Newer Aspects of Echocardiography

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SUMMARY
The recent increase in interest in echocardiography is partially due to the feasibility of using this technic to evaluate left ventricular performance in a noninvasive manner. It has been demonstrated that one can obtain an internal dimension of the left ventricular cavity and that this dimension is closely related to the corresponding volumes in uniformly contracting ventricles. Thus in patients with valvular heart disease, congenital heart disease, or cardiomyopathy, echocardiography provides an excellent noninvasive means of estimating diastolic volume, systolic volume, stroke volume, ejection fraction, and mean rate of circumferential shortening. In patients with segmental left ventricular disease, such as with coronary artery disease, these dimensions may not be true reflectors of the corresponding volumes. In such ventricles one probably should use echocardiography to evaluate the motion of individual segments of the chamber. To evaluate overall left ventricular function, one could use the mitral valve echoes to estimate mitral valve flow and left ventricular diastolic pressure. Echocardiography also provides a method of measuring wall thickness of the posterior left ventricular wall and the interventricular septum.

Many echocardiographic technics for the diagnosis of congenital heart disease have recently been described. Most of these technics obviously need further substantiation; however, the size of the list is impressive and makes one feel that even the more complicated forms of congenital heart disease may be unraveled with echocardiography. The use of a strip-chart recorder has greatly improved and broadened the echocardiographic examination. Besides making the examination technically easier, it provides a means of appreciating the interrelationship of many cardiac echoes.

A critical problem facing echocardiography is the maintenance of high-quality examinations. Unfortunately the examination is not easy, and it requires a well-trained, highly skilled individual. The acceptance of the technic by the clinician has produced a demand which exceeds the available manpower to do adequate echocardiography. As a result much of the echocardiography being done is totally inadequate. The technic is still new and relatively unproven, and it cannot tolerate much abuse by people not well trained. One possible safeguard to the maintenance of high-quality echocardiography is for clinicians to be familiar with what a good echocardiogram looks like. The difficulty with echocardiography is mainly in doing the examination, not necessarily in the interpretation. Thus if the technical quality can be maintained, there is no doubt that echocardiography will play an increasingly important role in clinical cardiology.

Additional Indexing Words:
Ultrasound Ultrasound cardiology Congenital heart disease Left ventricular function

As can be judged by the recent literature, there has been a rapid increase in interest and activity in echocardiography. Much of this interest was stimulated by the possibility of using echocardiography to evaluate left ventricular performance in a noninvasive manner. Figure 1 shows how one can obtain an "ice-pick" view of the left ventricle. The ultrasonic beam is directed so that it travels through the body of the left ventricle. It passes through the interventricular septum and through the posterior left ventricular wall below the atrioventricular groove. The left ventricular cavity is bordered anteriorly by the left side of the interventricular septum and posteriorly by the posterior left ventricular endocardium. All of the echoes are not seen on this echocardiogram because of a technical manipulation which permits the recording of both strong and weak echoes.

Figure 2 demonstrates another left ventricular echocardiogram. One can again see the cavity of the left ventricle bordered by the left side of the interventricular septum and the posterior left ventricular endocardium. Within the cavity of the

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Diagrammatic cross section of the heart together with the corresponding echocardiogram showing the path of the ultrasonic beam when examining the left ventricle. ARV = anterior right ventricular wall; RS = right septum; LS = left septum; EN = left ventricular posterior endocardium; EP = left ventricular posterior epicardium (from Amer J Cardiol, by permission).

The left ventricle are parts of the mitral valve. In this particular echogram the posterior left ventricular myocardium is more echo-producing than in figure 1. Whether or not the myocardium is echo-free or echo-producing is merely a function of the gain setting. The myocardium is bounded posteriorly by the stronger echo from the posterior left ventricular epicardium. This illustration demonstrates some of the measurements which can be made. One can obtain an internal dimension of the left ventricle between the borders of the left ventricular cavity. The measurements can be taken both in diastole and in systole. In addition one can measure the thickness of the left ventricular wall between the endocardial and epicardial echoes. The wall thickness has been correlated against angiographic, surgical, and autopsy measurements. The correlations have been quite good. The internal cavity dimensions have been correlated against angiographic volumes. Again the statistical relationship between the echocardiographic dimensions and the angiographic volumes has been quite good. In fact the preliminary data were so good that many people equated these ultrasound dimensions to left ventricular volumes. Unfortunately this conversion is not totally justified. We must remember that we are indeed only recording a single left ventricular dimension.

The left ventricular angiograms in figure 3 show the relationship of the ultrasonic beam to the left ventricle in both diastole and systole. The dimension obtained is probably somewhere between the short and long axis but is most likely closer to the short axis. As long as the ventricle contracts uniformly and retains its basic shape, then our single ultrasonic measurement correlates extremely well with the corresponding ventricular volumes. This technic then permits an estimate of diastolic, systolic, and stroke volumes together with ejection fraction and mean rate of circumferential fiber shortening. However, if the ventricle does not contract symmetrically or if the shape is grossly

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Figure 2

Echocardiogram of the left ventricle. The diastolic left ventricular internal dimension (LVIDd) is taken between the left side of the interventricular septum and the posterior left ventricular endocardium enddiastole, which corresponds to the R wave of the electrocardiogram. The systolic left ventricular internal dimensions (LVIDs) was taken just after the peak downward motion of the interventricular septum. The distance between the posterior left ventricular endocardium and epicardium represents the left ventricular wall thickness (LVWT) (from Progr Cardiovasc Dis, by permission).

distorted, such as with a ventricular aneurysm, then our measurements may be in error. This obvious limitation was recognized from the very beginning, however, in our enthusiasm many physicians overlooked these limitations, and thus they must be reemphasized.

Some investigators have been looking at the amplitude and velocity of motion of the posterior left ventricular wall. This technic was begun several years ago and has some theoretic validity. However, there are many technical limitations which must be recognized. First of all, technics which just use “posterior wall velocities” are not well standardized. One must define which echo from the posterior left ventricular wall is being recorded. Figure 1 illustrates how the number of echoes from the posterior left ventricular wall can vary depending on the gain setting. On the left hand side of the echogram the gain is low, and only the posterior left ventricular epicardial echo is recorded (EP). This echo is probably what most investigators call “posterior wall.” Changes in motion of this echo may be useful in judging alterations in left ventricular performance in a given individual, but it may be misleading to compare one patient with another because the
epicardial echo can be obtained from many different areas of the left ventricle and is not well standardized. There are echoes from the mitral annulus, pericardium, and even pleura which are very similar and are often confused with those from the true posterior left ventricular wall. A better system would be to measure the amplitude and velocity of the posterior left ventricular endocardial echo. This echo requires a higher gain setting (EN in fig. 1). The recording of this echo represents a much more standardized examination and avoids many of the pitfalls associated with just looking at the dominant “posterior wall” echo. Unfortunately the endocardial echo is also technically more difficult. In any case, I believe that looking at the amplitude and velocity of individual segments of the left ventricle is a perfectly valid means of assessing left ventricular function of those particular segments of the left ventricle. This application should be particularly productive in looking at segmental disease of the left ventricle as occurs with coronary artery disease.12 However, I must reemphasize that one has to be careful about judging how the total chamber is contracting by merely looking at one or even two small segments of the ventricle.

The mitral valve echoes can also provide some useful information concerning left ventricular function. We have found that in the nondiseased, unrestricted mitral valve the amount and duration of separation between the anterior and posterior leaflets is proportional to the amount of blood flowing through that orifice.13 This observation is demonstrated in figure 4. The mitral valve echogram in figure 4A is from a patient with low mitral valve flow as measured at cardiac catheterization. The distance between the leaflets is small as the valve orifice does not have to accommodate the inflow of much blood. The echogram in figure 4B demonstrates the situation in a patient with a large mitral flow. The separation of the leaflets is now considerably larger. We have studied a series of patients undergoing cardiac catheterization and have correlated the echocardiographic measurements of mitral valve flow against the catheterization determinations. Again in those patients who do not have any intrinsic mitral valve disease, this correlation is quite good. Thus there is a possibility that in those patients who have segmental disease of the left ventricle and in whom the ultrasonic dimensions are not valid for measuring stroke volume, one could resort to looking at mitral valve flow for left ventricular stroke volume. In fact, the

Figure 3

Lateral left ventricular angiogram during diastole (a) and systole (b) showing the relationship of the ultrasonic beam to the left ventricular cavity (from Arch Intern Med [Chicago], by permission).
two technics could be combined to give a semiquantitative estimate of how much segmental disease might be present.

The mitral valve echogram can also provide information concerning the left ventricular diastolic pressures. We have observed a distinct distortion of the pattern of the mitral valve motion in patients who have altered left ventricular diastolic pressures (fig. 5). Normally the mitral valve opens rapidly (D to E slope) and closes with the onset of atrial relaxation following the A point (fig. 5A). Closure is rapid, smooth, and uninterrupted. The movements of the mitral valve undoubtedly are due, in part, to the interrelationships between the left atrial and left ventricular pressures. With ventricular relaxation the ventricular pressure falls rapidly to a low level. When it drops below the relatively low left atrial pressure, the mitral valve opens, and there is a rapid inflow of blood from the left atrium to the left ventricle. This phenomenon is reflected in the mitral valve echo by a rapid opening of the valve (D to E slope). During middiastole the inflow of blood into the ventricle is markedly reduced, and the valve is in a semiclosed position. With atrial contraction the atrial pressure rises above the ventricular pressure, and the mitral valve reopen permitting the inflow of blood to the ventricle. Normally the amount of blood delivered represents a small percentage of the total mitral valve flow, and the left ventricle accepts this blood with only a gradual rise in pressure. With

![Figure 4](http://circ.ahajournals.org/)

Mitral valve echogram demonstrating that the separation between the anterior and posterior mitral leaflets during diastole is a function of the amount of flow passing through the mitral orifice. (A) is from a patient with low mitral flow, and (B) is from a patient with high mitral valve flow (from Feigenbaum, by permission).

![Figure 5](http://circ.ahajournals.org/)

Diagrams illustrating how the mitral valve echogram can reflect changes in left ventricular diastolic pressure. LV = left ventricular pressure; LA = left atrial pressure (see text for details). (From Feigenbaum, by permission.)
atrial relaxation there is a decreasing left atrial pressure and a gradually increasing ventricular pressure, and the mitral valve begins to close. Closure of the mitral valve is completed with the onset of ventricular systole and a rapid rise in ventricular pressure.

In patients who have a high left ventricular initial diastolic pressure, usually due to an increased end-systolic volume and congestive failure, the D to E slope or the rate of opening of the valve seems to be diminished, and the A wave may be increased (fig. 5C). A possible explanation for this finding is that, with an elevated left ventricular initial diastolic pressure and probable increased end-systolic volume, the flow of blood from the left atrium into this incompletely emptied left ventricle is decreased and is reflected by a diminished rate of opening of the mitral valve. The large A wave may indicate a higher percentage of blood being delivered to the ventricle with active atrial contraction.

An even more striking and frequent observation is that in patients who have poor left ventricular compliance either due to hypertrophy, ischemia, or fibrosis, there is abnormal closure of the mitral valve following atrial systole (fig. 5B). The A point begins slightly earlier than normal, and the C point is slightly delayed. Between the two points there may be a plateau which interrupts the ordinarily smooth closure. The end result is that the A-C interval is prolonged out of proportion to the P-R interval. The corresponding left ventricular and left atrial pressures usually exhibit a very large atrial component, and there is a marked increase in left ventricular end-diastolic pressure. The probable explanation for the abnormal pressure and echographic findings is decreased compliance of the left ventricle. Normally with atrial systole there is a gradual rise in atrial pressure and an even more gradual rise in the left ventricular pressure. The ventricle appears to be able to accept this blood with very little rise in pressure because of its relatively low compliance. In a poorly compliant or stiff left ventricle the sudden inflow of blood following atrial systole produces a very rapid rise in ventricular pressure as demonstrated by the large atrial component of the left ventricular diastolic pressure (fig. 5B). With this sudden rise in ventricular pressure the crossing of the ventricular and atrial pressures occurs sooner than normal, and the onset of mitral valve closure or the A point is early. Soon after atrial relaxation the ventricular and atrial pressures become almost equal, and there is an interruption to the normally smooth mitral valve closure. Following ventricular systole the mitral valve is finally closed at the C point. For various reasons, the C point appears to be delayed, thus contributing to the prolonged A-C interval.

Thus it seems that echocardiography may be able to provide some evaluation of the status of the left ventricle: (1) by looking at ventricular cavity dimensions; (2) by measuring the thickness of the posterior left ventricular wall and the interventricular septum especially in patients with hypertrophic subaortic stenosis; (3) by recording the velocity, amplitude, and pattern of motion in both systole and diastole of various segments of the left ventricular walls; (4) by judging the flow of blood through the mitral orifice in patients with nondiseased mitral valves; and (5) by using the pattern of mitral valve motion to reflect changes in the left ventricular diastolic pressure.

Again by examining the literature, it is obvious that there is a great deal of interest in using echocardiography in the diagnosis of congenital heart disease. To date echocardiographic technics have been described for the diagnosis of volume overload of the right ventricle such as with an atrial septal defect, large ventricular septal defects, tetralogy of Fallot, hypoplastic right and left ventricles, Ebstein's anomaly, hypertrophic and discrete subaortic stenosis, aortic atresia, single ventricle, double-outlet right ventricle, transposition of the great vessels, single atrioventricular valve, and truncus arteriosus. There is not sufficient time to describe all of these applications, and obviously many of these technics must be substantiated by other investigators. However, the number of applications is most impressive and makes one believe that echocardiography may be able to unravel even the more complicated forms of congenital heart disease.

To facilitate the diagnosis of congenital and coronary heart disease, the echocardiographic recordings are now being done on strip-chart recorders rather than with the usual Polaroid camera. This change makes the examination technically much easier, but even more importantly it provides another dimension to the echocardiogram. Figure 6 shows a diagram of the type of echocardiogram which can be obtained using a strip-chart recorder. With such a tracing one can continuously record many cardiac cycles. The recording can also be done as the ultrasonic transducer is moved from one area of the heart to another, and we no longer have only an "ice-pick view" of the heart. In this particular case the
ultrasonic beam is moved from the vicinity of the posterior papillary muscle, through the body of the ventricles, through the left ventricular outflow tract, and into the base of the heart through the root of the aorta and the left atrium. The corresponding echoes from the cardiac structures are appropriately labeled. This type of presentation has been called an “M-mode scan.” M-mode means that echo motion is being recorded. The word “scan” means that the ultrasonic transducer is being moved. I like to think that this display provides “three-dimensional” information. First of all we have depth displayed from the chest wall posteriorly, into and through the heart. In addition one can achieve some idea of the interrelationship of various cardiac echoes as the ultrasonic beam scans from the apex to the base of the heart. Thirdly we retain the ability to record echo motion at the rate of 1000/sec.

In the M-mode scan of the heart in figure 7, the ultrasonic beam again is moved from the apex to the base of the heart. With this type of echocardiogram one can see how the interventricular septum disappears in this patient with a very large ventricular septal defect. In the patient in figure 8 this same scanning technic shows how a small interventricular septum disappears as the ultrasonic beam leaves the apex of the heart. In addition there is a large atrioventricular valve which seems to spread from the posterior ventricle into the anterior ventricle. This echocardiogram is quite compatible with a large ventricular septal defect and a single atrioventricular valve, which proved to be the catheterization and angiographic diagnosis. By following the interventricular septum in figure 9, one notes that the septum abruptly ends and is straddled by a large, apparently single great artery (AO), in which one finds a large semilunar valve.

**Figure 6**
Diagram of an M-mode scan of the heart from the apex (1) to the base of the heart (4). ARV = anterior right ventricular wall; RV = right ventricular cavity; RS = right side of the interventricular septum; LS = left side of interventricular septum; LV = left ventricular cavity; PPM = posterior papillary muscle; PLV = posterior left ventricular wall; EN = posterior left ventricular endocardium; EP = posterior left ventricular epicardium; PER = pericardium; AMV = anterior mitral valve leaflet; PMV = posterior mitral valve leaflet; PLA = posterior left atrial wall; AV = aortic valve; AO = aorta; LA = cavity of the left atrium (from Progr Cardiacc Dis, by permission).

**Figure 7**
M-mode scan echocardiogram of a patient with a large ventricular septal defect. The interventricular septum (IVS) disappears as the ultrasonic beam sweeps from the apex to the root of the aorta (AO).
Figure 8

M-mode scan of the heart from a patient with a large interventricular septal defect and a single atrioventricular valve. The interventricular septal echoes are visible only toward the apex of the heart. As the beam scans toward the base of the heart, an atrioventricular valve echo moves from the vicinity of the left ventricle past where the interventricular septum should be into the anterior ventricular chamber (from Feigenbaum,18 by permission).

Figure 9

Echocardiogram from a patient with a truncus arteriosus. As the ultrasonic beam scans from the left ventricle to the base of the heart, the interventricular septum (IVS) disappears. The apparent aorta (AO) is very dilated and actually straddles the right and left ventricles and represents a true truncus. The apparent aortic valve (AV) can be noted in the large artery (from Feigenbaum,18 by permission).
As might be expected this patient had a truncus arteriosus.

Figure 10 shows how an M-mode scan echocardiogram can be useful in looking at a patient with coronary artery disease. Toward the apex of the heart the interventricular septum retains fairly normal motion. However, as one approaches the base of the heart, the septal motion disappears in this akinetic area of the left ventricle. We now have strip-chart recorders which are quite small and can be put on a portable cart so that this type of examination can be done at the bedside, in the coronary care unit, or even in the nursery examining newborn infants in an incubator.

Needless to say, echocardiography has come a long way. Not only has the activity and interest increased at a phenomenal rate, but the acceptability by the clinical cardiologist is increasing rapidly. In many respects the field is entering a critical stage. Originally there was a great deal of resistance and skepticism. Although this attitude is somewhat frustrating, it is also a very healthy thing to have in the development of any new application in medicine. We are now seeing a great deal of blind acceptance. People are not even legitimately questioning some of the new applications. As already indicated many physicians thought that the echocardiographic technic for measuring left ventricular dimensions automatically meant that they could record volumes. As in every field of medicine some of the echocardiographic data in the literature are probably inaccurate and misleading. Many people forget that echocardiography is technically very difficult. It takes a great deal of skill, time, and experience to be a good echocardiographer. Unfortunately the enthusiasm by the clinician has put a drain on the available manpower since there are relatively few people who can do these examinations acceptably, and there are even fewer people available to train such individuals. As you might expect, some people are doing echocardiography without adequate training.

I know of some exceptionally poor echocardiographs being done in various institutions. I learn of these examples because people usually inform me when they think echocardiography failed or proved to be in error. When I follow up these "echocardiographic mistakes," I usually find a person doing the examination who is totally untrained and who has a very poor understanding as to how to do the examination or interpret the tracings. I even know of a situation in which a normal mitral valve echogram was mounted upside down, and the echocardiographic interpretation was mitral stenosis. Unfortunately some of the echocardiograms in the literature also leave much to be desired.

I do not know exactly how we can keep this sort of activity to a minimum. I realize that poor quality exists in practically all phases of medicine. However, because echocardiography is so new and still

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Figure 10

An M-mode scan of the heart from a patient with an akinetic segment of the interventricular septum. With the ultrasonic beam directed toward the apex of the heart, normal septal motion can be seen (left brace). As the transducer is directed toward the base of the heart, all septal motion disappears in this akinetic area (right brace) (from Feigenbaum,19 by permission).
relatively unproven, the technic cannot tolerate excessive incompetence at this stage of its development. I think that one possible remedy is for the clinician to be as familiar with the echocardiographic tracings as possible. The difficulty with echocardiography is primarily in doing the examination. Interpretation of the tracings is not that difficult once one has taken time to look at some examples. I strongly feel that one safeguard to the quality and future of echocardiography would be to have as many cardiologists as possible become somewhat familiar with the technic. Hopefully one would at least know when a mitral valve echogram is upside down. As more and more cardiologists eventually become accustomed to looking at these recordings, we probably should be able to at least make a preliminary interpretation of our own echocardiograms just as we read our own electrocardiograms and chest X-rays.

There is no question in my mind that if we can maintain a high quality of echocardiographic examinations, the technic should be around for a long time and should play an increasingly important role not only in the everyday practice of clinical cardiology, but in many aspects of clinical investigation.

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