NUCLEAR MEDICINE AND ULTRASOUND

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Letter From the Editors

THE INTRODUCTION of ultrasound techniques into clinical medicine in the 1970s appears to parallel the introduction of radionuclide techniques one decade earlier. In both instances technical improvements in instrumentation have been greatly augmented by the ingenuity and perseverance of medical investigators in applying the new methodology to clinical problems. The community physician interested in radionuclide and ultrasound studies has been inundated by articles extolling the virtues and emphasizing the limitations of each method. After sifting through these medical archives, it becomes necessary to make an individual evaluation of the relative value of any new modality in its application to specific clinical problems.

The usefulness of any new diagnostic technique must be evaluated in comparison to existing established techniques. Does the new study provide similar or better information in a less traumatic, less costly, or less time-consuming manner? If so, it may replace the older technique. On this basis the pulmonary perfusion scan has essentially replaced contrast angiography as the routine examination in the study of embolic disease of the lung. Similarly, ultrasound studies of placental localization have replaced radionuclide techniques. Newly introduced techniques frequently offer different types of information that either complement existing methodology or may be applied to problems poorly elucidated by previous means. Ultrasound examination offers anatomic structural detail, while the advantage of nuclear medicine lies in its physiological functional approach to organ study. Depending upon the problem posed, one may select either or both modalities in the patient workup.

Since our readership is primarily concerned with nuclear medicine, we have asked Drs. Sweet and Arneil from Glasgow, Scotland, to orient us with an introductory article on ultrasound methodology. In addition to its use in obstetric and gynecologic studies, ultrasound has received a great deal of attention and clinical acceptance in work on the heart. Dr. Stuart Gottlieb is one of that small but ever growing group of individuals with expertise in both cardiovascular nuclear medicine and echocardiography. In two separate articles he and his associates at the University of Miami have extensively reviewed the applications of echocardiography to congenital and acquired heart disease. As with all other articles in this volume, correlation with radionuclide studies is presented, where applicable.

It is the aim of this volume to aid in an understanding of ultrasound techniques and how they may relate to nuclear medicine procedures in diagnosing a patient's problem. A knowledge of the capabilities and limitations of each method should help the clinician to utilize them with optimal results.

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An Introduction to the Use of Diagnostic Ultrasound

Elizabeth M. Sweet and G. C. Arneil

This article is meant to serve as a simple introduction to diagnostic ultrasound, explaining the nature of sonar and the basic equipment for its production and use. A scans, B scans, time–position scans, and Doppler-shift techniques are described, with some examples of the clinical applications of each. Some recent innovations such as scan conversion to improve gray scaling and electrocardiographically triggered cardiac sector scans are mentioned. The limitations of the technique are indicated, with measures that can be adopted to reduce them. The safety of the procedure is emphasized, with its freedom from the known biological effects of ionizing radiation.

PRODUCTION of sound waves with a frequency above the upper range of human hearing (25,000 cps or 25 kHz) has been practical since 1880. A quartz crystal vibrating in response to an electrical charge was the source then used.[1] Since 1916 the navies and fishing fleets of the world have been using sonar (sound navigation and ranging) in their search for submarines and shoals of herring. Medical sonar uses closely analogous techniques to obtain data on tissues within the human body.

Because sonar pulses are reflected by air, unlike audible sound, fluid continuity is required between the emitting source and target and between the target and receiver. As the beam penetrates the body the sonar pulse is reflected from tissue interfaces in the path of the beam. The more perpendicular the beam is to the line of the interface the stronger the echo will be, since an interface that is not perpendicular causes refraction rather than reflection, and the returning echoes may miss the transducer. By changing the frequency or the intensity of the sonar pulse, greater or less penetration may be obtained and the echo patterns may be altered. Fluid-filled cysts and organs that are transonic have reflecting surfaces only at their boundaries, which produce large echoes and are thus readily distinguished from solid masses containing many interfaces (Fig. 1).

Naturally occurring quartz crystals and synthetic ceramics known as ferroelectrics share a property known as the piezoelectric effect. This describes the property by which a voltage appears on the crystal faces on the application of pressure. The reverse piezoelectric effect is used to generate ultrasonic waves, and the piezoelectric effect is used to detect them (Fig. 2). The basic equipment required for making effective use of pulsed ultrasound consists of a generator, a transducer, and a memory oscilloscope (Fig. 3). The generator produces a pulsed voltage at a frequency that may vary between 50 and 3,000 pulses per second. The specific pulse rate frequency is chosen to allow a reasonable scan speed to be used while still leaving time for receipt of echoes between pulses and to avoid flickering on the display. The generator also provides the time base on the display oscilloscope.

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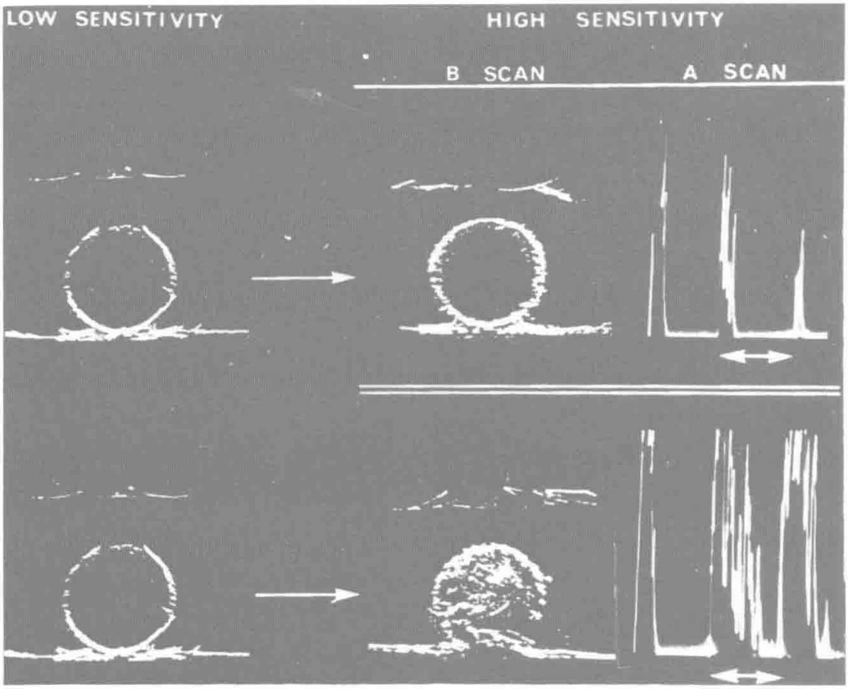

Fig. 1. Differentiating cysts (top) and solid tumors (bottom) by altering power of ultrasonic beam. (Reproduced by permission from Lyons EA, Murphy AV, Arneil GC: Sonar and its use in kidney disease in children. Arch Dis Child 47:777, 1972.)

A transducer incorporates a circular disk of a ferroelectric such as lead zirconate titanate mounted across a hollow cylinder that may, depending upon the application, be filled with backing material. Suitable voltages are applied to the crystal to generate a directional ultrasonic beam, the width and shape of which are related to the crystal diameter and shape. This beam will bounce off objects, and if emitted as a pulse it will give an echo that may be picked up by the same crystal and converted back to electrical energy. Since the time interval involved

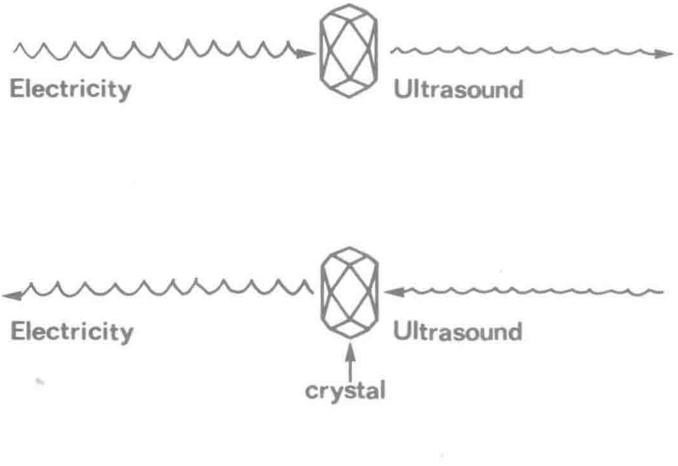

Fig. 2. Piezoelectric effect.

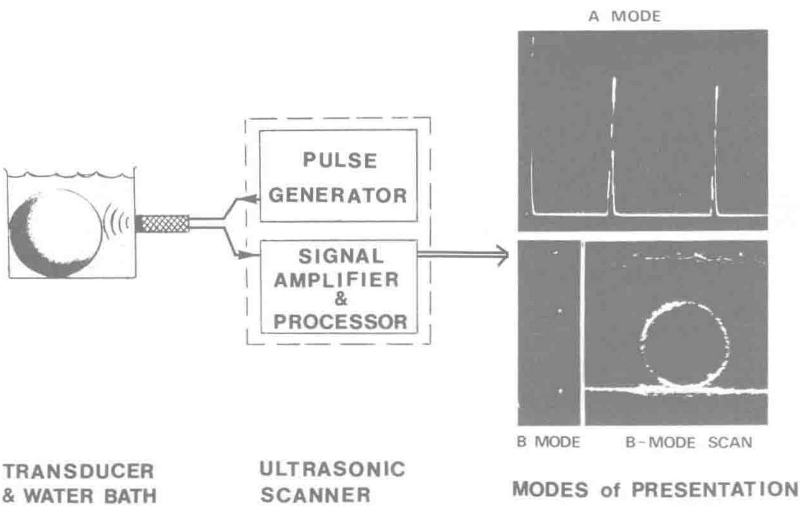

Fig. 3. Basic equipment for making use of diagnostic sonar. (Reproduced by permission from Lyons EA, Murphy AV, Arneil GC: Sonar and its use in kidney disease in children, Arch Dis Child 47:777, 1972.)

and the velocity of transmission through tissues are known, the distance of reflecting surfaces from the source may be calculated. The sound wave frequency produced by transducers varies between 0.5 MHz and 20 MHz (500,000 to 20,-000,000 cps)—the higher the frequency the lower the penetration (because absorption is less at lower frequencies) but the better the resolution. Sonar in ophthalmology is used at high frequencies, and in abdominal work the lower frequencies are employed.

The exclusion of air is essential, necessitating coupling of transducers and target through an oily medium such as olive or arachis oil or by transonic gels.[2] Alternatively, a water bath may be used for certain examinations. This may take the form of a plastic bag suspended from a rigid frame and then filled with warm water. The plastic bag is then "coupled" to the skin with a thin layer of oil.[3] A bath for use in ophthalmology may have an aperture with an adhesive margin in its base. This is pressed around the orbital margin before filling the bath with a suitable electrolyte solution such as Ringer lactate, which will be in direct contact with the conjunctiva.[4] In other circumstances the part of the body to be examined is immersed in the water bath itself. This technique has been used for examining breasts,[5] skull, and limbs. A bath is useful for examining superficial structures to overcome the near-zone phenomenon (Fig. 4). A confused jumble of echoes is obtained from the first 2–4 cm of tissue through which a sonar pulse passes, as the strong reflected echoes from superficial tissues are partly retransmitted as further pulses of reduced intensity. The water is transonic and acts as a stand-off for the transducer, reducing the effect of the dead space in front of the transducer and allowing useful information to be gathered from superficial body structures. The water in the bath must be more than the depth of the deepest tissue layers under investigation to avoid irritating reverberations. The use of a water bath in ophthalmology has been mentioned. Its value in young infants will

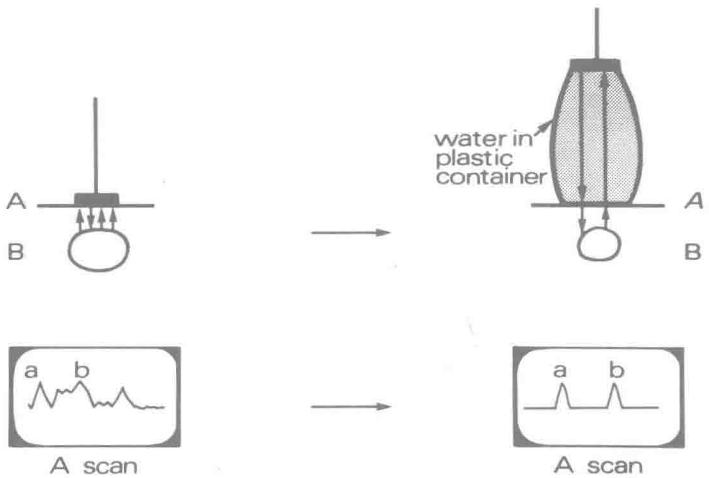

Fig. 4. Overcoming near-zone phenomenon.

be evident; here it also has two further advantages. Warm water can help to prevent cooling, which can be dangerous and rapid on exposure of a large body surface area to cool air; it is also comforting to the young infant recently emerged from the human water bath in his mother's womb. It overcomes the instinctive reaction of withdrawal from the transducer produced by direct-contact scanning in infants, toddlers, and ticklish persons of all ages, and in areas of tender scars.

Memory oscilloscopes record returning echoes received by the transducer after electronic processing. These, until recently, have been conventional cathode-ray or storage oscilloscopes, a permanent record being made by Polaroid prints, 35-mm photographic film, or hard-copy printouts on ultraviolet or photographic paper.

Diagnostic methods in use at present are (1) A-scan systems, (2) B-scan systems, (3) T-P (time–position) scan systems, and (4) Doppler-shift techniques. The first three make use of pulse-echo techniques, but continuous-wave beams are used in the Doppler-shift techniques.

A SCAN

A simple pulse and its echo shown as "blips" causing vertical deflections of a size proportional to echo strength on a longitudinal oscillographic time scale constitute the A scan or amplitude-modulated display. Since the baseline is horizontal with the blips, each vertical blip denotes reflection from a tissue interface and its distance from the source of the beam (Fig. 5). This type of display is used to good advantage in echoencephalography. The A scan has been used in abdominal echography to locate organs and cysts, but interpretation requires considerable expertise and it is now rarely used alone. Echoes from deeper structures are inevitably attenuated by partial reflection of the beam from more superficial structures and by absorption. By using amplification increasing with depth incorporated in the "swept gain control" more information on deeper structures can be obtained from A-scan displays. This selective amplification is also used in other scan systems.

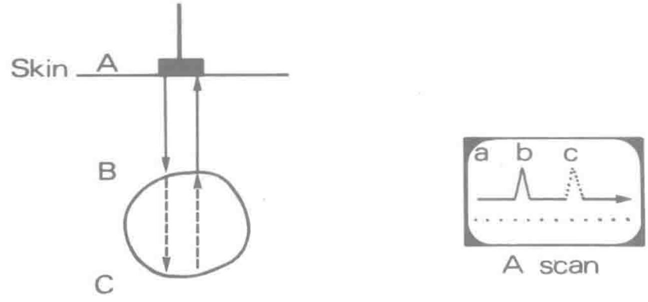

Fig. 5. A cyst demonstrated by A scan.

B SCAN

The B mode uses a brightness-modulated time base to produce more easily assimilated information. Each echo is marked by a bright dot rather than a blip, and the brightness increases as the echo becomes stronger (Fig. 6). This mode is used in two-dimensional or B scanning (also called sector scanning) and in T-P scanning. In B scanning the probe is moved in a linear path parallel to the skin surface. By continuously displaying the series of echoes on an oscilloscope a two-dimensional screen picture is built up (Fig. 7).

Compound B scanning involves oscillating the probe by gentle rocking movements as it traverses a linear path. This displays "tomographic" tissue slices, gathering more information by bringing more tissue interfaces perpendicular to the transducer. This enables delineation of the position and contours of fluid-containing or solid organs or cavities within the body. The scans may be in longitudinal, transverse, or oblique planes, and such a series of two-dimensional pictures will give a skilled reader a view of the organ or cavity under investigation that is virtually three-dimensional.

GRAY SCALING

The term gray scaling is used for a technique distinguishing echo intensity by the degree of blackening produced in the recording system. The introduction of

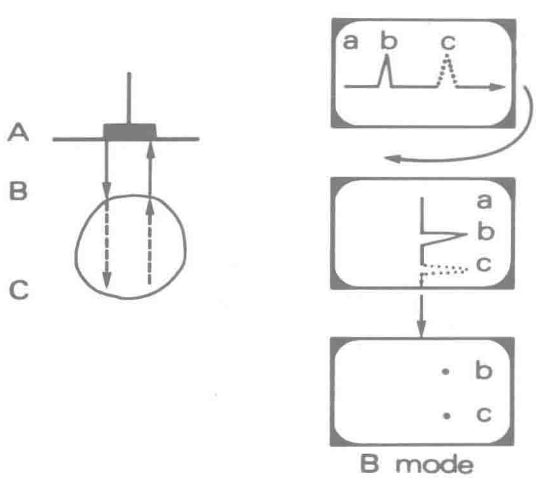

Fig. 6. A cyst demonstrated by A scan and B mode.

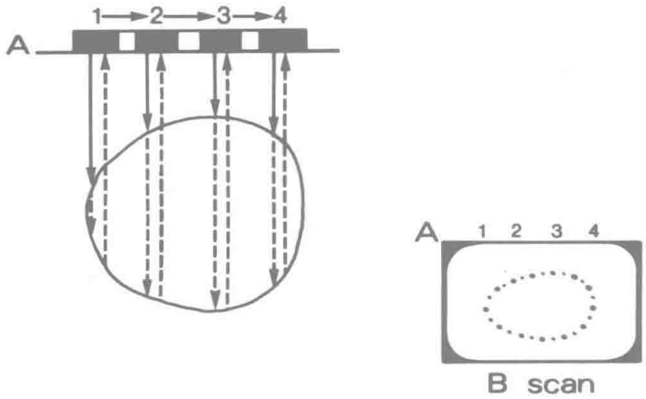

Fig. 7. A cyst demonstrated by B scan.

Lithicon cathode-ray tubes used with scan conversion techniques in place of the conventional simple storage oscilloscopes has provided a much improved gray-scale capability. Lithicon tubes are electrical "in" and electrical "out" storage tubes that cannot be viewed directly, but when used with scan conversion can be displayed on commercial television monitors. The dielectric target used gives high resolution—about 160 lines/cm compared to 20 lines/cm for conventional cathode-ray tubes and 8 lines/cm in storage tubes. Another advantage is that the target is a peak-value memory, and therefore there is no overloading of the recording system. This not only makes scanning techniques easier but also reduces the degree of skill required. Prolonged training is necessary for the earlier systems that are still in general use.

A further projected development is the incorporation of color instead of gray scaling to utilize the greater sensitivity of the rods of the human retina to the red end of the light spectrum.[6]

T-P SCANNING

In time–position scanning moving structures are investigated by displaying the echoes as dots along a longitudinal time scale. By slowly moving this time base in a vertical direction at a selected speed, moving structures are recorded as wavy lines showing the extent and direction of the movement, with rigid structures recorded as straight lines. Varying echo amplitudes caused by moving structures not being constantly perpendicular to the transducer may produce an interrupted tracing. The tracing may be recorded in a time exposure on a Polaroid film, on moving 35-mm film, or on a hard-copier using ultraviolet paper. This method is used in echocardiography to display heart wall, intracardiac septum, valve cusp, and outlet vessel movements. Simultaneous electrocardiographic (ECG) and phonocardiographic recordings may be displayed with the echocardiographic tracing (Fig. 8).

TRIGGERED B SCAN

This further development of echocardiography uses "gating" to produce two-dimensional scans of the heart in a particular phase of the cardiac cycle. By employing triggering from the ECG, tracing with a slow scan speed while tra-

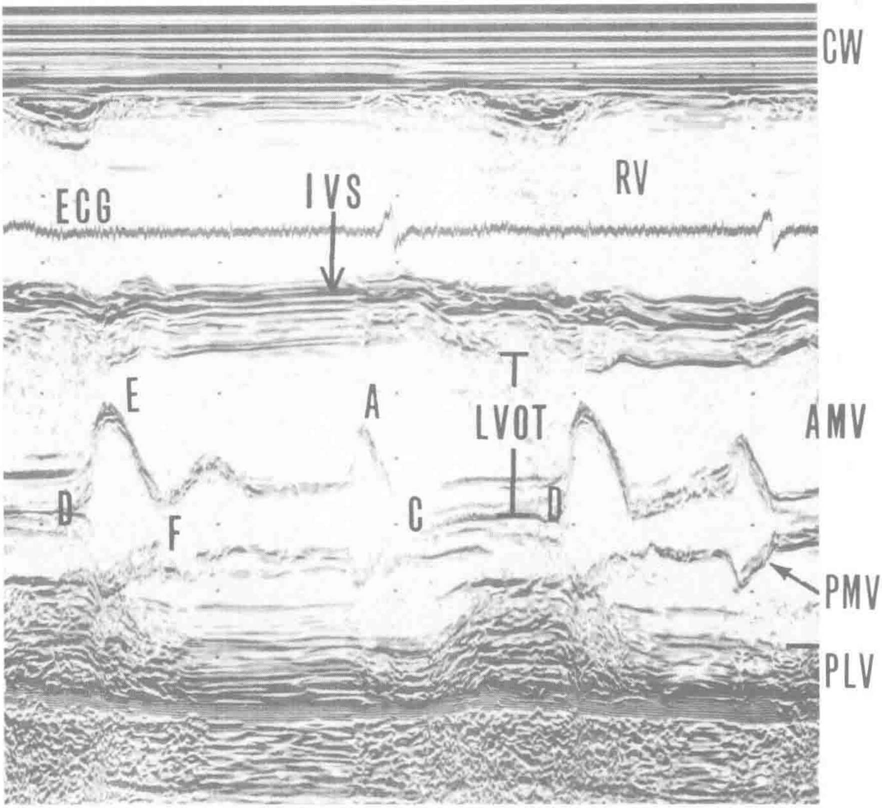

Fig. 8. Normal mitral valve. Note that there is a gradual anterior movement of the mitral valve leaflets during systole (C-D). LVOT = left ventricular outflow tract. AMV = anterior mitral valve leaflet. PMV = posterior mitral valve leaflet. CW = chest wall. RV = right ventricle. IVS = interventricular septum. (Reproduced courtesy of Dr. Stuart Gottlieb: *see also page 80*.)

versing a linear path on the chest wall, the pulses emitted at the same phase of each cardiac cycle can give a "frozen" picture of the heart chambers and valves in ventricular systole or diastole, depending on the point of the ECG tracing chosen as trigger (Fig. 9). This is only possible in the absence of cardiac arrhythmias.

MULTISCANNING

Multichannel transducers have been developed that will give B-mode displays of the heart, demonstrating structure movement without requiring transducer movement. This means that two-dimensional cardiac movement can be observed on the oscilloscope display—a technique analogous to single-plane cineangiocardiography. The display is similar in appearance to that of a television set.[7]

DOPPLER-SHIFT TECHNIQUES

Information about moving structures can be obtained by using continuous-wave ultrasound. The transducer employed is a double one, separate elements being used for transmission and reception. When the transmitted wave is reflected from a moving structure a frequency shift is produced and the receiver

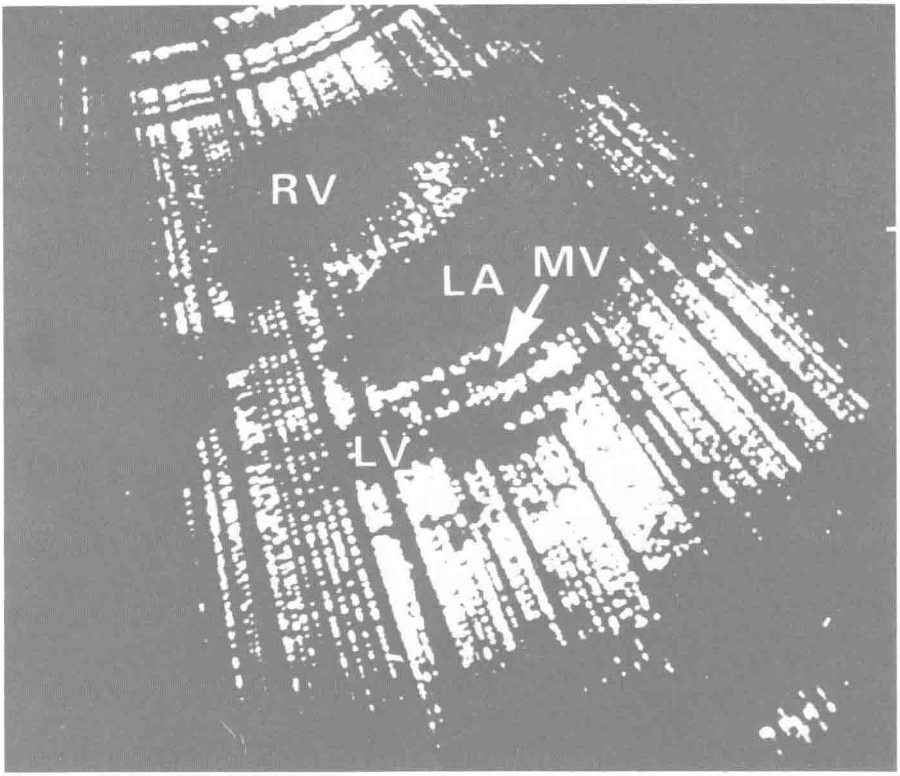

Fig. 9. B scan, triggered by ECG, to demonstrate heart chambers and mitral valve in ventricular systole. RV – right ventricular outflow tract, LA – left atrium, LV – left ventricle, MV – closed mitral valve.

picks up a wave of a slightly different frequency. The original transmitted signal is subtracted from the received signal to present the frequency difference as an audible note, whose pitch is related to the speed of movement of the target and whose volume is related to the number and size of moving interfaces detected. This technique is widely used in fetal heart monitoring, employing a low-frequency (2.5-MHz) transducer. It is also of value in investigating blood flow in superficial arteries, using high-frequency (10–15-MHz) transducers. Instruments have been developed that can distinguish direction as well as velocity of flow, and frequency spectrum analysis of signals is used rather than audible signals to separate simultaneously differing directions of flow at different velocities.

LIMITATIONS OF SCANNING TECHNIQUES

Resolution of information on display systems depends on the frequency of the transducer and on the absorption properties of the medium through which the sonar beam is directed. Although improved by compounding the scan, lateral resolution is more limiting than linear resolution (thus objects side by side are harder to separate than objects lying one behind the other), but in each case resolution is improved at high frequencies. Inevitably absorption also increases with increasing frequency, and consequently penetration of the beam is limited. In spite of swept gain facilities, information on deeper structures is limited by the forced use of lower frequency transducers to achieve sufficient penetration by the beam.

Another major limiting factor is that although most body tissues allow transmission of sonar at almost uniform velocities, bone speeds up the transmission and causes changes that may lead to erroneous estimation of the location of structures in A and B scans. "Shadows" with no echoes and no information can be produced for a few centimeters immediately deep to the bone. This is a very real drawback in intracranial diagnosis except with the thin neonatal skull. The rib cage also causes problems in echocardiography. Another important limiting factor in the chest comes into play as well. Since gas reflects ultrasound almost totally, the lungs are poor conductors. The cardiac window is therefore small and is closed or made smaller by pulmonary overinflation from any cause—for example, asthma or emphysema. In the abdomen intestinal gas will also act as an efficient reflector, preventing gain of information from structures deep to gas-filled stomach and bowel. For this reason it is often wise to examine the kidneys in the prone position. In echocardiography fast B scans are necessary to avoid blurring, but gating with ECG triggering helps overcome this problem.

HAZARDS

Hazards known to occur from the use of very high power continuous ultrasonic beams are of three types.[8] These should never be a problem with the currently available diagnostic apparatus. Thermal effects result from direct absorption from the beam and conversion of longitudinal waves to transverse waves by bone. Pressurization at high power can cause cell disruption. Cavitation, which is the creation and collapse of bubbles in fluid media, also occurs at high power.

Present diagnostic methods appear to be free from these hazards to patients, and a considerable amount of work that has been completed in recent years has confirmed this situation.[9,10]

Sonar is safe because the power used is low. It is believed that pulsed sonar is completely free from hazards, but there is some reservation on the safety of prolonged use of continuous ultrasound over a period of many hours.[11]

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