This paper describes an ultrasonic scanner having twenty adjacent elements. The apparatus has been designed to evaluate a non-invasive technique for visualising moving cross-sections of the heart, particularly the walls of the ventricle. Fast electronic switching from one element to another and appropriate display of the echoes results in the instantaneous and continuous display of a moving structure. This simple technique has probably not been applied to cardiology before. Limitations of the apparatus and some preliminary results are discussed.

Ultrasonic Viewer for Cross-Sectional Analyses of Moving Cardiac Structures

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In recent years there has been considerable interest in the use of ultrasound techniques in cardiology. Application in the study of mitral valve motion has been advocated. Such techniques are based on the measurement of echo travel time.

When a transmitter-receiver is used to send ultrasound pulses into the heart, discontinuities in the sound beam such as tissue-blood interfaces give rise to reflections. The time interval between pulse transmission and echo reception from such an interface is a measure of the distance between the transmitter and the reflecting discontinuity. With appropriate display methods the spatial structure can be derived from these echoes.

Most current techniques employ a single-element transducer. One such method, the A-scan, uses a transducer in a fixed intercostal position to study the one-dimensional tissue structure along the sound beam. With these techniques the motion of, for instance, the anterior leaflet of the mitral valve can be recorded[1,2,3]. From this the degree of constriction (stenosis) of the mitral valve opening can be estimated.

Further development of this method to give a two-dimensional cross-sectional view requires more than one sound beam, which in turn calls for physical movement of the transducer. Such a scan is obviously considerably more informative than the A-scan. However, the necessary mechanical motion of the transducer is time-consuming and this has so far made it impossible to get a clear cross-sectional display of the heart.

In this paper a method and preliminary results are described whereby an array of fixed elements rapidly scans (by means

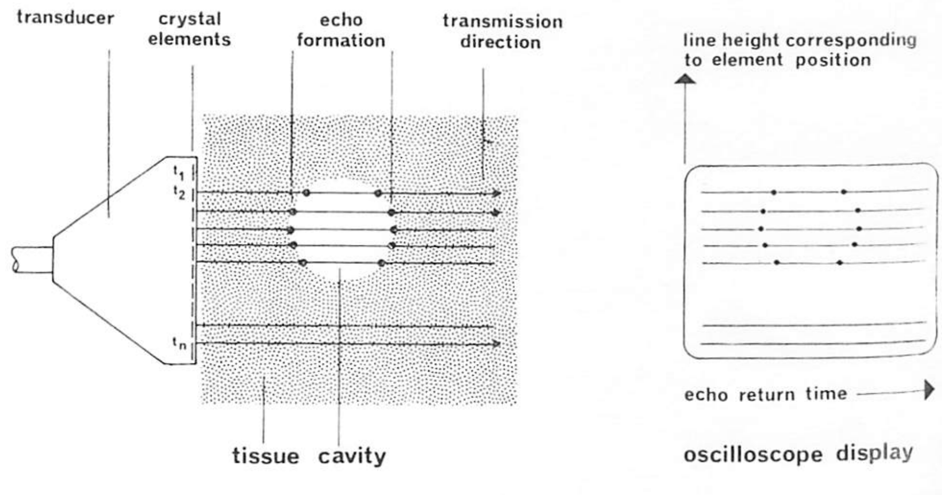

Fig. 1. Schematic drawing of a multi-element transducer and corresponding display.

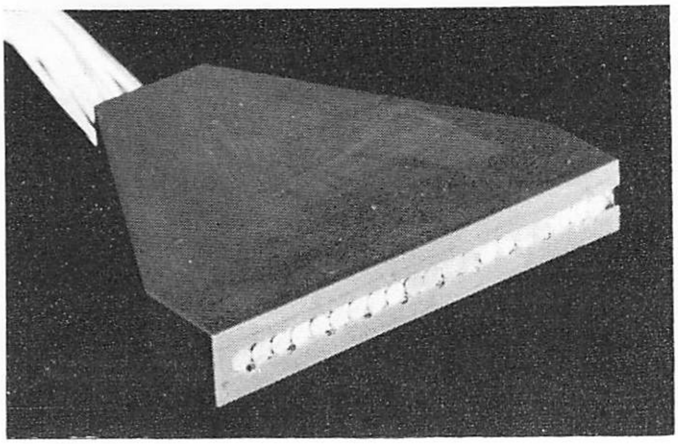

Fig. 2. A 20-element transducer (length 6.6 cm).

of electronic switching) the area to be explored, thus obviating any mechanical movement of a single element. With such a fast electronic scanner it is possible to produce an instantaneous echo-pattern and thus display the anatomic structure without any "smearing" from the movement of the heart. This method could be used, for instance, in the detection of any area of the heart which was akinetic, and thus help localise an infarct.

A comparable system has been utilised in ophthalmology by Buschmann[4]. He described a ten-element system whereby the single elements are mounted in an arc to match the eye-ball.

A thorough review of the literature has failed to indicate the application of the switching principle to cardiology.

So far only preliminary *in vivo* results have been obtained with the present apparatus, which is being modified in the light of results from *in vitro* work.

Principle and limitations of the design

The principle is best summarised as "the use of n parallel A-scans at almost the same instant".

A schematic drawing of a multi-element transducer is shown in Figure 1. The elements transmit a short acoustic pulse sequentially into the tissue. Returning echoes are displayed along a horizontal axis on the oscilloscope, while the vertical position of each line corresponds

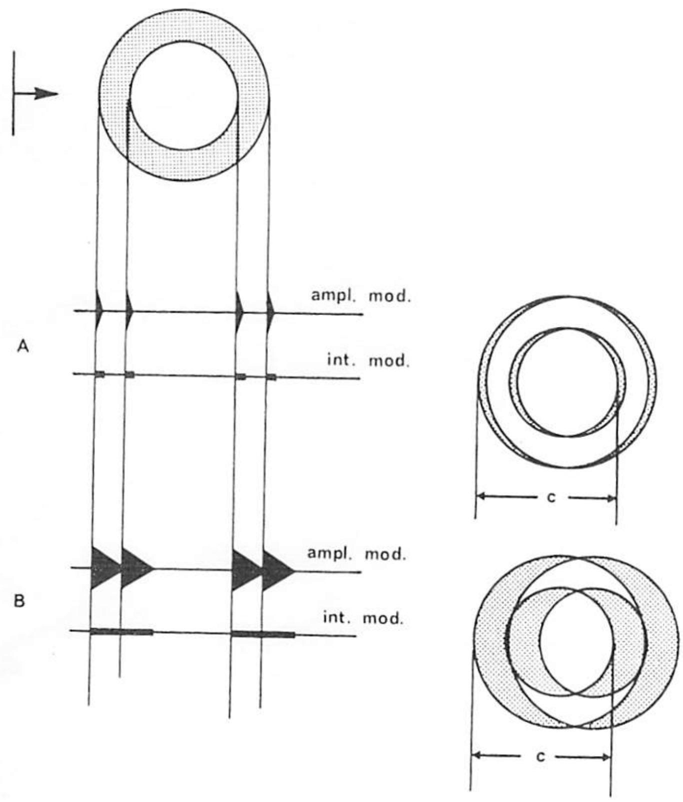

Fig. 3. Schematic construction of aortic echogram in the situation of short (A) and long (B) pulses.

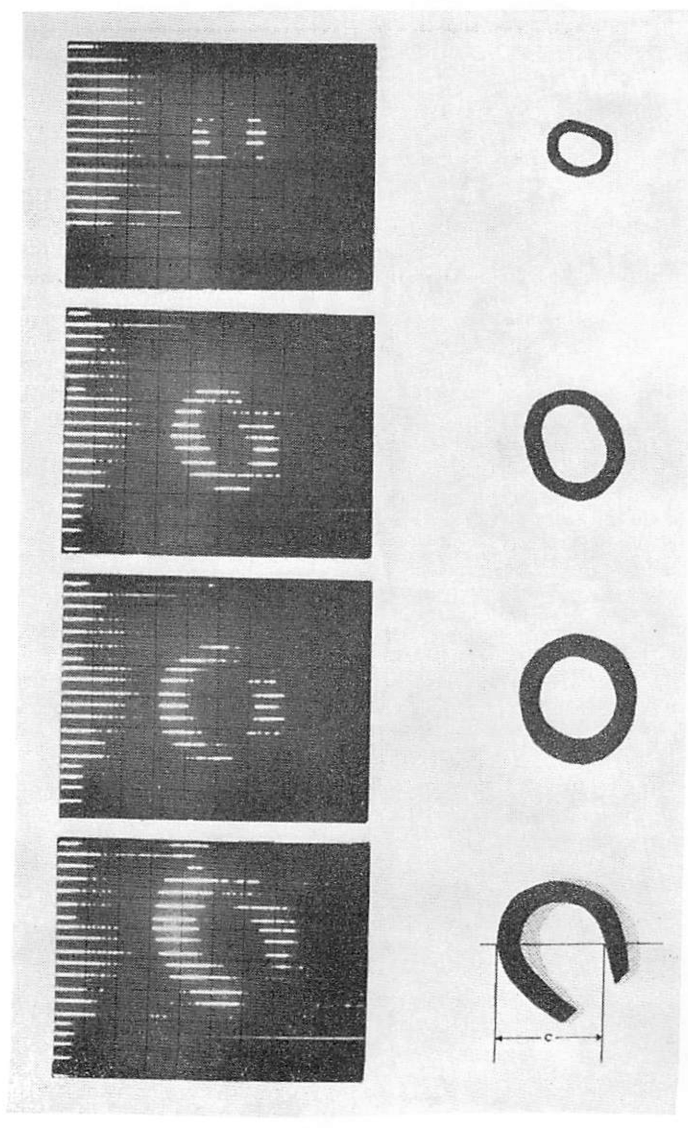

Fig. 4. Echograms of four aorta sections, each shown together with the corresponding "wet print".

to the position of the respective element. Under working conditions the horizontal lines are suppressed and only the echoes shown. Fast electronic scanning results in a repetition rate of 190 complete frames/second.

The transducer is shown in Figure 2. With this transducer (length 6·6 cm) the displayed cross-section measures approximately 6 × 15 cm.

One of the major drawbacks in ultrasound is the limited resolution. Resolution is an indication of the minimum distance apart at which two reflecting structures may be observed to be separate. Resolution may be divided into *lateral* and *axial* resolution.

Lateral resolution depends mainly on the acoustic beam-width, and thus on frequency and crystal geometry. With 3 mm diameter disc-shaped piezoelectric elements resonating at a frequency of 3 MHz, the beam-width at 6 cm distance in a water tank was measured to be 10 mm. (Beam-width is here defined as the lateral distance between the two points having 0·7 times the pressure amplitude in the main axis direction.)

Sound beams of adjacent elements may overlap. This will give rise to erroneous positioning of echoes on the display. Since beam-width increases with depth, distortion due to this effect is more apparent in areas far away from the transducer-face.

The axial resolution, which is the minimum distance apart at which two structures may be observed to be separate in the axial direction, depends mainly on the electrical characteristics of the apparatus and crystal (apparent echo-length on the display) and is at present of the order of 4 mm.

The axial resolution plays an important role in echogram distortion. A schematic construction of cross-sectional echogram of an aorta, as would result with the described apparatus, for both a short and a long echo-length, is shown in Figure 3. In "A" the situation under short echo conditions results in a fairly correct display of the actual aorta shape. In "B" no differentiation of wall thickness can be made. Only distance *c* remains correct. This situation appears in practice as

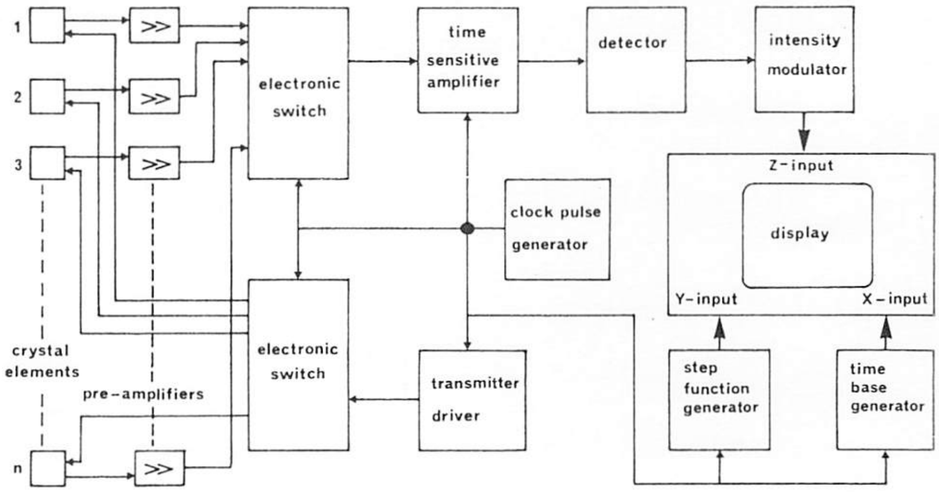

Fig. 5. Block diagram of a n *element system.*

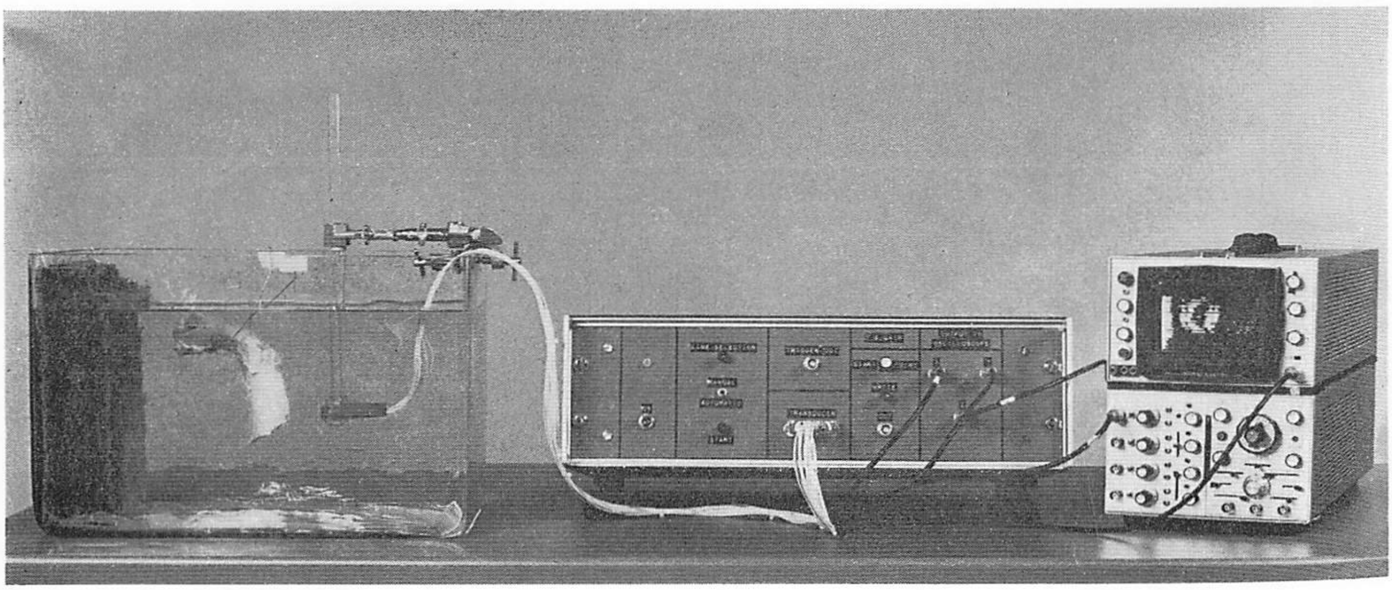

Fig. 6. The completed apparatus as used in an in vitro *experiment. Shown is, from left to right: the water tank with aorta section and transducer, the apparatus, and the displayed cross-section on the oscilloscope.*

shown in Figure 4. The figure represents *in vitro* echograms of aorta slices, together with the corresponding "wet print" on the same scale. As an example, the dotted area indicates the echogram error due to pulse-length.

A further limitation is caused by specular reflection. This means that observed structures are largely those perpendicular to the sound beam. These combined effects allow the viewing of the gross movement of larger structures only.

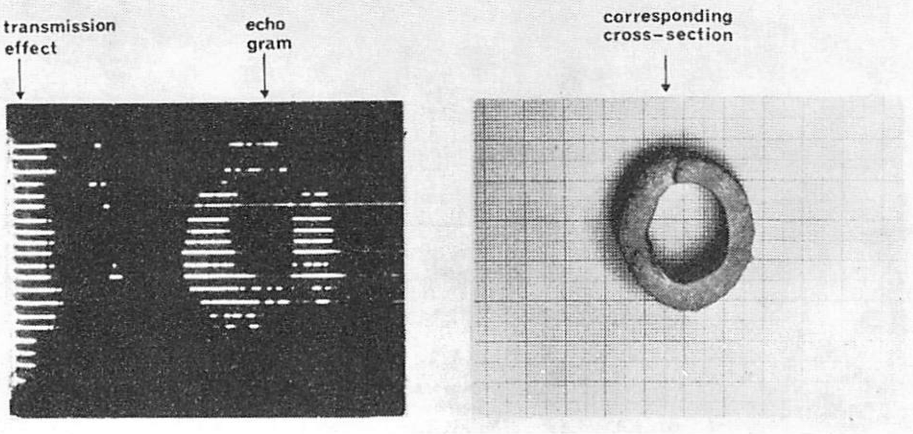

Fig. 8. Cross-sectional echogram of an aorta measured in vitro, *and the corresponding segment of the aorta (scale in cm).*

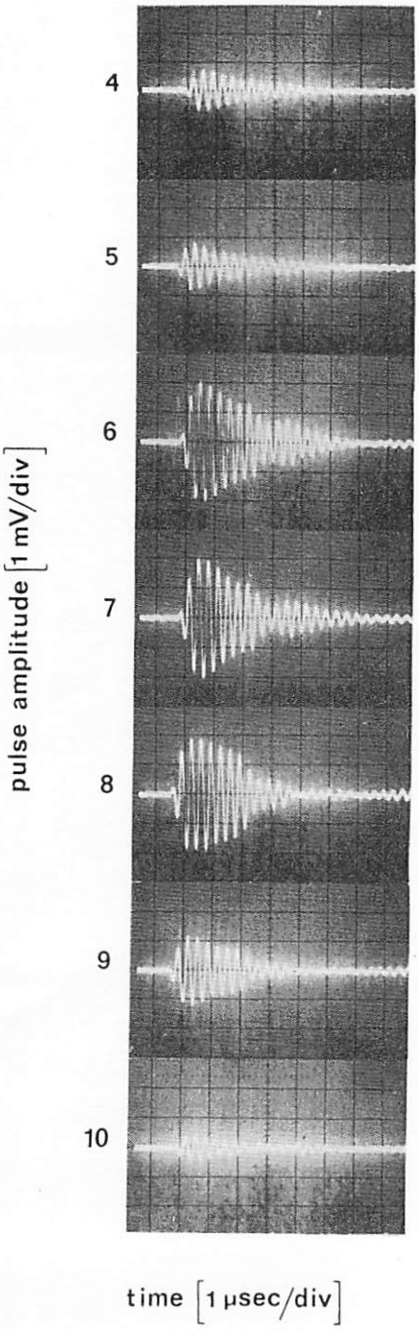

Fig. 7. Cluster of sound pulses, from a number of elements, as received by the calibration probe when it is positioned at a distance of 6 cm in front of element 7.

The apparatus

A block diagram of the principal components of the apparatus is given in Figure 5.

In transmission a tone burst (a sinusoidal current of short duration at the resonant frequency of the crystal) is fed through an electronic switch into a single crystal element. The element generates a short acoustic pulse. The echo signals arriving at this element when in the reception mode are amplified by a wideband preamplifier and fed through a switch into the processing part of the apparatus. This cycle is subsequently repeated for all elements.

The propagated sound is attenuated by spherical spreading and absorbtion in tissue, so the first stage of the processing part contains a time-sensitive gain amplifier to compensate for these effects.

The receiver gain is set as a function of the range, as described by Reid[5]. An envelope detector modifies the signal for the logarithmic intensity modulation circuit. This circuit displays the lowest and highest echo amplitudes as low and high intensity spots respectively, on the oscilloscope-screen.

The entire apparatus is tested under working conditions as shown in Figure 6.

Preliminary results

Since the apparatus has been developed for the display of moving structures, apparatus parameters, such as frequency and transducer size, have been chosen especially to suit applications in cardiology.

Low excitation voltage, required by the fast switching circuitry, has resulted in extremely low radiated intensities. These intensities were measured by means of a calibration probe[6]. The calibration graph of this sensor gives square root acoustic intensity as a function of sensor output at the relevant frequency.

The intensity of radiation produced by the apparatus was measured, using the calibration probe, at a distance of 6 cm from the multi-element transducer, in a water tank. This depth was chosen because it corresponds to approximately the centre of the left ventricle when the transducer is applied at the fourth left intercostal space.

In the case of a multi-element transducer as described, a position at 6 cm depth is insonified by the sound from not only one but a number of elements. This is mainly due to the single-element beam-width. Figure 7 shows the sound pulses that arrive at the calibration probe when it is positioned in front of element 7. For proper calculation of the average acoustic intensity it is necessary to consider the sound pulse cluster as shown in Figure 7, rather than the radiation from a single element alone.

Using the mentioned calibration curve, the average radiated intensity is measured to be as low as 0·004 mW/cm^2.

So far only a small number of patients has been studied. With the transducer attached to the left fourth intercostal area, moving left ventricular structures such as the posterior and anterior walls have been recognised and displayed instantaneously and continuously. The interpretation of these results has been rather difficult. The recordings were

(*Continued on page 508*)

apparatus. However, *in vivo* studies may prove to be possible after careful consideration of methods of incorporating the small coils into animals or other experimental vehicles.

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Intracranial Pressure Transducer

In the article "An Intracranial Pressure Transducer", by Dorsch *et al.* (BME October, p. 452), the thickness of the Latex membrane should have been given as 10 microns (not one micron).

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by N. Bom, C. T. Lancee, J. Honkoop and P. G. Hugenholtz

(*Continued from page 503*)

made on video tape. In general, the moving image is far more recognisable than a still photograph.

Extensive studies have been limited so far to *in vitro* applications. As it is obviously impossible to illustrate this study with a moving film, a rather artificial example is given of the *in vitro* cross-section echogram of the aorta of a calf in Figures 4, 6 (far right) and 8. It is evident that the approximate shape of the aorta is well recognisable. However, only part of the aorta section shows up in the echogram. This is due to the specular reflections. Poor axial resolution and image distortion was caused by long pulse response of the time-sensitive gain unit utilised in this study.

These preliminary trials served to indicate the apparatus' major fault areas. The apparatus is at present being redesigned. Changes will include a higher frequency, a shorter pulse length, a slightly elevated excitation voltage and a transducer modification.

An extensive series of clinical experiments is envisaged for the near future.

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