Ventriculographic Features Predictive of Surgical Outcome for Left Ventricular Aneurysm

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SUMMARY Although clinical and hemodynamic stability predicted outcome very well when left ventricular aneurysm was electively resected in 25 patients (95% survival), more discriminate criteria were essential for 20 patients undergoing urgent operation for severe myocardial decompensation (50% survival).

Three methods of ventriculographic analysis primarily sensitive to the function of the non-aneurysmal left ventricle were evaluated. These methods separated patients undergoing urgent operation into a population with high operative risk (<18% survival) and a population with low operative risk (>82% survival). These criteria also separated 15 patients undergoing operation within three months of myocardial infarction into a group with excellent prognosis (>85% survival) and a group with poor prognosis (<15% survival).

The high operative risk in patients undergoing urgent operation or operation within three months of myocardial infarction, when non-aneurysmal ventricular function is poor, may be too high; it should be undertaken only under unusual circumstances.

THE DEVELOPMENT of a left ventricular aneurysm is a serious sequel to the succession of myocardial insults caused by atherosclerotic coronary artery disease. The hemodynamic impairment of the paradoxically expanding ventricular segment, coupled with the chronic ischemia of coronary artery disease, may present as cardiogenic shock, medically refractory congestive heart failure, refractory ventricular dysrhythmias or crippling angina pectoris. The striking capacity of ventricular reconstruction and coronary revascularization to reverse this myocardial impairment is well-established, although operative mortality is significant and the degree of functional rehabilitation is not easily predicted.

The preoperative cardiac assessment of patients with left ventricular aneurysm has concentrated primarily on parameters which are sensitive to the performance of the entire left ventricle, including cardiac output, left ventricular end-diastolic pressure (LVEDP), left ventricular end-diastolic volume, stroke volume and ejection fraction. This study reviews our results with operative treatment of left ventricular aneurysm, and evaluates the contribution to preoperative assessment by indices sensitive primarily to the performance of the non-aneurysmal residual left ventricle. The prognostic capability of such parameters in patients undergoing urgent operation or operation soon after myocardial infarction is also discussed.

Materials and Methods

Patient Population

The records of 45 consecutive patients who have undergone resection or plication of left ventricular aneurysms were reviewed. Although this encompasses an interval from January 1970 to July 1977, only four patients underwent operation before January 1974. Left ventricular aneurysm was defined ventriculographically by the presence of discrete dyskinetic segments which lacked trabeculations.

There were 30 males and 15 females. The mean age at the time of operation for these 45 patients was 57 ± 11 years (range 24–74 years).

Clinical Presentation

At the time of operation two patients were in New York Heart Association (NYHA) functional class I, 12 patients were in class II, nine patients were in class III, and 22 patients were in class IV.

Myocardial infarctions were diagnosed by the presence of typical electrocardiographic and enzyme changes in association with the clinical history of unremitting chest pain not relieved by nitroglycerin. Using these criteria, we were unable to document previous myocardial infarctions in two patients. Thirty patients experienced one previous myocardial infarction, 10 patients had two previous myocardial infarctions, and three patients had three or more prior myocardial infarctions.

Intraaortic balloon pumping was routinely used in all patients who were in cardiogenic shock.

Operative Indications

Twenty patients underwent urgent operations. The indications for urgent operation included cardiogenic shock, recurrent ventricular tachycardia and ventricular fibrillation not controlled by intensive inpatient medical management, severe congestive heart failure refractory to maximal inpatient medical management, and, in one patient, an infected ventricular aneurysm. Cardiogenic shock was defined by the Myocardial Infarction Research Unit (MIRU) criteria and required the presence of 1) systolic arterial blood pressure less than 80 mm Hg, or a decrease of 80 mm Hg from control values; 2) a cardiac index less than 2.21/min/m²;
3) increased peripheral vascular resistance; 3) oliguria, with hourly urine output of under 20 ml; and 4) systemic manifestations of hypoperfusion, including peripheral vasoconstriction, mental confusion or obtundation. Congestive heart failure required the presence of an elevated LVEDP, bilateral pulmonary rales, a third heart sound noted by two observers, and dyspnea at rest.

Twenty-five patients underwent elective operation. These patients were hemodynamically stable, and in many of them myocardial revascularization was a primary operative objective. The indications for elective operation were one or more documented episodes of ventricular tachyarrhythmia, congestive heart failure, systemic arterial embolism, incapacitating angina pectoris, or severe coronary artery disease in asymptomatic patients.

Analysis of Left Ventricular Performance

All patients underwent left and right heart catheterization with left ventriculography in single (five patients) or biplane (40 patients) projections. All but one patient underwent selective coronary artery catheterization in multiple projections. Cardiac output determinations were performed only in critically ill patients.

Ventricular end-systolic and end-diastolic contours were obtained by tracing the ventriculographic silhouette directly on the glass screen of a Vanguard projector before transcription onto paper. Ventricular contractions initiated by a premature ventricular beat and the immediately subsequent ventricular contraction were excluded from the analysis of ventricular wall motion.

Total Ejection Fraction

Single plane ejection fractions were calculated using the formula:

\[
\text{EFS} = \left\{ 1 - \left( \frac{L_d}{L_s} \times \left\{ \frac{A_s}{A_d} \right\}^2 \right) \right\} \times 100\%
\]

(a)

where EFS = ejection fraction (single plane), \(L_d\) = long axis in diastole (cm), \(L_s\) = long axis in systole (cm), \(A_d\) = area of projected image in end-diastole (cm\(^2\)), and \(A_s\) = area of projected image in end-systole (cm\(^2\)).

Biplane ejection fractions were calculated using the formula:

\[
\text{EFB} = \left\{ 1 - \left( \frac{L_{ds}}{L_{ss}} \times \left\{ \frac{A_{s1}}{A_{d1}} \times \frac{A_{s2}}{A_{d2}} \right\} \right) \right\} \times 100\%
\]

(b)

where EFB = ejection fraction (biplane), \(L_{ds}\) = the shorter of the two diastolic long axes (cm), \(L_{ss}\) = the

Figure 1. Methods of analyzing segmental left ventricular function. \(L_d\) and \(M_d\) are the diastolic major and minor axes, respectively; \(L_s\) and \(M_s\) are the systolic major and minor axes, respectively.

shorter of the two systolic long axes (cm), \(A_{s1}\) and \(A_{s2}\) = the area of the two projected end-systolic images (cm\(^2\)), and \(A_{d1}\) and \(A_{d2}\) = the area of the two projected end-diastolic images (cm\(^2\)).

Contractile Segment Ejection Fraction

The contractile segment of the left ventricle was defined by excluding the dyskinetic region of the projected left ventricular silhouette (fig. 1). Single and biplane ejection fractions were calculated for the contractile segment using formulas (a) and (b). \(L_s\) and \(L_d\) were the longest chords measured from the midpoint of the aortic valve plane in the resulting left ventricular configuration.

Basilar Half Ejection Fraction

The basilar half of the left ventricle was defined by perpendicularly bisecting the diastolic long axis of the projected left ventricular silhouette, as illustrated in figure 1. Single and biplane ejection fractions were calculated for the basilar half using formulas (a) and (b). \(L_s\) and \(L_d\) were the longest chords measured from the midpoint of the aortic valve plane in the resulting left ventricular configuration.

Basilar Fractional Area Reduction

In this calculation the minor axis of the projected left ventricular image is assumed to represent the diameter of a circle, and ignores base-to-apical shortening. The major axis is constructed from the midpoint of the aortic valve plane to the apex in diastole. The minor axis is then defined by perpendicularly intercepting the major axis one-quarter of the distance from the aortic valve plane to the apex (fig. 1). The difference in area between two circles with
the diameter of the minor axis in diastole and systole is given by the formula:

\[
(\pi) \left( \frac{M_d}{2} \right)^2 - (\pi) \left( \frac{M_s}{2} \right)^2
\]

where \( M_d \) = the length of the minor axis in diastole (cm) and \( M_s \) = the length of the minor axis in systole (cm).

The percent change in area is obtained by the following formula:

\[
FAS = \left\{ \frac{(\pi) \left( \frac{M_d}{2} \right)^2 - (\pi) \left( \frac{M_s}{2} \right)^2}{(\pi) \left( \frac{M_d}{2} \right)^2} \right\} \times 100\%
\]

where \( FAS \) = fractional area change (single plane).

Simplified, this becomes

\[
FAS = \left\{ 1 - \left( \frac{M_s}{M_d} \right)^2 \right\} \times 100\%
\]

The calculation, used when biplane ventriculography was available, was the average value for the two single plane determinations.

Patients underwent operation using standardized techniques of cardiopulmonary bypass, aneurysmectomy, plication, saphenous vein bypass grafting, mitral valve replacement and ventricular septal defect repair.

Operative mortality was defined as death occurring from any cause during postoperative hospitalization. All patients surviving more than three months following operation were analyzed by NYHA classification, the presence of angina pectoris, the recurrence of ventricular tachyarrhythmias, the presence of congestive heart failure, subsequent myocardial infarctions and late death.

Statistical analysis of the results was performed using the chi square and \( t \) test with two-tailed limits.

Results

Operative Mortality

There were 11 hospital deaths, for an overall operative mortality of 24%. The important clinical distinction between urgent and elective operation is illustrated by their disparate mortality rates. Ninety-six percent (24 of 25) survived elective operation, compared to the 50% (10 of 20) survival in patients undergoing urgent operation (\( P < 0.005 \)). Five deaths occurred within 24 hours of operation, and one death occurred on the second, third, fourth, sixth, thirteenth, and fourteenth postoperative days. One patient hemorrhaged so profusely from lysed pericardial adhesions that cardiopulmonary bypass could not safely be terminated; the other 10 died of myocardial failure.

Late Mortality

There were four late deaths, for a cumulative mortality of 33%. One patient died soon after hospital discharge of anticoagulant induced hemorrhage. One patient suffered an acute myocardial infarction five weeks after aneurysmectomy, mitral valve replacement and coronary grafting. She died the same day from recurrent ventricular arrhythmias. One diabetic patient died four months after aneurysmectomy and single vessel grafting from generalized sepsis. The primary infectious focus was a sternal osteomyelitis which clinically appeared resolved at the time of discharge. One patient suffered an acute myocardial infarction 11 months after aneurysmectomy, and died from progressive myocardial failure four months later.

Parameters Influencing Survival

Previous Myocardial Infarctions

There did not appear to be a relationship between the number of documented myocardial infarctions and operative survival. Seventy-seven percent (23 of 30) with one proven infarction survived, identical to the 77% survival (10 of 13) in patients with two or more previous myocardial infarctions. The proximity of the
operation to the most recent infarction played a much more substantial role in survival (table 1). The mortality was 47% (seven of 15) for those undergoing operation less than three months following their most recent infarction. This was statistically higher than the 11% (three of 28) mortality observed when patients underwent operation more than three months after myocardial infarction ($P < 0.005$).

Operative Indications (table 2)

When left ventricular performance was so impaired that cardiogenic shock or medically refractory congestive heart failure were present at operation, mortality was high (table 2). Only four of eight patients (50%) in shock and nine of 18 (50%) in refractory failure survived operation. The 50% mortality associated with pronounced left ventricular decompensation was significantly greater than the 7% operative mortality observed in patients with greater myocardial reserve ($P < 0.005$). None of the other preoperative symptoms exerted a statistically significant influence on survival.

Functional Class

There were no operative deaths for the 14 patients in NYHA class I and class II. Twenty-two percent (two of nine) who were in class III did not survive the operation, while 41% (nine of 22) who were in class IV died during the postoperative hospitalization.

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Left Ventricular End-Diastolic Pressure

The mean LVEDP in operative survivors was $21 \pm 11$ mm Hg, which was not statistically different from the mean LVEDP of $28 \pm 9$ mm Hg found in nonsurvivors (fig. 2). Prognosis was poor when the LVEDP was $25 \text{ mm Hg}$ or higher; 92% (24 of 26) survived when LVEDP was under $25 \text{ mm Hg}$, significantly better than the 53% (10 of 19) survival when the LVEDP exceeded $25 \text{ mm Hg}$ ($P < 0.005$).

Total Ejection Fraction

The total ejection fraction was only relatively helpful as a guide to prognosis (fig. 3). The mean total ejection fraction in survivors ($39 \pm 16$%) was significantly higher than the mean total ejection fraction in nonsurvivors ($21 \pm 11$) ($P < 0.025$). Twenty-five patients (89%) with total ejection fraction of 30% or greater survived. This was statistically better than the 53% survival for 17 patients with total ejection fraction under 30% ($P < 0.025$).

Contractile Segment Ejection Fraction

The contractile segment ejection fraction was marginally more reliable than the total ejection fraction in prognostic capability. The mean value for the contractile segment ejection fraction in patients who...
The prognostic resolution was even greater when outcome of urgent operation was examined. Nine patients (82%) undergoing urgent operation survived when the basilar half ejection fraction exceeded 30%; only one patient (11%) survived an urgent operation when the basilar half ejection fraction was less than 30% (table 3).

**Basilar Fractional Area Reduction**

The fractional area reduction was as useful as the basilar half ejection fraction in predicting operative outcome (fig. 4). The mean value in survivors (48 ± 17%) was statistically higher than the mean value in nonsurvivors (32 ± 20%) (P < 0.01). Twenty-eight patients (93%) survived when fractional area reduction was greater than 30%. Only six patients (40%) survived when this parameter was 30% or lower (P < 0.005). Although eight patients (89%) survived urgent operation when fractional area reduction exceeded 30%, only two (18%) survived when this was 30% or less (table 3) (P < 0.005).

**Type of Operation Performed**

The operations performed, with the associated mortality are described in table 4. Although operative mortality was less when myocardial revascularization was performed, the difference was not statistically significant due to the small number of patients in whom aneurysmectomy alone was performed. Similarly, the addition of ventricular septal defect repair or mitral valve replacement was associated with

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**Table 4. Survival and Operation Performed**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Survival</th>
<th>Percent mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aneurysmectomy</td>
<td>4 of 8</td>
<td>50%</td>
</tr>
<tr>
<td>Aneurysmectomy and myocardial revascularization</td>
<td>15 of 21</td>
<td>29%</td>
</tr>
<tr>
<td>Aneurysmectomy, myocardial revascularization and mitral valve replacement</td>
<td>2 of 2</td>
<td>0%</td>
</tr>
<tr>
<td>Aneurysmectomy and ventricular septal defect repair</td>
<td>4 of 4</td>
<td>0%</td>
</tr>
<tr>
<td>Plication and myocardial revascularization</td>
<td>8 of 8</td>
<td>0%</td>
</tr>
<tr>
<td>Plication and ventricular septal defect repair</td>
<td>1 of 2</td>
<td>50%</td>
</tr>
</tbody>
</table>

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**Table 3. Survival and Segmental Ventricular Function**

<table>
<thead>
<tr>
<th></th>
<th>Contractile segment ejection fraction</th>
<th>Basilar half ejection fraction</th>
<th>Basilar fractional area reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;40</td>
<td>&gt;40</td>
<td>&lt;30</td>
</tr>
<tr>
<td><strong>Urgent operation</strong></td>
<td>4 of 11 (36%)</td>
<td>6 of 9 (67%)</td>
<td>1 of 9 (11%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 of 11 (18%)</td>
</tr>
<tr>
<td><strong>Operation within 3 months of myocardial infarction</strong></td>
<td>1 of 7 (14%)</td>
<td>7 of 8 (88%)</td>
<td>1 of 7 (14%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 of 7 (0%)</td>
</tr>
</tbody>
</table>
a relatively low mortality. Seven out of eight patients survived the operation.

**Long-term Follow-up**

Twenty-eight patients have currently survived more than three months from operation. The mean follow-up interval in these patients is 22 months. Fourteen patients are currently in NYHA functional class I, nine are in class II, and five are in class III. The mean number of functional classes improved is 1.1; only one patient has experienced a deterioration in functional status following operation. None of the long-term survivors have been hospitalized with an acute myocardial infarction, and only three patients have required inpatient management of congestive heart failure. Of the 13 long-term survivors complaining of angina pectoris before operation, only three currently report this symptom. None of the nine survivors with ventricular tachyarrhythmias before operation have required admission for recurrent episodes, and none have experienced syncopal attacks. One patient with no known history of ventricular tachycardia has required hospitalization on one occasion for this complaint, and is currently controlled with antiarrhythmic agents.

**Discussion**

The 24% operative mortality reported here is somewhat higher than in many recently reported studies and reflects the large proportion of patients in this series undergoing urgent ventricular reconstruction and myocardial revascularization for severe ventricular decompensation. The critically ill status of these 20 patients was indicated by the mean preoperative LVEDP of 29 mm Hg and the mean preoperative ejection fraction of only 29%.

Eight patients (40%) undergoing urgent operation were in cardiogenic shock by MIRU criteria at the time of operation. Although the mortality for cardiogenic shock managed solely by medical means has been reported in excess of 80%, our salvage in this series for such patients was 50%, comparable to the 43% salvage reported by Mundth.

Sixteen patients (80%) undergoing urgent operation were in congestive heart failure at the time of the procedure. This diagnosis has been previously associated with high operative risk and was demonstrated by Loop, using similar criteria to define failure, to be the overwhelmingly most important determinant of operative mortality in revascularization procedures.

The distinctly higher operative risk attendant with urgent procedures has been described by others; Kluge reported a 62% mortality for emergency operation, and felt that such procedures should be undertaken solely in an attempt to salvage desperately ill patients with ventricular tachyarrhythmias and intractable ventricular failure. Although urgent operative intervention can appreciably improve the short-term survival in selected critically ill patients, the mortality is considerable. The physician's dilemma is that of preoperatively identifying those patients liable to benefit from such intervention and those with such pronounced ventricular damage that operative risk is prohibitive.

In the past the search for sufficiently discriminate criteria has focused on preoperative LVEDP, aneurysm size, coronary score, NYHA functional class, and total ejection fraction. Many authors have emphasized the importance of good basilar contractility, noting the generally poor results when the basilar ventricular segments are hypokinetic. Watson recently reported a small series in which a hemispheroid model was used to characterize basilar ventricular function. He was able to correlate operative survival and the degree of postoperative functional improvement with calculated basilar ejection fraction, though he was unable to demonstrate any such correlation using preoperative LVEDP, cardiac index or total ejection fraction. The necessity for demonstrating good basilar ventricular contraction before operation is also related to the recent propensity for combining aneurysmectomy with saphenous vein bypass grafting. Although segmental hypokinesis can be demonstrated to improve in some patients after myocardial revascularization, we should not presume such benefit unless the ability to potenti ate dysfunctional myocardium is studied at the time of preoperative cardiac catheterization.

The three demonstrated methods for determination of segmental ejection fraction were successful in distinguishing two patient populations with disparate operative mortalities, independent of the procedure performed or the patient's preoperative clinical status (table 3). The basilar half ejection fraction clearly separated patients undergoing urgent operation into a group with 82% survival and a group with only 11% survival. Under identical circumstances the calculation of fractional area reduction defined one population with 89% survival and one population with only 18% survival. The failure of these two methods to determine accurately mortality in patients with poor basilar segmental contractility occurred in patients operated on for recurrent ventricular dysrhythmias. The intensive use of antiarrhythmic agents at the time of catheterization may have iatrogenically depressed segmental ventricular contractility; disruption of the arrhythmogenic pathway by excision or revascularization may have allowed the ventricle to attain a better inotropic state following the elimination of these exogenous myocardial depressants. The sole failure of the fractional area reduction to predict operative survival in a patient with good basilar segmental function occurred in an individual with greater than 90% occlusion of the left main coronary artery and Listeria monocytogenes endocarditis, two conditions which independently assert a substantial risk to survival.

These methods of analysis were of little value in predicting the outcome of elective operation primarily due to the minimal operative risk (4%) under such circumstances. The patient who has demonstrated
sufficient residual myocardial function to allow reconstruction to proceed at a time of operation has indicated his ability to tolerate the risks of operation.

The characteristically poor survival obtained when operation is performed in proximity to myocardial infarction was observed in this series; only 53% survived when the interval between operation and infarction was under three months.10, 17, 18 Although the operation would usually be delayed until this period has elapsed, sudden myocardial decompensation may prohibit such delay. The utility of our derived parameters of ventricular performance in such instances demonstrates the necessity for good basilar segmental contractility; mortality exceeded 86% when any of these three criteria described poor basilar function, and was under 15% when good basilar function was observed (table 3).

The principal objection to the use of the contractile segment ejection fraction and the basilar half ejection fraction as computed here is their utilization of formulae which calculate the fractional change in volume of an ellipsoid for the determination of the fractional volume change in a clearly dissimilar geometric structure. The risk of theoretical invalidity was accepted in an attempt to determine what relation, if any, might exist between operative risk or postoperative functional rehabilitation and the imprecise application of methods of proven acceptance. The objective de-marcation of the left ventricle into basilar and apical halves grew from our concern that sufficient bias might exist in such a retrospective analysis to invalidate the results of the subjective determination used to separate the ventricle into contractile and non-contractile portions. This bias was not evident in the ultimate analysis, as the mean difference in the ejection fractions calculated by the two methods was only 8%. The demonstrated clinical applicability of these methods must serve to repudiate any objection to their usage based solely on their geometric imprecision.

The fractional area change technique circumvented the objection to geometric imprecision inherent with the other two methods, since all current models of the left ventricular chamber, whether the traditional ellipsoid model of Dodge19 or the hemispherial model of Watson21 or the spheroid models proposed for the failing left ventricle by Rackley20 and Lewis21 use geometric structures with a circular cross-sectional configuration. The fractional change in area for a cross-section of the left ventricle is a derivative of the volume change for that segment, which, if integrated over the length of the major axis, would describe the ejection fraction of the left ventricular chamber. The objective construction of the major and minor axes eliminates bias, and the inherent simplicity of the technique avoids errors arising with planimetry methods.

Summary

We have demonstrated three methods for assessing operative risk in 45 patients undergoing operation for left ventricular aneurysm. The basilar half ejection fraction and the fractional area reduction were capable of defining a patient population with very low operative risk and a patient population with significantly higher operative risk.

These two methods clearly separated patients undergoing urgent operation into those with excellent prognosis (82–89% survival) and those with very limited prognosis (11–18% survival). Their discriminant capacity was similarly illustrated when operation was less than three months following myocardial infarction; in this case over 88% survived with good basilar ventricular contractility, and fewer than 15% survived with poor basilar segmental function. The very high operative risk associated with operation performed within three months of myocardial infarction, or under urgent circumstances, when basilar ventricular performance is poor, may well be too high; it should be undertaken only under unusual circumstances.

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