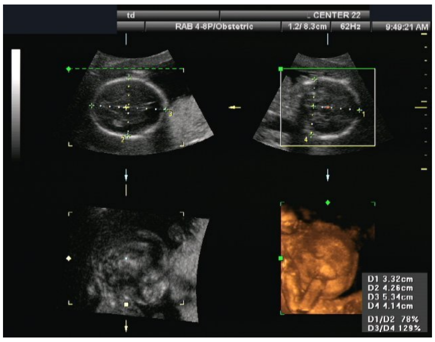
Medical ultrasonography

Diagnostic sonography (**ultrasonography**) is an ultrasound-based diagnostic imaging technique used to visualize subcutaneous body structures including tendons, muscles, joints, vessels and internal organs for possible pathology or lesions. Obstetric sonography is commonly used during pregnancy and is widely recognized by the public. There is a plethora of diagnostic and therapeutic applications practiced in medicine.

In physics, the term "ultrasound" applies to all acoustic energy (longitudinal, mechanical wave) with a frequency above the audible range of human hearing. The audible range of sound is 20 hertz-20 kilohertz. Ultrasound is frequency greater than 20 kilohertz.

Diagnostic applications

Typical diagnostic sonographic scanners operate in the frequency range of 2 to 18 megahertz, though frequencies up to 50-100 megahertz has been used experimentally in a technique known as biomicroscopy in special regions, e.g. like the anterior chamber of eye. The above frequencies are hundreds of times greater than the limit of human hearing, which is typically accepted as 20 kilohertz. The choice of frequency is a trade-off between spatial resolution of the image and imaging depth: lower frequencies produce less resolution but image deeper into the body.



Orthogonal planes of a 3 dimensional sonographic volume with transverse and coronal measurements for estimating foetal cranial volume.[1] ,[2]

Sonography (ultrasonography) is widely used in medicine. It is possible to perform both diagnosis and therapeutic procedures, using ultrasound to guide interventional procedures (for instance biopsies or drainage of fluid collections). Sonographers are medical professionals who perform scans for diagnostic purposes. Sonographers typically use a hand-held probe (called a transducer) that is placed directly on and moved over the patient.

Sonography is effective for imaging soft tissues of the body. Superficial structures such as muscles, tendons, testes, breast and the neonatal brain are imaged at a higher frequency (7-18 MHz), which provides better axial and lateral resolution. Deeper structures such as liver and kidney are imaged at a lower frequency 1-6 MHz with lower axial and lateral resolution but greater penetration.

Medical sonography is used in the study of many different systems:

System	Description	See also
Cardiology	Echocardiography is an essential tool in cardiology, to diagnose e.g. dilatation of parts of the heart and function of heart ventricles and valves	see echocardiography
Emergency Medicine	Point of care ultrasound has many applications in the Emergency Department, including the Focused Assessment with Sonography for Trauma (FAST) exam for assessing significant hemoperitoneum or pericardial tamponade after trauma. Ultrasound is routinely used in the Emergency Department to expedite the care of patients with right upper quadrant abdominal pain who may have gallstones or cholecystitis.	see FAST exam
Gastroenterology	In abdominal sonography, the solid organs of the abdomen such as the pancreas, aorta, inferior vena cava, liver, gall bladder, bile ducts, kidneys, and spleen are imaged. Sound waves are blocked by gas in the bowel, therefore there are limited diagnostic capabilities in this area. The appendix can sometimes be seen when inflamed e.g.: appendicitis.	
Gynecology		see gynecologic ultrasonography

Neurology	for assessing blood flow and stenoses in the carotid arteries (Carotid ultrasonography) and the big intracerebral arteries	see Carotid ultrasonography. Intracerebral: see Transcranial Doppler
Obstetrics	Obstetrical ultrasound is commonly used during pregnancy to check on the development of the foetus.	see obstetric ultrasonography
Ophthalmology		see A-scan ultrasonography, B-scan ultrasonography
Urology	to determine, for example, the amount of fluid retained in a patient's bladder. In a pelvic sonogram, organs of the pelvic region are imaged. This includes the uterus and ovaries or urinary bladder. Men are sometimes given a pelvic sonogram to check on the health of their bladder and prostate. There are two methods of performing a pelvic sonography - externally or internally. The internal pelvic sonogram is performed either transvaginally (in a woman) or transrectally (in a man). Sonographic imaging of the pelvic floor can produce important diagnostic information regarding the precise relationship of abnormal structures with other pelvic organs and it represents a useful hint to treat patients with symptoms related to pelvic prolapse, double incontinence and obstructed defecation.[3]	
Musculoskeletal	tendons, muscles, nerves, and bone surfaces	
Cardiovascular system	To assess patency and possible obstruction of arteries Arterial sonography, diagnose DVT (Thrombosonography) and determine extent and severity of venous insufficiency (venosonography)	Intravascular ultrasound

Other types of uses include:

- Intervenional; biopsy, emptying fluids, intrauterine transfusion (Hemolytic disease of the newborn)
- Contrast-enhanced ultrasound

A general-purpose sonographic machine may be able to be used for most imaging purposes. Usually specialty applications may be served only by use of a specialty transducer. Most ultrasound procedures are done using a transducer on the surface of the body, but improved diagnostic confidence is often possible if a transducer can be placed inside the body. For this purpose, specialty transducers, including endovaginal, endorectal, and transesophageal transducers are commonly employed. At the extreme of this, very small transducers can be mounted on small diameter catheters and placed into blood vessels to image the walls and disease of those vessels.

Therapeutic applications

Therapeutic applications use ultrasound to bring heat or agitation into the body. Therefore much higher energies are used than in diagnostic ultrasound. In many cases the range of frequencies used are also very different.

- Ultrasound may be used to clean teeth in dental hygiene.
- Ultrasound sources may be used to generate regional heating and mechanical changes in biological tissue, e.g. in occupational therapy, physical therapy and cancer treatment. However the use of ultrasound in the treatment of musculoskeletal conditions has fallen out of favor.[4] [5]
- Focused ultrasound may be used to generate highly localized heating to treat cysts and tumors (benign or malignant), This is known as Focused Ultrasound Surgery (FUS) or High Intensity Focused Ultrasound (HIFU). These procedures generally use lower frequencies than medical diagnostic ultrasound (from 250 kHz to 2000 kHz), but significantly higher energies. HIFU treatment is often guided by MRI.
- Focused ultrasound may be used to break up kidney stones by lithotripsy.
- Ultrasound may be used for cataract treatment by phacoemulsification.
- Additional physiological effects of low-intensity ultrasound have recently been discovered, e.g. its ability to stimulate bone-growth and its potential to disrupt the blood-brain barrier for drug delivery.
- Procoagulant at 5-12 MHz

From sound to image

The creation of an image from sound is done in three steps - producing a sound wave, receiving echoes, and interpreting those echoes.

Producing a sound wave

A sound wave is typically produced by a piezoelectric transducer encased in a housing which can take a number of forms. Strong, short electrical pulses from the ultrasound machine make the transducer ring at the desired frequency. The frequencies can be anywhere between 2 and 18 MHz. The sound is focused either by the shape of the transducer, a lens in front of the transducer, or a complex set of control pulses from the ultrasound scanner machine (Beamforming). This focusing produces an arc-shaped sound wave from the face of the transducer. The wave travels into the body and comes into focus at a desired depth.

Medical sonographic instrument

Older technology transducers focus their beam with physical lenses. Newer technology transducers use phased array techniques to enable the sonographic machine to change the direction and depth of focus. Almost all piezoelectric transducers are made of ceramic.

Materials on the face of the transducer enable the sound to be transmitted efficiently into the body (usually seeming to be a rubbery coating, a form of impedance matching). In addition, a water-based gel is placed between the patient's skin and the probe.

The sound wave is partially reflected from the layers between different tissues. Specifically, sound is reflected anywhere there are density changes in the body: e.g. blood cells in blood plasma, small structures in organs, etc. Some of the reflections return to the transducer.

Receiving the echoes

The return of the sound wave to the transducer results in the same process that it took to send the sound wave, except in reverse. The return sound wave vibrates the transducer, the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image.

Forming the image

The sonographic scanner must determine three things from each received echo:

1. How long it took the echo to be received from when the sound was transmitted.
2. From this the focal length for the phased array is deduced, enabling a sharp image of that echo at that depth (this is not possible while producing a sound wave).
3. How strong the echo was. It could be noted that sound wave is not a click, but a pulse with a specific carrier frequency. Moving objects change this frequency on reflection, so that it is only a matter of electronics to have simultaneous Doppler sonography.

Once the ultrasonic scanner determines these three things, it can locate which pixel in the image to light up and to what intensity and at what hue if frequency is processed (see redshift for a natural mapping to hue).

Transforming the received signal into a digital image may be explained by using a blank spreadsheet as an analogy. We imagine our transducer is a long, flat transducer at the top of the sheet. We will send pulses down the 'columns' of our spreadsheet (A, B, C, etc.). We listen at each column for any return echoes. When we hear an echo, we note how long it took for the echo to return. The longer the wait, the deeper the row (1,2,3, etc.). The strength of the echo determines the brightness setting for that cell (white for a strong echo, black for a weak echo, and varying shades of grey for everything in between.) When all the echoes are recorded on the sheet, we have a greyscale image.

Displaying the image

Images from the sonographic scanner can be displayed, captured, and broadcast through a computer using a frame grabber to capture and digitize the analog video signal. The captured signal can then be post-processed on the computer itself.[6]

For computational details see also: Confocal laser scanning microscopy, Radar,

Sound in the body

Linear Array Transducer

Ultrasonography (sonography) uses a probe containing one or more acoustic transducers to send pulses of sound into a material. Whenever a sound wave encounters a material with a different density (acoustical impedance), part of the sound wave is reflected back to the probe and is detected as an echo. The time it takes for the echo to travel back to the probe is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. If the pulse hits gases or solids, the density difference is so great that most of the acoustic energy is reflected and it becomes impossible to see deeper.

The frequencies used for medical imaging are generally in the range of 1 to 18 MHz. Higher frequencies have a correspondingly smaller wavelength, and can be used to make sonograms with smaller details. However, the attenuation of the sound wave is increased at higher frequencies, so in order to have better penetration of deeper tissues, a lower frequency (3-5 MHz) is used.

Seeing deep into the body with sonography is very difficult. Some acoustic energy is lost every time an echo is formed, but most of it (approximately $0.3\frac{\mathrm{dB}}{\mathrm{cm\ depth}\cdot\mathrm{MHz}}$) is lost from acoustic absorption.

The speed of sound is different in different materials, and is dependent on the acoustical impedance of the material. However, the sonographic instrument assumes that the acoustic velocity is constant at 1540 m/s. An effect of this assumption is that in a real body with non-uniform tissues, the beam becomes somewhat de-focused and image resolution is reduced.

To generate a 2D-image, the ultrasonic beam is swept. A transducer may be swept mechanically by rotating or swinging. Or a 1D phased array transducer may be use to sweep the beam electronically. The received data is processed and used to construct the image. The image is then a 2D representation of the slice into the body.

3D images can be generated by acquiring a series of adjacent 2D images. Commonly a specialised probe that mechanically scans a conventional 2D-image transducer is used. However, since the mechanical scanning is slow, it is difficult to make 3D images of moving tissues. Recently, 2D phased array transducers that can sweep the beam in 3D have been developed. These can image faster and can even be used to make live 3D images of a beating heart.

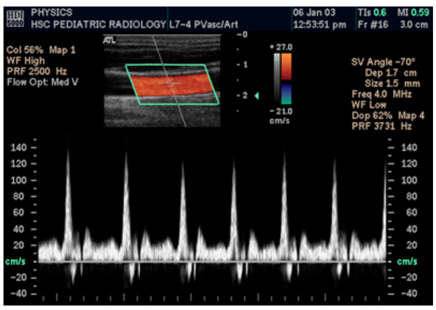
Doppler ultrasonography is used to study blood flow and muscle motion. The different detected speeds are represented in color for ease of interpretation, for example leaky heart valves: the leak shows up as a flash of unique color. Colors may alternatively be used to represent the amplitudes of the received echoes.

Modes of sonography

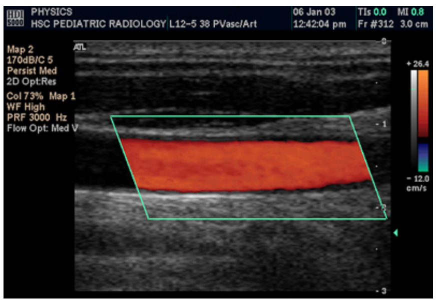
Several different modes of ultrasound are used in medical imaging[7] . These are:

- **A-mode**: A-mode is the simplest type of ultrasound. A single transducer scans a line through the body with the echoes plotted on screen as a function of depth. Therapeutic ultrasound aimed at a specific tumor or calculus is also A-mode, to allow for pinpoint accurate focus of the destructive wave energy.
- **B-mode**: In B-mode ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen.
- **M-mode**: M stands for motion. In m-mode a rapid sequence of B-mode scans whose images follow each other in sequence on screen enables doctors to see and measure range of motion, as the organ boundaries that produce reflections move relative to the probe.
- **Doppler mode**: This mode makes use of the Doppler effect in measuring and visualizing blood flow
  - **Color doppler**: Velocity information is presented as a color coded overlay on top of a B-mode image
  - **Continuous doppler**: Doppler information is sampled along a line through the body, and all velocities detected at each time point is presented (on a time line)
  - **Pulsed wave (PW) doppler**: Doppler information is sampled from only a small sample volume (defined in 2D image), and presented on a timeline
  - **Duplex**: a common name for the simultaneous presentation of 2D and (usually) PW doppler information. (Using modern ultrasound machines color doppler is almost always also used, hence the alternative name **Triplex**.

Doppler sonography



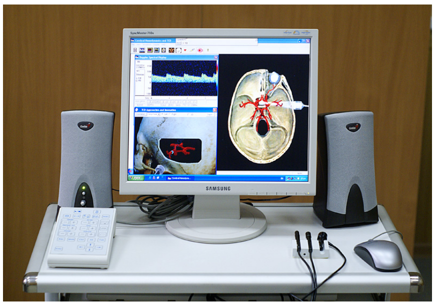
Spectral Doppler of Common Carotid Artery



Colour Doppler of Common Carotid Artery

Sonography can be enhanced with Doppler measurements, which employ the Doppler effect to assess whether structures (usually blood) are moving towards or away from the probe, and its relative velocity. By calculating the frequency shift of a particular sample volume, for example flow in an artery or a jet of blood flow over a heart valve, its speed and direction can be determined and visualised. This is particularly useful in cardiovascular studies (sonography of the vascular system and heart) and essential in many areas such as determining reverse blood flow in the liver vasculature in portal hypertension. The Doppler information is displayed graphically using spectral Doppler, or as an image using color Doppler (directional Doppler) or power Doppler (non directional Doppler). This Doppler shift falls in the audible range and is often presented audibly using stereo speakers: this produces a very distinctive, although synthetic, pulsating sound.

Most modern sonographic machines use pulsed Doppler to measure velocity. Pulsed wave machines transmit and receive series of pulses. The frequency shift of each pulse is ignored, however the relative phase changes of the pulses are used to obtain the frequency shift (since frequency is the rate of change of phase). The major advantages of pulsed Doppler over continuous wave is that distance information is obtained (the time between the transmitted and received pulses can be converted into a distance with knowledge of the speed of sound) and gain correction is applied. The disadvantage of pulsed Doppler is that the measurements can suffer from aliasing. The terminology "Doppler ultrasound" or "Doppler sonography", has been accepted to apply to both pulsed and continuous Doppler systems despite the different mechanisms by which the velocity is measured.


Computer-enhanced transcranial doppler.

It should be noted here that there are no standards for the display of color Doppler. Some laboratories insist on showing arteries as red and veins as blue, as medical illustrators usually show them, even though, as a result, a tortuous vessel may have portions with flow toward and away relative to the transducer. This can result in the illogical appearance of blood flow that appears to be in both directions in the same vessel. Other laboratories use red to indicate flow toward the transducer and blue away from the transducer which is the reverse of 150 years of astronomical literature on the Doppler effect. Still other laboratories prefer to display the sonographic Doppler color map more in accord with the prior published physics with the red shift representing longer waves of echoes (scattered) from blood flowing away from the transducer; and with blue representing the shorter waves of echoes reflecting from blood flowing toward the transducer. Because of this confusion and lack of standards in the various laboratories, the sonographer must understand the underlying acoustic physics of color Doppler and the physiology of normal and abnormal blood flow in the human body.See:[8] [9] [10] [11]

Contrast media

The use of microbubble contrast media in medical sonography to improve ultrasound signal backscatter is known as contrast-enhanced ultrasound. This technique is currently used in echocardiography, and may have future applications in molecular imaging and drug delivery.

Compression ultrasonography

Compression ultrasonography is a technique used for diagnosing deep vein thrombosis and combines ultrasonography of the deep veins with venous compression.[12] The technique can be used on deep veins of the upper and lower extremities, with some laboratories limiting the examination to the common femoral vein and the popliteal vein, whereas other laboratories examine the deep veins from the inguinal region to the calf, including the calf veins.[12]

Compression ultrasonography in B-mode has both high sensitivity and specificity for detecting proximal deep vein thrombosis in symptomatic patients. The sensitivity lies somewhere between 90 to 100% for the diagnosis of symptomatic deep vein thrombosis, and the specificity ranges between 95 to 100%.[12]

Attributes

As with all imaging modalities, ultrasonography has in list of positive and negative attributes.

Strengths

- It images muscle, soft tissue, and bone surfaces very well and is particularly useful for delineating the interfaces between solid and fluid-filled spaces.
- It renders "live" images, where the operator can dynamically select the most useful section for diagnosing and documenting changes, often enabling rapid diagnoses. Live images also allow for ultrasound-guided biopsies or injections, which can be cumbersome with other imaging modalities.
- It shows the structure of organs.
- It has no known long-term side effects and rarely causes any discomfort to the patient.
- Equipment is widely available and comparatively flexible.
- Small, easily carried scanners are available; examinations can be performed at the bedside.
- Relatively inexpensive compared to other modes of investigation, such as computed X-ray tomography, DEXA or magnetic resonance imaging.
- Spatial resolution is better in high frequency ultrasound transducers than it is in most other imaging modalities.

Weaknesses

- Sonographic devices have trouble penetrating bone. For example, sonography of the adult brain is very limited though improvements are being made in transcranial ultrasonography.
- Sonography performs very poorly when there is a gas between the transducer and the organ of interest, due to the extreme differences in acoustic impedance. For example, overlying gas in the gastrointestinal tract often makes ultrasound scanning of the pancreas difficult, and lung imaging is not possible (apart from demarcating pleural effusions).
- Even in the absence of bone or air, the depth penetration of ultrasound may be limited depending on the frequency of imaging. Consequently, there might be difficulties imaging structures deep in the body, especially in obese patients.
- Body habitus has a large influence on image quality, image quality and accuarcy of diagnosis is limited with obese patients, overlying subcutaneous fat attuates the sound beam and a lower frequency tranducer is required (with lower resolution)

The method is operator-dependent. A high level of skill and experience is needed to acquire good-quality images and make accurate diagnoses.

- There is no scout image as there is with CT and MRI. Once an image has been acquired there is no exact way to tell which part of the body was imaged.

Risks and side-effects

Ultrasonography is generally considered a "safe" imaging modality.[13] However slight detrimental effects have been occasionally observed (see below). Diagnostic ultrasound studies of the foetus are generally considered to be safe during pregnancy. This diagnostic procedure should be performed only when there is a valid medical indication, and the lowest possible ultrasonic exposure setting should be used to gain the necessary diagnostic information under the "as low as reasonably achievable" or ALARA principle.

World Health Organizations technical report series 875(1998).[14] supports that ultrasound is harmless: "Diagnostic ultrasound is recognized as a safe, effective, and highly flexible imaging modality capable of providing clinically relevant information about most parts of the body in a rapid and cost-effective fashion". Although there is no evidence ultrasound could be harmful for the foetus, US Food and Drug Administration views promotion, selling, or leasing of ultrasound equipment for making "keepsake foetal videos" to be an unapproved use of a medical device.

Studies on the safety of ultrasound

- A study at the Yale School of Medicine found a correlation between prolonged and frequent use of ultrasound and abnormal neuronal migration in mice.[15] A meta-analysis of several ultrasonography studies found no statistically significant harmful effects from ultrasonography, but mentioned that there was a lack of data on long-term substantive outcomes such as neurodevelopment.[16]

Regulation

Diagnostic and therapeutic ultrasound equipment is regulated in the USA by the FDA, and worldwide by other national regulatory agencies. The FDA limits acoustic output using several metrics. Generally other regulatory agencies around the world accept the FDA-established guidelines.

Currently New Mexico is the only state in the USA which regulates diagnostic medical sonographers. Certification examinations for sonographers are available in the US from three organizations: The American Registry of Diagnostic Medical Sonography, [17]Cardiovascular Credentialing International [18] and the American Registry of Radiological Technologists [19].

The primary regulated metrics are MI (Mechanical Index) a metric associated with the cavitation bio-effect, and TI (Thermal Index) a metric associated with the tissue heating bio-effect. The FDA requires that the machine not exceed limits that they have established. This requires self-regulation on the part of the manufacturer in terms of the calibration of the machine. The established limits are reasonably conservative so as to maintain diagnostic ultrasound as a safe imaging modality.

In India, lack of social security and consequent son-preference has popularized the use of ultrasound technology to identify and abort female foetuses. India's Pre-natal Diagnostic Techniques act [20] makes use of ultrasound for sex selection illegal, but unscrupulous Indian doctors and would-be parents continue to discriminate against the girl child.

Career Information

According to the Society of Diagnostic Medical Sonography [21], a diagnostic medical sonographer in the United States of America earns an average of $66,768 (2008). Sonographers work in a variety of settings including hospitals, clinics, physician offices, and mobile labs. Some even use their skills and knowledge in veterinary offices. Information [22] about a career in Diagnostic Medical Sonography is available from the Society of Diagnostic Medical Sonography. The US Department of Labor also provides information about the field in its Occupation Outlook Handbook [23].

History

United States

Ultrasonic energy was first applied to the human body for medical purposes by Dr. George Ludwig at the Naval Medical Research Institute, Bethesda, Maryland in the late 1940s.[24] [25] English born and educated John Wild (1914–2009) first used ultrasound to assess the thickness of bowel tissue as early as 1949: for his early work he has been described as the "father of medical ultrasound"[26] .

In 1962, after about two years of work, Joseph Holmes, William Wright, and Ralph Meyerdirk developed the first compound contact B-mode scanner. Their work had been supported by U.S. Public Health Services and the University of Colorado. Wright and Meyerdirk left the University to form Physionic Engineering Inc., which launched the first commercial hand-held articulated arm compound contact B-mode scanner in 1963. This was the start of the most popular design in the history of ultrasound scanners. [27]

The first demonstration of color Doppler was by Geoff Stevenson, who was involved in the early developments and medical use of Doppler shifted ultrasonic energy.[28]

Sweden

Medical ultrasonography was used 1953 at Lund University by cardiologist Inge Edler and Carl Hellmuth Hertz, the son of Gustav Ludwig Hertz, who was a graduate student at the department of nuclear physics.

Edler had asked Hertz if it was possible to use radar to look into the body, but Hertz said this was impossible. However, he said, it might be possible to use ultrasonography. Hertz was familiar with using ultrasonic reflectoscopes for nondestructive materials testing, and together they developed the idea of using this method in medicine.

The first successful measurement of heart activity was made on October 29, 1953 using a device borrowed from the ship construction company Kockums in Malmö. On December 16 the same year, the method was used to generate an echo-encephalogram (ultrasonic probe of the brain). Edler and Hertz published their findings in 1954.[29]

Scotland

Parallel developments in Glasgow, Scotland by Professor Ian Donald and colleagues at the Glasgow Royal Maternity Hospital (GRMH) led to the first diagnostic applications of the technique. Donald was an obstetrician with a self-confessed "childish interest in machines, electronic and otherwise", who, having treated the wife of one of the company's directors, was invited to visit the Research Department of boilermakers Babcock & Wilcox at Renfrew, where he used their industrial ultrasound equipment to conduct experiments on various morbid anatomical specimens and assess their ultrasonic characteristics. Together with the medical physicist Tom Brown and fellow obstetrician Dr John MacVicar, Donald refined the equipment to enable differentiation of pathology in live volunteer patients. These findings were reported in *The Lancet* on 7 June 1958[30] as "Investigation of Abdominal Masses by Pulsed Ultrasound" - possibly one of the most important papers ever published in the field of diagnostic medical imaging.

At GRMH, Professor Donald and Dr James Willocks then refined their techniques to obstetric applications including foetal head measurement to assess the size and growth of the foetus. With the opening of the new Queen Mother's Hospital in Yorkhill in 1964, it became possible to improve these methods even further. Dr Stuart Campbell's pioneering work on foetal cephalometry led to it acquiring long-term status as the definitive method of study of foetal growth. As the technical quality of the scans was further developed, it soon became possible to study pregnancy from start to finish and diagnose its many complications such as multiple pregnancy, foetal abnormality and *placenta praevia*. Diagnostic ultrasound has since been imported into practically every other area of medicine.

See also

- Emergency ultrasound
- 3D ultrasound
- Duplex ultrasonography
- Doppler fetal monitor
- European Master in Molecular Imaging

External links

- American Institute of Ultrasound in Medicine [31] Professional Association
- About the discovery of medical ultrasonography [32]
- History of medical sonography (ultrasound) [33]
- Procedures in Ultrasound (Sonography) [34] for patients, from RadiologyInfo.org
- Careers in the vascular ultrasound field [35]
- Sonography of the female pelvic floor:clinical indications and techniques [36] Illustrate the clinical utility of this non-invasive diagnostic technique.
- A Pilot Study of Comprehensive Ultrasound Education at the Wayne State University School of Medicine: http://www.jultrasoundmed.org/cgi/content/abstract/27/5/745?ck=nck

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