ULTRASONICS IN OBSTETRICS AND GYNAECOLOGY

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PART I

The diagnostic uses of ultrasonic echo sounding are being more extensively exploited in obstetrics and gynaecology at present than in any other branch of medicine. The term “sonar” is used to cover this subject in order to distinguish it from the use of high power ultrasound which is used in a number of destructive processes in industry and as a therapeutic source of heat generation at depth within the tissues in therapeutics. Sonar employs energies so low that it is difficult even to measure them.

The breakthrough, if such it can be called, came most easily in gynaecology and obstetrics6,9 because in the former, tumour masses come readily to laparotomy, often within a matter of days, and a diagnosis can be quickly confirmed or revised. Medical disorders such as, for example, hepatomegaly and splenomegaly are less immediately explored surgically and by the time the case comes to necropsy the whole picture may have altered from the time at which the original sonar investigation was made. In pregnancy the outcome of the case is likely to be known within a matter of weeks and again there is a ready feedback of information. In this way it is possible for those of us who work in this field to develop an extensive experience very rapidly over the space of a few years and our mistakes have been every bit as instructive as our successes.

Definition
Sonar stands for “sound navigation and ranging” and is akin to “radar.” This was a subject which was developed by Professor Langevin for the French and British Admiralties during the First World War to combat the growing U-boat menace. Later in time of peace it was used for oceanographic exploration. The term therefore acknowledges its historical maritime origins.

The reason for using ultrasound instead of ordinary sound is that the energy generated as ultrasound is emitted in beam form with very little divergence. The precise point of origin of an echo therefore can be determined and when dealing with a multiplicity of echoes such as occurs within the human body, their positions can be mapped out and displayed by cathode ray oscillography.

Differences between Sonar and X-rays
Both forms of energy can penetrate tissues far more efficiently than light or heat which absorb the energy more extensively from the surface inwards. Both ultrasonic and X-ray energies are transmitted in wave form but thereafter all points of similarity cease. In the case of X-rays the energy belongs to the electromagnetic spectrum in which the higher the frequency, (and therefore the shorter and more refined the wavelength) the more effective is the penetration of body tis-

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Ultrasound on the other hand is simply sound of such a high frequency (and therefore short wavelength) that it is inaudible to animal hearing, which in the case of the human seldom exceeds a frequency of 20,000 vibrations a second (20 kHz). In medical diagnosis, sonar uses frequencies in the megahertz, i.e., million vibrations per second range but unlike X-rays the higher the frequency, the less readily does the ultrasonic beam penetrate tissues. Penetration must therefore be secured by a sufficiently low frequency at the same time with a sacrifice of resolution. At a commonly employed frequency of 2½ million vibrations a second (2½ MHz) the wavelength in tissue is of the order of 0.7 mm. and is too coarse for histological purposes. Therein lies an inherent limitation. The diagnosis of malignancy, for example, can be no more than suggested on inferential grounds and still rests upon histological study.

A radiograph is essentially a shadow picture with the patient situated between the source of X-rays and a screen or photographic plate on the far side. Shadows depend partly upon the densities of the tissues traversed and to an even more important extent upon their mineral content, particularly calcium. Ultrasonic pictures on the other hand are "reflection maps." Numerous attempts have been made to produce shadow pictures, as in the case of X-rays but there is no method comparable to the photographic film for recording ultrasonic shadows by a through transmission technique which requires a mosaic diaphragm of some quartz type of material with piezo-electric qualities (see later) which has to be maintained under vacuum and scanned by an electron beam. The need for the vacuum on one side of the material limits the size that can be used to about 10 cm. at most and compared with photographic film, the resolution of any picture is very low.

From the above it will be seen that X-rays of a fetus in utero are useless until the fetal skeleton at least has enough mineral content to give a shadow, whereas in the case of sonar the fetus in its surrounding liquor is not so very different from a submarine in the ocean and the echo phenomenon can be utilised.

**Generation of ultrasonic energy and processing of signals**

This requires a transducer, i.e. something which transforms one type of energy into another and vice versa, in this case electrical energy into mechanical, and mechanical into electrical. This is achieved by the piezo-electric effect, direct and converse. Only certain materials, initially quartz, and nowadays more usually barium titanate, or lead zirconate, have these piezo-electric qualities when cut as crystals along a certain given axis. Wafers of this crystalline material are struck by a thyratron-controlled electrical discharge and respond by mechanical distortion at right angles to that discharge (the converse piezo-electric effect). The crystals are damped so that each electrical "blow" causes a brief mechanical oscillation lasting about 1½ microseconds. These electrical blows are distributed at a predetermined pulse repetition frequency (PFR) and the frequency with which the crystal rings, expressed in megahertz, depends upon the material, its thickness and dimensions. The commonly employed pulse repetition frequencies range from 25 up to 1,000 per second. We use a PFR of 600. It will be seen therefore that between each pulse there is a relatively long silent period during which the transducer is capable of receiving returning echoes. Each echo arrives back in turn, accord-
ing to the depths from which it is received, in the form of mechanical energy which on striking the crystal face is converted by the piezo-electric effect into an electrical signal which after very extensive amplification and processing can be applied to the deflection plates, cathode or grid of a cathode ray oscilloscope for visual display or for any other display method of choice.

Commonly in obstetrics and gynaecology one crystal is used to transmit and to receive ultrasonic energy, except in the case of continuous ultrasonic machines employing the Doppler principle (see later) which employ two transducers.

Echoes are generated whenever an ultrasonic beam in its passage through the body encounters a boundary, or interface as it is now known, between two different types of tissue. Every tissue in the body has its own specific acoustic impedance which is a product of the speed of the sound wave passing through it and the density of that tissue. Both of these factors are known.

The greater the difference in acoustic impedance of the tissues on either side of an interface, the stronger will be the echo. Where the difference in acoustic impedance is very large, for example at a gas interface between the wall of intestine and the flatus contained within its lumen, more than 99 per cent of the energy is reflected. This limits the usefulness of sonar in gastrointestinal diagnosis. More commonly only some of the energy is reflected, a little may be absorbed in the form of heat too small to be measured and the rest, in somewhat attenuated form, passes onwards into the rest of the body until it meets the next tissue interface and so on.

Ultimately the echoes may become so weak and the ultrasonic beams so attenuated that no information at depth can be obtained. To some extent this disadvantage can be countered by increasing the sensitivity of the amplifier, particularly to echoes emanating from a great depth, by a compensating electronic system of "time-varied gain;" that is to say, the longer it takes an echo to return, and therefore the greater its depth, the more is it automatically magnified. In this way the echo from the far parietal bone of the fetal head can be magnified to match that of the proximal parietal bone and likewise a posteriorly situated placenta can be visualised from the anterior aspect of the patient.

Where there are few interfaces, little energy will be reflected or absorbed, nor will there be much attenuation. In no instance is this more obvious than in the case of fluid containing structures such as cysts. One of our earliest observations was therefore that cysts demonstrated their far walls with great clarity, whereas a fibromyoma tended to attenuate the ultrasonic beam until it was progressively harder to make out its dimensions and depth. The bladder too transmits ultrasound equally well when full of urine, since it behaves like an ovarian cyst.

These early observations led to a ready ability to distinguish between solid and cystic masses and our first interest was in differentiating massive ascites from massive ovarian cysts. In the case of cysts the contours could be readily mapped whereas in ascites, the intervention of bowel, floating amongst the fluid, produced a mass of echoes whose distribution might help to indicate the nature of the ascites, for example, that due to peritoneal carcinomatosis. An ovarian cyst containing many echo reflecting components might suggest by its very complexity that it might be malignant, although,
as already stated, the diagnosis of malignancy must rest on histological examination.

It has already been mentioned that the penetration which can be achieved by the ultrasonic beam is inversely proportional to the frequency and therefore by coarser wavelengths. This provides a measure of the transparency of a given tumour mass to ultrasound. We now refer to its “transonicity.” A fluid-filled cyst is transonic at a high frequency for example of 5 MHz, as easily as 2½ MHz, whereas a fibromyoma might be easily transonic at 1½ MHz, and be poorly so at 2½ MHz, and not at all at 5 MHz. However, the vascularity of a tumour mass influences its transonic properties and in pregnancy, fibromyomata are more transonic than they would be in the non-pregnant, or particularly in the postmenopausal state. Areas of degeneration produce echoes within the substance of the fibroid since they may interrupt the steady attenuation of the beam as it passes through them.

When making a diagnosis therefore, whether it be of tumour mass, placental tissue or pelvic viscera in general, these physical factors have to be taken into account, namely the frequencies employed, the power and amplification settings expressed as a ratio in terms of decibels, the time-varied gain used, also expressed in decibels, and the resulting character of the echoes.

The Two Types of Diagnostic Ultrasound

In medical practice two main varieties are used. The least complicated is that which employs the Doppler effect. A continuous beam of ultrasound is aimed at a moving, reflecting interface, such as, for example, the fetal heart. The movement towards and away from the transducer shortens or lengthens respectively the time taken for that echo to return to it and hence the apparent frequency is notably changed. This alteration can be processed either as an auditory or visual signal. With such apparatus the fetal heart can be picked up, often from the 11th week of pregnancy onwards. The use of the Doppler principle is also applied to circulation blood flow studies but it will be noted that this simple information depends on the existence of moving structures.

The other main class of ultrasonic echo sounding depends upon the pulse/echo principle. This allows echoes to be spatially separated in time and therefore to be mapped. It is therefore used in differential diagnosis since the appearances, often characteristic, are increasingly recognised. The two methods can be used in conjunction.

Methods of Presentation or Display

A-Scan

The simplest form is unidimensional, employing A-scan. In this the echoes are superimposed as vertical deflections or “blips” on the time base sweep of a cathode ray tube, the signal being applied to the appropriate deflector plate (Fig. 1). The distance from left to right on this time base sweep represents the depth of origin of the reflecting interface and the height of the blip represents the strength of that echo, which in its turn depends on the difference in acoustic impedance on either side of the interface. In the case of the fetal skull these differences in acoustic impedance, compared with liquor and surrounding uterine muscle, are considerable and the echoes are readily recognised. Time varied gain compensation can bring the far echo from the posterior parietal bone up to parity with the near one. The midline structures, mainly the
falx, produce a weaker echo, midway between the two. Biparietal cephalometry provides the most frequent indication for the use of A-scan.

A-scan is applicable in the measurement of the distances between structures whose position is known. In ultrasonic echo sounding, as in the case of light physics, the laws of reflection and refraction apply and good echoes can only be received if the ultrasonic beam strikes the reflecting interface at perpendicular or what is called “normal incidence,” otherwise the reflected beam is diverted away from the receiving transducer, and if the angle of incidence exceeds the critical angle, refraction too will occur, with consequent misleading distortion.

Biparietal cephalometry is only accurate and useful in so far as the true diameter can be identified. By mapping the head first by a two-dimensional technique (see later) and calculating the angles of its attitude correctly a proper A-scan measurement can be made. This technique requires practice and precision but we aim for errors of less than 1 mm. (Figs. 1 & 2).

Biparietal cephalometry supplies about two-thirds of the workload of most ultrasonic departments in obstetric units. It is the only measurement of the head which can be made independent of the presentation or the degree of flexion or deflexion attitudes. Fortunately it is also the easiest to reach, particularly in vertex presentations, since the head commonly engages in the occipito-lateral position, and the anterior parietal eminence is fairly accessible provided the head is not too deeply engaged. (In this event the examination can be facilitated by allowing the patient’s bladder to fill and lowering the head of the examination couch in order to disengage the head sufficiently.)

Numerous studies have shown there is more correlation between the biparietal diameter of the fetal head and the maturity of the fetus than the actual weight. If the thoracic measurements are combined with biparietal measurements a better estimate of fetal weight can be made. The sequential study of biparietal diameters provides as index of intra-uterine growth rate and therefore of fetal wellbeing and it is standard practice with us and many other units to use this technique at repeated intervals and to plot the growth curve in conjunction with oestriol excretion rates in the hope of recognising, thereby, the fetus which is showing intrauterine growth retardation (Fig. 3). In this instance the slope of the curve becomes more horizontal than the norm. We use the curve established by Campbell while in our department. In contrast mistaken dates will show a growth slope which, although not coinciding with the accepted curve, runs more or less parallel to it.

This technique serves to monitor intrauterine fetal health on the basis of the argument that a fetus outrunning its placental nutritional reserve fails to grow adequately. This also helps to reduce mistakes in estimating maturity especially when induction is being contemplated. Lastly, it may indicate a degree of disproportion likely to complicate labour due to an overgrown head. X-ray cephalometry is by comparison notoriously unreliable, since any errors in estimating the distance of the fetal head from the X-ray tube or screen are thereby magnified.

The best estimates of maturity can be made before the thirtieth week, up to which time the head is so circular that its diameter is easily measured. From the thirtieth week onwards the head acquires
a more oval shape with a longer occipito-frontal than biparietal diameter and therefore the technique becomes not only more difficult but also more open to error. Readings therefore early in pregnancy are of great value.

Two-Dimensional-Scan Presentation

In this system the signal from the returning echo to the transducer is applied to the cathode or grid of a cathode ray tube, thereby increasing or reducing the electron emission from the cathode gun. This alters the brightness of the dot of light created by the impinging electron beam on the tube phosphor. The brightness is thus intensity modulated according to echo strength. Furthermore, the direction of the ultrasonic beam is taken into account in the positioning of this dot of light upon the cathode ray screen, so that it geometrically represents its position of origin within the body. In this way a whole succession of dots can build up a continuous contour (Fig. 2). Bearing in mind the need for an ultrasonic beam to strike an interface at normal incidence, B-scanning may miss a great deal of available information unless it is compounded by a system of transducer rocking so that as many interfaces as possible are identified, if not from one direction then from another.4, 5, 9 Thereby more echo information may be obtained but always at the expense of some resolution. Even so, echoing interfaces which are not orientated at normal incidence in all three dimensions, may deflect echo information and the structure may only be properly visualised if the whole probe system is tilted into a more appropriate plane. A search technique is therefore always necessary. In the case of fetal cephalometry we commonly search for the head first of all in longitudinal section to find its angle of asynclitism if any, and we then scan transversely at the predetermined point with the whole scanning head tilted to this angle.2 The measurements should match whether the biparietal dimensions are measured in longitudinal or transverse section. Failure to carry out this technique in full is bound to lead to bad results. Where the maximum degree of resolution is required as, for example, in gray scaling (see later) it is important not to "overwrite" echo information by compound sector scanning, in fact each reflecting interface should be seen only once and at standard exposure. It is therefore necessary first to identify the structure under examination both as to its position and spatial relationship and to employ, with our technique, a simple, once-over radial scan at a predetermined speed.5

Time-Motion Display

This is used to depict graphically the movement pattern of a structure, such as for example the fetal heart (Fig. 4). While the Doppler technique is successful for simply detecting its presence and its rate, it indicates nothing of the pattern of movement itself. Robinson in this department has developed time motion scanning for the earliest detection of the fetal heart within the first few weeks of pregnancy.13 First of all the fetus is identified within its sac by compound B-scanning. Simultaneously the A-mode is applied to a second screen and pulsation is watched for in the form of vertical blips being displaced at an appropriate rate, around 160 beats per second, from left to right and vice versa, on the A-scan trace. Having therefore determined which point of the fetal mass on B-scan contains the pulsating structure, the third method of display is now brought into play in which the time-base
sweep is spread at a known rate across the face of the tube from below upwards. The echoes, instead of being represented as blips are now converted to intensity modulated light dots and with the movement progressively of the time-base sweep these light dots trace a movement pattern across the face of the tube (Fig. 4). The fetal heart can thus be detected far more early than by the Doppler technique, even by the 6th week after the onset of the last menstrual period. Proof positive is thus obtained, even at this early stage, of continuing intrauterine fetal life. This movement pattern can also be sought in any structure which might be thought to be the second head of a twin when in fact one might be looking at the thorax and heart of a single fetus. The pulsating structure prevents one from making such a mistaken diagnosis of twins. 8

Patient Management

For a diagnostic technique to be acceptable it must not involve the patient in pain, indignity or hazard. Sonar meets these requirements admirably. The patient lies simply upon an examination couch and normally the examination is made through the anterior abdominal wall. Since an air interface reflects over 99 per cent of ultrasonic energy, good contact has to be made with the patient's skin. Here two techniques are available. The earliest methods involved immersing the patient naked in a tank of water. This is clearly not acceptable particularly in the sick or the pregnant. Another alternative is to apply a flexible tank of water to the abdominal wall, coupled with some air-excluding jelly. This method is still used but for the patient who is supine it increases the likelihood of hypotensive phenomena. It is cumbersome, uncomfortable and restricting. Furthermore the interface between tank and skin reflects very powerfully and the depth of water has to exceed that of any subsequent echo thereafter, otherwise a series of false reverberations will be set up which interfere with the resulting picture.

The Australian technique of having a patient on a more or less vertical frame gets rid at least of the supine, hypotensive difficulties. 11 Our own preference has always been for direct contact scanning, applying the transducer probe directly to the abdominal wall. Coupling is achieved by first liberally smearing the abdominal wall with an oil-excluding lubricant. Olive oil is easily the least objectionable. Poor quality pictures are commonly obtained from an insufficiently liberal use of air-excluding oil.

The technique is quick and this is important as sometimes patients begin to feel faint from lying in the dorsal position on a hard examination couch due to the supine hypotensive syndrome. In this case the examination must either be halted and the patient turned onto her side, or the need for this may be temporarily postponed by raising her feet up in the air on top of the shoulders of an assistant and also lowering the head end of the couch.

References