Cardiovascular Surgery

Clinical Outcome After Surgical Correction of Mitral Regurgitation Due to Papillary Muscle Rupture

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Background—Papillary muscle rupture (PMR) is an infrequent but catastrophic complication of acute myocardial infarction (MI). Although always considered, surgical treatment is often denied because of high operative mortality. Moreover, the effects of surgery for PMR on long-term outcome, particularly compared with expected outcome after MI, are undefined.

Methods and Results—Fifty-four consecutive patients (age, 70±8 years; 74% male) underwent mitral surgery for post-MI PMR from January 1980 through December 2000. Severe presentation (cardiogenic shock, pulmonary edema, or cardiac arrest) was noted in 91% preoperatively. Performance of coronary artery bypass graft was associated with lower operative mortality (odds ratio, 0.18; 95% CI, 0.04 to 0.83; P=0.011), whereas there was a trend for lower mortality after surgery after 1990 (odds ratio, 0.28; 95% CI, 0.06 to 1.3). Thus, operative mortality (overall, 18.5%) decreased from 67% up to 1990 without coronary artery bypass graft to 8.7% after 1990 with coronary artery bypass graft. Overall 5-year survival was 65±7%, and survival free of congestive heart failure was 52±7%. Five-year survival of 30-day operative survivors was 79±4%, identical (P=0.24) to that of matched controls with MI (similar age, sex, ejection fraction, MI location, and MI year). Survival free of congestive heart failure was similar in PMR cases and MI controls (10-year survival, 28±8% versus 36±6%; P=0.46).

Conclusions—Surgery for post-MI PMR involves a notable operative mortality, but there are recent trends for lower operative risk, particularly with associated coronary artery bypass graft. Long term after surgery, outcome is restored to that of similar MI without PMR. These encouraging observations emphasize the importance of prompt diagnosis and aggressive therapeutic approach for patients incurring PMR after MI. (Circulation. 2008;118:1528-1534.)

Key Words: coronary disease ■ mitral valve ■ myocardial infarction ■ heart failure ■ surgery ■ survival ■ valves

Papillary muscle rupture (PMR) occurs in 1% to 3% of patients with acute myocardial infarction (MI) and leads to acute severe mitral regurgitation (MR), pulmonary edema, and cardiogenic shock.1,2 The natural history of this devastating complication is extremely poor, and studies in the presurgical era showed, under medical treatment alone, an in-hospital mortality of up to 80%.3-7 Since the first valvular replacement performed in PMR in 1965,8 several reports have documented that surgical rescue of this acute complication of MI is possible.4,9,10 However, the diagnosis of PMR is not always easy because patients are often elderly and frequently diagnosed with a particularly severe clinical presentation, all factors associated with high operative mortality.2,11 Thus, surgical treatment, although recommended by guidelines,12 is often considered too risky,4 and a large proportion of patients with acute MR after MI may not be offered surgery.3 However, recent reports have demonstrated that for surgery of MR in general, a marked reduction in operative mortality has been observed lately,13 particularly in elderly patients. With increased use of valve repair, long-term outcome compares well with that of the general population.13 Compared with these large MR series, PMR series have been relatively small,11 despite important collaborative work,4 and it is uncertain whether encouraging results observed with MR in general apply specifically to surgery for PMR.4 Thus, for mitral surgery for PMR performed at our institution, our aim was to analyze trends in performance of valve repair13 and trends in operative risk over time and in relation to use of associated coronary artery bypass graft surgery (CABG).4 We also analyzed follow-up events occurring in operative survivors and compared them with those in a reference cohort with MI in the community to define the quality of long-term outcome after surgical correction of PMR.

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Methods

Study Design and Setting
All consecutive patients undergoing a first valve surgery for MR resulting from post-MI PMR, proven by surgical inspection of mitral

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lesions, from January 1, 1980, through December 31, 2000, were enrolled in the study. Patients with previous mitral surgery or aortic valve replacement and patients with concomitant rupture of ventricular septum or free wall at diagnosis were excluded. Valve lesions were carefully examined to exclude patients with organic MR not resulting from PMR, in particular those with MR caused by ruptured chordae of the mitral valve.

Preoperative diagnosis of MI was based on the presence of any 2 of the following criteria: prolonged (≥30 minutes) ischemic chest pain, persistent ECG changes of the Q wave or ST-T segments, or increased myocardial enzymatic levels, which for most of the study relied on serum creatinine kinase. The diagnosis of MI was confirmed in all cases by surgical inspection of the myocardium.

All preoperative echocardiograms were performed within routine clinical practice using comprehensive standard imaging.14 The diagnosis of severe MR complicating MI was established preoperatively by color-flow imaging and/or by left ventricular angiography and during surgery by direct observation in all patients. Diagnosis of ischemic MR resulting from PMR used standard echocardiographic criteria15,16 and was confirmed in all patients during MR surgery at our institution on the basis of direct visualization of lesions. Mitral valve repair (MRep) or replacement (MVR) was performed according to the surgeon’s assessment of the lesions. Clinical characteristics and surgical approaches were obtained through review of medical records. During long-term follow-up (up to 2006 or death), patients were cared for by their personal physicians. Follow-up events were obtained by examination of medical records, from questionnaires, and by telephone calls to patients, relatives, and/or physicians. Autopsy records and death certificates were examined for cause of death.17

Statistical Analysis
Continuous variables are reported as mean±SD; categorical variables are given as percentages of group totals. Group comparisons used a standard t test or χ² test as appropriate. The short-term end point was operative mortality defined as occurring within 30 days after surgery. The association of operative period (up to and after 1990), valve repair, and associated CABG with operative mortality was evaluated with logistic regression. Adjusted odds ratios (ORs) for these primary clinical factors were evaluated by use of a propensity score–adjusting variable. The propensity score was obtained by fitting a logistic regression model for CABG and operative period as end points and age, sex, and ejection fraction (EF) as predictors. Because of the low number of operative deaths, resampling techniques were used to verify the stability of the final regression models.18 Long-term end points were overall survival, congestive heart failure (CHF),19 and the combined end point of death or CHF. Event rates were estimated by the Kaplan-Meier method. To examine the quality of long-term outcome of patients who survived the operative period, we compared outcome with that of matched patients with acute MI who survived the first 30 days after MI. Cases were matched to controls selected from all patients with first MI during the study period from Olmsted County, Minnesota, who had been consecutively enrolled in an MI registry aimed at analyzing outcome of MI in the community.20 The controls and cases (as groups) were propensity matched (2 controls for 1 case) for age, sex, year of MI, MI location, and EF. Values of P<0.05 were considered significant.

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results
Study Population
During the study period, 54 patients had mitral valve surgery for ischemic MR resulting from PMR. The rupture involved mostly (90%) the posterior papillary muscle. The PMR was complete on at least 1 head of papillary muscle in 51 patients (94%) and was partial in 3 patients (6%). The preoperative and operative characteristics of the patients are summarized in the Table. The patients were relatively old (70±8 years), were mostly men (74%), and had severe clinical and hemodynamic alterations at surgery. Indeed, 91% were in cardiogenic shock and/or pulmonary edema and/or had a cardiac arrest complicating the MI. Only 8 patients were in atrial fibrillation before surgery. The EF was on average in the low-normal level (56±13%).

Twenty-five patients were operated on up to 1990; 29 patients were operated on after 1990. The differences between the periods up to and after 1990 involved recent increased use of MRep (1 of 25 [4%] versus 12 of 29 [41%]; P<0.01), longer bypass time (52±74 versus 122±53 minutes; P<0.01), and higher EF (50±13% versus 57±11%; P=0.04), with a trend for older age (69±8 versus 72±8 years; P=0.13) but no difference in presentation with shock/pulmonary edema/cardiac arrest (92% versus 90%; P=0.80) or in CABG performance (76% versus 79%; P=0.77). Surgery was performed 6±22 days after the first symptoms, within the first month in 45 (83%) and after the first month in 9 (17%). These latter patients also had a critical presentation (89% with cardiac arrest, pulmonary edema, or cardiogenic shock) and did not differ regarding variables listed in the Table from those operated on within the first month (all P>0.15) apart from a lower EF (44±14%; P=0.004).

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**Table. Baseline and Operative Characteristics of Patients Who Underwent Surgery for PMR**

<table>
<thead>
<tr>
<th>Variables Overall (n=54)</th>
<th>MRep (n=13)</th>
<th>MVR (n=41)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>70±8</td>
<td>71±7</td>
</tr>
<tr>
<td>Male sex, %</td>
<td>74</td>
<td>85</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>55</td>
<td>46</td>
</tr>
<tr>
<td>Diabetes, %</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Creatinine, mg/dL</td>
<td>1.5±0.6</td>
<td>1.3±0.6</td>
</tr>
<tr>
<td>Atrial fibrillation, %</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>NYHA class III–IV, %</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Acute systolic murmur, %</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>CS/PE/CA, %</td>
<td>91</td>
<td>77</td>
</tr>
<tr>
<td>EF, %</td>
<td>56±13</td>
<td>60±8</td>
</tr>
<tr>
<td>LVD, mm</td>
<td>58±8</td>
<td>57±2</td>
</tr>
<tr>
<td>LA, mm</td>
<td>46±5</td>
<td>47±3</td>
</tr>
<tr>
<td><strong>Surgical characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bypass time, min</td>
<td>89±72</td>
<td>120±43</td>
</tr>
<tr>
<td>CABG, %</td>
<td>78</td>
<td>85</td>
</tr>
<tr>
<td>IABP, %</td>
<td>75</td>
<td>54</td>
</tr>
<tr>
<td>Complete revascularization, %</td>
<td>54</td>
<td>61</td>
</tr>
<tr>
<td>Inotropes after day 1, %</td>
<td>77</td>
<td>62</td>
</tr>
<tr>
<td>Low cardiac output, %</td>
<td>42</td>
<td>23</td>
</tr>
<tr>
<td>Stay in hospital, d</td>
<td>20±18</td>
<td>17±5</td>
</tr>
</tbody>
</table>

NYHA indicates New York Heart Association; CS, cardiogenic shock; PE, pulmonary edema; CA, cardiac arrest; LVD, left ventricular diastolic diameter; LA, left atrial diameter; and IABP, intraaortic balloon pump.
Surgical Management and Early Outcome

MVR was performed in 41 patients; MRep was done in 13 patients. MRep consisted of reattachment of the ruptured papillary muscle with or without ring annuloplasty. The types of prosthesis used for MVR were Carpentier-Edwards (Irvine, Calif) in 18 patients, Starr-Edwards (Irvine, Calif) in 5 patients, St Jude (Minneapolis, Minn) in 6 patients, Ionescu- Shiley in 4 patients, Hancock (Minneapolis, Minn) in 7 patients, and Medtronic-Hall (Minneapolis, Minn) intact in 1 patient. Preoperative characteristics stratified by MRep and MVR in the Table show that MRep was feasible in patients with similarly severe characteristics but tended to require longer bypass time ($P=0.077$).

Preoperative angiography, performed in all patients except 1, showed single-vessel coronary artery disease (CAD) in 17 patients (31%), 2-vessel CAD in 19 patients (35%), 3-vessel CAD in 14 patients (26%), and left main CAD in 3 patients (6%). Among patients with coronary angiography, revascularization was not considered feasible or indicated in 11, and CABG was performed in 42 patients. CABG was associated with MRep in 11 patients (85%) and with MVR in 31 patients (75%). Complete revascularization of territories with obstructive CAD was feasible in 28 patients (54%). The right coronary artery was revascularized in 30 patients, the left circumflex in 25 patients, the left descending anterior in 17 patients, and the diagonal in 6 patients. Patients with and without associated CABG showed no significant difference in baseline characteristics, although those with CABG tended to be older (71±8 versus 67±9 years; $P=0.12$) but with a trend toward higher EF (55±11% versus 49±15%; $P=0.12$).

Postoperatively, 10 patients (18.5%) died within 30 days of surgery. Two patients died during surgery, and 1 died during the first postoperative day as a result of refractory left ventricular failure. Two patients died of myocardial rupture on postoperative days 3 and 5. Three patients died of MI progression on days 3, 4, and 7. Two patients died of noncardiac events on days 8 and 24.

Operative mortality tended to be lower after MRep (7.7%) than after MVR (22%), but this difference did not reach significance ($P=0.21$) because of the small number of MRep.

Overall, there were 38 deaths during 6.4±5 years of follow-up; 10 were immediately after surgery. Among the 44 operative survivors, during a mean follow-up of 7.9±4.3 years, 28 deaths occurred. Among these 28 late deaths, 5 were after MRep and 23 were after MVR. Cause of late death was cardiac in 18 patients, CAD in 8 patients, left ventricular failure in 7, arrhythmic sudden death in 1, prosthetic dysfunction in 1, thromboembolism in 1, noncardiac in 6, and unclear in 4 patients. Overall long-term outcome, including operative mortality, is indicated in Figure 2, with 5-year overall survival of 65±7% and 10-year survival of 40±9%.
survival free of CHF of 52±7%. In an analysis of overall long-term outcome, including operative outcome, there was no difference between MRep and MVR in terms of survival (5-year survival, 62±13% versus 66±7%; P=0.48) and an insignificant trend for higher survival free of CHF with MRep (5-year survival, 62±13% versus 49±8%; P=0.13). The trend after concomitant CABG for higher overall survival (5-year survival, 71±7% versus 42±14%; P=0.16) and for higher survival free of CHF (5-year survival, 57±8% versus 33±14%; P=0.18) did not reach statistical significance. After propensity-score adjustment for age, sex, EF, severity of CAD, and year of surgery, CABG showed only a weak trend toward lower long-term mortality (adjusted relative risk, 0.45; 95% CI, 0.20 to 1.1; P=0.077). The patients operated on beyond the first month displayed no benefit in long-term outcome (all P>0.5).

The symptomatic benefit for PMR operative survivors was evident; at the last follow-up, 30 patients were in New York Heart Association functional class I or II (68%), and 36 patients were in Canadian Cardiovascular Society angina class I or II (82%). Early after surgery, 9 patients showed a mild degree of MR, 7 after MRep and 1 after MVR (P=0.01), and 1 patient had severe MR in the MRep group. Throughout follow-up, a total of 6 patients developed significant MR (greater than moderate), 4 in the MRep group and 2 in the MVR group (P=0.021), and 2 of them eventually underwent a redo mitral surgery (linearized rate for reoperation, 0.9% per year). Reoperation for any reason was performed in 3 patients, 2 patients after MVR and 1 patient after MRep.

The outcome of the 44 operative survivors of PMR surgery was compared with that of 88 propensity-matched patients with first MI diagnosed in the community who had survived the first 30 days after MI. In addition to the same MI location and year of occurrence (mean year of MI, 1992; P=0.66), the cases and controls were similar. Indeed, comparing these 44 PMR operative survivor cases and the 88 post-MI first-month survivor controls, age was 70.6±7 versus 70.2±7.4 years (P=0.80), sex was female in 25% of both groups (P=1.0), EF was 54.5±11.6% versus 52.2±10.7% (P=0.26), and diabetes was present in 16% versus 23% (P=0.37). Late survival was almost identical in cases and controls (5-year survival, 79±4% in both groups; P=0.24; Figure 3). Late outcome also was similar for survival free of CHF in cases and controls (10-year survival, 28±8% versus 36±6%; P=0.46).

Discussion

The present study represents, to the best of our knowledge, the largest report of patients undergoing mitral valve surgery for severe MR caused by post-MI PMR, allowing us to underscore new trends for surgical outcome. Our observations are consistent with the extreme severity of this condition but also are encouraging. Although operative risk is notable, it is encouraging to note the relatively low operative mortality, now <10%, for patients who underwent surgery after 1990 and with concomitant CABG. Long-term outcome, although imperfect, also is quite remarkable in that it is almost identical to that of patients without PMR but with similar MI location, year of occurrence, age, sex, and EF who demonstrate similar survival and survival free of CHF. Thus, beyond the initial phase of high risk, despite the severity of clinical presentation and the major cardiac surgery, life expectancy is restored to that of patients with a similar MI without PMR. These results emphasize the importance of surgical treatment of patients with PMR after MI to restore life expectancy.

Immediate Postoperative Outcome

Operative mortality within 30 days of surgery has consistently been high in previous studies of patients with post-MI PMR, although the operative risk noted in our study is among the lowest. However, because of the relative rarity of the disease, series have been encompassing long time periods and evolving surgical techniques, so it is important to identify recent trends that may be favorable. Recent surgery for PMR more often used repair procedures in patients as severe as those who underwent MVR, although repair required longer cardiopulmonary bypass support. MRep has recently been used increasingly in all types of MR and has been considered to improve survival. We cannot conclude that repair provides a better outcome than MVR for PMR because of the sample size issue; larger collaborative studies are necessary to examine this hypothesis. The only recommendation that can be made currently is to assess the lesions carefully to determine those with the potential to be safely repaired.

We also observed that patients who underwent associated CABG incurred lower operative mortality and that there was also a trend for lower mortality after 1990. Indeed, in the patients who received CABG after 1990, operative mortality, despite being much higher than in organic MR, is relatively low at 8.7%. Taking into account the severity of the disease in PMR, a high operative mortality contrasting with that of degenerative MR is not surprising. Indeed, most patients were in critical condition at surgery, and previous studies in the presurgical era have shown an overwhelmingly poor progno-
sis CABG on the outcome of patients undergoing mitral surgery for PMR remains unclear, but CABG is essential for improved outcome. Because mortality in the postoperative period is due primarily to inadequate myocardial function and recurrent MI, complete revascularization is theoretically desirable. However, benefits of this approach have to be weighed with the risk of preoperative coronary angiography in hemodynamically unstable patients and with the risks of a prolonged surgical procedure. Our finding linking associated CABG with improved immediate postoperative survival is consistent with recent observations and emphasizes the importance of assessing and revascularizing the CAD that led to the MI and PMR, despite the acuteness of clinical presentation.

Optimal timing of surgical intervention remains controversial. Previous studies suggested higher mortality when surgery was performed within 30 days compared with when surgery was delayed. In the present study, surgery was rarely delayed, and among patients initially delayed for surgery, sudden hemodynamic deterioration often required prompt surgery. Nevertheless, operative mortality was virtually identical between delayed and nondelayed patients, so the present study supports an aggressive surgical treatment without delay.

**Long-Term Outcome**

Long-term outcome after surgery for PMR is imperfect and affected by the high operative mortality, an observation common to most series reporting the results of PMR surgery. However, for the operative survivors, our series, which gathered population-based controls with similar MI location, MI year, age, sex, and EF who survived the first month after MI, provides unique and important information on long-term outcome. Our observation is that survival (79% at 5 years) is identical between cases with PMR after surgery and controls. Similarly, survival free of CHF is identical in cases and controls. This favorable long-term outcome is particularly remarkable in view of the clinical presentation of PMR with shock, pulmonary edema, or cardiac arrest in >90% of patients. Thus, it is remarkable that the extreme severity of presentation related to the mechanical complication of MI does not affect long-term outcome of operative survivors who return to the expected outcome of patients with MI. This restoration of life expectancy by surgery is consistent with the limited extent of the infarcted area, most often in the context of an inferior wall infarction causing PMR. In addition, the frequently limited extent of obstructive CAD in patients suffering a PMR observed in our study may contribute to restoration of life expectancy, particularly in patients who can be revascularized by simultaneous CABG. This finding of improved outcome with CABG is consistent with the results of the Should We Emergently Revascularize Occluded Coronaries in Cardiogenic Shock (SHOCK) trial, which demonstrated improved long-term survival with early revascularization for cardiogenic shock complicating MI.

Our encouraging finding of life-expectancy restoration is particularly remarkable in view of the spontaneously catastrophic outcome of post-MI MR, particularly that caused by PMR, and underscores the importance of appreciating MR and of considering the diagnosis of PMR in patients with acute hemodynamic compromise in whom this diagnosis may be challenging. These findings also emphasize the importance of surgical correction of PMR after MI, even in patients with severe presentation. Operating without delay does not carry excess risk, emphasizing the feasibility of early suppression of this mechanical complication of MI.

**Study Limitations**

Revascularization by thrombolysis or percutaneous coronary intervention of acute MI has resulted in improved outcomes and may affect observed outcomes in our control population. However, when the matching procedure was rerun and limited to controls who received revascularization during the acute MI, 79 controls were identified (age, 69±7 years; male, 72%; EF, 52±10%; diabetes, 19%; all P>0.20 compared with operative survivors of PMR surgery) who had survival (82±4% versus 79±4% at 5 years; P=0.82) similar to that of patients after PMR surgery.

Survival free of CHF was similar between these additional controls and the patients after PMR surgery (P>0.4). Thus, this issue does not affect our conclusion that for survivors of PMR surgery, outcome is restored to that of similar standard MI.

Selection of cases for surgery may play a role in postoperative outcome and in improving treatment results. However, throughout the study period, only 1 patient diagnosed with post-MI PMR was not considered a surgical candidate, so this issue is not relevant to the improved operative mortality observed over time in our study.

The series of post-MI PMR are all small, so a limited number of predictors of outcome can be examined and may not reach statistical significance. In that regard, despite the relative size of our series, the relative benefits of MRep versus MVR remain to be defined in larger collaborative studies (70 repairs and 233 MVRs would be required to provide 80% power to detect a difference in mortality). Although the observed event rates for postoperative mortality are suggestive of beneficial outcomes for CABG and the recent era of improved surgical procedures, the nonrandomized nature of this study and the limited number of subjects ultimately limit our ability to determine independent contributors to survival without overfitting the data.

**Conclusions**

The present relatively large report of surgery for PMR after MI reveals the generically high operative mortality involved in correcting this catastrophic mechanical complication of MI but is particularly important in demonstrating recent improvements in surgical risk, particularly in patients who undergo simultaneous CABG. Once this initial high-risk phase has been overcome, surgery for PMR restores long-term outcome to that of a similar uncomplicated MI. These most recent encouraging developments emphasize the importance of...
prompt diagnosis and an aggressive therapeutic approach for patients incurring PMR after MI.

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**Disclosures**
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**References**
CLINICAL PERSPECTIVE

Papillary muscle rupture (PMR) after myocardial infarction (MI) is rare but deadly. Radical treatment for PMR is mitral valve surgery, which is associated with high operative mortality. PMR presentation is usually catastrophic, and diagnosis often is difficult because the murmur is heard inconsistently. Long-term outcome of surgery is uncertain because of the small sizes of the published series. Thus, clinical management is difficult, and surgical decisions may be tentative. To address these issues, we examined the outcome of 54 patients who underwent post-MI PMR surgery between 1980 and 2000 at our institution. We confirmed the seriousness of PMR presentation with shock, pulmonary edema, or cardiac arrest in 91%. Operative mortality was high but was lower with coronary artery bypass graft and tended to decrease in recent years, declining from 67% (before 1990 without coronary artery bypass graft) to 8.7% (after 1990 with coronary artery bypass graft). Another development was valve repair, feasible in 41% after 1990, but its impact on outcome cannot be determined because of the small sample. We compared the long-term outcome of operative survivors with that of patients with similar MI but without PMR who had survived the first 30 days after MI. This comparison showed identical 5-year survival and similar heart failure rates. Thus, our study, while emphasizing the seriousness of PMR, is encouraging: Recent surgery is more often reparative, has markedly improved operative risk with coronary artery bypass graft, and results in restoration of long-term life expectancy and morbidity to that of a similar but uncomplicated MI. These most recent encouraging developments emphasize the importance of prompt diagnosis and aggressive therapeutic approach for patients incurring PMR after MI.

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