The use of cross-sectional echocardiography in a general hospital

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Summary

Three hundred and five patients routinely referred to a general hospital were surveyed to assess the advantages of cross-sectional echocardiography (CSE) over the conventional M mode method. CSE provided a dynamic display of the movement of the heart, particularly left ventricular function, and facilitated the location of cardiac structures. It was valuable in assessing the degree of mitral stenosis and the type of left ventricular outflow obstruction. Mitral valve prolapse, pericardial effusion, intracardiac tumours and congenital heart disease were more easily diagnosed than by M mode techniques, but the origin of the basal systolic murmur still remained a problem.

It was concluded that the 2 systems were complementary, and that CSE provided important additional information which improved the diagnostic capability of echocardiography.

Introduction

Cross-sectional echocardiography (CSE) is reported to have advantages over conventional M mode echocardiography in the diagnosis and assessment of a variety of congenital and acquired cardiac disorders (Roelandt, 1975; Feigenbaum, 1976). Most reports of CSE come from major cardiac centres with many cases undergoing specialized investigation before surgery. The spectrum of disease which presents to general medical units includes a high proportion of patients referred for primary diagnosis of cardiac disease, many with minor lesions. The purpose of this study is to assess the value and limitations of CSE in the management of patients from the medical wards and out-patient clinics of a general hospital.

Materials and methods

The instrument used in this study was a commercially available 30° sector scanner (Smith Kline Instruments Eko-Sector I). Images were viewed in real time during the examination or later from videotape recordings, and still photographs were obtained from single frames using a Polaroid camera.

Patients were referred from the general medical and paediatric departments of the Royal Lancaster

Infirmary and the Westmorland County Hospital. A total of 305 subjects (152 male, 153 female) were investigated in the first year. Patients investigated in the Coronary Care Unit were excluded from this review.

Cross-sectional studies were performed in either the supine or left lateral position. Long axis parasternal views were used to assess the thickness and movement of the mitral valve in mitral stenosis, and the area of the mitral valve orifice was measured using short axis views. The position of the probe was altered until the smallest orifice was seen. Using a stop frame from the video-tape recording, the internal location cursor was adjusted so that there was exactly one cm between the markers. The valve orifice was then traced on a transparent plastic sheet and measured with graph paper. Alternatively, it was measured directly on the screen using a graticule.

Images of the aortic root and valve, inter-ventricular septum, left ventricle, left atrium, tricuspid valve, pulmonary valve and right ventricular outflow tract were assessed from long and short axis parasternal views.

The cardiac apex was located by palpation and, using the short axis position and directing the probe towards the base of the heart, a four chamber view of both atria and ventricles and the interatrial and interventricular septa was obtained. The transducer was then angled in a lateral direction to obtain short and long axis views of the apex of the left ventricle. The body of the left ventricle was subsequently viewed by moving the transducer medial to the apex beat.

Additional views from the suprasternal notch and subxiphoid region were used when indicated.

Results

Mitral valve disease

Sixty-five patients (19 male, 46 female) were investigated (Table 1). Forty-three patients, including 11 post-valvotomy subjects, were examined to assess the severity of mitral stenosis using short axis views (Fig. 1), the mitral valve orifice area could be measured in 51% of subjects (range 0.6 cm² to 2.8 cm²).

TABLE 1. Summary of the findings in a group of 305 patients referred to the Medical Unit of a general hospital. The figures in parenthesis refer to the total in the group. The figures on the right refer to numbers of patients

Mitral valve disease (65)	Mitral stenosis	32
	Post-valvotomy	11
	Systolic click and murmur	11
	Atrial fibrillation	11
Left ventricular outflow tract obstruction (64)	Acquired valvar aortic stenosis	51
	Congenital domed valve	6
	Hypertrophic obstructive cardiomyopathy	7
Possible left ventricular aneurysm (21) (inadequate recordings—2)	Persistent elevation of ST segment, post-infarction (aneurysm suggested in 5)	7
	Unstable angina or cardiac failure post-infarction (aneurysm suggested in 4)	12
Obscure heart disease (39)	See Table 2	
Congenital heart disease (21)	Atrial septal defect	6
	Ventricular septal defect	10
	Tetralogy of Fallot	2
	Hypoplastic left heart syndrome	1
	Transposition	1
	Severe valvar pulmonary stenosis	1
Mid-systolic murmur (62) (inadequate recordings—2)	No abnormality detected	49
	Acquired valvar aortic stenosis	4
	Congenita aortic stenosis	1
	Pulmonary stenosis	5
	Mitral valve prolapse	1
Miscellaneous (33)	See Table 3

FIG. 1. Short axis view of the mitral valve showing valve orifice in a patient with mitral stenosis. (IVS, interventricular septum; LV, left ventricle; PLVW, posterior left ventricular wall).

Difficulty in measuring the area in the other patients resulted from an inability to obtain an adequate record of both leaflets simultaneously. Long axis views showed restricted mobility and thickening of the mitral valve leaflets in these patients.

Of the remaining 22 patients, 11 were investigated because of a systolic click and murmur (9) or a systolic click alone (2). Mitral valve prolapse was demonstrated in 6 subjects, 3 with posterior leaflet prolapse and 3 with both anterior and posterior leaflet prolapse. Four subjects had normal echocardiograms and these included both patients with the systolic click. The recordings in the final patient in this group were inadequate for full analysis of leaflet movement. Mitral stenosis was found in 2 of the 11 patients with atrial fibrillation; one of these had clinical evidence of mitral stenosis (a short mid diastolic murmur and an opening snap were recorded on a phonocardiogram) but the other patient had no abnormal auscultatory signs.

Left ventricular outflow tract obstruction

Sixty-four patients (46 male, 18 female) were referred because of basal systolic murmurs and evidence of left ventricular hypertrophy (Table 1). Valvar obstruction was characterized by limited leaflet movement and a mass of echoes at valve level in the aortic root. These dense echoes tended to obscure leaflet movement but at least one leaflet was seen on long axis in 88% of cases and the leaflets remained within the lumen of the aortic root. In normal subjects the linear echoes lie parallel to the walls of the aorta in systole where they merge with the walls. Patients with a low cardiac output showed failure of the leaflets to appose to the aortic walls but were distinguished from patients with aortic stenosis by the normal appearance of the leaflets and the absence of dense echoes. The domed, thickened leaflets typical of congenital aortic stenosis were readily recognized on cross-sectional studies, but M mode echocardiograms were better than CSE for identifying hypertrophic obstructive cardiomyopathy.

Left ventricular aneurysms

A total of 21 patients (15 male, 6 female) were investigated because of possible left ventricular aneurysm (Table 1). Of the 9 subjects with aneurysms suggested by cross-sectional studies, discrete apical areas of abnormal wall motion were detected in 7, and the apex plus the anterior wall were involved in 2 patients (Fig. 2a, b). Confirmation of the site of the aneurysm by left ventricular angiography was obtained in 4 cases.

The remaining 10 patients showed generalized poor left ventricular wall motion and these abnormal

features persisted in 3 of those who were reinvestigated after a period of intensive medical therapy. Invasive cardiac investigations were avoided in these patients.

Obscure heart disease

The 39 patients (23 male, 16 female) who were referred with clinical evidence of heart disease but no obvious cause were sub-divided into 2 groups (Table 2). Cross-sectional studies were largely

TABLE 2. Eventual diagnosis in patients presenting with obscure heart disease

Group I. Large heart with or without failure:	
Intracardiac tumour	2
Congestive cardiomyopathy	7
Presumed ischaemic/hypertensive heart disease	7
Pulmonary heart disease	1
No abnormality shown	1
Group II. Abnormal chest X-ray/ECG or dyspnoea and chest pain:	
Ischaemic heart disease	3
Pulmonary thromboembolic disease	2
Pericardial cyst	1
Asymmetric septal hypertrophy	1
No definite heart disease	14

unhelpful in these patients, apart from the 2 patients with left atrial tumours which were readily and quickly recognized (Fig. 3). In the patient with the provisional diagnosis of pericardial cyst, the boundaries and relationships of a large echo-free space lateral to the right ventricle was clearly demonstrated, but confirmation was not obtained because the patient refused further investigation.

Congenital heart disease

Twenty-one patients (9 male, 12 female) were investigated (Table 1). These patients were referred to broaden the experience of the echocardiographers rather than for primary cardiac diagnosis, hence 13 patients were studied after diagnosis had been made by cardiac catheterization, and 3 were referred following surgical correction of a defect. Of the 6 patients with atrial septal defects (ASDs), 3 had secundum defects with insignificant shunts on cardiac catheterization and the echocardiograms were normal. Two patients with Eisenmenger ASDs showed increased right ventricular dimensions, and one of these had bidirectional shunting on angiography which was confirmed by to and fro movement of 'microbubbles' across the defect on 4-chamber view cross-sectional contrast imaging. The final patient in this group was investigated after repair of a primum defect and mitral leaflet prolapse was shown on CSE. Poor recordings were obtained from

FIG. 2. Long axis view of the apex of the left ventricle in a patient with an apical aneurysm, (a) systole, (b) diastole (IVS, interventricular septum; LV, left ventricle; PLVW, posterior left ventricular wall).

one patient with an Eisenmenger ventricular septal defect (VSD), the site of the septal patch was visualized in one patient following repair of a VSD and the remaining patient showed the appearance of diastolic microbubbles in the left ventricle.

Of the 2 patients with Fallot's tetralogy, one was investigated after total correction and the cross-sectional studies showed an intact ventricular septum and a normal-looking right ventricular outflow tract and pulmonary valve; the other was a 9-month-old male with Down's syndrome and cyanotic heart disease. Echocardiography showed normal relations of the great vessels but the inter-ventricular septum and pulmonary valve were inadequately visualized. The patient with a D-transposition had atrial and ventricular septal defects, pulmonary atresia and patent ductus arteriosus on cardiac catheterization. The cross-sectional echocardiogram showed a single atrio-ventricular valve, and only one ventricular chamber and one great vessel were recorded. Cross-sectional studies demonstrated thickened pulmonary valve leaflets which remained fixed in the lumen during systole in the patient with severe valvar pulmonary stenosis. Although the left ventricle was not clearly seen in the patient with hypoplastic left heart syndrome, it

was uncertain whether this was due to technical difficulties, and the diagnosis was established at cardiac catheterization.

Before studying these patients, the authors experimented with different techniques to obtain contrast echocardiograms, and the most reliable method proved to be the fast injection of normal saline through a 19 gauge butterfly needle via the right antecubital fossa. Blood from the patient was almost as good as normal saline, and indocyanine green had no advantage and was expensive. Since using the standardized method there have been 3 failures in 16 consecutive contrast studies.

Mid-systolic murmurs

Sixty-two patients (20 male, 42 female) were referred with basal mid-systolic murmurs and were included in this group if chest X-ray and electrocardiograph were normal (Table 1). Thirteen of the female patients were investigated after a murmur had been noted during pregnancy. Adequate cross-sectional views of aortic and pulmonary valves were obtained in all but 2 patients.

Miscellaneous

Thirty-three patients (18 male, 15 female) were

FIG. 3. A long axis view showing the tumour in the left atrium. (AAO, anterior aortic root; PAO, posterior aortic root; AV, aortic valve leaflets).

included in this group (Table 3). The presence of pericardial effusion was rapidly and clearly demonstrated by cross-sectional echocardiography in all 10 patients, and serial studies showed the effect of treatment. One of these patients with a haemopericardium provided a dramatic image of the 'swinging heart' on CSE.

The cross-sectional long axis views of the aortic valve in the patients with aortic regurgitation showed a characteristic, rapid superior-inferior motion of the leaflets in diastole, and the hyperdynamic motion of the dilated left ventricle was appreciated.

TABLE 3. The reasons for echocardiography in a miscellaneous group of patients

Pericardial effusion	10
Aortic regurgitation	7
Tricuspid regurgitation	4
Systemic emboli	4
Vascular disease	2
Myocardial infarction	2
Angina after coronary artery bypass grafting	1
Prosthetic valves	3

Apical views of the right ventricle with peripheral intravenous injection of normal saline were used to obtain contrast echocardiograms in 2 of the 4 patients with tricuspid regurgitation and prolonged to and fro movement of contrast over the tricuspid valve was demonstrated. In one of these patients, it was not possible to get adequate images from the subxiphoid region.

The 2 patients referred with possible aortic dissection had normal cross-sectional images of the ascending and proximal descending aorta using suprasternal views and were subsequently proved to have no significant aortic disease. Cross-sectional studies were unhelpful in the remaining 10 patients.

Discussion

Conventional M mode echocardiography provides information on the motion of the heart and intracardiac structures and allows measurement of axial dimensions. Relative movement of different structures is difficult to judge when motion is at an

angle to the sound beam axis and the resultant images bear little resemblance to familiar cardiac anatomy. Real time cross-sectional imaging provides a recognizable display of cardiac structures, and lateral relationships are displayed so that the shape and size, as well as the relative motion, of structures can be appreciated. Details of a technique for complete ultrasonic examination of the heart using 2-dimensional real time echocardiography are provided in the report by Tajik *et al.* (1978).

The spatial orientation provided by cross-sectional echocardiography permits the localization of discrete areas of abnormal left ventricular function. The cross-sectional technique successfully identified the site of abnormal left ventricular motion in 100% of 31 cases of wall aneurysm compared with correct diagnosis in 48% using M mode echocardiography (Weyman *et al.*, 1976c), although a further study (Kisslo *et al.*, 1977) points out the difficulty of defining abnormal left ventricular motion without considerable experience with cross-sectional techniques, and discusses discrepancies between diagnoses made by CSE and bi-plane ciné-angiography. The results in the present subjects should be interpreted with caution in view of the small numbers involved but it is encouraging that in the patients who have progressed to ciné-angiography, the site of the left ventricular aneurysm has confirmed the echocardiographic prediction. Vigorous movement of the 'normal' myocardium contrasts with the poor movement of the aneurysm and may seem to 'point' to the abnormal area and should always lead to a careful search for an aneurysm. The authors avoid invasive investigation of subjects with poor generalized left ventricular wall motion but repeat cross-sectional recordings are reviewed after intensive medical treatment.

Cross-sectional echocardiography is superior to the M mode technique in localizing the site of obstruction in patients with left ventricular outflow tract disease (Weyman *et al.*, 1976a; Williams, Sahn and Friedman, 1976). Two varieties of valvar aortic stenosis are recognized. Calcific stenosis shows thickened aortic valve leaflets with limited mobility and a mass of echoes at valve level in the aortic lumen. The authors have not attempted to assess the severity of valve obstruction; although measurements of cusp separation in systole have given a good approximation of the degree of stenosis (Weyman *et al.*, 1975), doubt has been thrown on the validity of such measurements to assess the degree of obstruction (Chang, Clements and Chang, 1977). The congenital domed valve is easily recognized by cross-sectional studies, whereas M mode echocardiograms may show an apparently normal aortic valve if the echo beam passes through the apex of the dome.

Although others have demonstrated the value of

CSE in the diagnosis of supravulvar (Weyman *et al.*, 1978a) and fixed subvalvar aortic stenosis (Weyman *et al.*, 1976c; Ten Cate *et al.*, 1979), the present authors have no patients with either lesion in this series, and they have not found any disadvantage of cross-sectional imaging over M mode studies in the diagnosis of hypertrophic obstructive cardiomyopathy.

The diagnosis of mitral stenosis by M mode echocardiography depends on reduced amplitude of the anterior leaflet, thickened leaflets, anterior diastolic movement of the posterior leaflet and diminished anterior mitral leaflet closing rate (E-F slope). The amplitude of motion reduces deeper in the left ventricle, leaflet thickness may vary in different parts of the valve and the posterior leaflet may move in the normal direction in patients with proved mitral stenosis and hence all these features can be misleading. The E-F slope has been widely used to assess the severity of mitral valve obstruction but the method is insensitive and attempts have been made to improve sensitivity (Shiu, 1977). Furthermore, other conditions which can mimic mitral stenosis by producing a slow E-F slope include pulmonary arterial hypertension, left atrial myxoma, severe aortic stenosis and non-obstructive cardiomyopathy (McLaurin *et al.*, 1973). The long axis cross-sectional view of the mitral valve leaflets enables close inspection of pattern of leaflet motion and the typical 'bowing' of the anterior leaflet, and the extent of leaflet thickening is readily appreciated. The use of short axis views to measure the size of the mitral valve orifice correlates well with operative and catheter estimates (Henry *et al.*, 1975a; Nicol, Gilbert and Kisslo, 1977; Wann *et al.*, 1978a).

Although short axis cross-sectional studies have been used recently to detect significant rheumatic mitral regurgitation (Wann *et al.*, 1978b) echocardiography has been used mainly in the clarification of mitral regurgitation due to mitral valve prolapse (Leading Article, 1979). The present results suggest that CSE is valuable in the diagnosis of prolapse of both mitral leaflets, particularly the anterior.

The value of M mode echocardiography in the diagnosis of pericardial effusion and intracardiac tumours, in particular left atrial myxoma, is attested by reports from early days in the use of the technique (Feigenbaum, Waldhausen and Hyde, 1965; Effert and Domanig, 1959). Pericardial effusion is readily recognized with careful M mode recording but the authors have been impressed with the rapidity and ease of detection using CSE and the 'swinging heart' is dramatically visualized on real time cross-section imaging. Appreciation of the size, shape, movement and relations of intracardiac tumours is facilitated by cross-sectional echocardiography,

and CSE is more accurate than M mode echocardiography in differentiating a left atrial tumour from an extracardiac tumour compressing the left atrium (Yoshikawa *et al.*, 1978).

A common problem in general hospital practice is the patient who presents with a basal systolic murmur and no specific X-ray or ECG abnormalities. Invasive studies are only justifiable in a small proportion of these patients, and echocardiography is the non-invasive technique most likely to provide specific diagnostic information. Aortic valve disease is demonstrated on CSE in all the patients in this study with clear radiation of the bruit into the neck, but similar abnormalities are shown in other patients although the systolic murmur is confined to the praecordium. Also, it is suspected that the low incidence of pulmonary stenosis in the present series represents under-diagnosis. Stenosis of the pulmonary valve of moderate or severe degree is suggested by a presystolic 'a' wave depth of greater than 8 mm on the posterior pulmonary leaflet by M mode echocardiography (Weyman *et al.*, 1974). It is further suggested that CSE is more specific and sensitive, and subjects with minor gradients (<50 mmHg) show typical doming of the pulmonary cusps (Feigenbaum, Weyman and Dillon, 1977; Weyman, 1977). In the present patients with minor pulmonary stenosis suspected on clinical and phonocardiographic grounds, the M mode studies show 'a' waves of 6–10 mm but doming has not been demonstrated by cross-sectional imaging. In the single patient with severe valvar pulmonary stenosis, the pulmonary leaflets appear to 'stick' in the pulmonary artery but doming is not evident. An advantage of the cross-sectional technique is the ease with which the pulmonary valve is located, compared with the effort and time spent on trying to locate the valve with M mode echocardiography.

Cross-sectional echocardiography is particularly valuable in cyanotic congenital heart disease (Sahn *et al.*, 1974; Henry *et al.*, 1975b; Maron *et al.*, 1975; Houston, Gregory and Coleman, 1977; Hagler *et al.*, 1979) although the experience required in the diagnosis of complex defects limits the usefulness in general hospitals. Silverman and Schiller (1978) have used the 4-chamber view to detect septal defects and to define endocardial cushion defects, tricuspid atresia and Ebstein's anomaly, and the value of cross-sectional imaging has been demonstrated in supralvalvar aortic stenosis and aortic hypoplasia (Weyman *et al.*, 1978a), coarctation of the aorta (Weyman *et al.*, 1978b), patent ductus arteriosus in infants and children (Sahn and Allen, 1978) and atrial septal defects (Kronik, Slany and Moesslacher, 1979; Fraker *et al.*, 1979).

The authors conclude that real-time CSE has advantages over M mode techniques in the diagnosis

of the site of left ventricular outflow tract obstruction, left ventricular aneurysms, pericardial effusion, intracardiac tumours, congenital heart lesions and, in the assessment of mitral valve disease, particularly the severity of mitral stenosis. Pollick (1978) has shown the value of M mode echocardiography in a district general hospital, and the authors have demonstrated that cross-sectional imaging increases the usefulness of echocardiography. The main limitation is the extra cost. This should be weighed against the enhanced diagnostic capability in patients who do not warrant invasive procedures, the avoidance of cardiac catheterization in some patients, the reduction in time taken to perform catheterization when echocardiograms have pinpointed specific problems which require further study, and the ability to observe the progress of cardiac disease or the results of surgery by repeated ultrasound studies.

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