Left Ventricular Aneurysm
Preoperative Hemodynamics, Chamber Volume, and Results of Aneurysmectomy

By Linley E. Watson, M.D., Donald W. Dickhaus, M.D., and Richard H. Martin, M.D.

SUMMARY
Angiocardiographic characteristics of the residual contracting left ventricle (LV) have been examined in 16 patients with anterolateral ventricular aneurysms (VA). In each patient a contractile section (CS) of the LV was clearly demarcated from the remaining aneurysmal section (AS). Using a double hemispheroid model, volumes of CS and AS were separately estimated by a modified area-length method. The volume of CS plus AS agreed closely with the volume of total LV estimated by the conventional area-length method. End-diastolic volume (EDV) of total LV ranged from 79 to 312 ml/m². Aneurysmal section volume ranged from 8 to 264 ml/m². End-diastolic volume of the contractile section ranged from 52 to 159 ml/m² (mean, 100 ± 8 (SE); normal, 78 ± 6). Contractile section ejection fraction (EF) showed a wide range, from 15% to 79% (mean 40% ± 17% SD). Nine patients underwent resection of VA. Three of six operated patients with CS EF < 44% died; no survivor in this group has improved by more than one functional class (New York Heart Association classification). Three operated patients had CS EF > 45%; all survived and are improved, two having moved from class IV to class I. These data suggest that the EF of the contracting residual LV may be an important predictor of the outcome of resection of VA.

RECOGNITION of ventricular aneurysm is attributed to the English surgeon John Hunter in the 18th century. Successful surgical resection of ventricular aneurysms began in the 1950s, but operation for ventricular aneurysm has an appreciable mortality, and does not always result in dramatic postoperative improvement. This study examined parameters measured during cardiac catheterization of patients with anterolateral ventricular aneurysms to determine their relationship to the severity of the patient's presenting hemodynamic impairment and for their value in predicting the postoperative result.

Case Material
Sixteen patients were studied who had anterolateral ventricular aneurysms detected by left ventricular cineangiography taken in the right anterior oblique projection (RAO). Ventricular aneurysm was defined as a clearly demarcated dyskinetic section of the left ventricle observed during sinus rhythm. The ages of the patients ranged from 44 to 65 years; there were 14 males and two females. The duration of cardiac symptoms ranged from three months to two years prior to the time of catheterization. None had had arterial emboli. Seven of the 16 patients had angina. Fourteen of the 16 had severe congestive heart failure, five being considered New York Heart Association functional class IV and 11, class III. The ECGs of all 16 patients at the time of the study showed diagnostic Q waves and all but one of the ECGs showed persistent ST-segment elevation greater than 0.2 mV in the precordial leads at least three months after the acute myocardial infarction. Two of 16 patients were under treatment for ventricular tachyarrhythmias.

All 16 patients had a greater than 70% occlusion of the left anterior descending coronary artery and 14 had marked obstruction of one or more other major coronary vessels. For comparison, control data were obtained on 11 normal subjects whose catheterization studies showed innocent heart murmurs or noncardiac chest wall pain. This control group did not differ from the patients with respect to sex distribution or body surface area. They were younger, with a mean age of 38 for the control group versus 51 years for the patients.

Nine of the 16 patients underwent surgical resection of the aneurysm. Saphenous vein bypass grafts were implanted in those remaining coronary arteries with significant obstructions. Three of the patients died in the immediate postoperative period and the remaining six have been followed from one to three years. Clinical evaluation of postoperative improvement was assessed at six to 12 months by staff cardiologists who were not aware of the preoperative catheterization results.

Methods
All studies were done with the patients at rest, supine, in postprandial state, and unsedated. Pressures were recorded on a multichannel photographic recorder using strain gauge transducers. Cardiac output was measured by the

From the Division of Cardiology, University of Missouri-Columbia, School of Medicine and Columbia Veterans Administration Hospital, Columbia, Missouri.

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Address for reprints: Linley E. Watson, M.D., Cardiovascular Laboratory, Columbia Veterans Administration Hospital, 807 Stadium Drive, Columbia, Missouri 65201.

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Fick technique or Indocyanine green dye dilution curves. After measuring pressures and immediately after measuring cardiac output, 45 to 55 cc of 75% hypaque were injected into the left ventricular cavity with the patient in the RAO position. Thirty-five millimeter cineangiograms were recorded at 60 frames per second. End-diastolic and end-systolic volumes of the total LV were obtained using the prolate spheroid modification of the area-length method of Dodge and coworkers, after correction for X-ray magnification. Specifically, just prior to left ventriculography, tube height and the long axis of the left ventricle in 45° right anterior oblique as estimated by palpation of the apex point were measured. Subsequently, with the image tube repositioned at the previously measured height, a rectangular grid of known dimension was positioned in the center beam at the same plane as the long axis of the patient's left ventricle and filmed for use to determine X-ray magnification factors. Pincushion distortion of the X-ray equipment used was determined to cause an error of less than 2% in planimetered areas of centered objects occupying up to 90% of the field. Therefore, pincushion distortion was not corrected for individual cases. Coronary arteriography was then carried out. Coronary lesions were graded and scored by the method of Friesinger et al.

Eight nonporous, radiopaque models of known dimensions were filmed in the same average position as the patient studied. The volumes derived by calculation from known dimensions, by area-length calculations from the cineradiographic film projections, and from weighed water displacement were compared. As shown in figure 1, the correlation coefficient of the three methods of volume determination was greater than 0.99. All possible combinations of these eight geometric shapes were again filmed in the same position as used for the patients studied. These known geometric images were then compared visually to the left ventriculograms of the first ten patients studied. The best visual fit between the known geometric model pairs and the ventriculograms of patients with ventricular aneurysms was that of two hemispheres; therefore, the double hemispheric model was used for all subsequent analysis of patients included in this study. Inasmuch as the regression equation derived from the known geometric models did not significantly differ from those reported previously by Kasser and Kennedy, the Kasser-Kennedy regression equation was used in all volume calculations reported in this paper.

In all patients with aneurysms, the left ventriculogram could be readily separated into two sections as shown in figure 2. The section of the left ventricle that showed a definite inward movement of all portions of ventricular wall during systole was denoted as the contractile section. The other portion, denoted as the aneurysmal section, showed systolic expansion with or without associated areas of akinesis during systole. A line of demarcation separating these two sections of left ventricle both at end-diastole and end-systole was drawn; in all cases this line was nearly coincidental at end-systole and end-diastole.

For each of the two sections the longest length perpendicular to the line of demarcation (designated L) was measured as shown in figure 3. The best estimate of the radius (r) perpendicular to L was calculated from the planimetered area of each section by the formula for the area of a hemiellipse where:

\[ r = \frac{2 \cdot \text{Area}}{\pi \cdot L} \]

Substituting for r as obtained above and including the appropriate magnification correction factor and regression coefficient, the formula for the volume (V) of the hemispheroid is:

\[ V = 0.788 \cdot \frac{8A^2}{3\pi L} + 8.4 \]

where 0.788 and 8.4 are regression coefficients, cf is the magnification correction factor, A is the planimetered area of the LV subchamber, and L is the maximum perpendicular length of the subchamber.

Using this technique, four volumes were obtained; i.e., the end-diastolic volumes and end-systolic volumes of the

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Cineradiographic volumes by area-length method of several known geometric models of left ventricle on abscissa compared to direct calculated and water displacement (Archimedes) volumes on ordinate.

Figure 1

Cine Volume (ml) / Planimetered Area (cm²)

V = 0.367 \cdot V_cine \cdot L; \ r = 0.98
V = 0.830 \cdot V_cine \cdot 8.4; \ r = 0.991
A = 0.864 \cdot V_cine + 2.3; \ r = 0.98
V_cine = \frac{2 \cdot \text{Area}}{\pi \cdot L}
V = \frac{8A^2}{3\pi L} + 8.4

Figure 2

Tracing of representative left ventricular angiogram at end-diastole (---) and end-systole (- - - -).
contractile section and of the aneurysmal section, respectively. From these four section volumes, the volume of the total left ventricle could be estimated by algebraic addition of the volumes of each subchamber at end-diastole and end-systole. The ejection fraction (EF) for the total left ventricle and for the contractile section of the left ventricle was calculated from the formula:

$$EF = \frac{(EDV - ESV)}{EDV}$$

The stroke work dissipated into the aneurysm per beat was estimated by the formula:

$$ASW = ASI \times 1.055 \times (SEP - LVEDP) \times 13.6$$

where $ASW = $ aneurysm stroke work (gm-m/beat/m²); $ASI = $ stroke index of aneurysm measured by angiogram (ml); $SEP = $ mean left ventricular systolic ejection pressure (mm Hg); $LVEDP = $ left ventricular end-diastolic pressure (mm Hg); 1.055 is the specific gravity of blood; 13.6 is the specific gravity of mercury. Since the aneurysm expands during systole, the stroke work attributed to it is negative.

Means of normals were compared to patients by Student's t-test and were reported as significantly different if they obtained a t value exceeding the 0.05 level of significance. Parameters measured on the same ventriculogram were compared by the paired t-test. Correlation coefficients for parametric data were calculated and tested to determine whether they were statistically different from zero; correlation of parameters to operative result was done using the Spearman rank correlation coefficient.11

**Results**

End-diastolic volume of the total LV of aneurysm patients was 153 ± 14 ml as estimated by the conventional prolate spheroid area-length method and 163 ± 15 ml when measured as the sum of the volumes of contractile and aneurysmal sections by the hemispheric area-length method. The correlation coefficient for measurements by these two techniques was 0.99 and the regression equation of the double hemispheric on the prolate spheroid volume was $y = 1.06x + 2.4$.

Table 1 presents a comparison of four standard hemodynamic parameters in the normal group and the patients with ventricular aneurysm. Compared to normals, the aneurysm patients had depressed cardiac indices and ejection fractions, elevated end-diastolic pressures and elevated end-diastolic volumes. All differences are significant. These observations are similar to others reported in the literature.2, 12

Ventricular aneurysm end-systolic volume, expansile stroke volume and dissipated stroke work are presented in table 2. These measurements varied widely. Each parameter was examined for correlation with total left ventricular volume, cardiac index, left ventricular end-diastolic pressure and postoperative improvement. No significant correlations were found.

The end-diastolic volume and ejection fraction of the contractile section of ventricles with aneurysms are compared with these measurements of the total

**Table 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normals (mean ± se)</th>
<th>Aneurysm (mean ± se)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI (L/min/m²)</td>
<td>3.6 ± 0.3</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td>LVEDP (mm Hg)</td>
<td>8.7 ± 1.2</td>
<td>26.5 ± 3.1</td>
</tr>
<tr>
<td>Total LVEDV</td>
<td>78 ± 6</td>
<td>163 ± 15</td>
</tr>
<tr>
<td>Total LV EF (%)</td>
<td>66 ± 2</td>
<td>19 ± 2</td>
</tr>
</tbody>
</table>

Abbreviations: se = standard error; CI = cardiac index; LV = left ventricular; EDP = end-diastolic pressure; EDV = end-diastolic volume; EF = ejection fraction.

**Table 2**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Mean ± se</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESV (ml/m²)</td>
<td>8 – 264</td>
<td>71 ± 16</td>
</tr>
<tr>
<td>Expansile SV (ml/m²)</td>
<td>1 – 22</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Dissipated SW (gm/m/beat)</td>
<td>1.3 – 47.9</td>
<td>9.3 ± 3.2</td>
</tr>
</tbody>
</table>

Abbreviations: ESV = end-systolic volume; SV = stroke volume; SW = stroke work.

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**Figure 3**

Double hemispheroid model of RAO left ventriculogram for calculating volumes of contractile section and aneurysmal section individually.
left ventricle of normals in figures 4 and 5. The mean end-diastolic volume of the contractile section was 101 ml/m² compared to 78 ml/m² for the total LV of normals. The contractile portion of left ventricles with aneurysm had an ejection fraction of 40% ± 17 (SD) compared to 66% ± 6 for normals. In three patients the contractile section ejection fraction was within or above the normal range. The ejection fraction of the contractile section did not correlate with the patient's cardiac index, end-diastolic pressure, or ejection fraction of the total left ventricle.

There was no significant correlation between postoperative improvement and the preoperative cardiac index, end-diastolic pressure, total end-diastolic volume, total left ventricular ejection fraction or severity of coronary artery disease. Of all the preoperative parameters studied, only the contractile section ejection fraction (fig. 6) was found to correlate with the result of resection of ventricular aneurysm.

Discussion

The patients in this series do not represent a random sample of the total population of patients with ventricular aneurysm since patients who were not severely disabled were not studied. In addition the results of this study apply only to patients with anterolateral and apical ventricular aneurysms, since the single plane right anterior oblique angiographic technique used does not adequately define inferior and posterior aneurysms. Biplane ventriculography is needed for inferior and posterior aneurysms; however, there is evidence that the left ventricle with anterolateral wall disease in the right anterior oblique view provides an adequate image for the measurements needed to calculate ejection fractions. ¹³

As with all models for estimating ventricular volume from angiographic films, the double hemisphere method described is limited by the degree that the diseased left ventricle conforms to the geometrical model used. To further validate this model would require imaging of pathological specimens of ventricles with ventricular aneurysm and comparison of

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**Figure 4**

End-diastolic volumes of normal left ventricle compared to the contractile section of left ventricles with aneurysm. Bars represent mean plus or minus standard error of mean.

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**Figure 5**

Ejection fraction of normal left ventricles compared to the contractile section of the left ventricles with aneurysms. Bars represent mean plus or minus standard error of mean.

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**Figure 6**

Correlation of contractile section ejection fraction to postoperative outcome. Improvement scored by change in NYHA function classes, e.g., a preoperative class IV to a postoperative class III improved by 1; a class IV to class I, by 3, etc.
calculated and true volumes. Pathological material was not available to us and would likely be limited to inoperable cases.

If the proposed model permits a legitimate estimate of the volumes of the contractile and aneurysmal sections, the algebraic sum of the two sections should agree with the total left ventricular volume as calculated by the conventional area-length method. This was indeed found to be the case, although the double hemispheroid model overestimated the total left ventricular volume by about 6%.

The results of this study suggest that the absolute volume of the aneurysm, of the contractile section, and of the total left ventricle are not sensitive parameters in determining the outcome of resection of ventricular aneurysm, and that only the ejection fraction of the contractile section is important in this regard. Since the ejection fraction is a rational number, the proportional errors involved in absolute volume calculations cancel out, thereby reducing the importance of potential errors in absolute volume estimation.

This investigation represents the first study using a double hemispheroid model to analyze ventriculography with respect to preoperative hemodynamic parameters and clinical result of aneurysmectomy. Kitamura et al. studied a group of 25 cases with akinetic as well as dyskinetic ventricles. We were unable to reproduce their relationship between parameters of depressed left ventricular function and noncontractile surface area. The difference in our results may be due to the fact that Kitamura et al. combined dyskinetic and akinetic segments of the left ventricle in their analysis. They employed formulae for estimating the surface area of the akinetic portion of the left ventricle as discussed by Crawford et al. Our hemispheroid model was applied only to angiograms with predominantly dyskinetic abnormalities since we and others believe the presence of dyskinesis to be essential for the angiographic diagnosis of ventricular aneurysm. Key et al. comment upon "good left ventricular deep constrictor activity" and good operative results. Kluge et al. classified the "quality of basal myocardial contractility" and described a relationship to immediate postoperative survival, although statistical analysis was not performed. The current study is consistent with their opinions and offers a quantitative method to measure the function of left ventricular contractile section. Basta et al. reported measuring the ejection fraction of the left ventricle exclusive of aneurysm in patients with refractory ventricular arrhythmias due to both traumatic and postinfarction aneurysms. The method they employed, as described originally by Lewis and Sandler, estimates ejection fraction from changes in the minor axis; however, Lewis and Sandler specifically excluded patients with localized disorders of contraction.

Within this group of patients, all of whom were preselected for severe symptomatology, there was no relationship between relative symptomatology and the size of the aneurysm. This finding may represent an artifact, since patients were chosen for study because of severe symptoms and could have been expected, therefore, to have severe hemodynamic impairment. It would also be expected if the population studied represented patients with a combination of two problems, namely mechanical disadvantage from the ventricular aneurysm per se, and impairment of the pumping function of the residual contractile left ventricle. The data suggest that these problems were indeed present to variable degrees in individual patients.

Since the contractile section as defined in this study represents that portion of the left ventricle which will remain after resection of ventricular aneurysm, an estimate of the performance of this section as a pump preoperatively would be expected to be an important determinant of the operative outcome. Our data, while limited, appear to support this prediction, and thus agree with the results of studies which have shown the ejection fraction of the total left ventricle to be an important predictor of the outcome of open heart surgery. 21-22

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