Predictors of Low Cardiac Output Syndrome After Isolated Aortic Valve Surgery

Manjula D. Maganti, MSc; Vivek Rao, MD, PhD; Michael A. Borger, MD, PhD; Joan Ivanov, PhD; Tirone E. David, MD

Background—Low cardiac output syndrome (LCOS), defined as the need for postoperative intraaortic balloon pump or inotropic support for >30 minutes in the intensive care unit, remains a relatively common complication of aortic valve (AV) surgery. The aim of this study is to identify the preoperative predictors of LCOS in patients undergoing isolated AV surgery.

Methods and Results—We conducted a retrospective review of data prospectively entered into an institutional database. Between 1990 and 2003, 2255 patients underwent isolated AV surgery with no other concomitant cardiac surgery. The independent predictors of LCOS and operative mortality (OM) were determined by stepwise logistic regression analysis. The overall prevalence of LCOS was 3.9%. The independent predictors of LCOS were (odds ratio in parentheses) renal failure (5.0), earlier year of operation (4.4), left ventricular ejection fraction <40% (3.6), shock (3.2), female gender (2.8), and increasing age (1.02). Overall OM was 2.9%. The OM was higher in patients who experienced LCOS (38% versus 1.5%; \(P<0.001\)). The independent predictors of mortality were (odds ratio in parentheses) preoperative renal failure (8.3), urgency of surgery (3.4), previous stroke (2.9), congestive heart failure (2.6), previous cardiac surgery (2.3), hypertension (1.7), and small AV size (1.3).

Conclusions—Low-output syndrome is associated with significantly increased morbidity and mortality. Novel strategies to preserve renal function, optimization of preexisting heart failure symptoms, and avoidance of prosthesis-patient mismatch may reduce the incidence of LCOS and lead to improved results after AV surgery. (Circulation. 2005; 112[suppl 1]:I-448–I-452.)

Key Words: aortic valve surgery ■ low cardiac output syndrome ■ operative mortality ■ outcomes

The results of aortic valve (AV) surgery continue to improve with time. We have demonstrated previously that operative mortality (OM) and morbidity has not increased for valvular surgery, despite a higher proportion of high-risk patients over time.1 However, the development of low cardiac output syndrome (LCOS) continues to be an important complication, associated with high morbidity and mortality. The predictors of LCOS after isolated coronary bypass surgery (CABG) have been identified previously by our group.2 However, risk factors for LCOS in CABG patients (such as incomplete revascularization) may not be relevant in patients undergoing isolated AV surgery. Left ventricular (LV) hypertrophy and/or dilatation from aortic stenosis or regurgitation may have important effects on postoperative myocardial function. Additionally, the impact of poor preoperative LV function may be more pronounced in patients with aortic regurgitation than those with aortic stenosis.

Identifying the risk factors for impaired postoperative myocardial performance may help to improve the clinical results of AV surgery and may potentially influence the choice of prosthesis. For example, patients at high risk for postoperative LCOS should receive prostheses with adequate orifice areas and hemo-dynamic performance to minimize postoperative transvalvular gradients. Another example is in transplant-eligible patients with severe LV dysfunction. A bioprosthesis may be favored in this instance to facilitate subsequent mechanical circulatory support.

Data Source
Clinical, operative, and outcome data were collected prospectively in a computerized institutional database on all of the patients undergoing cardiac surgery. We conducted a retrospective review of our institutional database to identify patients that underwent isolated AV surgery. Between 1990 and 2003, 2255 patients underwent isolated AV surgery (replacement or repair) with no other concomitant cardiac or extracardiac procedures.

Explanatory Variables
Core baseline explanatory variables collected since 1990 included age, sex, LV grade [based on LV ejection fraction (EF): grade 1,
LVEF ≥60%; grade 2, LVEF 40% to 59%; grade 3, LVEF 20% to 39%; grade 4, LVEF <20%]. urgency of operation (elective; semiurgent, indicating an operation during the same admission as a cardiac catheterization or a cardiac event; urgent, indicating an operation within 72 hours of an event; or emergent, indicating an operation within 12 hours of an event), New York Heart Association (NYHA) class, AV lesion (stenotic, regurgitant, or mixed, as determined by echocardiography), and infective endocarditis (active endocarditis, active endocarditis with abscess formation, remote endocarditis, or none). LVEF was measured by ventriculography or echocardiography, and the most recent preoperative value was recorded. Other explanatory variables collected to more fully characterize these patients included recent myocardial infarction (MI), diabetes, dyslipidemia, peripheral vascular disease (PVD), history of hypertension, preoperative stroke, or transient ischemic attack (TIA). Details of this database have been published elsewhere.1

**Study Outcomes**

Our primary outcomes in this study were LCOS and OM. OM was defined as any postoperative death occurring within 30 days or during the same hospital admission. LCOS was diagnosed if the patient required an intraaortic balloon pump (IABP) to be weaned from cardiopulmonary bypass (CPB) or in the intensive care unit because of hemodynamic compromise. LCOS was also diagnosed if the patient required inotropic medication (dopamine, dobutamine, milrinone, or epinephrine) to maintain the systolic blood pressure >90 mm Hg and the cardiac output >2.2 L/min/m² for ≥30 minutes in the intensive care unit after correction of all of the electrolyte and blood gas abnormalities and after adjusting the preload to its optimal value.3 Afterload reduction was also attempted when possible. Patients who received <4 μg/kg of dopamine to increase renal perfusion were not considered to have LCOS. Patients who received vasoconstricting medications because of a high cardiac output (>2.5L/min/m²) and low peripheral resistance were also not considered to have LCOS. In patients who received an IABP before surgery, LCOS was determined if, in addition to IABP support, they required significant postoperative inotropic support as described above.

**Statistical Analysis**

Statistical analysis was done with SAS 8.1 software (SAS Institute).4 χ² tests were used to evaluate categorical data univariately when the minimum number of observations in a category was >5, otherwise Fisher’s exact test was used. Categorical variables were expressed as percentages. The Student t test was used to analyze continuous variables that had normal distribution, and Wilcoxon rank test was used for variables that had nonparametric distribution. Continuous variables were expressed as mean ±SD. Variables that had an univariate probability value of <0.25 or those judged to be clinically important were selected for inclusion in a logistic regression model by stepwise selection. Multivariable logistic regression methods were used to calculate factor-adjusted odds ratios (ORs) and to determine the independent predictors of LCOS and OM. Model discrimination was evaluated by the area under the receiver-operator-characteristic (ROC) curve,5,6 and calibration was assessed with the Hosmer-Lemeshow goodness-of-fit statistic.7

**Results**

**Demographics**

Patients were arbitrarily divided into 3 groups according to year of operation (1990 to 1993, n = 741; 1994 to 1998, n = 813; 1999 to 2003; n = 678) to account for improved outcomes over time. LCOS developed in 87 patients (3.9%). Intraoperative Data

Prevalence of LCOS over 3 time periods of this study. The prevalence of LCOS was highest in the earlier years of operation and lowest in the most recent years.

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Earlier year of operation (OR = 4.4; 95% CI, 2.2 to 8.9); LVEF (OR = 3.6; 95% CI, 1.9 to 6.8); preoperative shock (OR = 3.2; 95% CI, 1.7 to 7.2); female gender (OR = 2.8; 95% CI, 1.7 to 4.6); and increasing age (OR = 1.02; 95% CI, 1.01 to 1.04). Table 2 presents the detailed results of the multivariable analysis. The multivariable model for LCOS was robust, with an area under the ROC of 0.78 and a Hosmer-Lemeshow goodness-of-fit probability value of 0.4, indicating good model calibration and discrimination.

OM
Univariate analysis showed that OM was significantly higher in women (3.9% versus 2.2%; P = 0.018); diabetics (5.2% versus 2.7%; P = 0.03); patients with hypertension (4.4% versus 2.3%; P = 0.007); patients undergoing urgent or emergent operation (9.3% versus 1.7% in elective operation); patients with a LVEF ≤ 40% (OR = 4.9; 95% CI, 2.3 to 10.9); earlier year of operation (OR = 4.4; 95% CI, 2.2 to 8.9); LVEF < 40% (OR = 3.6; 95% CI, 1.9 to 6.8); preoperative shock (OR = 3.2; 95% CI, 1.5 to 7.2); female gender (OR = 2.8; 95% CI, 1.7 to 4.6); and increasing age (OR = 1.02; 95% CI, 1.01 to 1.04). Table 2 presents the detailed results of the multivariable analysis. The multivariable model for LCOS was robust, with an area under the ROC of 0.78 and a Hosmer-Lemeshow goodness-of-fit probability value of 0.4, indicating good model calibration and discrimination.

Figure 2. Mean length of stay. Patients who developed LCOS required longer ventilatory support, longer postoperative intensive care unit stay, and longer hospital stay.

Figure 3. Hospital outcomes. Hospital mortality and the incidence of postoperative MI, stroke, reexploration for bleeding, and renal failure were significantly higher in patients who developed LCOS.
TABLE 2. Multivariable Predictors of LCOS

<table>
<thead>
<tr>
<th>Variables</th>
<th>Regression Coefficient ± SE</th>
<th>OR</th>
<th>95% CI</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative renal failure</td>
<td>1.60 ± 0.4</td>
<td>4.9</td>
<td>2.3–10.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Year of operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990–1993</td>
<td>1.48 ± 0.4</td>
<td>4.4</td>
<td>2.2–8.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVEF 40–60%</td>
<td>0.63 ± 0.3</td>
<td>1.9</td>
<td>1.1–3.2</td>
<td>0.03</td>
</tr>
<tr>
<td>&lt;40%</td>
<td>1.28 ± 0.3</td>
<td>3.6</td>
<td>1.9–6.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Shock</td>
<td>1.17 ± 0.4</td>
<td>3.2</td>
<td>1.5–7.2</td>
<td>0.004</td>
</tr>
<tr>
<td>Sex</td>
<td>1.04 ± 0.2</td>
<td>2.8</td>
<td>1.7–4.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age</td>
<td>0.02 ± 0.01</td>
<td>1.02</td>
<td>1.01–1.04</td>
<td>0.02</td>
</tr>
</tbody>
</table>

<40% (5.1% versus 1.5% in patients with LVEF ≥60%; P<0.001); patients with NYHA class IV symptoms (6.9% versus 0.65% in NYHA class I; P<0.001); patients who had a preoperative stroke or TIA (8.8% versus 2.3%; P<0.001); patients with PVD (9.1% versus 2.7%; P=0.003); patients with congestive heart failure (4.4% versus 0.9%; P<0.001); patients who had preoperative shock (14.9% versus 2.6%; P<0.001); patients with preoperative renal failure (25.9% versus 2.3%; P<0.001); patients undergoing repeat operation (6.1% versus 2%; P<0.001); and in patients with infective endocarditis (8.7% in patients with active or active abscess endocarditis versus 2.6% in patients with remote or no endocarditis). Patients who died postoperatively were older (63±13 years versus 58±15 years; P=0.01), had a longer postoperative intensive care unit stay (204±336 hours versus 51±69 hours; P<0.001), and required more hours of ventilator support (143±281 versus 17±41; P<0.001).

Predictors of OM
Multivariable logistic regression analyses revealed the following 7 independent predictors of OM (Table 3): preoperative renal failure (OR=8.3; 95% CI, 3.8 to 18.4); urgent surgery (OR=3.5; 95% CI, 1.7 to 6.8); previous stroke or TIA (OR=2.9; 95% CI, 1.6 to 5.4); congestive heart failure (OR=2.6; 95% CI, 1.2 to 5.9); previous cardiac surgery (OR=2.3; 95% CI, 1.3 to 4); hypertension (OR=1.7; 95% CI, 1.01 to 3); and small AV size (OR=1.3; 95% CI, 1.1 to 1.4). The multivariable model for OM had good model discrimination with an area under the ROC curve of 0.82, and good model calibration with a Hosmer-Lemeshow goodness-of-fit probability value of 0.35.

TABLE 3. Multivariable Predictors of OM

<table>
<thead>
<tr>
<th>Variables</th>
<th>Regression Coefficient ± SE</th>
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<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative renal failure</td>
<td>2.12 ± 0.4</td>
<td>8.3</td>
<td>3.8–18.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Urgent/emergent surgery</td>
<td>1.23 ± 0.4</td>
<td>3.5</td>
<td>1.7–6.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preoperative stroke</td>
<td>1.08 ± 0.3</td>
<td>2.9</td>
<td>1.6–5.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>0.96 ± 0.4</td>
<td>2.6</td>
<td>1.2–5.9</td>
<td>0.02</td>
</tr>
<tr>
<td>Reoperative surgery</td>
<td>0.83 ± 0.3</td>
<td>2.3</td>
<td>1.3–4</td>
<td>0.004</td>
</tr>
<tr>
<td>Hypertension</td>
<td>0.55 ± 0.3</td>
<td>1.7</td>
<td>1.01–3</td>
<td>0.04</td>
</tr>
<tr>
<td>Small aortic valve size</td>
<td>0.23 ± 0.1</td>
<td>1.3</td>
<td>1.1–1.4</td>
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</tr>
</tbody>
</table>

Discussion
The current study evaluated the clinical outcomes of a large consecutive series of patients undergoing AV replacement or repair over a 14-year time period. To the best of our knowledge, this is the first article to focus on the determinants of LCOS in patients undergoing isolated AV surgery. We found that the prevalence of postoperative LCOS fell over time, consistent with our previously documented improvements in cardiac surgical outcomes over time.1,8 However, the morbidity and mortality associated with LCOS continues to be substantial, as demonstrated in Figures 2 and 3. In fact, the mortality associated with the development of LCOS increased from 33% (17 of 52) to 60% (6 of 10) over the 3 eras in this study.

Although the development of LCOS was associated with a significant increase in OM (from 1.5% to 38.0%), the independent predictors of LCOS and mortality were not identical. Furthermore, in comparison with a similar study performed in an isolated CABG population, the predictors of LCOS after AV surgery are substantially different.2

We found that in this population, the most influential predictor of LCOS was the presence of preoperative renal insufficiency (OR 4.9). Patients with renal failure have several abnormalities that may lead to postoperative LCOS. It has been well documented that patients on hemodialysis have high perioperative mortality rates and poor long-term outcomes. Herzog et al9 identified >5000 dialysis patients undergoing aortic and/or mitral valve surgery through the U.S. Renal Data System over a 20-year period. The perioperative rate was >20%, and the 2-year survival rate was only 40%, irrespective of whether a mechanical or tissue valve was implanted. Our results suggest that one of the important causes of the increased mortality rates may be because of postoperative LCOS.

Interestingly, hypertension emerged as a weak predictor of OM (OR=1.7) but failed to emerge as a predictor of LCOS. Hypertension is usually associated with myocardial hypertrophy, which may be exacerbated by concomitant aortic stenosis. Myocardial hypertrophy is a risk factor for inadequate cardioplegic delivery (especially to the right ventricle).10 Inadequate myocardial protection would be expected to result in higher rates of LCOS; however, this was not observed in this study. In a previous study by Tosson et al,11 hypertension was not found to be a predictor of mortality in patients undergoing AV surgery (with or without concomitant CABG).

The impact of preoperative LV function was less significant in this cohort (OR=3.6) compared with that seen in our previous study (OR=5.7 in isolated CABG). Surprisingly, preoperative LV function was more important in patients with aortic stenosis than regurgitation. Conventional wisdom dictates that poor preoperative LV function is associated with a worse prognosis after surgery in patients with aortic insufficiency than in patients with aortic stenosis. However, a review of the literature reveals that several studies have shown no differences in perioperative outcomes for patients with aortic insufficiency or insufficiency in the setting of severe LV dysfunction.12–15 In fact, a study from Muenster, Germany, actually demonstrated higher 1-year mortality in patients with aortic stenosis.14
failed to emerge as a predictor of LCOS. We have documented previously the effect of prosthesis-patient mismatch (PPM) on long-term survival after AVR.\textsuperscript{16} We also demonstrated that PPM was an independent risk factor for OM. Unfortunately, because of the wide variety of prostheses implanted in this study, we were unable to calculate predicted effective orifice areas for each patient. Our surrogate variable of prosthesis size is less sensitive than indexed effective orifice areas as a marker of PPM. Several elegant studies have documented the relationship between PPM and postoperative outcomes.\textsuperscript{17–19} Furthermore, Blais et al\textsuperscript{17} demonstrated that the degree of PPM influenced OM after AVR with a risk of 3\% in patients with no or mild mismatch rising to 24\% in patients with severe mismatch.

It is not surprising that preoperative shock and advanced age emerged as predictors of low-output syndrome. However, the emergence of female gender (OR=2.8) as a risk factor for postoperative LCOS is difficult to explain. Although female gender has been shown to be a predictor of both LCOS and mortality in a CABG population, we believe that this is the first study to identify gender as an important risk factor in an isolated AVR population. Previous studies have hypothesized that the increased risk in female patients was attributable to their smaller body size and correspondingly small coronary anatomy.\textsuperscript{20,21} In this study, the average prosthesis size was significantly larger in male compared with female patients (25±2 mm versus 23±2 mm; \(P<0.001\)). Again, differences in body surface area, valve sizing nomenclature, and varying prosthesis types makes it difficult to interpret the significance of a 2-mm mean difference in average prosthesis size.\textsuperscript{22}

In summary, this study is the first to distinguish the preoperative predictors of postoperative LCOS from those of OM in a population of patients undergoing isolated AVR replacement. In contrast to a previous study in isolated CABG patients, it appears that the development of LCOS is less likely a result of inadequate myocardial protection but rather more heavily dependent on physiological variables. In agreement with our previous study, the development of postoperative LCOS is associated with significant morbidity and mortality.

Our results suggest that LCOS is highly prevalent in female patients with preoperative renal insufficiency and poor LV function. Consideration should be made in this high-risk patient population to optimize perioperative hemodynamics by avoiding PPM, either by annular enlargement or by the use of more favorable prostheses, such as stentless valves. Furthermore, this study provides valuable information to predict which patients may require postoperative mechanical circulatory support. As such, the results of this study may have important implications for the choice of valve substitute and/or operative procedures in patients undergoing isolated AVR replacement.

**Acknowledgments**

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**References**


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