Accuracy of Subxiphoid Echocardiography for Assessing Left Ventricular Size and Performance

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SUMMARY  No data are available comparing subxiphoid M-mode echocardiography with left ventricular (LV) cineangiography, although in some patients an LV echogram can only be obtained by this approach. Therefore, we studied 41 patients without coronary artery disease and with symmetric ventricular contraction documented by cineangiography. Twenty-three patients had adequate LV echograms recorded from both the subxiphoid and standard left sternal border (LSB) transducer positions and were analyzed further. Estimations of end-diastolic volume, end-systolic volume and ejection fraction from the subxiphoid echogram compared favorably with the angiographic determinations (r = 0.92, 0.98 and 0.78, respectively). End-diastolic volume by subxiphoid echo averaged 138 ± 94 ml (SD), not statistically different from the angiogram volume of 135 ± 91 ml. Subxiphoid echo overestimated ejection fraction at 71 ± 15% compared with 58 ± 16% by angiography (p < 0.001), as did the standard LSB echo technique at 69 ± 17% (p < 0.001). Mean LV measurements by both echo methods were nearly identical: end-diastolic dimension, subxiphoid 5.0 ± 1.0 cm and LSB 5.0 ± 1.0 cm (r = 0.94); end-systolic dimension, subxiphoid 3.5 ± 1.2 cm and LSB 3.4 ± 1.3 cm (r = 0.99); percent dimensional shortening, subxiphoid 35 ± 10% and LSB 34 ± 11% (r = 0.95); mean normalized rate of dimensional shortening, subxiphoid 1.4 ± 0.4 sec⁻¹ and LSB 1.3 ± 0.4 sec⁻¹ (r = 0.90). Therefore, subxiphoid echocardiography, like the standard LSB method, is a valid technique for assessing LV size and performance in patients without LV dyssynergy.

M-MODE ECHOCARDIOGRAPHIC estimates of left ventricular size and performance from the standard left parasternal approach have generally correlated well with similar determinations by left ventricular cineangiography.¹⁻⁴ The correlation between the techniques is especially high when patients with coronary artery disease and other causes of asymmetric ventricular contraction are excluded.⁵,⁶ Unfortunately, adequate echocardiograms of the left ventricle cannot always be obtained in every patient using the standard approach. Chang, Feigenbaum and Dillon reported that left ventricular echograms could be recorded in some patients by using a subxiphoid transducer position. Also, in patients where left ventricular echograms could be recorded by both positions, they found that subxiphoid ventricular dimension measurements were similar to those by the standard parasternal approach.⁷⁻¹⁰ Kline and associates found that left ventricular echograms could only be recorded in their patients with chronic lung disease by the subxiphoid approach and that abnormal echo measures of left ventricular size and performance in these patients accurately identified those with high pulmonary artery wedge pressures and reduced radionuclide ejection fractions.¹¹

However, there has been no systematic study comparing left ventricular echocardiographic measures obtained by the subxiphoid transducer position to the results of left ventricular cineangiography. Accordingly, we prospectively evaluated left ventricular size and performance by M-mode echocardiography using both the subxiphoid and the standard parasternal approach in patients without coronary artery disease and with cineangiographically demonstrable symmetric left ventricular contraction. The purposes of this study were: 1) to assess the yield of adequate left ventricular echograms by the subxiphoid transducer position; 2) to compare measures of left ventricular size and performance by this technique to the results of the standard left parasternal echogram and left ventricular cineangiography; and 3) to assess the limitations and interpretive difficulties of subxiphoid echocardiography.

Methods

Patients

Forty-one patients in sinus rhythm without conduction disturbances or aortic regurgitation were evaluated.¹²⁻¹⁴ Symmetric left ventricular contraction and the absence of coronary artery disease were documented by cineangiography in all patients before inclusion in the study. Our patients were not preselected on the basis of a particular body habitus in which the subxiphoid echogram may have greater value than the standard approach for assessing left ventricular size and performance. Twenty-three of the 41 patients (56%) had high-quality left ventricular echograms obtained by both echocardiographic transducer positions and were analyzed further. There were five men and 18 women. Their ages ranged from 26–71 years (mean 50 years). Seventeen patients were studied for atypical chest pain and were found to have normal coronary arteries; three patients had primary
congestive cardiomyopathy; one patient had mitral stenosis; one patient had a ventricular septal defect; and one patient had constrictive pericarditis.

Echocardiograms

Echocardiograms were performed within 48 hours of cardiac catheterization on either a Picker Echoview System 80-C interfaced with an Irex 101 Continutrace strip chart recorder or an Electronics for Medicine Echo IV System. Transducers were either a 2.25-MHz, 7-cm focus or a 1.9-MHz, 10-cm focus. The standard left parasternal transducer position for obtaining left ventricular echoes was used as previously described.15 The subxiphoid echocardiographic technique of Feigenbaum was used.16 Briefly, patients were positioned supine or in a shallow, left lateral decubitus position. Their heads were slightly elevated to 20–30°. The transducer was positioned to the right of the xiphoid process, depressed beneath the xiphoid process, and angulated leftward and slightly posterior toward the left clavicle. This required relaxed abdominal musculature that was facilitated by flexing the legs. After the mitral valve was visualized, the transducer was angulated inferiorly. When the left septal and left ventricular posterolateral wall endocardial echoes were clearly identified at the level of the chordae tendineae just below the mitral valve leaflets, the left ventricular echogram was recorded. A representative example of left ventricular echograms by both echocardiographic transducer positions is shown in figure 1.

The following measurements were made on the echograms using our previously described technique:14 1) End-diastolic dimension (EDD) was measured from the left septal endocardial echo to the posterolateral left ventricular endocardial echo at the peak of the QRS complex. 2) End-systolic dimension (ESD) was taken as the minimum distance between the two endocardial surfaces during systole. 3) Left ventricular ejection time (ET) was measured from the simultaneous indirect carotid pulse tracing. 4) Heart rate was determined from the simultaneously recorded ECG. Each measurement represents the average of at least five beats.

The following calculations were performed from these measures: 1) End-diastolic volume (EDV) and end-systolic volume ( ESV) were obtained by cubing the corresponding dimensional measures. 2) Ejection fraction (EF) was calculated as:

$$EF = \frac{EDD^3 - ESD^3}{EDD^3} \times 100\%.$$ 3) Percent dimensional shortening (%ΔD) was calculated as:

$$%\Delta D = \frac{EDD - ESD}{EDD} \times 100\%.$$ 4) Mean normalized rate of dimensional shortening (Vd) was calculated as:

$$Vd = \frac{EDD - ESD}{EDD \times ET}.$$  

Cineangiograms

Contrast ventriculography was performed in the 30° right anterior oblique position with a power injection of 40–50 ml of Renografin-76 (meglumine diatrizoate) at 15 ml/sec and 400–500 p.s.i. Cine-frames were exposed at 60 frames/sec. A grid con-

![Figure 1. Left ventricular echograms from one of our patients by the subxiphoid (left panel) and standard (right panel) transducer positions. Note both the characteristic increase in echo densities between the transducer and left ventricular cavity, and smaller scale with the subxiphoid approach. CPT = carotid pulse tracing; EDD = end-diastolic dimension; ESD = end-systolic dimension. One-centimeter scales are at the left of each panel.](http://circ.ahajournals.org/)

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sisting of 1-cm squares was used to correct for magnification. End-diastole was inscribed after atrial systole at the point of maximal outward displacement of the left ventricle and end-systole at the point of maximal inward motion. The left ventricular long axis was measured from the midpoint of the aortic valve plane to the apex.\(^\text{17}\) Angiographic volumes were calculated by the area-length method using the Kasser-Kennedy method.\(^\text{18}\)

Data Analysis

The subxiphoid echoes, the standard echoes and the angiograms were reviewed by three investigators, each of whom did not have knowledge of the results of the other two. The corresponding dimensions, volume estimates and performance indices determined by each technique were compared using the \(t\) test for paired data. Also, correlation coefficients and standard errors of the estimate were determined by linear regression analysis.

Results

Of the 41 patients prospectively analyzed in this study, 32 (78\%) had technically adequate left ventricular echograms obtained from the standard left parasternal approach. From the subxiphoid transducer position, 26 patients (63\%) had similar adequate left ventricular echograms. Nine patients (22\%) had acceptable left sternal border and poor subxiphoid echograms; and conversely, three patients (7\%) had good subxiphoid and poor left sternal border echograms. Therefore, the overall yield of adequate left ventricular echograms increased to 35 of 41 patients (85\%) with the addition of the subxiphoid echocardiographic approach. In six patients (15\%) neither echocardiographic technique could record the left ventricle adequately.

Subxiphoid vs Left Sternal Border Echogram

In the 23 patients with technically adequate left ventricular echograms by both techniques, the subxiphoid echo EDD (±SD) averaged 5.0 ± 1.0 cm (range 3.2–7.3 cm) and the average value of the left parasternal EDD was also 5.0 ± 1.0 cm (range 3.4–7.4 cm). As illustrated in figure 2 (left panel), the correlation coefficient (0.94) between the two measures of EDD was excellent and the SEE (0.08) was small.

ESD by the subxiphoid and left sternal border techniques averaged 3.3 ± 1.2 cm (range 1.5–6.2 cm) and 3.4 ± 1.3 cm (range 1.7–6.6 cm), respectively. No significant difference was noted; and as demonstrated in figure 2 (right panel), the correlation coefficient was excellent (0.99) and the SEE was negligible (0.03). The average dimensional shortening for the subxiphoid echo technique was 35 ± 10\% (range 10–52\%) and for the left sternal border technique was 34 ± 11\% (range 8–51\%), which were not significantly different. The high correlation \((r = 0.95)\) and the small SEE (0.06) are shown in figure 3 (left panel).

The values for mean normalized rate of dimensional shortening from the subxiphoid and left parasternal transducer positions averaged 1.4 ± 0.4 sec\(^{-1}\) (range 0.5–2.0 sec\(^{-1}\)) and 1.3 ± 0.4 sec\(^{-1}\) (range 0.4–2.0 sec\(^{-1}\)), respectively. No significant difference in these values was found. The correlation coefficient was good (0.90) and the SEE was small (0.09) (fig. 3, right panel).

**Figure 2.** Left ventricular end-diastolic dimensions (left panel) and end-systolic dimensions (right panel) from the subxiphoid approach (ordinates, EDD\(_{\text{SUB X}}\) and ESD\(_{\text{SUB X}}\)) is compared with the standard method (abscissas, EDD\(_{\text{LSB}}\) and ESD\(_{\text{LSB}}\)). The line of identity (dark line), regression line (broken line) and 95\% confidence limits (fine lines) are shown in each panel. The regression equation, correlation coefficient, and standard error of the estimate are included.
Subxiphoid and Left Sternal Border Echograms vs Angiography

EDVs from the subxiphoid echograms and from the left sternal border echogram were 138 ± 94 ml (range 33–386 ml) and 138 ± 93 ml (range 38–375 ml), respectively. These values were not statistically different from the angiographically determined EDV of 135 ± 91 ml (range 52–374 ml). The subxiphoid EDV correlates well with the angiographically determined EDV (r = 0.92, SEE = 0.09; fig. 4, left panel). Similarly, a high correlation (r = 0.90) and small SEE (0.10) were obtained between the left sternal border EDV and angiographically determined EDV (fig. 4, right panel).

The subxiphoid ESV of 52 ± 67 ml (range 4–243 ml) and the left sternal border ESV of 57 ± 78 ml (range 5–291 ml) are both significantly different from the angiographically determined ESV of 66 ± 75 ml (range 19–300 ml) at p < 0.01. Both echocardiographic techniques underestimate the volume of the smaller ventricles. However, the ESV obtained by both echocardiographic methods correlates well with the angiographic ESV (r = 0.98) and the SEE is negligible (0.04) (fig. 5).

Left ventricular volumes were also calculated for
both echocardiographic techniques using a regression equation that compensates for large and small ventricles that are probably not ellipsoidal. The resulting correlations with angiographic volumes were not different.8

Both echocardiographic methods overestimate EF compared with angiography. The EF obtained from the subxiphoid echo method and from the left sternal border approach were 71 ± 15% (range 26-89%) and 69 ± 17% (range 22-88%), respectively. When these values were compared with the angiographic EF of 58 ± 16% (range 22-78%), significant differences were obtained at the p < 0.001 level. Twenty-one of 23 patients from the subxiphoid approach and 22 of 23 patients from the standard parasternal approach had ejection fractions lying on or above the line of identity compared with the angiographic EF (fig. 6). The correlation between the subxiphoid and angiographic EF was good (r = 0.78) and the SEE was small (0.13). Similarly, the left sternal border EF correlated well with the angiographic EF (r = 0.82) with an equally small SEE (0.13). The percent dimensional shortening (%ΔD) by both the subxiphoid and left sternal border echo techniques compared well with the angiographic EF (r = 0.75 and 0.78, respectively). However, the SEEs were moderately large (6.62 and 7.04, respectively).

Discussion

The subxiphoid and left sternal border echocardiographic techniques should provide similar information concerning left ventricular size and performance if certain assumptions are true. These assumptions are: 1) The left ventricular cavity is represented best by a prolate ellipse; and 2) both the subxiphoid and the left sternal border echocardiographic approaches identify a left ventricular minor dimension. Initial angio-

graphic investigations provided evidence that the prolate ellipse was the best geometric reference figure for the left ventricular cavity.17 Consequently, for an echocardiographic method to adequately reflect left ventricular volume, a left ventricular minor dimension should be closely approximated. The standard echocardiographic and cineangiographic left ventricular dimensional measurements have correlated well in several studies.1, 2, 5, 6 Consequently, some investigators believe the minor axis of the left ventricle is identified by the standard left parasternal approach.1, 2 However, Feigenbaum et al. suggested that the echo beam actually traverses the left ventricular cavity obliquely.3 An obliquity of only 10° off the minor axis can produce an error in minor dimensional measurements of 5–10%,13 which would be magnified in a left ventricular volume calculation. Nevertheless, the resultant volume calculations from these echocardiographic dimensional measurements have correlated well with angiographic volumes in many studies,1, 2, 5, 6 suggesting that a minor axis is closely approximated. In addition, %ΔD, whether of a minor dimension or not, should reflect left ventricular performance in a symmetrically contracting ventricle.19

Chang and Feigenbaum, in a group of 22 patients with adequate subxiphoid and left sternal border echograms, found comparable values for left ventricular internal dimensions.9 These data implied that the left ventricles of their patients were symmetrical and that the true minor dimension was being recorded by both echo approaches. If these suggestions are valid, an imaginary plane could be constructed perpendicular to the midpoint of the left ventricular long axis yielding an infinite number of nearly identical minor axes, one of which might be identified by each of these echo methods. To test these assumptions and to further validate the subxiphoid technique, we compared estimates of left ventricular size and per-
formance from the subxiphoid transducer position with the standard left parasternal transducer position and with the results of cineangiography in the same patient.

In our study population, the subxiphoid echocardiographic EDD and ESD correlated highly with similar determinations by the left sternal border approach. Since EDD and ESD by these two echocardiographic techniques were not statistically different, correlated highly, and had negligible standard errors of the estimate, it would suggest that one of many almost identical left ventricular minor dimensions was identified by each echo method. Although each of these echo approaches examined a different area of the left ventricle, %ΔD and mean normalized rate of dimensional shortening correlated highly for both echocardiographic methods. Consequently, not only are similar minor axes probably identified, but in patients with symmetric left ventricular contraction, left ventricular performance in different segments of the left ventricle is also nearly identical.

Using the standard left parasternal echocardiographic approach alone, good correlations have been found between echocardiographically determined volumes and ejection fraction, whether calculated as the cube of the dimensional measures2–3,5,7 or by regression equations,1,8 and angiographic volumes and ejection fraction. In our group of patients, calculations of EDV, ESV and EF by both the subxiphoid and left sternal border echocardiographic techniques correlated well with the corresponding angiographic volumes and EF. Left ventricular EDV by echo was not overestimated in most of our patients with enlarged left ventricles on angiography as previously reported.1,8 Using our upper limit for the normal range of EDV of 172 ml for angiography20 and 171 ml for echocardiography (unpublished data in our laboratory on 50 normal subjects), one patient had an abnormally large volume by the subxiphoid approach and angiography, while the left sternal border echogram misrepresented the volume as within the normal range. Both echo methods significantly underestimated ESV, which was primarily noted for volumes of less than 50 ml. Therefore, at these volumes in small ventricles and at end-systole, the ellipse model is probably no longer a valid assumption for volume calculations, since the minor dimension becomes less than one-half the long axis.19

As a consequence of both echocardiographic methods underestimating ESV, EFs were usually overestimated (fig. 6). This finding concurs with the previous report of Quinnones et al. for the left sternal border method alone.7 Using 56% as the lower limit of the normal range for angio EF20 and 61% for echo EF in our laboratory (unpublished data), two patients had depressed EFs by cineangiography and normal EFs by subxiphoid echocardiography. Also, one of these two patients had a normal EF from the standard echo approach. For this group of patients, the %ΔD determined by both echo techniques did not improve on the direct correlations between echocardiographic and angiographic EF. This is similar to data reported for the standard parasternal echogram alone.7 When both echocardiographic EFs were compared with the angiographic EF, the standard errors of the estimate were small. However, the standard errors of the estimate were moderately large when %ΔD by both echocardiographic techniques was compared with the angiographic EF. This suggests that the angiographic EF is much better estimated by the echocardiographic EF than by the %ΔD. Therefore, the subxiphoid and standard echocardiographic techniques provide similar information about left ventricular volumes and EF in patients with symmetrically contracting ventricles, and both predict to a similar degree the corresponding angiographic data.

Despite these favorable results, the subxiphoid echocardiographic technique has limitations. We could obtain adequate left ventricular echograms in only 26 of 41 patients (63%) by this approach. Patients who did not have adequate subxiphoid echograms were usually obese and presumably had high diaphragms and a horizontal cardiac position. In two patients excluded from this study, one for poor posterolateral left ventricular wall definition and the other because of atrial fibrillation, paradoxic septal motion from the subxiphoid transducer position was noted. In each case, septal motion from the left parasternal approach was normal. This particular disparity may well be due to the level at which the echo beam traversed the septum from the subxiphoid approach in these two patients. If the echo beam crossed the septum somewhat superior to the hinge point, paradoxic septal motion would be recorded where normal septal motion would be expected below this point.21 This may have been the case in the patient where the mitral annulus rather than the left ventricular wall was recorded posteriorly. The problem in the patient with atrial fibrillation is unclear. Perhaps he had a small isolated area of abnormal septal movement not detected by cineangiography, although he was free of coronary artery disease. Since the subxiphoid approach examines a different part of the septum than that transversed from the standard parasternal position, such areas may be detected by this technique. Indeed, the ability to observe the more posterior aspect of the septum from the subxiphoid position could be of value in detecting the extent of myocardial damage in patients with coronary artery disease.

Implications

The percentage of patients in whom an echogram of the left ventricle cannot be satisfactorily obtained from the left sternal border transducer position ranges from 18–26%.2,5,11 We obtained adequate left ventricular echograms from the left sternal border approach in 78% of our patients. In the nine patients who had inadequate left sternal border echograms, three had adequate subxiphoid echograms of the left ventricle, decreasing the number of inadequate echograms by one-third. This improvement occurred in three patients who had barrel-chest configurations secon-
boundary to emphysema. Consequently, the subxiphoid echocardiographic technique permits adequate left ventricular echograms in certain patients in whom left ventricular size and performance could not otherwise be evaluated by M-mode echocardiography. In addition, the subxiphoid echocardiographic technique is comparable to the standard left parasatal approach for estimating left ventricular size and performance as determined by cineangangiography. Therefore, we believe that the subxiphoid transducer position is a valid echocardiographic method for assessing left ventricular size and performance in patients with symmetrically contracting ventricles.

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