointed out to the volume rendering community by **Wolfgang Krueger**. Another key pioneer was **Gabor Herman** at the City University of New York, who in a 1979 paper with **Ksun Kao Liu** proposed using cube-shaped voxels to display computed tomography data.^^

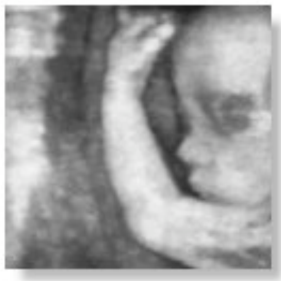
(From citations by Dr. Marc Leroy, Stanford University. Excerpted with permission).

Cleft lip in 3-D **

Medison®, which had acquired **Kretztechnik**® in 1996 continued to produce more advanced versions of the **Voluson** series of scanners that produced some of the best 3-D images in the market. **Bernard Benoit** in Nice, France working in collaboration with **Kretztechnik**®, published some of the earliest, most stunning and convincing **3-D images** in the mid- 1990s using prototype **Voluson** scanners (see picture of cleft lip on the left). His pictures had been responsible for drawing the attention of many to this new scanning modality.

In the second half of the 1990's at least **twenty other important centers** worldwide were embarking on distinctive laboratory and clinical research into 3-D ultrasound, usually backed by work done at their own university's medical physics and bio-engineering departments, or commercial enterprises. Many of the innovations relied heavily on software programming. **3-D ultrasound technology** would not have been a viable commercial proposition if not for the fact that computer technology was in the mid to late 1990s at a stage where the computations can be done with **staggering speed and at an acceptable cost**.

In November **1996**, with technical assistance from Takashi Okai and Shiro Kozuma from **ALOKA**®, **Kazunori Baba** published in the **Lancet** their initial experience with **real-time processable 3-D**, which used a simpler algorithm compared to conventional 3-D rendering. **Fetal surfaces** are demonstrated in near real-time imaging basing on simple '**accoustic impedance thresholding**' to identify fetal surfaces in the amniotic fluid. Image quality was very high and required less expensive computers to make the calculations. However the viewing direction is limited to that of the probe so that a desirable direction may not always be possible. Sufficient amniotic fluid is also prerequisite to a good scan. Similarily image clarity depends on the difference between the accoustic impedance of the fetal skin and that of amniotic fluid which made good images difficult to obtain before 20 weeks. **Aloka**® adapted the technology into their commercial scanners.



3-D image of the fetus from real-time processable 3-D

Other early manufacturers of 3-D systems included **ATL**®, **Tom-Tec Imaging Systems**®, **GE-Vingmed**®, **3D-EchoTech**®, and **Life Imaging Systems Inc.**®. The first English textbook on 3-D ultrasound in Obstetrics and Gynecology came out in **1996** which was edited by **Kazunori Baba** and **Davor Jurkovic**, King's College Hospital, London.

Eberhard Merz hosted the **First World Congress on 3-D Ultrasound in Obstetrics and Gynecology** in Mainz in 1997. Many important teething issues surrounding the new practice of 3-D sonography were discussed. In 1999 the **3D Focus group** was formed by the **ISUOG** to look after matters concerning the practice and education of 3-D ultrasound in Obstetrics and Gynecology.

The increasing availabililty of **3-D ultrasound** has resulted largely from the rapid advancement in computer technology and the decreasing

cost of micro-processor electronics. The benefits that 3-D has bought to ultrasound diagnosis has quickly become a matter for debate. The important advantages of 3-D over conventional 2-D ultrasound as it is at the turn of the millenium are its ability to enhance **maternal-fetal bonding**, improved comprehension of certain fetal anomalies by parents, Improved recognition and better confirmation of certain anomalies such as cleft lips, polydactyl, micrognathia, malformed ears, club foot, vertebral malformations and other anomalies appearing on the '**exterior**' of the fetus, consequent to the benefit of **volume** and **surface rendering**. The development of **transvaginal 3-D probes** have further enhanced its value in the early diagnosis of congenital malformations.

Reports of the use of 3D ultrasound appearing in health and parenting magazines

In a recent article by **Asim Kurjak** and his team, "*Three-dimensional sonography in prenatal diagnosis: a luxury or a necessity?*" (Journal of Perinatology, issue 3, 2000), he concluded,

> ".... the main advantages of three-dimensional ultrasound in perinatal medicine and antenatal diagnosis include scanning in the coronal plane, improved assessment of complex anatomic structures, surface analysis of minor defects, volumetric measuring of organs, "plastic" transparent imaging of fetal skeleton, spatial presentation of blood flow arborization and, finally, storage of scanned volumes and images. It is our decided opinion that three-dimensional sonography has gained a valuable place in prenatal diagnosis, becoming a necessity for every modern perinatal unit .... ".


Stuart Campbell at a 3-D scan

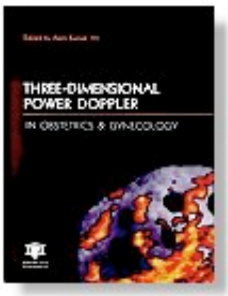
Stuart Campbell at the St. Georges Hospital in London was one of the early proponents for the 3-D scan to be an important catalyst for **mothers to bond to their babies**. What are known as '**re-assurance scans**' and the perhaps misnamed '**entertainment scans**' have started to develop. The attraction of being able to look at the face of your baby before birth was enthusiastically reported in lay parenting and health magazines. Manufacturers had adopted an unprecedented "**profit marketing**" strategy to advertise to providers and "**reverse marketing**" strategy to advertise to **consumers**, particularly after the arrival of the **4-D** (dynamic or motion 3-D) machines.


F M Chang

Barbara Maier and his group (**Horst Steiner**, **Alf Staudach** etc.) in a study in Salzburg in **1996** reported that mothers are more incentive to endure pregnancy-related difficulties, reduced anxiety, and improved capacity to cope. **Pretorius** reported in the same year that **improved bonding** between the mother and fetus could motivate mothers to refrain from smoking and other harmful behaviors during pregnancy.


Harm-Gerd Blass

Usefulness has been reported for calculating **volumes of the gestational sac**, fetal lungs and heart from second trimester to term, placental volume, liver volume, and thigh and abdominal volume for the **estimation of fetal weight**. **Andreas Lee** with the **Kratochwil** group evaluated the accuracy of fetal weight estimation using 3-D abdominal and thigh volumes and reported in **1994** similar mean errors as compared to standard 2-D evaluations. **Fong-Ming Chang**'s group at the National Cheng Kung University Hospital in **Taiwan**, Republic of China reported in **1997** the feasibility of predicting birth weight by upper arm volume measured in 3-D. In **1998**, **Harm-Gerd Blaas** at **Tronheim**, Norway published **3-D studies of embryos** that were less than 10mm and further expanded the usefulness and importance of 3-D sonography as an **in-vivo** research tool in **fetal embryology**. Transvaginal 3-D work on early fetal anatomy and malformations had also come out of **Ilan Timor-Tritsch**'s center in New York. **3-D power doppler** in the study of placental blood circulation was first described in **1996** by **C J Ritchie** in a proprietary setup at the Bioengineering Department of the University of Washington, Seattle. **Dolores Pretorius** published on its usefulness and techniques in **1998**. The Croatian group led by **Asim Kurjak** and **Sanja Kupesic** expounded this new diagnostic entity further. Their book "***Three-Dimensional Power Doppler in Obstetrics and Gynecology***" was published in **2000**.




Davor Jurkovic

In gynecological applications, **Davor Jurkovic** at Kings convincingly demonstrated in **1995** the usefulness of 3-D ultrasound in accurately differentiating uterine anomalies such as bicornuate uterus and septate uteri. Similarly the assessment of the endometrial cavity with **3-D sonohysterography** and characterization of endometrial masses, adhesions, tubo-ovarian masses, hydrosalpinges, ovarian cysts, small intraovarian tumors and mullerian anomalies have all been quickly and convincingly demonstrated. Diagnostic accuracy of malignant ovarian tumors can be up to 100 percent as reported by **Bonilla-Musoles** in 1995, who also demonstrated the value of 3-D examination over the convention 2-D transvaginal scans and 2-D sonohysterography in the diagnosis of **endometrial lesions**. **3-D color power doppler** is valuable for visualization of intra-tumor flow and thus is useful in evaluating in particular cervical carcinomas and ovarian carcinomas. It is envisaged that the investigation will lead to greater appreciation of **tumor angiogenesis**. Another potential benefit of 3-D ultrasound lies in data documentation, storage, and networking. Digitally saved volumes of patient data can be readily transferred to a remote site for interpretation or second-opinion consultation. How much these all add up to make 3-D ultrasound **cost-effective** and an indispensible tool in Obstetrics and Gynecology will remain to be seen.

Epilogue

The **evolution of diagnostic ultrasonography** has been the combined efforts of physicists, mechanical, electrical and bio-medical engineers, computer technologists, clincians, sonographers, researchers, university and government administrators as well as adventurous and perceptive commercial enterprises.

I particularly salute the **ingenious engineers** and **physicists** throughout the history of the development as they are the true heroes behind the entire 'scientific' advance in ultrasonic imaging. Without them the innovative ideas of the brightest clinicians cannot be put into action. Developments in echocardiography, neurosonography, ophthalmology and breast echography have all supplemented the advancement in ultrasound instrumentations and methodologies in Obstetrical and Gynecological sonography. The first linear-arrays for example were invented for the purpose of ophthalmologic and cardiac investigations. Ultrasonography has very quickly become the single most important diagnostic investigation in the field of Obstetrics and the **healthcare for women**.

Interestingly, diagnostic medical ultrasound had evolved from technology used in mapping waves through liquid (the **sonar**), through air (the **radar**) and through solids (the **metal-flaw detector**). The **A-scan** which had evolved from the sonar and early metal-flaw detectors would not have a lasting impact on clinical medicine without evolving into the **B-scan** which had it's origin in the military radar. The A-scan did not provide sufficiently accurate, reproducible and interpretable information to allow a firm diagnosis to be made, particularly in Gynecology. The bistable B-scan would not have advanced to become a respectable diagnostic tool as it is now, without the development of the **scan-converter** and **gray-scaling**. The gray scale **compound static scanner**, with the incorporation of progressive electronic and computer technology available in the late 1970s had establish itself as a genuine stand-alone clinical diagnostic tool, providing hitherto unavailable information to the clinician regarding a particular disease condition. **Howry's** original concept of deriving clear outline anatomical pictures by selectively recording larger echoes from major interfaces and suppressing any other small echoes was completely reversed in later developments, where attempts are made to detect the smallest echoes in the presence of noise and displaying them in finer spatial detail and echo amplitudes.

The arrival of the **real-time scanners** have added further impetus to ultrasound techniques and had established ultrasonography as **the most important imaging modality** in Obstetrics and Gynecology.
The concept of the **transvaginal scanner** was in situ in the early 1950's but was unable to make any real headway until the appearance of sophisticated mechanical and electronic sectoral real-time vaginal scanners in the mid 1980's. Ovum retrieval has for example, interestingly gone from a transabdominal scan - transabdominal puncture approach to a transabdominal - transvaginal approach and further onto the universally accepted transvaginal - transvaginal approach.

A **'technology push'** situation further evolved when enhancement in diagnostic capabilities of scanners was propelled by the almost explosive advancements in electronic and microprocessor technology, occurring most significantly in the 1980s and 90s. The advent of ultrasonography in Obstetrics has also 'created' the new specialty called **Prenatal diagnosis** that has developed by leaps and bounds since it's early conception. Ultrasound has markedly enhanced and pushed forward the study of congenital abnormalities among obstetricians, pediatricians, geneticist, pathologist and other allied specialties. All of a sudden, obstetricians started to learn about so many congenital malformations that they have not even heard of.

On the other hand, every single measurable parts of the fetus has been measured and their changes throughout gestation documented. It is of interest to note that historically **the 4 basic fetal measurements**, namely the **BPD**, the **CRL**, the **AC** and the **FL** had evolved successively at different time periods (' 62/' 68, ' 73, ' 75, ' 80 respectively) each being brought on by technical developments in ultrasound instrumentations at that time (B-scan, gray-scale, real-time). **Stuart Campbell** published the first BPD chart in 1971. Since then, charts and tables had become an important and integral part of Obstetric practice, at which Obstetricians and Gynecologists were slowly getting used to.

Fetal malformations were diagnosed with increasing accuracy and at an **earlier gestation**. Bold, daring and visionary clinicians and researchers invented new interventional techniques that work under the guidance of ultrasound to diagnose fetal disease and gynecological conditions. Doppler devices moved progressively from depicting **flow velocity waveforms** to **color flow mapping**, **power doppler** and **doppler tissue imaging**. Velocimetric parameters of the umbilical artery, the middle cerebral artery and the ductus venosus had made their appearance one after another again subsequent to progressive developments in the imaging apparatus. **3-D ultrasound** made the scene in the late 1980's and further revolutionarised sonography in obstetrics and gynecology.

It is regretable that **John Wild's** original conception of precise quantitative detection of cancer echoes with ultrasound also had not materialize to the initial expectations. So was the application of tissue characterization in the specialty. On the other hand, all the improvements in machinery and earlier detection of abnormal structures in the fetus have nevertheless brought along with it "false positives" and difficult-to-be-sure diagnosis that could generate much undue anxiety in patients. Such could only have far-reaching effects on a woman's perception of child-bearing.

I am still finding it awsome to imagine the "wire-frame" images of **Douglass Howry** and **Ian Donald** could have now become "**photo-realistic**", and between all these are the unfolding magnificence of the invention and genius of science and man's endeavour to find-out and to perfect. From the detection of life to the measuring of fetal sizes; from the determination of morphological normality to the evaluation of circulatory and growth dynamics, all have been making profound changes to the entire concept of **routine** antenatal care and **Obstetric practice**.

J. W.

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- It is not possible to include all the names who have contributed significantly to the advancement of Obstetrical and Gynecological sonography, some who may have been less well-known than the others and some who may not have published so extensively in the English language. Apologies are extended to those whose contribution has not been fully credited in this article.

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