Identification of Ultrasound Echoes from the Left Ventricle by Use of Intracardiac Injections of Indocyanine Green

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SUMMARY
This study was designed to identify the ultrasound echoes originating from the left ventricle. Injections of indocyanine green and saline were made directly in the left ventricular cavity via a cardiac catheter in patients undergoing routine diagnostic cardiac catheterization. The injections produced a cloud of echoes that filled the left ventricular cavity and outlined the left side of the interventricular septum and the endocardial surface of the posterior left ventricular wall. The results of this study verified the origin of echoes that are vital to the ultrasound technics for the detection of pericardial effusion, left ventricular wall size, left ventricular cavity size, and left ventricular stroke volume. This study also provided ways of distinguishing between the true left ventricular wall echoes and intracavitary echoes that often cause confusion.

Additional Indexing Words:
Echocardiography Ultrasound cardiology

ECHOCARDIOGRAPHY or ultrasound cardiology is a promising diagnostic tool with many potential applications in clinical and investigative cardiology. This noninvasive cardiac examination has been used to detect mitral stenosis,1-3 tricuspid stenosis,4-6 pericardial effusion,4-9 idiopathic hypertrophic subaortic stenosis,10 atrial tumors,11 left ventricular wall thickness,12 left ventricular stroke volume,13 and the size of individual cardiac chambers.14,15

Despite the many obvious advantages of echocardiography, there remain several weaknesses that must be appreciated and must be overcome before this diagnostic procedure can realize its full potential. One such weakness stems from the fact that all echocardiographic technics are dependent upon proper recognition and identification of individual cardiac echoes. Unfortunately, experimental proof of the origin of cardiac echoes is scant, and at times identification of echoes can be quite difficult. This problem is especially evident in those technics that require the recording of echoes from the left ventricle. These technics include the detection of pericardial effusion,5 the determination of left ventricular wall thickness,12 left ventricular stroke volume,13 and left ventricular size.15 Although the exact origin of these left ventricular echoes is basic to the validity of these diagnostic procedures, proof of their origin is lacking. Furthermore, since many of the left ventricular echoes have similar patterns of motion, it is frequently difficult to distinguish one from another.

Gramiak and associates16 described the phenomenon of producing ultrasound echoes within the heart utilizing intracardiac injections of indocyanine green. They offered this technic as a means of verifying the origin of cardiac echoes. This study was designed to use intracardiac injections of indocyanine green to...
identify the echoes originating from the left ventricle.

Methods

Ultrasound examinations were performed on 56 patients undergoing routine diagnostic cardiac catheterization whereby a catheter was introduced into the left ventricle either via the retrograde or transseptal route. A Smith-Kline Instrument Ekoline 20, Mark II echograph was used for the ultrasound examinations. This echograph has a repetition rate of 1,000 per second and has a fast time constant modification of the echoes. This modification causes the echoes to be thin and appear as fine lines. All photographs were taken by the M-mode presentation whereby the echoes are represented as dots that move across the face of the oscilloscope, permitting echo motion to be recorded. Photographs were taken directly from the face of the oscilloscope with a Polaroid camera.

The patients were examined in the recumbent position. Utilizing Aquasonic gel as a coupling medium, a 3 inch diameter, 2.25 megahertz transducer was placed in the fourth or fifth intercostal space along the left sternal border and directed posteriorly, a little laterally, and a little inferiorly. The exact direction of the transducer was adjusted so that echoes were recorded from the posterior wall of the left ventricle and the interventricular septum. It also was necessary to adjust the sensitivity, reject, and damping controls for both the near and far fields to record the echoes properly. These controls essentially determined the number of echoes recorded. If the controls were too low, not all of the echoes were recorded. On the other hand, if too many echoes were recorded, they might all blend in together and identification of the individual echoes would be difficult. It was especially important to have the oscilloscope focused properly so that the echoes appeared as fine lines. While recording these left ventricular echoes, 1 ml of indocyanine green dye followed by 3 to 4 ml of saline were rapidly injected by hand into the left ventricle via the cardiac catheter.

Results

The intracardiac injections produced echoes to some degree in all 56 patients. In some patients there were only a few faint echoes recorded, whereas in most subjects the injections produced a cloud of echoes in the left ventricle. The number of echoes produced seemed to depend in part on the vigor with which the injections were made, the position of the catheter, the effective cardiac output, and the presence of mitral or aortic regurgitation. The best recordings were in those patients with either a low cardiac output or valvular regurgitation, or both, whereby the dye apparently stayed in the left ventricle a while.

A diagram of a cross section of the heart together with the direction of the ultrasound beam is shown in figure 1. To the right of the diagram is an actual echogram of a normal subject. The relations between the cardiac echoes and the corresponding anatomic structures are indicated. Figure 2 demonstrates a typical echogram of the left ventricle during the injection of the indocyanine green dye. The dye appears as a shower or cloud of numerous small echoes that fill and thus identify the left ventricular cavity. The cloud of echoes goes up to the left side of the interventricular septum (LS) and the endocardium (EN) of the posterior left ventricular wall. In this particular echogram the posterior myocardium (M), which is the space between the endocardium and epicardium (EP), is relatively echo-free. Whether or not the myocardium is echo-free or echo-producing depends on the gain, damping, and reject controls, all of which essentially regulate the

![Diagram demonstrating the relationship of the ultrasound beam and the heart. To the right is an actual echogram. The lines connect the corresponding echoes and anatomic structures. (Reproduced from Popp RL, Wolfe SB, Hirata T, et al.15 with permission of The American College of Cardiology.)](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.41.4.616)
number of echoes recorded. Figure 3A demonstrates a posterior myocardium that is again echo-free. The damping was varied during the recording to help with the identification of echoes. Figure 3B illustrates how the myocardium can be filled with echoes as the damping is reduced and more echoes are recorded. In

figure 3C the indocyanine green verifies the identification of the septal and posterior endocardial echoes.

In figure 2 the epicardium (EP) is labeled. Figure 3 provides evidence to justify this label. This particular patient had a small amount of unsuspected pericardial effusion which was first detected during the ultrasound examination. The pericardial fluid was verified at cardiac surgery a few days later. The presence of this fluid provided an opportunity to have a “double contrast” study. The indocyanine green identified the endocardium (EN) while the pericardial fluid (PF) delineated the epicardium (EP) and pericardium (P). This echogram demonstrates that the epicardial echo is stronger than the endocardial echo. This finding was to be expected since the relatively smooth epicardium in contact with pericardial fluid is a better reflecting surface than is the interface produced by the irregular endocardium and intracardiac blood. This finding supports the observation that when obtaining an echogram on a patient with pericardial effusion and a single myocardial echo is recorded, it most likely arises from the epicardium.

The use of intracardiac injections helps to verify the technic of using ultrasound to measure the thickness of the left ventricular wall. With the use of calibration dots, which are 1 cm apart, the distance between the endocardial and epicardial echoes during diastole is 1 cm or less in figures 2, 3, and 4. The echograms in figure 5 are from a patient with aortic stenosis and a thick left ventricular wall as confirmed by surgery. The diastolic distance between the endocardial and epicardial echoes is 1.5 cm.

In figure 5A as in figure 4 there are some intramyocardial echoes that could be confused with the true epicardium. Figure 5B shows an echogram whereby the dye produced a more dense cloud of echoes and the myocardium is more clearly defined. In this echogram the confusing myocardial echoes are not so distinct, and the true epicardium is more readily apparent.

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Patient with a small amount of pericardial effusion and intracardiac dye studies. The dye identifies the endocardium (EN) while the pericardial fluid (PF) separates the epicardium (EP) and pericardium (P). The myocardium (M) is the space between the endocardium and epicardium. A thin echo-free line can be seen separating the pericardium from the pleura (PL).

Figure 5
Indocyanine green injections in a patient with a thick left ventricular wall. The dye produced a more dense cloud of echoes in B than in A.

The ultrasound technic for estimating the size of the right and left ventricles depends on the identification of the interventricular septum as well as the posterior left ventricular wall. The echogram in figure 6 was obtained.

Figure 6
Echogram of a patient with aortic insufficiency and a dilated left ventricle. The echoes from the indocyanine green partially fill the large left ventricular cavity.

Figure 7
Intracardiac dye injection in a patient with a large right ventricle and a small left ventricle. RS, right side of interventricular septum; LS, left side of interventricular septum; AM, anterior mitral valve; PM, posterior mitral valve; EN, endocardium.
in a patient with aortic insufficiency and a markedly dilated left ventricle. The distance between the interventricular septum and the posterior endocardium was 7.0 cm. Figure 7 illustrates the findings in a patient with primary pulmonary hypertension who had a large right ventricle and a small left ventricle. The distance between the left septum and the posterior left ventricular endocardium was only 2.9 cm.

There are several intracavitary left ventricular echoes that must be appreciated when examining the left ventricle with ultrasound. One or more of these echoes are visible to some extent in almost all of the echograms illustrated, but they are most apparent in figure 7 (echoes AM and PM). The fact that the indocyanine green obscures these echoes proves that they originate from within the left ventricular cavity. The first echo (AM) is just posterior to the interventricular septum and originates from the anterior leaflet of the mitral valve. Figure 8 represents another echogram obtained from the same patient.

**Figure 8**

Another echogram from the same patient as in figure 6. The angle of the transducer is altered slightly so that the anterior mitral valve echo (AM) assumes the more classic pattern of motion.

**Figure 9**

Two echograms from the same patient. (See text for explanation of echoes).

illustrated in figure 7. In figure 8 the characteristic pattern of the anterior mitral leaflet is more obvious. The pattern of motion is distorted in figure 7 because of the position and direction of the transducer.

Another echo that has offered a great deal of confusion is between the anterior mitral and posterior endocardial echoes. One of the reasons for the confusion is because there may be more than one echo recorded in this area. Figure 9 shows two echograms from the same patient. The anterior mitral leaflet (AM) and the posterior endocardium (EN) are readily apparent in both photographs. In figure 9A there is an echo (PM) which is posterior to the anterior mitral valve and has a pattern of motion almost exactly opposite to that of the anterior leaflet. This echo undoubtedly originates from the posterior mitral leaflet. In

**Figure 10**

Three recordings of mitral valve echoes from the same patient. A. Anterior mitral valve (AM), posterior mitral valve (PM), and echo “X” appear as separate echoes. B. With decreased damping the space between echoes PM and “X” fill with echoes. C. As the direction of the transducer is moved from the left ventricle toward the left atrium, both PM and “X” echoes seem to become part of the left atrial wall (LAW).
figure 9B there is another echo in this general area, but it has a distinctly different pattern of motion. The motion is similar but not identical to that of the posterior endocardial echo. The amplitude of motion is less than the endocardial echo, and there is frequently a notch in the echo just at the beginning of ventricular diastole (fig. 9B). Since the exact origin of this echo is not clear, it is labeled "X."

Figure 10 shows another series of echo-grams from a single patient. Both the posterior mitral valve echo and echo "X" are visible in all three photographs. In figure 10A the echoes appear as two separate structures. As the damping is reduced, the space between the two echoes fills in with echoes (fig. 10B), suggesting that the PM and "X" echoes are part of the same intracardiac structure. When the transducer is directed superiorly toward the left atrium (fig. 10C), both PM and "X" echoes apparently blend into the left atrial endocardium. These findings suggest that both echoes originate from the posterior mitral valve. The echo labeled PM may be from the edge of the leaflet and echo "X" from the attachment of the posterior valve to the annulus. Irrespective of the exact origin of echoes PM and "X," they must be recognized so as not to confuse them with the endocardial echo. Secondly, they are frequently used for landmarks in finding the true posterior endocardial echo, since the best endocardial echoes are frequently recorded when either the PM or "X" echoes are also recorded.

Discussion

The necessity to verify the origin of cardiac echoes and the need to be able to distinguish properly one cardiac echo from another are absolutely essential if echocardiography is to grow in importance as a diagnostic procedure. These two problems are inseparable because the proper identification and recognition of echoes actually depend on knowledge concerning the origin of the echo. Several investigators have attempted to verify the origin of cardiac echoes using autopsy material. They introduced probes through the heart where they presumed the ultrasound beam was traveling. There are, of course, many potential errors in comparing the findings in a beating heart with one following death. The use of intracardiac injections of indocyanine green, as used in this study, has the advantage of providing identification of echoes in the beating heart while the echo in question is being recorded.

Having proven the origin of an echo, one needs to be able to locate and identify that echo without the benefit of intracardiac injections. There are essentially three ways in which cardiac echoes can be distinguished from each other. Recognizing echo motion during the cardiac cycle with or without the benefit of some reference, such as an electrocardiogram, is the most effective means of identifying cardiac echoes. The difference in echo motion may be very apparent, as when comparing the motion of the anterior mitral leaflet with the posterior endocardium, or it may be quite subtle, as between the posterior endocardium and echo "X."

The location of the echo is the second way in which cardiac echoes are identified. Knowing where an echo is in relation to a known echo helps tremendously in the identification of that echo. The third technic for distinguishing individual echoes makes use of differences in echo intensity. By altering the controls, it is possible to record these differences in intensity. This technic is especially useful in identifying the various echoes originating from the posterior left ventricular wall since in most patients the location and motion of these echoes are quite similar. By using echo motion, echo location, and echo intensity, the number of unidentified cardiac echoes should be minimized.

The mechanisms responsible for the echoes produced by the indocyanine green are still not completely known. Graniak and associates believe that these echoes are partially due to tiny bubbles of air suspended in the dye. Further studies with use of injections of several different substances suggest that cavitation produced by the jet of fluid from the catheter tip might be responsible for the production of tiny bubbles, which in turn are
the source of the echoes. No concerted effort was made in this present study to add any information as to the source of these echoes; however, the rate of injection of the dye did seem to influence the number of echoes produced.

Irrespective of how the intracardiac injections produced the echoes, this study demonstrates how such injections can be useful in identifying cardiac echoes. By verifying the origin of the ultrasound echoes coming from the left ventricle, this study provides evidence substantiating the validity of those ultrasound examinations that depend upon proper identification of these echoes. The results of this study also should be of great assistance to those who are already using or intend to use echocardiography and are faced with the problem of identifying cardiac echoes. In addition, this increase in knowledge concerning the identity of left ventricular echoes should form the basis for the development of newer and even better ways of examining this very important cardiac chamber with ultrasound.

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