Relationship Between Echocardiography, Cardiac Output, and Abnormally Contracting Segments in Patients with Ischemic Heart Disease

By R. Leldon Sweet, M.D., Roger E. Moraski, M.D., Richard O. Russell, Jr., M.D., and Charles E. Rackley, M.D.

SUMMARY
Twenty-four patients with proven coronary artery disease and abnormally-contracting segments were studied by both echocardiography and biplane angiographic techniques. Comparison was made between the left ventricular biplane angiographic volumes and those obtained from echocardiographic measurements which were calculated from cubed function and regression equation methods. The percent abnormally contracting segment (ACS) was obtained from biplane left ventricular angiography and was calculated from the diastolic and systolic anteroposterior and lateral angiograms. The angiographic end-diastolic volume correlated with that calculated from the echocardiographic dimensions with an r value of 0.865 and SE of ± 2.64 ml. The angiographic end-systolic volume and echo end-systolic volume did not correlate as well, with an r = 0.7063. The difference in stroke volume predicted by the diastolic and systolic echocardiographic dimensions and the actual stroke volume determined by Fick technique was related to the percent abnormally contracting segment of the left ventricle (r = 0.8967). The percent ACS could be estimated from echo and Fick stroke volume measurements by the cube function and regression equations. Echo ventricular volume determinations were analyzed for the cube function method and the regression equations of Fortuin et al. and Teichholz and coworkers, with the methods of Fortuin et al. producing the most sensitive relationship: % ACS = 0.32 (SV echo - SV Fick) % + 8.9%. The correlation coefficient for the estimate was 0.8967 with a SE of ± 4.78 %.

In patients with coronary artery disease and abnormally contracting segments, echocardiography can provide reliable measurements of left ventricular end-diastolic volume but estimates of end-systolic volume are less accurate. If mitral regurgitation or a ventricular aneurysm can be excluded, the difference in echocardiographic and forward stroke volume by an independent method is related to the angiographic abnormally contracting segment, and this relationship permits estimation of the size of the abnormally contracting segment.

Since the introduction of echocardiography as a clinical cardiovascular technique, its applications have rapidly expanded. An area which has attracted considerable interest is the generation of data on left ventricular volumes and function. Previous studies by several investigators have compared ventricular volumes calculated from left ventricular interval dimensions by echocardiography to those obtained from biplane angiography.\(^1\)\(^,\)\(^2\) A good correlation over a wide range of ventricular volumes was reported in patients with symmetrically contracting ventricles. More recently, questions have arisen over the validity of echocardiographic volume estimates in patients with segmental abnormalities of ventricular contraction and also in patients with very large ventricular volumes.\(^3\)\(^,\)\(^4\)

This study was undertaken to compare the reliability and reproducibility of echocardiographically determined left ventricular volumes to those made from biplane angiography in patients with abnormally contracting segments. The discrepancy in end-systolic volume and stroke volume documented by the two methods was utilized to estimate the size of the abnormally contracting segment of the left ventricle.

Methods and Materials
In 24 patients undergoing right and left heart catheterization and biplane angiography, comparison was made between echocardiographic left ventricular end-diastolic volume, end-systolic volume, and stroke volume with similar measurements obtained from angiographic tech-
niques. All patients had angiographically demonstrated segmental abnormalities in left ventricular contraction and significant coronary artery disease by coronary arteriography. Patients with associated valvular disease, mitral regurgitation, left-to-right shunts, and ventricular aneurysms were specifically excluded from the study. This group was composed of 22 males and two females, with a mean age of 45 years. The patients were studied supine in the postprandial state. Duplicate resting determinations of cardiac output were obtained by the Fick principle. Both angiographic and echocardiographic studies were obtained within the same 24 hour period. Coronary arteriograms were performed by the Judkins' technique using cineangiography and large film angiography in several radiographic projections. Patients received atropine as a routine medication, but nitroglycerin was not administered routinely unless severe chest pain developed. Significant coronary artery disease was judged to be present when there was 50% or greater luminal narrowing in at least one projection.

Angiographic Ventricular Volume Measurements

Following coronary arteriography, a #8 pigtail catheter was advanced retrograde from the femoral artery into the left ventricle. During a period of observation for at least 10 minutes, patients remained comfortable and hemodynamic measurements were similar to those observed during the determination of cardiac output. After the injection of 50 to 60 ml of 76% sodium and meglumine diatrizoate into the left ventricle, biplane angiograms were taken at six frames/sec. Left ventricular volumes were calculated utilizing the area-length method of Dodge and co-workers. The size of the abnormally contracting segment of the ventricle was calculated according to the method of Feild et al. and expressed as a percentage of diastolic ventricular perimeter. Both the anteroposterior (AP) and lateral views were analyzed with the central X-ray beam marker and edge of the film being utilized for superimposition of the systolic and diastolic angiograms. The perimeter of the diastolic silhouette in both views was measured, and then the systolic angiogram superimposed. The length of abnormally contracting segment was identified, measured, and expressed as a percentage (% ACS) of the diastolic ventricular perimeter. An average value for the abnormally contracting segment was derived from both AP and lateral silhouettes.

Echocardiographic Measurements

The ultrasound examinations were performed with a commercially available ultrasonoscope utilizing a 2.25 MHz transducer, 0.5 inches in diameter, with a 10 cm focal length and a repetition rate of 1000 cycles/sec. The technique described by Feigenbaum et al. and by Popp and Harrison was followed for recording the echoes. All patients were examined in the reclining position with approximately 30° elevation of the head of the bed. Aquasonic gel was used to insure optimal contact of the transducer with the chest wall. The transducer was placed at the fourth and fifth interspace to the left of the sternum and was directed posteriorly and somewhat laterally and inferiorly until a strong posterior left ventricular wall and pericardial echo was recorded. The transducer was then rotated superomedially until the mitral valve motion was identified. The coarse and near damping and reject modalities were adjusted to obtain simultaneously clear recordings of the septal and posterior wall and the cardiac surfaces. The slow sweep of the time motion presentation was used in recording the echoes on a strip chart record-

ing system. Calibration was performed by recording dots that represented 1 cm separation in vertical distance and 0.5 sec separation in horizontal distance. A simultaneous electrocardiogram was recorded for timing and identification of echoes in the cardiac cycle.

The left ventricular dimensions at end-diastole and end-systole were measured from the endocardial echoes of the posterior left ventricular wall to the left side of the interventricular septal echo using as reference the simultaneously recorded electrocardiographic lead. The diastolic dimension was always measured perpendicularly on the record at the peak of the electrocardiographic R wave and the systolic dimension perpendicularly at the end of the T wave. The relationship of the ultrasonic beam to the lateral diastolic and systolic angiograms is illustrated in figure 1. Observations on the extent of the systolic movement of the interventricular septum and posterior wall of the left ventricle were also recorded.

The ultrasonic examinations were performed before angiographic studies, and all left ventricular dimension and volume calculations made before the angiographic determinations were known. The echocardiographic measurements were made by two observers, and all measurements were expressed as average values.

Echocardiogram Calculation

Estimates of left ventricular volume were obtained by the cubed function technique of Pombo and associates as follows:

\[ \text{EDV} = (D_d)^3 \]

where \( \text{EDV} = \) end-diastolic volume in ml; \( D_d = \) echocardiographic diastolic dimension in cm. and

\[ \text{ESV} = (D_s)^3 \]

The direction of the ultrasonic beam is superimposed on lateral end-diastolic (solid line) and end-systolic (dashed line) angiograms in a patient with coronary artery disease and an abnormally contracting segment of the ventricle. The solid dot is the lead marker used as the central reference point to superimpose the angiograms. For orientation the top of the illustration would represent the sternum and the lower portion, the spine. The inferior abnormally contracting segment would not influence the end-diastolic and end-systolic echocardiographic dimensions, but the echocardiographic end-systolic volume would calculate smaller than the angiographic end-systolic volume.
where ESV = end-systolic volume in ml; \( D_s \) = echocardiographic systolic dimension in cm.

The left ventricular volumes were also calculated from the echocardiographic ventricular dimensions employing the volume formulae previously presented by Fortuin and co-workers.\(^4\) The formulae were expressed as follows:

\[
EDV = 59 \times D_s - 153
\]

and

\[
ESV = 47 \times D_s - 120
\]

Left ventricular end-diastolic and end-systolic volumes were calculated by the respective echocardiographic dimension using the equation described by Teichholz et al.\(^10\)

\[
V = \frac{7.0}{2.4 + D^3}
\]

where \( D \) = either echocardiographic diastolic or systolic dimension in cm.

Left ventricular stroke volume was calculated from the difference between end-diastolic volume and end-systolic volume.

### Statistical Methods

Statistical analysis of the data obtained was performed by linear regression methods. Standard error of the estimates are given for EDV, ESV, and \%ACS.

### Results

Table 1 summarizes the echocardiographic, angiographic, and hemodynamic findings in the 24 patients studied. All patients were in sinus rhythm for both techniques of study, and the heart rates during echocardiographic and angiographic studies were comparable. However, in patients 4, 8, 9, and 16, there was variation in heart rate greater than 17 beats per minute between the ultrasonic and angiographic examinations. There was generally close agreement between determinations of the stroke volume obtained from the Fick technique and the angiographic

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Echocardiographic, Angiographic, and Hemodynamic Findings in 24 Patients with Coronary Artery Disease and Abnormal Wall Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Echo EDV(ml)</td>
</tr>
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<td>5.10 3.20</td>
</tr>
<tr>
<td>2</td>
<td>6.25 5.00</td>
</tr>
<tr>
<td>3</td>
<td>5.90 4.85</td>
</tr>
<tr>
<td>4</td>
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<td>6.55 3.70</td>
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<td>4.75 4.00</td>
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<td>4.95 4.30</td>
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<td>5.80 4.40</td>
</tr>
<tr>
<td>24</td>
<td>4.45 3.95</td>
</tr>
</tbody>
</table>

Abbreviations: EDV = end-diastolic volume; ESV = end-systolic volume; SV = stroke volume; ACS = abnormally contracting segment; CA = coronary arteries; Ant = anterior; Inf = inferior; Ap = apical.
method. In four patients, 3, 4, 10 and 16, cardiac output by the Fick method was not completed due to technical difficulties. The echocardiographic calculations of end-diastolic and end-systolic volumes shown in table 1 were calculated from the regression equations of Fortuin and associates. The number of coronary arteries demonstrating significant anatomical lesions is noted as is the size of the abnormal contracting segments of the left ventricle as calculated by the method of Feild et al.\textsuperscript{7}

A comparison of left ventricular volume determinations by the cubed function method of Pombo et al.,\textsuperscript{1} the regression equations of Fortuin and associates,\textsuperscript{2} and the regression equation of Teichholz and colleagues\textsuperscript{10} is presented in table 2. Descriptions of the systolic motion of the interventricular septum and posterior wall of the left ventricle are listed in table 3. Septal and posterior wall motion was described as normal or abnormal, the latter included diminished motion as well as akinesis. In ten of the 24 patients, systolic motion of the ventricular septum or posterior wall was considered abnormal and in one patient both septal movement and posterior wall motion were abnormal. In these 11 patients the area of asynergy probably involved that portion of the ventricle examined with the echocardiogram.

Figure 2 shows the relationship between the left ventricular end-diastolic volumes as measured by this large film biplane angiographic technique and those obtained from echocardiographic left ventricular internal dimension at end-diastole (D\textsubscript{a}) by the equations of Fortuin et al. The correlation coefficient between the angiographic and echocardiographic end-diastolic volumes was quite good, with an r value of 0.865. The end-diastolic volumes by echocardiography ranged from 124 to 269 ml, and by angiography from

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|}
\hline
\textbf{Patient} & \textbf{Pombo\textsuperscript{1}} (ml) & \textbf{Fortuin\textsuperscript{2}} (ml) & \textbf{Teichholz\textsuperscript{10}} & \textbf{Pombo\textsuperscript{1}} (ml) & \textbf{Fortuin\textsuperscript{2}} (ml) & \textbf{Teichholz\textsuperscript{10}} & \textbf{Pombo\textsuperscript{1}} (ml) & \textbf{Fortuin\textsuperscript{2}} (ml) & \textbf{Teichholz\textsuperscript{10}} \\
\hline
1 & 133 & 148 & 124 & 33 & 30 & 41 & 100 & 118 & 83 \\
2 & 244 & 216 & 198 & 125 & 115 & 118 & 119 & 101 & 80 \\
3 & 205 & 195 & 173 & 114 & 108 & 110 & 91 & 87 & 63 \\
4 & 238 & 213 & 194 & 121 & 112 & 116 & 117 & 101 & 78 \\
6 & 150 & 179 & 157 & 51 & 54 & 58 & 129 & 125 & 99 \\
7 & 129 & 146 & 121 & 51 & 54 & 58 & 78 & 92 & 63 \\
8 & 107 & 127 & 105 & 64 & 68 & 70 & 43 & 59 & 35 \\
9 & 216 & 201 & 180 & 66 & 70 & 72 & 150 & 131 & 108 \\
10 & 111 & 130 & 108 & 39 & 40 & 47 & 72 & 90 & 61 \\
11 & 238 & 213 & 194 & 114 & 108 & 110 & 124 & 105 & 84 \\
12 & 176 & 177 & 154 & 80 & 82 & 83 & 90 & 95 & 71 \\
13 & 121 & 130 & 116 & 80 & 82 & 83 & 41 & 57 & 33 \\
14 & 104 & 124 & 102 & 51 & 54 & 58 & 53 & 70 & 44 \\
15 & 157 & 166 & 141 & 101 & 99 & 100 & 56 & 67 & 41 \\
16 & 281 & 234 & 220 & 157 & 134 & 141 & 124 & 100 & 79 \\
17 & 185 & 183 & 160 & 104 & 101 & 102 & 81 & 82 & 58 \\
18 & 145 & 157 & 132 & 71 & 75 & 76 & 74 & 82 & 56 \\
19 & 185 & 183 & 160 & 91 & 92 & 92 & 94 & 91 & 68 \\
20 & 125 & 142 & 118 & 51 & 54 & 58 & 74 & 88 & 60 \\
21 & 149 & 159 & 135 & 74 & 77 & 79 & 75 & 82 & 56 \\
22 & 140 & 154 & 130 & 64 & 68 & 70 & 76 & 86 & 60 \\
23 & 195 & 189 & 167 & 85 & 87 & 88 & 110 & 102 & 79 \\
24 & 162 & 169 & 144 & 62 & 66 & 68 & 100 & 103 & 76 \\
\hline
\end{tabular}
\caption{Comparison of Left Ventricular Volume Determinations by Three Methods}
\end{table}

\textsuperscript{Comparison of Left Ventricular Volume Determinations by Three Methods}

Figure 2

Measurements of left ventricular end-diastolic volume calculated by echocardiography and angiography using the regression equation of Fortuin et al. are compared in 24 patients with coronary artery disease and abnormally contracting segments.
The echocardiographically determined end-systolic volumes varied from 30 to 148 ml and angiographic volume from 53 to 212 ml. The echocardiographically determined end-systolic volumes were smaller than those measured by angiography in 21 of the 24 patients.

As shown in Table 1, the disparity between echocardiographic and angiographic end-systolic volume determinations resulted in a difference in left ventricular stroke volume between the two methods. The echocardiographically calculated stroke volume is generally larger than the angiographic or Fick stroke volume measurements in the same patient. This difference in echo and Fick stroke volume resulted from the underestimation of the left ventricular end-systolic volume by the ultrasonic technique. Figure 4 demonstrates that the difference in echocardiographic stroke volume and Fick stroke volume is related to the extent of abnormally contracting segments calculated from biplane angiography. The relationship was found to be highly significant with a correlation coefficient of 0.8967. When the angiographic abnormally contracting segment was less than 9%, stroke volume measurements were either similar by ultrasonic and Fick techniques or the Fick stroke volume was larger than the echocardiographic value.

From the first 12 patients studied, a regression equation was developed from the method of Fortuin et al. to predict the percentage abnormally contracting segment of the left ventricle.

\[
\% \text{ ACS} = 0.32 (SV_{echo} - SV_{Fick}) + 8.97\%
\]

where \% ACS = percent abnormally contracting segment.

Table 3
Echo Wall Motion

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<th>Patients</th>
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</tr>
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</table>

126 to 275 ml. The standard error of the estimate (SEE) about the regression line was \( \pm 22.64 \) ml.

The comparison of end-systolic volume determinations by angiography and echocardiography is shown in Figure 3. Correlation is less good, with an \( r \) value of 0.7063 and SEE \( \pm 32.05 \) ml.

**Figure 3**
End-systolic volume measurements by echocardiography and angiography are compared in patients with coronary artery disease and asynergy of the ventricle. The correlation coefficient is less that shown in Figure 2 and the standard error of estimate greater. The echocardiographically determined end-systolic volumes were smaller than those calculated by angiography in 21 of the 24 patients.

**Figure 4**
The difference between echocardiographic stroke volume and Fick stroke volume in 20 patients is significantly related to the size of the angiographic abnormally contracting segment.
ment of the left ventricular chamber; SV = stroke volume obtained from echocardiographic and Fick techniques.

The regression equation utilizes the difference in stroke volume measurements obtained by echocardiographic and Fick techniques as a predictor of the percentage of abnormally contracting ventricle.

Since the regression equation was calculated from the first 12 patients, additional regression equations were determined from the 20 patients with echocardiographic and Fick stroke volume measurements by the three methods of echo volume estimations.

The cube function method of Pombo et al. was
\[
\% \text{ACS} = 0.21 \times (SV_{\text{echo}} - SV_{\text{Fick}}) + 10.94 \%
\]
and \( r = 0.91 \) (see \( \pm 4.50 \)).

The regression equation method of Fortuin and associates was
\[
\% \text{ACS} = 0.30 \times (SV_{\text{echo}} - SV_{\text{Fick}}) + 8.41 \%
\]
where \( r = 0.90 \) (see \( \pm 4.78 \)).

The regression equation method of Teichholz and colleagues was
\[
\% \text{ACS} = 0.30 \times (SV_{\text{echo}} - SV_{\text{Fick}}) + 15.93 \%
\]
where \( r = 0.91 \) (see \( \pm 4.43 \)).

In figure 5, the relationship between the ACS determined by difference in echo and Fick stroke volume and the angiographic method is illustrated. In addition to the initial 12 patients who determined the regression equation, eight patients had the percentage abnormally contracting segment predicted prospectively from the echocardiographic and Fick stroke volumes. The estimated abnormally contracting segments calculated from the difference in echocardiographic and Fick stroke volume were similar to those obtained by angiography. When the stroke volume by echocardiography was less than the Fick stroke volume, patients revealed an abnormally contracting segment of less than 9%. In six patients (8, 13, 15, 17, 18, and 20), the echo stroke volume calculated was less than the Fick stroke volume. In five of the six patients there was abnormal motion of either the septum or posterior wall. However, all patients except #13 had an angiographic ACS less than 9% as was predicted by the regression equation.

Discussion

The echocardiogram has enlarged tremendously the horizons in the field of noninvasive cardiology. Initially, attention was focused on the ability to make specific anatomic diagnoses, i.e., mitral stenosis, pericardial effusion, etc. However, as technological advances were made, more definitions of intracardiac structures became possible and internal dimensions could be obtained. Gramiak et al. demonstrated that the intracardiac injection of indocyanine green dye produced a cloud of echoes that completely filled the left ventricular cavity. With clearance of the dye, repeat echograms then clearly defined the limits of the septal and posterior wall endocardium. By recording a simultaneous series of calibration dots 1 cm apart in vertical distance, it became possible to obtain a single dimension of the left ventricular cavity. The dimension delineated by ultrasound lies somewhere between the true long and short diameters of the left ventricle. The relationship obtained by comparison of the echocardiographic dimensions, \( D_c \) and \( D_a \), with the angiographic minor diameter supports the hypothesis that the echo dimension is quite close to the angiographic minor dimension. Nevertheless, major reservations have arisen over the limitations of the single-crystal ultrasonic technique when applied to patients with coronary artery disease.

Pombo et al. proposed that left ventricular volumes could be accurately predicted making several assumptions utilizing the volume formula of a prolate ellipse (D) expressed as \( V = \frac{4}{3} D_1D_2L \) where \( D_1 \) and \( D_2 \) are the angiographic anteroposterior and lateral minor diameters and \( L \) is the longer of the major diameters. The assumptions required for volume estimation from echocardiographic internal dimensions are: 1) the echocardiographic dimension is similar to the angiographic minor diameter; 2) that the longer major diameter (L) is twice the minor diameter; and 3) that ventricular geometry is symmetrical in both diastole.

\[
\text{Figure 5}
\]

In 20 patients, the size of the angiocardiographic abnormally contracting segment was significantly related to the size of the echocardiographic abnormally contracting segment. The 12 patients indicated by the solid circles provided the data for the regression equation derived from the relationship of size by abnormally contracting segment to the difference between echocardiographic and Fick stroke volume. In the eight patients shown with open circles, the size of the abnormally contracting segment was predicted from the echocardiographic and Fick stroke volumes.

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and systole. A major criticism of this method has been that as the ventricle enlarges, the geometry becomes more spherical and less ellipsoid, thus rendering one assumption invalid, i.e., $2 \times D$ becomes considerably greater than $L$. Aware of this potential deficiency, Fortuin and associates examined 27 patients possessing a wide range of ventricular volumes and compared left ventricular volume measurements by echocardiography and biplane angiography. Regression formulae for estimation of ventricular volumes from echo dimensions were expressed as follows: $EDV = 59 D_a^2 - 153$, $ESV = 47 D_a^2 - 120$. Although these formulae do not result in overestimation of the large ventricular volumes, there is a tendency to underestimate the volume of the normal ventricle. In both Pombo's and Fortuin's studies, 27 patients were examined in each study. Pombo's group contained five of 27 with ischemic heart disease, and Fortuin's group contained only one of 27 with ischemic heart disease. In neither study was evidence of abnormal ventricular contraction and/or ventricular aneurysm formation presented. Teichholz et al. more recently noted that a curvilinear relationship was found between $D$ and $L/D$, with $L/D$ varying from less than 1.4:1 for large values of $D$ and volumes to greater than 3:1 for small values. A modification of the cube function was developed by these investigators which was felt to allow more accurate prediction at the extremes of ventricular sizes. As shown in Table 3, the calculations of left ventricular end-diastolic volumes were similar by all three methods of calculation, but the regression formulae of Fortuin et al. provided more accurate measurements over a wide range of ventricular volumes than did the cubed function of Pombo and coworkers or the equation of Teichholz and colleagues.

The present study was composed of a highly select group of 24 patients, all of whom were known to have coronary artery disease and suspected areas of asynergy which were quantitated from biplane angiocardiography. Patients with mitral regurgitation or discrete ventricular aneurysms were specifically excluded from this investigation. Although the dynamic definition of a ventricular aneurysm remains difficult, patients with recognizable distortion of the left ventricle on standard chest films or during fluoroscopy were not included in the present study. For purposes of analysis, the systolic angiocardiograms that had minimal excursion beyond the borders of the diastolic angiocardiograms were considered areas of akinesis rather than aneurysms. This clinical group is thus unique and considerably different in makeup from any previously reported. The patients were selected in this manner to provide objective information on the usefulness of echocardiographic determination of left ventricular volume in coronary artery disease with asynergy.

The end-diastolic volume was reliably estimated from echocardiographic internal dimensions utilizing the cubed function and regression formulae. The regression formulae of Fortuin and associates produced values for the large chamber volumes more similar to those obtained from angiocardiography than did the cubed function equations. The geometry of the systolic silhouette becomes asymmetrical in the presence of ventricular asynergy, and this is the major reason for the lower correlation coefficient between echocardiographic and angiocardiographic estimations of end-systolic volume. The echocardiographically determined end-systolic volumes were smaller than those measured by angiocardiography in 21 of the 24 patients with abnormally contracting segments. This discrepancy can be attributed to the asymmetric contraction of the ventricle due to areas of asynergy, reduced encroachment of the ventricular scar on the area where echo dimensions are recorded and exaggerated wall motion of the segment examined by echo when other areas of the ventricle are not contracting.

The disparity in measurement of end-systolic volume is further evident in the comparison of stroke volume measurements obtained from echocardiography to those calculated from angiocardiography or the Fick technique. This difference in left ventricular stroke volume determinations theoretically is related to systolic changes in ventricular configuration, and the abnormal contraction of a ventricular segment produces an increased end-systolic volume. As a result of this localized asynergy of the ventricle, the echocardiographic stroke volume calculated larger than the angiocardiographic or Fick stroke volume. This difference in stroke volume is related to the extent of abnormally contracting segment. However, significant changes in heart rate may influence the size of the abnormally contracting segment as well as alter the stroke volume determined from the cardiac output. If the echo stroke volume is similar to or less than the Fick stroke volume during similar heart rates, the size of the abnormally contracting segment is less than 9% of the ventricular diastolic perimeter. In five of the six patients in whom the echo stroke volume was less than the Fick stroke volume the angiographic ACS was less than 9%. The data obtained from this investigation indicate that this relationship is significant.

The regression equations developed from the data in this study allow prediction of the size of the abnormally contracting segment of the left ventricle in selected patients with coronary artery disease. The necessary measurements require echocardiography.
and an independent determination of cardiac output. In patients with acute myocardial infarction and suspected asynergy of the left ventricle, cardiac output can be measured by the thermodilution technique with the Swan-Ganz catheter. Mitral regurgitation or a ruptured ventricular septum could be recognized by the right heart procedure. In patients with their initial myocardial infarction a ventricular aneurysm would not develop until the late phases of recovery. Left ventricular dimensions and stroke volume can be obtained from echocardiograms. The stroke volume estimations from echocardiography and thermodilution can then be entered in the regression equation and the size of the abnormally contracting segment estimated. Under these conditions the size of the abnormally contracting segment would reflect the size of the recent myocardial infarction which could be examined serially during the convalescent period.

Therefore, after exclusion of patients with mitral valve incompetence and ventricular aneurysms, the results of the present study on the usefulness of echocardiography in patients with coronary artery disease and abnormally contracting segments of the left ventricle reveal that: 1) echocardiographic end-diastolic volumes correlated with values obtained from biplane angiocardiography; 2) the regression formulae of Fortuin et al provided more accurate measurements over a wide range of end-diastolic ventricular volumes than did the cubed function equation of Pombo and co-workers or the equation of Teichholz and colleagues; 3) the echocardiographic end-systolic volumes did not correlate as closely with the angiocardiographic measurements; 4) the difference between echocardiographic and Fick stroke volume was related to the size of the angiographically determined abnormally contracting segment of the left ventricle; and, 5) a regression equation was derived, % ACS = 0.32 (SVecho - SVFick) + 8.97% which provides an estimate of the size of the abnormally contracting segment of the left ventricle.

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References

Relationship between echocardiography, cardiac output, and abnormally contracting segments in patients with ischemic heart disease.
R L Sweet, R E Moraski, R O Russell, Jr and C E Rackley

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