Clinical Applications of Echocardiography

P. G. MILLS, BM, MRCP(UK)

Visiting Assistant Professor, Department of Medicine, University of North Carolina, Chapel Hill, North Carolina

Following a decade of haemodynamic, surgical, and pathological correlations, echocardiography has proved to be a useful technique for the non-invasive diagnosis of certain cardiac abnormalities. To some extent the clinical value of echocardiography depends upon the referral of appropriate patients; it is therefore important for general physicians as well as cardiologists to be aware of the advances in this changing and progressing field. With most new investigations, there is a period during which the capabilities and the limitations of the new method need to be assessed in clinical practice. Therefore, the purpose of this review is to illustrate both the useful applications of echocardiography, and the conditions in which it adds little or nothing to a careful history, examination, chest X-ray and electrocardiogram. The more common clinical applications of echocardiography in adults will be discussed, without considering its many uses in paediatric cardiology (Goldberg et al., 1975), or the technical details that are well summarised elsewhere (Feigenbaum, 1976).

The technique of echocardiography requires skill and experience, the scope and quality of the study often depending on the echocardiographer. It is important that, before starting the study, the echocardiographer should be aware of the clinical problem and the diagnostic possibilities being entertained, so that the particular cardiac structures in which the clinician is interested can be studied as fully as possible. The value of the echocardiographic study is invariably enhanced by further consultation between clinician and echocardiographer after the latter has completed his or her assessment.

Before considering specific diagnoses, it is worth while outlining the basic observations that can be made by echocardiography. The pattern of motion of all four cardiac valves may be recorded. In general, more complete records of aortic and mitral valves (Fig. 1) are obtained than of pulmonary and tricuspid. However, when the right ventricle and pulmonary artery are dilated, the pulmonary and tricuspid valves are more clearly seen.

A number of quantitative measurements may be made, the accuracy of these depending upon the quality of the record—
1. Anteroposterior dimension of the left atrium.
2. Diameter of the aortic root (Fig. 2).
3. Thickness of the interventricular septum (Fig. 1).
4. Thickness of free left ventricular wall (Fig. 1).
5. Dimension of the right ventricular cavity.
6. End systolic (ESD) and end diastolic dimensions (EDD) of the left ventricle (Fig. 1).

The end systolic and end diastolic dimensions provide an accurate (Gibson and Brown, 1975) non-invasive means of assessing left ventricular cavity size, thus reflecting left ventricular disease (Gibson and Brown, 1973). A variety of methods has been used to attempt to measure left ventricular function more directly by using echocardiography (Gibson and Brown, 1975; Rosenblatt et al., 1976). The two most commonly used indices are percentage shortening of end diastolic dimension

\[
\frac{EDD - ESD}{EDD}
\]

and mean circumferential fibre shortening (VCF)

\[
\frac{EDD - ESD}{EDD} \times \text{left ventricular ejection time.}
\]

The precise role of these measurements in routine clinical practice remains to be determined.

Echocardiography is a sensitive technique for detecting calcification of the mitral and aortic valve cusps and, also, in the aortic root and mitral annulus. In marked contrast to its ability to establish the presence of intracardiac tumours, echocardiography cannot reliably detect thrombus in either the left atrium or the left ventricle. With the rare exceptions of pseudo-aneurysms (Roelandt et al., 1975), left ventricular aneurysms cannot be defined sufficiently accurately for left ventricular angiography to be unnecessary. At present, the resolution of echocardiography does not allow direct study of the anatomy of the coronary arteries.

PERICARDIAL EFFUSION

One of the earliest successful applications of echocardiography was the detection of fluid within the pericardial space (Feigenbaum, 1970), and subsequent experience has confirmed that pericardial effusions may be reliably diagnosed by this method. Fluid is recognised ultrasonically by a reduced intensity of echo signals and therefore a pericardial effusion is seen as a relatively echo-free space between the epicardial and pericardial layers of the heart. Pericarditis without an associated effusion cannot be diagnosed by echocardiography, and the presence of
Fig. 1. The normal left ventricle and mitral valve motion are illustrated.

In this echocardiogram and that shown in Fig. 2 the direction of the ultrasound beam has been changed during the recording so that different cardiac structures can be recorded. In this figure, normal diastolic mitral valve motion with rapid opening during early diastolic filling and reopening during atrial systole are seen. Thickening of the left ventricular wall and septum, with reduction in left ventricular cavity size, may be seen during systole. The thickness of the posterior ventricular wall is measured from the endocardium to the pericardium.

Fig. 2. Echocardiographic scan of the heart from the mitral valve to the aortic valve in a patient with Marfan's syndrome.

The aortic root is very dilated with a diameter of 9 cm, the upper limit of normal being 3.5 cm. This patient required aortic valve replacement and an ascending aortic dacron graft.
pericardial thickening cannot be detected with certainty. The echocardiographic examination is carried out with the patient in the supine or semi-left lateral position, when fluid in the pericardial space will accumulate posteriorly. As the size of the effusion increases and the elastic limits of the pericardium are reached, fluid will accumulate in the anterior pericardial space. This allows echocardiography to estimate roughly the amount of pericardial fluid present. Small effusions are often seen in association with rheumatic valvular heart disease or right ventricular failure, when they probably have no significant clinical implication. When an anterior as well as a posterior echo-free space is noted echocardiographically, this generally signifies the presence of a large effusion (Fig. 3). Important differential diagnoses of an anterior pericardial effusion are a mediastinal cyst or pericardial fat. In such cases no echo-free space posterior to the heart is found, and it is wise, therefore, to require that both anterior and posterior echo-free spaces be detected before making a diagnosis of a large pericardial effusion.

Fig. 3. Echocardiogram showing a posterior pericardial effusion between epicardium and pericardium, with some anterior fluid also present between the right ventricle and the chest wall.
Although there are interesting alterations of valve motion seen in patients with tamponade, this remains a clinical diagnosis, and the need for, and timing of, pericardiocentesis to relieve tamponade are not determined by echocardiographic findings. It is, however, reassuring for the clinician to know before starting the potentially dangerous procedure of pericardiocentesis that echocardiography has shown the presence of a pericardial effusion.

**MITRAL STENOSIS**

Echocardiography has proved to be a reliable non-invasive means of diagnosing mitral stenosis (Fig. 4). It is of particular value in severe pulmonary hypertension or severe aortic stenosis when the clinical diagnosis of mitral stenosis is both difficult and important. Unfortunately, early hopes that the rate of closing of the valve cusps during diastole (E-F slope) could predict the severity of the mitral stenosis in individual patients have not been fulfilled (Cope *et al.*, 1975). Other aspects of the echocardiographic examination may provide useful information: the excursion (mobility) of the leaflets and the degree of calcification assist in

![Echocardiogram of mitral stenosis](image-url)

*Fig. 4. Echocardiogram of mitral stenosis illustrating the very slow rate of closure during diastole.*

There are multiple parallel echoes from the leaflets indicating thickening or calcification.
assessing the suitability of the valve for valvotomy rather than replacement (Nanda et al., 1975). The left atrial size reflects the severity of the mitral valve disease, and the size of the right ventricle and motion of the pulmonary valve give some indication of the degree of pulmonary hypertension present (Nanda et al., 1974a). Thus, the role of echocardiography lies in establishing the presence of mitral stenosis, the severity being determined by combined clinical and echocardiographic features.

**LEFT ATRIAL MYXOMA**

The differentiation of mitral valve disease from a left atrial myxoma is one of the most important clinical applications of echocardiography. The technique is also useful for excluding a myxoma as the cause of unexplained systemic emboli. The characteristic echocardiographic features are of a homogeneous mass of echoes appearing between the two mitral leaflets during ventricular diastole (Fig. 5) and appearing in the left atrium during ventricular systole. Myxomas of the right heart have also been detected (Farooki et al., 1976). It cannot be over-emphasised that myxomas are rare but eminently treatable lesions which, because of embolic phenomena, may present to the neurologist and the vascular or general surgeon as

![Echocardiogram of a left atrial myxoma, in this view lying between the leaflets of the mitral valve during diastole. During systole the tumour was seen echocardiographically in the left atrium.](image-url)
well as to general physicians and cardiologists. With the proviso that the myxoma is large enough to be detected echocardiographically, a size that probably coincides with clinical significance, echocardiography seems to be both accurate and sensitive in establishing the diagnosis. Indeed, when the echo features are typical of a myxoma, it has become acceptable clinical practice to proceed directly to surgery without prior cardiac catheterisation.

MITRAL REGURGITATION
There are no specific echocardiographic features of mitral regurgitation, the diagnosis being made clinically from the characteristics of the murmur. Depending upon the severity of the lesion, a hyperdynamic motion of the left ventricular wall may be seen, and the cavity size will reflect an increase in the stroke volume. These changes are due to left ventricular volume overload and do not differentiate mitral from aortic regurgitation. Furthermore, it should be noted that in patients with (a) acute mitral regurgitation or (b) mitral regurgitation as the cause of left ventricular failure, hyperdynamic ventricular wall motion may not be found (McDonald, 1976). Echocardiography is useful in differentiating between rheumatic mitral valve disease, mitral valve prolapse, or left ventricular dysfunction as the cause of the mitral regurgitation.

MITRAL VALVE PROLAPSE (FLOPPY MITRAL VALVE)
The development of echocardiographic criteria for the detection of mitral valve prolapse has led to widespread recognition of this condition (Popp, 1974a; DeMaria, 1974). The chief value of establishing the diagnosis is to account for troublesome, but vague symptoms, such as atypical chest pain or palpitation. Prophylaxis against bacterial endocarditis is advisable, and the possible late development of increasing mitral regurgitation or ruptured chordae tendinae should be borne in mind (Allen et al., 1974). The diagnosis may, of course, be made from the typical auscultatory features of a mid-systolic click and/or late systolic murmur. Echocardiography is valuable in confirming the mitral valve as the origin of the auscultatory signs (Fig. 6), and may detect mitral valve prolapse when there are no associated auscultatory features.

In practice it may be difficult or impossible to decide whether or not a particular echocardiographic record shows evidence of mitral valve prolapse. A clear-cut example presents no difficulty, but the echocardiogram may be equivocal, and 'compatible with' or 'unable to exclude' mitral valve prolapse may be the only conclusion that can be reached. In such cases the clinician should use this information cautiously, avoiding the creation of 'echocardiographic disease'.

AORTIC STENOSIS
As in mitral stenosis, the plane of the ultrasound beam crosses the plane of the stenosed aortic valve at 90 degrees and, therefore, the orifice area cannot be
directly assessed. In adults, aortic stenosis is generally associated with calcification of the valve, and echocardiography is usually more sensitive than plain chest X-rays in detecting the presence of this calcification. Some indication of the severity of the stenosis may be gained by assessing the degree of left ventricular hypertrophy, and, being independent of the thickness of the chest wall, echocardiography may be more accurate for this purpose than electrocardiography.

The echocardiographic pattern of aortic valve motion is often helpful in patients who have other causes of left ventricular outflow tract obstruction. Characteristic patterns of motion are seen in fibrous subaortic stenosis (Popp et al., 1974a,b; Davis et al., 1974) (Fig. 7) and in obstructing hypertrophic cardiomyopathy, allowing these diagnoses to be made non-invasively. This has the advantage of allowing appropriate planning of subsequent cardiac catheterisation, if this procedure is indicated. The presence of a bicuspid aortic valve, which may or may not be stenotic, is indicated by an aortic ejection sound (Leech et al., 1975), and the finding of a clearly eccentrically located aortic cusp closure line in diastole confirms this diagnosis (Nanda et al., 1974b). Unfortunately, the degree of associated stenosis cannot be assessed from the aortic valve echocardiogram.

Fig. 6. Echocardiogram from a patient with mitral valve prolapse showing posterior motion of the mitral valve starting in midsystole — indicated by the arrow — coinciding with the late systolic murmur at the mitral area.
AORTIC REGURGITATION

In patients with aortic incompetence the diastolic jet of blood from the aorta to the left ventricle may strike the anterior leaflet of the mitral valve. This phenomenon is reflected echocardiographically by a ‘fluttering’ movement of the anterior mitral cusp and is a useful indicator of the presence of aortic regurgitation (Fig. 8). Mitral valve flutter depends on the direction of the regurgitant jet, and therefore its absence does not exclude aortic regurgitation. In rheumatic valvular disease the mitral valve leaflets may be thickened because of the additional presence of mitral stenosis; consequently, fluttering of the anterior leaflet may not be observed even though aortic regurgitation is present. In chronic

Fig. 7. Echo and phonocardiogram in a patient with fibrous subaortic stenosis. An ejection systolic murmur, unaccompanied by an ejection sound, is recorded. At the start of the murmur it can be seen that the upper (‘anterior’) aortic cusp abruptly returns to the position of the cusps in diastole. Both cusps flutter during systole, presumably reflecting the turbulent flow that has been generated by the subvalvular obstruction.
aortic regurgitation, the increase in left ventricular cavity size is a useful indicator of the severity of the lesion.

In acute aortic regurgitation the timing of mitral valve closure is an important indicator of left ventricular end diastolic pressure. When mitral valve closure occurs prior to the QRS complex in the presence of a normal PR interval, the left ventricular ejection diastolic pressure is usually greater than 40 mm Hg (Mann et al., 1975). Despite appropriate antibiotics, patients with endocarditis of the aortic valve may decompensate haemodynamically. This can happen in the absence of symptoms and without the radiographic signs of an enlarging heart size or pulmonary venous hypertension. Premature mitral valve closure is therefore a useful means of selecting those patients with aortic valve endocarditis who require cardiac catheterisation to assess the possible need for early valve replacement.

Fig. 8. Showing fluttering of the anterior mitral valve leaflet often seen in patients with aortic regurgitation.
A similar phenomenon on the left ventricular aspect of the septum is also seen in this patient.
INFECTIVE ENDOCARDITIS
Although echocardiographic abnormalities of the mitral, aortic (Roy et al., 1976), and tricuspid valves (Kisslo et al., 1976) have been reported in infective endocarditis, it should be emphasised that echocardiography can neither establish nor exclude the diagnosis of endocarditis. The echocardiographic abnormality consists of echoes reflected from vegetations (Fig. 9), and this finding suggests that the vegetations are large (Wann et al., 1976).

CONGESTIVE CARDIOMYOPATHY
The typical echocardiographic features of this condition reflect poor left ventricular function and consist of a dilated left ventricular cavity with poor systolic excursion of the interventricular septum and posterior ventricular wall (Fig. 10). Both leaflets of the mitral valve are clearly seen within the dilated left ventricle. The excursion of the leaflets appears reduced and may in fact be so because of the reduced cardiac output, but the relatively large ventricular cavity has the effect of making the mitral valve excursion appear smaller than usual (Fig. 10). With marked reduction of left ventricular function the pattern of aortic

Fig. 9. Echocardiographic scan of the left ventricular outflow tract and aortic valve in a patient with *Streptococcus viridans* endocarditis.

The mass of echoes labelled 'vegetations' were found at surgery to originate from a large friable mass of necrotic tissue attached loosely to the aortic cusps.
valve motion is also affected, reflecting a decrease in systolic flow. The opening movement of the valve cusps is concave, and in late systole the cusps tend to drift towards the closed position, in contrast to the normal abrupt closing movement. In severe cases, left atrial and right ventricular enlargement are also seen. Echocardiography is useful not only in establishing or confirming a diagnosis of left ventricular dysfunction, but also in determining whether or not mitral or aortic valve disease, that might be amenable to surgical treatment, is also present. The diagnosis of congestive cardiomyopathy does not carry striking therapeutic possibilities, and therefore the opportunity to make the diagnosis without recourse to cardiac catheterisation is particularly appropriate.

Fig. 10. Typical findings of severe left ventricular function. The left ventricular cavity is dilated, and movement of the septum and posterior left ventricular wall are much reduced.
Two clinical points should be made—
(a) A not uncommon problem is that of a patient with left ventricular failure in whom a pansystolic murmur is heard at the apex of the heart. It may be impossible to decide clinically whether these findings represent mitral regurgitation of valvular origin, or mitral regurgitation secondary to left ventricular dysfunction. The echocardiographic picture of ventricular function can usually differentiate between these two diagnoses. In significant organic mitral regurgitation, increased amplitude of the left ventricular motion is seen echocardiographically, whereas in primary cardiomyopathy the wall motion is reduced.
(b) Echocardiography cannot differentiate primary congestive cardiomyopathy from ‘ischaemic cardiomyopathy’ in which severe coronary artery disease is associated with diffusely poor ventricular function. However, the difference between these two diagnoses in terms of available therapy and prognosis is probably academic.

HYPERTROPHIC CARDIOMYOPATHY
The pathological hallmark of hypertrophic cardiomyopathy is a thickened interventricular septum which may or may not be associated with obstruction to outflow of either left or right ventricle. Echocardiography possesses a unique

![Diagram of interventricular septum](image)

Fig. 11. This figure illustrates the typical thickened immobile interventricular septum seen in hypertrophic cardiomyopathy. This may be compared with the normal interventricular septum shown in Fig. 1.
ability to measure the thickness of the interventricular septum. It has been suggested (Henry et al., 1973a) that when the ratio of septal to left ventricular wall thickness is greater than 1.3 : 1, the echocardiographic diagnosis of asymmetric septal hypertrophy has been established, and that this finding is seen only in hypertrophic cardiomyopathy. Similar echocardiographic appearances, however, may be found in patients with right or left ventricular hypertrophy from any cause, and therefore, consideration of the echocardiographic data together with the other clinical information is especially important when considering this diagnosis. The finding of an immobile septum, at least one-and-a half times thicker than the posterior ventricular wall, in association with a small left ventricular cavity, strongly suggests the diagnosis of hypertrophic cardiomyopathy (Fig. 11).

Obstruction to left ventricular outflow due to hypertrophic cardiomyopathy is recognised echocardiographically by (a) anterior motion of the mitral valve during systole (SAM — Fig. 12); and (b) a tendency for the aortic valve cusps to close during mid to late systole (Feizi and Emanuel, 1975). It has been suggested (Henry et al., 1973b) that the degree of SAM correlates with the degree of

Fig. 12. Echocardiogram from a patient with obstructing hypertrophic cardiomyopathy. SAM = systolic anterior motion of the mitral valve, in this patient the mitral valve apparently touching the interventricular septum during systole. At postmortem in such patients a ‘contact’ lesion is sometimes seen on the endocardial surface of the septum.
obstruction of the outflow tract, but the fact that a two-dimensional event is being seen in only one dimension limits the accuracy of this observation. Echocardiography is useful both in establishing the diagnosis of hypertrophic cardiomyopathy and also in assessing whether or not there is associated obstruction to left ventricular outflow. Many of these patients may have vague and previously unexplained symptoms, and the establishing of a definite diagnosis often leads to improved management.

**Movement of the Interventricular Septum**

When there is volume overload of the right ventricle, as in atrial septal defect, anomalous venous return, or tricuspid regurgitation, the interventricular septum moves anteriorly rather than posteriorly during systole. This phenomenon is known as ‘paradoxical’ septal motion (Fig. 13). In the presence of left bundle branch block (McDonald, 1973) a similar motion of the septum is seen, although careful analysis reveals differences from that seen in right ventricular overload. An atrial septal defect is one of the most common causes of paradoxical septal

---

**Fig. 13.** In this patient with tricuspid regurgitation, the interventricular septum moves anteriorly (towards the top of the tracing) at the start of systole following the QRS. This complex pattern of motion is seen in conditions with right ventricular volume overload, and is known as paradoxical septal motion.
motion. This echocardiographic finding in the presence of the typical auscultatory, electrocardiographic and radiographic features, has led to a report from one centre (Radtke et al., 1976) of surgery being undertaken without prior cardiac catheterisation in 20 per cent of patients with an atrial septal defect. Consideration of this management would, of course, depend upon the individual preferences of the physicians and surgeons involved.

Patients who develop tricuspid regurgitation following mitral valve replacement present a clinical problem in deciding whether their poor progress is due to left ventricular muscle disease, or malfunction of the mitral prosthesis. Following valve replacement septal motion is usually abnormal (Burggraf and Craigie, 1975), and in the presence of tricuspid regurgitation, paradoxical septal motion would be the expected echocardiographic finding. Thus, if normal septal motion is found in such a patient it suggests that there is severe left ventricular volume overload. Provided aortic regurgitation can be excluded, a paraprosthetic mitral leak, which may not cause a murmur, is the likely explanation (Miller et al., 1973).

CROSS-SECTIONAL ECHOCARDIOGRAPHY
Recently, the scope of echocardiography has been expanded by adding a further 'dimension'. In conventional or 'M' mode echocardiography, cardiac structures and their motion are recorded in terms of their distance from the transducer placed on the chest wall. In cross-sectional echocardiography, the ultrasonic beam is directed through an 'arc' to build up a picture of cardiac motion in either the longitudinal or horizontal axes of the heart. There are a number of techniques by which this may be achieved (Feigenbaum, 1976), the simplest to appreciate being a device analogous to the head of an electric toothbrush on which the transducer is located and rocked rapidly back and forth. The resulting cine films have intriguing research possibilities and may turn out to be accurate means of assessing the valve areas of stenotic aortic (Weyman et al., 1975) or mitral valves (Henry et al., 1975). They also possess considerable potential for studying left ventricular wall motion (Kisslo et al., 1977). In these respects cross-sectional echocardiography should still be regarded as a research tool.

SUMMARY
Echocardiography is helpful to the clinician in a number of situations. In a patient with the radiological finding of cardiomegaly, the possibilities of a pericardial effusion, left or right ventricular volume overload, or severe ventricular dysfunction, may readily and accurately be assessed. The technique is a useful adjunct in assessing the severity of many valvular lesions and in some cases establishing the aetiology of the lesion. The ability to diagnose left atrial myxomas is unique and invaluable. Mitral valve prolapse and hypertrophic cardiomyopathy are now being recognised more frequently, and may provide an 'organic' reason for long-standing unexplained symptoms.
Finally, while echocardiography is of value in certain clearly defined areas, it should not be regarded as a panacea for all cardiac diagnostic or management problems.

Acknowledgements
I am grateful to Dr Ernest Craige of the University of North Carolina, and Dr Aubrey Leatham of St George's Hospital, London, both of whom have been a major influence on the concepts presented in this paper.

I would like to thank Mrs Kay Woodruff for her secretarial assistance.

References
Allen, H., Harris, A. and Leatham, A. (1974) British Heart Journal, 36, 2525.
Burggraf, G. and Craig, E. (1975) American Journal of Cardiology, 35, 473.
Cope, G. D., Kisslo, J. A., Johnson, M. L. and Behar, V. S. (1975) Circulation, 52, 664.
Davis, R., Feigenbaum, H., Chang, S., Konecke, L. and Dillon, J. (1974) American Journal of Cardiology, 33, 277.
DeMaria, A. N., Kind, J. F., Bogren, H. G. Lies, J. E. and Mason, D. T. (1974) Circulation, 50, 33.
Farooki, Z., Green, E. and Arciniegas, E. (1976) British Heart Journal, 38, 580.
Feigenbaum, H. (1970) American Journal of Cardiology, 26, 475.
Feigenbaum, H. (1976) Echocardiography, p. 30. Philadelphia: Lea and Febiger.
Feizi, O. and Emanuel, R. (1975) British Heart Journal, 37, 1286.
Fortuin, N., Hood, W., Sherman, M. and Craig, E. (1971) Circulation, 44, 575.
Gibson, D. G. and Brown, D. (1973) British Heart Journal, 35, 1141.
Gibson, D. G. and Brown, D. J. (1975) British Heart Journal, 37, 677.
Goldberg, S. J., Allen, H. D. and Sahn, D. J. (1975) Paediatric and Adolescent Echocardiography, Year Book Medical Publishers.
Henry, W. L., Clarke, C. E., Glancy, D. L. and Epstein, S. E. (1973a) New England Journal of Medicine, 288, 989.
Henry, W. L., Clarke, C. E. and Epstein, S. E. (1973b) Circulation, 47, 225.
Henry, W. L., Griffith, J. M., Michaelis, L. L., McIntosh, C. L., Morrow, A. G. and Epstein, S. F. (1975) Circulation, 51, 827.
Kisslo, J., Von Ramon, D., Haney, R., Jones, R., Juk, S. and Behar, V. (1976) American Journal of Cardiology, 38, 502.
Kisslo, J., Robertson, D., Gilbert, B., Von Ramon, D. and Behar, V. (1977) Circulation, 55, 134.
Leech, G., Mills, P. and Leatham, A. (1975) Circulation, 51, II, 78.
McDonald, I. G. (1973) Circulation, 48, 272.
McDonald, I. G. (1976) Circulation, 53, 865.
Mann, T., McLaurin, L., Grossman, W. and Craigie, E. (1975) New England Journal of Medicine, 293, 108.
Miller, H. C., Gibson, D. G. and Stephens, S. D. (1973) British Heart Journal, 35, 1217.
Nanda, N., Gramiak, R., Robinson, T. and Shah, P. (1974a) Circulation, 50, 575.
Nanda, N., Gramiak, R., Manning, J., Mahony, E., Lipchik, E. and De Weese, J. (1974b) Circulation, 49, 870.
Nanda, N., Gramiak, R., Shah, P. and De Weese, J. (1975) Circulation, 51, 263.
Popp, R. L., Brown, O. R., Silverman, J. F. and Harrison, D. C. (1974a) Circulation, 49, 428.
Popp, R. L., Silverman, J. F. and French, J. W. (1974b) Circulation, 49, 226.
Radtke, W., Tajik, A., Gau, G. Schattenberg, T., Guiliani, E. and Tancredi, R. (1976) Annals of Internal Medicine, 84, 246.
Roelandt, J., Vanden Brand, M., Vletter, W., Nanta, J. and Hugenholtz, P. (1975) Circulation, 52, 466.
Rosenblatt, A., Clark, R., Burgess, J. and Cohn, K. (1976) Circulation, 54, 509.
Roy, P., Tajik, A., Giuliani, E., Schattenberg, T., Gau, G. and Frye, R. (1976) Circulation, 53, 474.
Wann, L. S., Dillon, J. C., Weyman, A. E. and Feigenbaum, H. (1976) New England Journal of Medicine, 295, 135.
Weyman, A., Feigenbaum, H., Dillon, J. and Chang, S. (1975) Circulation, 52, 828.