Regional Wall Motion Analysis Predicts Survival and Functional Outcome After Subendocardial Resection in Patients With Prior Anterior Myocardial Infarction

Sunil Nath, MD; David E. Haines, MD; Irving L. Kron, MD; Michael J. Barber, MD, PhD; and John P. DiMarco, MD, PhD

Methods and Results. Centerline chord motion analysis was used to derive wall motion score from the preoperative contrast right anterior oblique ventriculogram. Multivariate analysis revealed wall motion score to be a significant independent predictor of both long-term survival ($p<0.01$) and New York Heart Association (NYHA) functional class I or II status at 6 months ($p<0.01$) and at 24 months ($p<0.001$) after surgery. Patients with a wall motion score of $>16\%$ had a better 5-year actuarial survival (74\% versus 45\%, $p=0.02$) and were more likely to be NYHA class I or II at 6 months (87\% versus 58\%, $p<0.01$) and at 24 months (82\% versus 34\%, $p<0.0001$) after subendocardial resection.

Conclusions. A wall motion score derived from centerline chord motion analysis is a sensitive predictor of survival and functional outcome after subendocardial resection. Patients with a wall motion score of $>16\%$ have an excellent prognosis after subendocardial resection. In contrast, patients with a wall motion score of $\leq 16\%$ have a poorer outcome and should be considered candidates only if other forms of therapy have failed or are unavailable. (Circulation 1993;88:70-76)

Key Words • tachycardia, ventricular • surgery • left ventricle • prognosis

Since its introduction by Josephson et al,1 electrophysiologically guided subendocardial resection has become a well-established approach for the treatment of ventricular tachycardia associated with prior myocardial infarction. We and other groups2-8 have reported that the procedure can be performed with an operative mortality of between 5\% and 15\% and with successful ablation of all clinical and inducible monomorphic tachycardia in $>75\%$ of survivors of surgery. In the more recent series, sudden death and nonfatal ventricular tachycardia recurrence have been uncommon during long-term follow-up. However, long-term all-cause mortality after surgery has remained high, with most late deaths attributed to progressive heart failure. In addition, only limited data concerning the long-term functional status of patients after subendocardial resection are available in the literature.

Several preoperative factors have been found to be predictors of immediate operative survival and successful arrhythmia ablation,2,4-9,10 but predictors of late mortality and functional outcome have not been well characterized. Preoperative left ventricular ejection fraction has been most commonly assessed, but its ability to predict surgical outcome has been controversial. Martin et al11 did not find it a useful predictor of survival in their series of 62 patients, whereas Lawrie et al12 reported that left ventricular ejection fraction was a significant predictor of short-term total mortality. Similar discrepancies throughout the literature have led one author to comment that there is "no quantitative measure of left ventricular dysfunction that can predict the risk of surgery."13

We hypothesized that a quantitative measure of regional rather than global left ventricular function would

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TABLE 1. Clinical Characteristics After Subendocardial Resection in Patients With Prior Myocardial Infarction

<table>
<thead>
<tr>
<th></th>
<th>All patients (n=80)</th>
<th>Patients with WMS &gt;16% (n=32)</th>
<th>Patients with WMS ≤16% (n=48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>61±10</td>
<td>60±10</td>
<td>61±10</td>
</tr>
<tr>
<td>Sex</td>
<td>Male</td>
<td>58 (73%)</td>
<td>19 (59%)*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22 (27%)</td>
<td>13 (41%)*</td>
</tr>
<tr>
<td>Presenting arrhythmia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustained monomorphic VT</td>
<td>61 (77%)</td>
<td>22 (69%)</td>
<td>39 (82%)</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>11 (13%)</td>
<td>6 (18%)</td>
<td>5 (10%)</td>
</tr>
<tr>
<td>Syncope</td>
<td>8 (10%)</td>
<td>4 (13%)</td>
<td>4 (8%)</td>
</tr>
<tr>
<td>No. of VT episodes</td>
<td>5±11</td>
<td>3±4</td>
<td>5±14</td>
</tr>
<tr>
<td>No. of AAD trials</td>
<td>2±2</td>
<td>2±2</td>
<td>2±2</td>
</tr>
<tr>
<td>Preoperative amiodarone</td>
<td>9 (11%)</td>
<td>4 (13%)</td>
<td>5 (10%)</td>
</tr>
<tr>
<td>Recent MI (≥60 days)</td>
<td>34 (42%)</td>
<td>12 (37%)</td>
<td>22 (45%)</td>
</tr>
<tr>
<td>Preoperative shock</td>
<td>4 (5%)</td>
<td>1 (3%)</td>
<td>3 (6%)</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>31±11</td>
<td>40±8†</td>
<td>25±9†</td>
</tr>
<tr>
<td>WMS (%)</td>
<td>15±12</td>
<td>27±10</td>
<td>7±6†</td>
</tr>
<tr>
<td>No. of stenosed coronary arteries (≥50%)</td>
<td>2±1</td>
<td>2±1</td>
<td>2±1</td>
</tr>
<tr>
<td>Minimum CL of VT induced at baseline EPS (msec)</td>
<td>285±61</td>
<td>276±66</td>
<td>291±58</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time (min)</td>
<td>94±23</td>
<td>91±20</td>
<td>96±25</td>
</tr>
<tr>
<td>CABG</td>
<td>50 (62%)</td>
<td>20 (62%)</td>
<td>30 (62%)</td>
</tr>
<tr>
<td>MVR</td>
<td>4 (5%)</td>
<td>1 (3%)</td>
<td>3 (6%)</td>
</tr>
<tr>
<td>Clinical or inducible VT at postoperative EPS (% of in-hospital survivors)</td>
<td>9 (12%)</td>
<td>4 (13%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>4 (5%)</td>
<td>0 (0%)</td>
<td>4 (8%)</td>
</tr>
</tbody>
</table>

WMS, wall motion score; VT, ventricular tachycardia; AAD, antiarrhythmic drug; MI, myocardial infarction; LVEF, left ventricular ejection fraction; CL, cycle length; EPS, electrophysiological study; CABG, coronary artery bypass graft surgery; MVR, mitral valve replacement.

*p<0.05; †p=0.0001.

serve as an accurate predictor of both long-term mortality and functional status after subendocardial resection. In this retrospective study, we describe the ability of regional wall motion analysis using a chordal technique to predict both long-term mortality and functional outcome in 80 patients with prior anterior myocardial infarction who had undergone electrophysiologically guided subendocardial resection for sustained ventricular tachycardia.

Methods

Patient Population

Between September 1983 and January 1991, 101 patients with prior myocardial infarction and sustained monomorphic ventricular tachycardia or cardiac arrest underwent left ventricular aneurysm resection and map-guided sequential subendocardial resection at our institution. Nine patients with inferior aneurysms and 12 patients whose preoperative contrast left ventriculograms were technically inadequate for the analysis described in this study are excluded from this report. The clinical characteristics of the 80 remaining patients who constituted the study group are shown in Table 1. Patients were defined as having preoperative cardiogenic shock if they demonstrated a systolic blood pressure of <80 mm Hg and showed clinical signs of peripheral hypoperfusion and/or had a measured cardiac index of ≤1.8 L/min.

Preoperative Evaluation

All patients underwent preoperative contrast ventriculography and selective coronary angiography by standard techniques. A significant coronary artery stenosis was defined as a ≥50% visual cross-sectional narrowing of the blood vessel in any angiographic view. A left ventricular aneurysm was defined by a diastolic deformity with dyskinetic movement on contrast ventriculography. Endocardial contours were traced from the preoperative right anterior oblique (RAO) ventriculogram in end systole and end diastole. Global left ventricular ejection fraction was calculated as described by Sandler and Dodge12 and Kennedy et al13 (Trinity Computing Systems, Houston, Tex). Centerline chord motion analysis, as described by Sheehan et al,14 was used to quantitatively assess regional left ventricular function (Trinity Computing Systems) (Figure 1). In this technique, endocardial motion is measured along 100 chords constructed perpendicular to a centerline drawn midway between the end-diastolic and end-systolic contours in the RAO projection. The last 20 chords are not analyzed because they reflect primarily motion of the mitral valve. The motion of each chord is then normalized for heart size by dividing by the length of the end-diastolic circumference. This value is then converted into units of standard deviation (SD) from the normal mean motion of each chord as derived from a
normal reference population. Normal motion is considered to be between 1 and \(-1\) SD from reference. Hypokinetic motion is defined as \(<-1\) SD and hyperkinetic motion as \(>1\) SD from reference. In this study, wall motion score was defined as the number of chords displaying normal or hyperkinetic motion expressed as a percentage of the 80 chords analyzed.

**Electrophysiological Studies**

The initial electrophysiological study was performed with the patient in the fasting state at least 24-48 hours after discontinuation of all prior antiarrhythmic drug therapy whenever possible. The electrophysiological techniques and stimulation protocol used in our laboratory have been described previously. Briefly, the stimulation protocol at both the initial and postoperative studies includes single, double, and triple extrastimuli delivered after an eight-beat ventricular drive at two basic cycle lengths from two right ventricular sites. Ventricular tachycardia was defined as sustained if it lasted at least 30 seconds or required countershock within 30 seconds because of hemodynamic deterioration. A sustained arrhythmia was the end point at both the initial study and the postoperative study. Ventricular fibrillation or rapid polymorphic ventricular tachycardia induced with triple extrastimuli in patients who had previously manifested only monomorphic ventricular tachycardia clinically and during preoperative electrophysiological testing was not considered to be a clinically relevant arrhythmia at the postoperative study. Postoperative studies were performed 7-10 days after surgery or when the patient was clinically stable.

**Surgical Techniques**

The surgical techniques used in this series are the same as have been described in our previous reports. All patients were anesthetized with nitrous oxide, narcotics, and muscle relaxants. Normothermic cardiopulmonary bypass was initiated with the perfusate temperature maintained at 38-40°C. Epicardial reference electrodes were placed on the right ventricular free wall and the lateral and posterolateral left ventricular free walls. Initial attempts to elicit sustained ventricular tachycardia with programmed stimulation were made before the ventriculotomy. After induction of ventricular tachycardia, the aneurysm was incised for mapping. Endocardial mapping was performed with a hand-held bipolar electrode and a sequential clockwise mapping technique beginning at the aneurysm border and continuing 1 cm inside this border. After the initial endocardial map was completed, a map-guided subendocardial resection was performed during continued normothermic bypass. After completion of the resection, programmed stimulation was repeated. If the same tachycardia or another ventricular tachycardia with a new morphology was induced, endocardial mapping was...
repeated and another subendocardial resection or a cryoablation at the site of origin of ventricular tachycardia was performed. Repetive sequences of programmed stimulation using up to three extrastimuli from two different sites, endocardial mapping and subendocardial resection, and/or cryothermal ablation were carried out until stable monomorphic ventricular tachycardia was no longer inducible or only ventricular fibrillation was repeatedly induced. In patients in whom ventricular tachycardia was not inducible or not map-pable, a visually guided resection of all endocardial scar was performed.16

After completion of the subendocardial resection, the ventriculotomy was closed, and if no further procedures were required, the patient was weaned from normothermic bypass. If revascularization or mitral valve replacement was required, the patient was cooled after completion of the subendocardial resections and cryo-ablations, the aorta was cross-clamped, cold crystalloid cardioplegia was administered, and the surgical procedure was completed by standard techniques.

Long-term Follow-up

Long-term follow-up was obtained in all 76 patients discharged from the hospital. Data concerning mortality and functional class were obtained by one of the investigators by either direct or telephone contact with the patient, the patient's family members, or the patient's local physician. Each patient was assigned a New York Heart Association (NYHA) functional class at 6 and 24 months after hospital discharge. Late mortality was classified as nonarrhythmic (usually congestive heart failure) or sudden (including arrhythmias associated with acute myocardial infarction) according to the criteria proposed by the Cardiac Arrhythmia Pilot Study investigators.17

Statistical Analysis

Data were compiled in a computerized data bank (RS1, BBN Software Products Corp., Cambridge, Mass) and analyzed with BMDP (BMDP Statistical Software, University of California Press, 1985). Preoperative clinical variables (age, sex, presenting arrhythmia, number of ventricular tachycardia episodes before surgery, number of antiarrhythmic drug trials before surgery, preoperative amiodarone use, myocardial infarction ≤60 days before surgery, and preoperative shock), preoperative electrophysiological findings (number of different ventricular tachycardia morphologies induced at the preoperative electrophysiological study and the minimum cycle length of the ventricular tachycardias induced), preoperative angiographic findings (left ventricular ejection fraction, wall motion score, and the number of stenosed coronary arteries), intraoperative variables (concomitant coronary artery bypass grafting and need for mitral valve replacement), and postoperative electrophysiological findings (clinical or inducible ventricular tachycardia in the postoperative period) influencing total mortality and late heart failure mortality were compared by use of a Cox regression model. In this model, variables are excluded in stepwise fashion whenever the probability value for a significant association is p>0.1. Survival curves for total mortality and event-free probability curves from heart failure mortality were constructed by a life table analysis according to

![Graph showing relation between wall motion score (WMS) and left ventricular ejection fraction (LVEF). Note that there is considerable divergence from the regression line between ejection fractions of 20% and 40%.](image)

**FIGURE 2.** Graph showing relation between wall motion score (WMS) and left ventricular ejection fraction (LVEF). Note that there is considerable divergence from the regression line between ejection fractions of 20% and 40%.

The method of Kaplan and Meier. Subgroup comparisons were made by the χ² or Fisher's exact test where appropriate. Survival curves were compared by the Breslow test. Statistical significance was defined as a probability value of p<0.05. All continuous variables are presented as mean ±SD.

Results

The mean left ventricular ejection fraction for the entire study population was 31±11%, and the mean wall motion score was 15±12%. There was a good linear correlation between these two variables (r = 0.79) for the entire study population. However, in patients with an ejection fraction between 20% and 40%, a group that composed 63% of the study population, there was a relatively poor correlation between ejection fraction and wall motion score (r = 0.68) (Figures 2 and 3).

In-Hospital Mortality

Seventy-six patients (95%) survived to hospital discharge. Cause of in-hospital mortality included a persistent low cardiac output state (three patients) and a

![Chordal analysis of preoperative right anterior oblique ventriculograms from two representative patients in the study group. Patient A had a left ventricular ejection fraction (LVEF) of 28% but a wall motion score (WMS) of only 1% because of poor systolic function remote from the dyskinetic anteroapical segment. Notice that the dyskinesia in this patient was not continuous along the entire segment. Patient B had a slightly lower LVEF of 22% because of a large discrete anteroapical aneurysm (outlined by the arrows) but had a WMS of 21% because of preserved systolic function of the nonaneurysmal segments. Patient A died 1 month after hospital discharge of heart failure. Patient B, 2 years after discharge, is New York Heart Association Functional class I.](image)

**FIGURE 3.** Chordal analysis of preoperative right anterior oblique ventriculograms from two representative patients in the study group. Patient A had a left ventricular ejection fraction (LVEF) of 28% but a wall motion score (WMS) of only 1% because of poor systolic function remote from the dyskinetic anteroapical segment. Notice that the dyskinesia in this patient was not continuous along the entire segment. Patient B had a slightly lower LVEF of 22% because of a large discrete anteroapical aneurysm (outlined by the arrows) but had a WMS of 21% because of preserved systolic function of the nonaneurysmal segments. Patient A died 1 month after hospital discharge of heart failure. Patient B, 2 years after discharge, is New York Heart Association Functional class I.
perioperative stroke (one patient). Three of the four deaths were among patients who had presented to the operating room in shock. We have previously reported that preoperative shock is the most powerful predictor of in-hospital mortality.2

Total Mortality

During a mean follow-up of 30±20 months, there were 27 total deaths (including in-hospital mortality). Heart failure (11 patients) and sudden cardiac death (seven patients) were the two most common causes of late mortality. Wall motion score (p=0.001), left ventricular ejection fraction (p=0.002), the number of stenosed coronary arteries (p=0.01), and preoperative shock (p=0.02) were all significant univariate predictors of total mortality. However, by Cox regression analysis, wall motion score (p=0.001), preoperative shock (p=0.009), and the number of stenosed coronary arteries (p=0.01) were the only significant predictors of total mortality after surgery.

Since wall motion score was the most powerful predictor of total mortality, the mortality data were analyzed on the basis of wall motion score alone. By setting the wall motion score at specific values, this analysis revealed that a score of >16% or ≤16% was the best discriminator of long-term survival. The 32 patients with a wall motion score of >16% had a significantly better long-term survival than the 48 patients with a score of ≤16% (p=0.02). The 1-, 3-, and 5-year actuarial survival figures were 94%, 74%, and 74%, respectively, for the >16% group, compared with 73%, 57%, and 45%, respectively, for the ≤16% group (Figure 4).

Late Heart Failure Mortality

There were 11 heart failure deaths during long-term follow-up. Wall motion score (p=0.003), need for mitral valve replacement (p=0.04), and left ventricular ejection fraction (p=0.05) were all univariate predictors of late heart failure mortality. By Cox regression analysis, wall motion score (p=0.003) and the need for mitral valve replacement (p=0.04) were the only significant predictors of late heart failure mortality.

Patients with a wall motion score of ≤16% were significantly more likely to die of heart failure during long-term follow-up than patients with a score of >16% (p=0.02). Ten of the 11 heart failure deaths occurred in the group of 48 patients with a wall motion score of ≤16%, compared with only one heart failure death in the group of 32 patients with a score of >16% (Figure 5).

Functional Status

Among the 76 patients released from the hospital, 73% were NYHA functional class I or II at 6 months and 54% were class I or II at 24 months after discharge. Wall motion score and left ventricular ejection fraction were both significant univariate predictors of class I or II status at 6 months (p=0.01 and p=0.05, respectively) and at 24 months (p<0.001 and p<0.01, respectively) after discharge. By multivariate analysis, however, wall motion score was the only significant independent predictor of class I or II status at both time intervals. Six months after hospital discharge, 87% of patients with a wall motion score of >16% were class I or II, compared with 58% of patients with a wall motion score of ≤16% (p<0.01). This difference was accentuated during longer follow-up. After 24 months, 82% of patients with a wall motion score of >16% were still class I or II, compared with only 34% of patients with a wall motion score of ≤16% (p<0.0001) (Figure 6).

Discussion

There are several potential criteria by which the results of surgery for ventricular tachycardia may be evaluated. Previous studies have focused primarily on surgical mortality and acute and chronic arrhythmia suppression. However, long-term survival and functional status after surgery are also important criteria for evaluation because these outcomes should strongly influence a clinical decision for operative therapy. In this report, we have retrospectively assessed the prognostic value of preoperative regional left ventricular function analyzed by a centerline chord motion technique in a large group of patients who underwent surgery for ventricular tachycardia. A wall motion score derived from this analysis was more effective than global left ventricular ejection fraction as a predictor of both total...
mortality and the development of heart failure after surgery. Functional class in stable patients has also been shown to effectively predict prognosis, but assessment of functional class in candidates for ventricular tachycardia surgery, who are often recovering from a recent myocardial infarction or cardiac arrest with its associated complications, may be difficult. This study demonstrates that by quantitatively measuring preoperative regional wall motion, an objective assessment of long-term mortality risk and functional outcome can be obtained before subendocardial resection.

There have been earlier attempts to use regional ventricular function as a predictor of outcome after subendocardial resection. Garan et al. found that regional function in the nonaneurysmal segment, expressed as an “excess ejection fraction,” was the only independent predictor of operative survival in a series of 36 patients. Martin et al. calculated a mean ejection fraction for a residual contracting left ventricular section but did not find a significant relation between this value and mortality. van Hemel et al. selected 23 patients for surgery on the basis of a left ventricular segmental wall motion analysis different from the technique used in this study and found improved survival in these patients compared with historical controls. These studies were relatively small, included patients with both anterior and inferior aneurysms, and provided little information about long-term functional status. Our series extends these earlier observations to a larger group of patients and, importantly, provides observations on regional wall motion as an effective predictor of both mortality and functional outcome. Patients with a wall motion score of ≤16% had a 5-year mortality of 55%, and 51% of patients had died of heart failure or were in NYHA class III or IV heart failure within 2 years after the operation. In contrast, patients with a wall motion score of >16% had less acute and long-term mortality and were much less likely to develop heart failure after surgery.

The in-hospital and long-term mortality rates in this series are similar to those that have been reported in large series of patients who underwent left ventricular aneurysm resection. Cosgrove et al. reviewed 17 series and found an operative mortality of 9.9%. Komeda et al. reported a 5-year actuarial survival of 84% in a series of 336 patients; however, only 3.5% of their patients had a history of ventricular tachycardia or cardiac arrest. Magovern et al. and Stephenson et al. both found that mortality was higher in patients undergoing aneurysm resection who had a history of sustained ventricular arrhythmias. Although they did not use a quantitative tool such as used in this study, Louagie et al. also found that measurement of regional function was more useful than global ejection fraction as a predictor of outcome after aneurysm resection, with a power of discrimination similar to what we observed between high- and low-risk patient groups in our study. Our data and the results of these earlier studies suggest that, given an approach effective at ablating arrhythmias, long-term mortality will depend largely on the preoperative ventricular anatomy and function.

**Clinical Implications**

During the early years of surgical ablative therapy for ventricular tachycardia, surgery was often used as a heroic “last resort” among patients with arrhythmias that were uncontrollable with antiarrhythmic drugs. In those clinical circumstances, a substantial operative and long-term mortality was considered acceptable, and long-term functional outcome was usually a secondary consideration. Today, with the availability of a broader spectrum of antiarrhythmic drugs and highly effective antiarrhythmic devices, elective surgical therapy for ventricular tachycardia should be considered only if it can offer effective control of the patient’s arrhythmia, low operative and long-term mortality, and a good long-term functional outcome. Our data indicate that if regional wall motion is measured by a reproducible, quantitative technique, these outcomes for patients undergoing electrophysiologically guided subendocardial resection can be predicted with reasonable accuracy. Patients with a low (≤16%) wall motion score should be considered candidates for elective surgical ablation using techniques similar to ours only if other forms of therapy have failed or cannot be used. Emergency surgery in patients with shock, although still justified, will account for most of the early mortality.

**Limitations**

This was a retrospective survey of patients who underwent surgery during a 7-year period. Although the basic surgical and electrophysiological techniques remained constant during this interval, experience at the center gained during the course of the study certainly affected the clinical decisions that were made. We also...
excluded patients with inferior aneurysms from our analysis because the number of such patients operated on at our institution has been relatively small and this group could, therefore, not be separately analyzed. Finally, it may be that our data will not be applicable to other surgical approaches that do not use aggressive sequential resections and cryoablations for arrhythmia control. If less damaging procedures were to become available, preoperative regional wall motion might become a less significant prognostic factor.

Conclusions

Regional wall motion is a critical predictor for survival and functional status after surgery for sustained ventricular tachyarrhythmias. Regional wall motion may be assessed quantitatively by centerline chord motion analysis, and the wall motion score obtained is an effective predictor of outcome after surgery.

References

Regional wall motion analysis predicts survival and functional outcome after subendocardial resection in patients with prior anterior myocardial infarction.
S Nath, D E Haines, I L Kron, M J Barber and J P DiMarco

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