Two-dimensional echocardiography with a wide angle (60°) sector scanner¹

A. B. HOUSTON, N. L. GREGORY, A. SHAW, D. J. WHEATLEY², AND E. N. COLEMAN

From the Department of Cardiology and the University Department of Child Health, Royal Hospital for Sick Children, and the Department of Clinical Physics and Bio-Engineering, Glasgow

A wide angle (60°) sector scanner producing a real-time two-dimensional echocardiogram has been used to examine healthy infants, children, and adults. Its method of use is described and findings from longitudinal and transverse scans are presented.

The points of difference between the various types of electronic and mechanical two-dimensional scanning systems are discussed. This equipment minimises problems of chest contact and rib and lung interference and, by providing echocardiograms of high line density from a wide angle, is a suitable real-time two-dimensional scanning system for examining patients of all ages.

Echocardiography is an established technique in the assessment of congenital and acquired heart disease (Feigenbaum, 1972). Since Edler and Hertz (1954) first recorded the movements of the heart walls it has been found that it is possible using time-position echocardiography to recognise the walls of both ventricles, the left atrium, and the cusps of the atrioventricular and semilunar valves. In recent years real-time two-dimensional systems have been introduced for echocardiography. Multiple element systems have been developed (Bom *et al.*, 1973) using electronic switching between transducers in a linear array and (von Ramm and Thurstone, 1976) an electronic steered beam; versions of these and other multiple element systems are commercially available. Mechanical two-dimensional scanning systems in which a single transducer is rapidly oscillated through an arc of a circle have also been produced (Griffith and Henry, 1974; Nishimura *et al.*, 1976; Shaw *et al.*, 1976). The structures previously visualised by time-position echocardiography have been identified by two-dimensional systems and confirmed by contrast studies (Sahn *et al.*, 1974b). In addition these systems have allowed identification of the main pulmonary artery, but reports have differed on the

appearance of the great arteries when seen in transverse section at their origins (Sahn *et al.*, 1974b; Henry *et al.*, 1975).

This report summarises our technique and experience in examining the normal heart using a mechanical real time wide-angle (60°) sector scanner.

Equipment

The ultrasonic equipment used is a hand-held mechanical 60° sector scanner in which an oscillating transducer is ultrasonically coupled to the patient through an oil-filled cell which also separates the patient from the movement of the transducer (Shaw *et al.*, 1976). Developments since the original description of this equipment permit the use of interchangeable transducers for work with adults, children, and neonates. The specifications of these transducers are 2.5 MHz 15 mm diameter, 2.5 MHz 12.5 mm diameter, and 5 MHz 6 mm diameter and they are focused for optimum performance in the ranges 8 to 12 cm, 5 to 10 cm and 2 to 4 cm, respectively. The scanner is used in conjunction with a Nuclear Enterprises Diasonograph (NE 4200) which has minor modifications to permit control of the transmitter pulse generator from the scanner interface unit and to allow the interface unit to gate the storage display under electrocardiographic control from the Diasonograph Cardiac Module. The display now consists of 128 equally spaced lines of information in each complete oscillation of the transducer; at maximum

¹ Supported in part by a research grant from the Equipment Research Committee of the Chief Scientist's Organisation of the Scottish Home and Health Department.

² Present address: Department of Clinical Surgery, University of Edinburgh, Edinburgh.

Received for publication 18 February 1977

speed 25 frames of 64 lines are generated per second. The echocardiogram is normally viewed from the variable persistence monitor in its 'conventional' mode, through a television camera and monitor system, and recorded on a video recorder controlled with a foot-operated switch. Electrocardiographic information is included in the telerecording by means of a light which flashes in time with pulses from the electrocardiographic unit and by a digital indication of elapsed time after the electrocardiographic pulse. An alternative viewing system, which provides a static view of the heart and permits immediate photography, is provided by electrocardiographic controlled gating of the storage monitor. The display may be rewritten once in each heart cycle, at any point in the cycle, and when an appropriate view has been selected it can be stored for inspection or photography. All the illustrations in this report were obtained by this technique, but it is also possible to photograph still frame pictures from the television system. In normal use, with the patient supine, the weight of the scanner is supported by a spring tension cord device which hangs from a single track above him. This system permits free tilting and rotation of the scanner to any normally required position. This and the use of a foot-operated switch on the tape recorder allows the examination to be carried out by a single operator.

Method

The scanning planes employed are longitudinal and transverse. Because of the variability of the axis and position of the heart these planes cannot be based on standard thoracic cage sites, but rather on approximately standard views of the heart which the operator obtains by altering the position and angulation of the scanner in such a way as to make allowances for differences in cardiac position and chest configuration.

Longitudinal scans from normal subjects are illustrated in Fig. 1. The anterior mitral valve leaflet is used as a landmark to obtain this scan which corresponds to the standard time-position sweep from the mitral valve leaflets to the aorta. Such a section is most frequently obtained with the scanning head in the 4th left interspace at the left sternal edge, the scanning plane being perpendicular to the chest wall and directed towards the right shoulder. If satisfactory views are not obtained in this position the scanning head is moved to the 5th or 3rd interspace and, if necessary, further lateral from the left sternal edge. In each position the scanner is rotated and tilted to obtain an optimal view. The mitral valve cusps, and aorta and aortic valve cusps cannot always be seen in a single

plane and minor alterations in transducer angulation may be required to display these structures individually. In adults the apical region of the left ventricle is visualised by tilting the scanner inferiorly or positioning it in a lower interspace. After a satisfactory longitudinal scan has been obtained, the scanner is held on the same site and rotated through approximately 90° to obtain a low transverse scan through the body of the left ventricle. In this position a sweep performed from the apex towards the base of the heart as with conventional single crystal echocardiography allows visualisation of the entire length of the posterior wall of the left ventricle. This position is the best for obtaining a section through the mitral valve orifice, the anterior and posterior cusps being readily visualised (Fig. 2). Tilting the plane of scan to the right brings the right ventricle and tricuspid valve into view anterior to the ventricular septum. The origins of the great arteries are most clearly identified in a high transverse scan, obtained with the transducer moved one interspace higher to position the aorta at the level of the valve, as identified by its cusps, in the centre of the scanning arc. The aorta cut in transverse section (Fig. 3) is seen as an approximately circular echo free space with the valve cusps as a central linear echo in diastole which disappears in systole. In the normal heart the right ventricular outflow crosses the aortic root obliquely before passing posteriorly and to the left as the main pulmonary artery. For assessment of the relations and sizes of the great arteries the plane of scan in the high transverse view is altered to lie along the right ventricular outflow and through the main pulmonary artery, by angling the scanner towards the lateral third of the left clavicle and tilting it superiorly. The high transverse scan thus obtained (Fig. 3) shows the right ventricular outflow as an echo free space passing anterior to and then to the left of the aorta as the main pulmonary artery with the echoes from the cusps of the pulmonary valve indicating the transition between them. The pulmonary valve as a rule lies anterior and to the left of the aorta though in infants it may lie directly anterior to the aortic valve. A scan through the right ventricular outflow and main pulmonary artery may section the aorta somewhat obliquely rather than transversely and minor alterations in the plane of scan are then required to show the aorta in direct transverse section. Since it is not always possible to obtain optimal views of both great arteries and semilunar valves in a single plane, the operator's impression of their relations as the scanning plane is altered may be necessary for correct interpretation of the examination. In our experience with normal subjects a high transverse

Fig. 1 Longitudinal scans from normal subjects. (a) Adult in early diastole showing aortic valve closed and mitral valve about to open. (b) Infant weighing 2.9 kg, heart rate 150 per minute, in mid-diastole with mitral valve open. Ao, aortic root; AoV, aortic valve cusps; VS, ventricular septum; LA, left atrium; aML, anterior mitral leaflet; LV, left ventricle; CT, chordae tendineae; aRV, anterior right ventricular wall; PM, papillary muscle.

scan does not show the two great arteries simultaneously as circular spaces with central cusp echoes.

Discussion

The recent introduction of two-dimensional scanning systems as an adjunct to conventional single crystal echocardiography has widened the scope, and thus the usefulness, of echocardiographic examination. Two basic systems were initially devised, the multiple element array (Bom *et al.*, 1973) and the mechanical sector scanner (Griffith and Henry, 1974; Nishimura *et al.*, 1976; Shaw *et al.*, 1976). Recently, an electronic steered beam system scanning a 60° sector has been developed (von Ramm and Thurstone, 1976). Sector scanners, because of their relatively small area of skin contact, minimise the interference presented by ribs and lungs. Problems of poor contact and patient discomfort caused by transducer movement, reported with some mechanical scanners (Griffith and Henry, 1974; Nishimura *et al.*, 1976), have been largely overcome by the oil-filled cell incorporated within our scanner (Shaw *et al.*, 1976), and in the electronically steered beam system. Mechanical sector

Fig. 2 Transverse scan from normal adult subject at the level of the tips of the mitral valve. This view in early diastole shows the orifice of the partially open mitral valve. L and R: subject's left and right sides; RV, right ventricle; MVO, mitral valve orifice; aML, anterior mitral valve leaflet; pML, posterior mitral valve leaflet; VS, ventricular septum.

Fig. 3 High transverse view through the right ventricular outflow and main pulmonary artery.

scanners also have the advantage of using conventional circular transducers which, unlike the multiple element systems and the rectangular arrays of steered beam systems, give optimum resolution both within the plane of scan and at right angles to this plane. The high line density (128/60° with this system) in the near field of the mechanical scanner produces particularly clear pictures in infants, whereas the phased array system described by von Ramm and Thurstone (1976) is unable to record the proximal 30 to 40 mm of the scan. The clinical importance of these points is illustrated in Fig. 1b, which shows the aorta with a diameter of about 8 mm to be clearly resolved and not overlaid by echoes from adjacent structures; the right ventricular wall is clearly visualised only 14 mm from the scanner and all the structures of interest are within 40 mm. This capacity to produce well-resolved images of small objects close to the transducer is of particular importance in studying infants with congenital heart disease. The main disadvantage of sector scanners, a rather narrow near field of view, is partly balanced by the increased line density in the near field. There is also wider coverage of deeper structures; with the 60° scanning angle a posterior heart wall lying 80 mm deep in the chest is imaged over a length of 100 mm. Structures lying behind the sternum can be seen from a parasternal position. We have found that our system gives a satisfactory view of the posterior wall of the left ventricle in longitudinal and transverse sections, but the scanner may have to be tilted headwards if the aorta and the whole posterior wall of the left ventricle are to be seen in one plane. For a longitudinal view of the entire length of the ventricular

septum the scanner may have to be moved between two sites. The aorta, right ventricular outflow, and main pulmonary artery are adequately shown in a single transverse scan within the 60° scanning angle.

The use of a multiple element system and of a 30° sector scanner in normal and abnormal hearts has been extensively reported (Sahn *et al.*, 1974a, b; Henry *et al.*, 1975). To a certain extent the findings appear to have been influenced by the technique used. Sahn *et al.* (1974a) with a multiple element system use standard positions on the chest to obtain their scans, but the present findings are more in accord with those of Henry *et al.* (1975) who adjust the plane of scan to obtain optimal views, and use different interspaces and scanning angles as required. The longitudinal scan, in accordance with previous reports, provides an image of all the structures shown in the conventional sweep of time-position echocardiography, but with the advantage that anatomical relations are more clearly defined. The low transverse sweep displays the posterior wall of the left ventricle and much of the anterior wall but distinct views of the lateral walls may not always be obtained; the mid-position of this sweep shows the entire mitral valve orifice. In the high transverse scan, adjusted to lie along the right ventricular outflow, the aorta is recorded in transverse section with the right ventricular outflow crossing anterior to it before turning posteriorly to its left as the main pulmonary artery. This appearance is similar to that reported by Henry *et al.* (1975). Our transverse scans do not show the great arteries simultaneously as circular spaces with central cusp echoes as implied by Sahn *et al.* (1974b); this difference could be ex-

plained by the better lateral resolution of single element scanners.

We conclude that sector scanners provide views of all the major structures of the heart and that our 60° mechanical system with its coupling cell and interchangeable transducers yields satisfactory two-dimensional displays of the heart at all ages and without discomfort to the patient.

References

- Bom, N., Lancée, C. T., van Zwieten, G., Kloster, F. E., and Roelandt, J. (1973). Multiscan echocardiography. 1. Technical description. *Circulation*, **48**, 1066-1074.
- Edler, I., and Hertz, C. H. (1954). The use of ultrasonic reflectoscope for the continuous recording of movements of heart walls. *Kungliga Fysiografiska Sällskapet i Lund Forhandlingar*, **5**, 24-27.
- Feigenbaum, H. (1972). *Echocardiography*. Lea and Febiger, Philadelphia.
- Griffith, J. M., and Henry, W. L. (1974). A sector scanner for real time two-dimensional echocardiography. *Circulation*, **49**, 1147-1152.
- Henry, W. L., Maron, B. J., Griffith, J. M., Redwood, D. R., and Epstein, S. E. (1975). Differential diagnosis of anomalies of the great arteries by real-time two-dimensional echocardiography. *Circulation*, **51**, 283-291.
- Nishimura, K., Hibi, N., Kato, T., Fukui, Y., Arakawa, T., Tatematsu, H., Miwa, A., Tada, H., Kambe, T., Nakagawa, K., and Takemura, Y. (1976). Real-time observation of cardiac movement and structures in congenital and acquired heart diseases employing high-speed ultrasonocardiography. *American Heart Journal*, **92**, 340-350.
- Sahn, D. J., Terry, R., O'Rourke, R., Leopold, G., and Friedman, W. F. (1974a). Multiple crystal cross-sectional echocardiography in the diagnosis of cyanotic congenital heart disease. *Circulation*, **50**, 230-238.
- Sahn, D. J., Williams, D. E., Shackelton, S., and Friedman, W. F. (1974b). The validity of structure identification for cross-sectional echocardiography. *Journal of Clinical Ultrasound*, **2**, 201-216.
- Shaw, A., Paton, J. S., Gregory, N. L., and Wheatley, D. J. (1976). A real time 2-dimensional ultrasonic scanner for clinical use. *Ultrasonics*, **14**, 35-40.
- Von Ramm, O. T., and Thurstone, F. L. (1976). Cardiac imaging using a phased array ultrasound system. 1. System design. *Circulation*, **53**, 258-267.

Requests for reprints to Dr. A. B. Houston, Royal Hospital for Sick Children, Yorkhill, Glasgow G3 8SJ.