Aborted Off-Pump Coronary Artery Bypass Patients Have Much Worse Outcomes Than On-Pump or Successful Off-Pump Patients

Ruyun Jin, MD; Loren F. Hiratzka, MD; Gary L. Grunkemeier, PhD; Albert Krause, MD; U. Scott Page III, MD

Background—Off-pump coronary artery bypass graft (CABG) surgery is purported to reduce perioperative mortality and morbidity compared with on-pump coronary bypass graft surgery. However, the outcomes of patients for whom an off-pump strategy must be changed to an on-pump procedure during surgery have not been extensively studied.

Methods and Results—The Merged Cardiac Registry (Health Data Research, Inc) contains 70,514 isolated CABG performed from January 1998 to March 2004 in 40 facilities. Among them, 62,634 patients begun and completed on-pump bypass (CPB); 7,880 patients begun off-pump, of which 7,424 (94.2%) completed off-pump coronary artery bypass (OPCAB), whereas 456 (5.8%) were converted to on-pump (CONVERT). CONVERT patients were more severely ill. The observed mortality of CONVERT, CPB, and OPCAB was 9.9%, 3.0%, and 1.6%, respectively, and the observed-to-predicted ratio was 2.77, 1.20, and 0.74, respectively. CONVERT also had more morbidity than either OPCAB or CPB. Finally, a risk model was created to identify patients who might be at risk for conversion from off-pump to on-pump CABG.

Conclusions—Patients who are intended for an off-pump strategy and then require conversion to on-pump have significantly higher operative mortality and morbidity than either completed OPCAB or CPB patients. In addition, the operative mortality and morbidity are far in excess of that predicted preoperatively. Based on these results, strong consideration should be given for a planned strategy of CPB for those patients with preoperative hemodynamic instability requiring a salvage CABG operation, left ventricular hypertrophy, or previous CABG. (Circulation. 2005; 112[suppl I]:I-332–I-337.)

Key Words: coronary disease ■ mortality ■ off-pump ■ on-pump ■ surgery

Coronary artery bypass graft surgery (CABG) performed without the use of cardiopulmonary bypass, or off-pump, is purported to be associated with lower morbidity and perhaps lower mortality compared with CABG performed with cardiopulmonary bypass. However, some patients require intraoperative conversion from an intended off-pump strategy to an on-pump procedure for a variety of reasons. Patients who have a conversion from off-pump to an on-pump procedure have been reported to have a poorer outcome than patients having a successfully completed off-pump procedure. We reviewed the preoperative risk variables and outcomes of patients in a large multi-institutional registry to determine: (1) morbidity and mortality of patients requiring off-pump to on-pump conversion compared with patients having completed off-pump, or on-pump CABG; and (2) preoperative variables that might identify those patients at greater risk for requiring conversion to on-pump CABG.

Materials and Methods

Clinical Material

The Merged Cardiac Registry (MCR) is an international database containing >434,000 cardiac surgery procedures. Most contributors to the MCR use the Patient Analysis and Tracking System (PATS) database software. Data are collected on cardiac surgery patients by participating sites and then entered into each site’s database. At least yearly, the new data in each site’s registry are sent to Health Data Research, Inc (www.healthdataresearch.com) for integration into the MCR.

We studied 70,514 patients who underwent isolated CABG in 40 MCR facilities from January 1998 to March 2004. A total of 62,634 were performed entirely on-pump (CPB) and 7,880 were intention-to-treat (ITT) off-pump. Among those ITT off-pump cases, 7,424 were started and finished off-pump (OPCAB), and the remaining 456 cases were started off-pump but converted to on-pump (CONVERT).

Statistical Methods

Demographic, historical, and perioperative variables known to affect mortality were selected for analysis. Comparisons of these variables...
Results

Demography and Medical History

Patient characteristics are tabulated by subgroup in Table 1. CONVERT patients were in general at higher risk in that they were older, with smaller body surface area, had higher percentage of females, and with more preoperative comorbidities. Pulmonary hypertension was more prevalent in OPCAB and CPB patients and New York Heart Association Functional class 3 or 4 was more prevalent in CPB patients.

Unadjusted Mortality and Morbidity

The unadjusted mortality and morbidity rates are listed in Table 2. The CONVERT patients had higher mortality and morbidity rates than OPCAB and CPB patients. Because the

among the groups were performed using ANOVA and χ² test. Then the comparison between CONVERT and OPCAB patients or between CONVERT and CPB patients were performed using t tests for continuous variables and χ² tests for categorical variables.

Two previously developed risk models for CABG hospital mortality were used: a built-in Bayesian regression model in PATS and an external logistic regression model developed from patients in the Providence Health System Cardiovascular Study Group (PHS) database. The predicted risk of hospital mortality was calculated for each patient using both of these risk models. The observed-to-predicted (O/E) ratio was computed for various subgroups as the sum of the observed deaths divided by the sum of the predicted deaths.

A new model was developed to predict the risk of off-pump conversion to on-pump by logistic regression. The model were used to identify the independent risk factors associated with converting to on-pump CABG (CONVERT), among the population of attempted off-pump CABG patients (OPCAB and CONVERT). The c index (equal to the area under the receiver operating characteristic curve) was used to measure model discrimination.

Statistical analyses were performed using PATS version 3.2 (Axis Clinical Software Inc, Portland, Ore), SPSS version 11.0 (SPSS Inc, Chicago, Ill), and S-PLUS version 6.1 (Insightful Corporation, Seattle, Wash).
patients’ acuities are quite different, we compared mortality using risk-adjustment models.

**Risk-Adjusted Mortality**

The predicted risk for in-hospital mortality was calculated from the PATS program using a Bayesian risk model. OPCAB and CPB had lower mortality than expected, with an O/E ratio of 0.57 and 0.95 respectively, both significantly <1. CONVERT had higher mortality than expected, with an O/E ratio of 2.18, significantly >1 (Table 3 and Figure 1).

The predicted risk for in-hospital mortality was also calculated from a logistic regression risk model. 69 593 cases (99%) had all risk factors available. Again, OPCAB had significantly lower mortality than expected, with an O/E ratio of 0.74 and an upper confidence limit of 0.90. CPB and CONVERT had significantly higher mortality than expected, with an O/E ratio of 1.20 and 2.77, respectively (Table 3 and Figure 1).

**Variation Among Hospitals**

Among the 40 facilities, there were 34 facilities having any off-pump cases. Figure 2 shows the relationships among the number of off-pump cases, the percentage of CONVERT and the mortality of off-pump cases, using a matrix of 3 scatterplots. Each scatterplot is identified by an uppercase letter. Four facilities have <10 off-pump cases and are excluded from the figure.

The center with the highest ITT off-pump mortality (>14%) has a very low number (N =35) of off-pump cases (Figure 2A). The 3 centers with the highest number of ITT off-pump have low mortality (<2%) and a low percentage of CONVERT (<4%) (Figure 2A and 2B). The high percentages of aborted off-pump cases come from centers with low numbers of ITT off-pump cases (<52) (Figure 2B). Also a trend can be seen (Figure 2C) of a higher CONVERT rate in centers with higher mortality.

Thus, there is an inverse relationship between the number of ITT off-pump cases by a hospital and the proportion of patients who aborted from off-pump and the off-pump mortality.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>OPCAB</th>
<th>CONVERT</th>
<th>CPB</th>
<th>(\text{O/E Ratio}^{P})</th>
<th>(\text{ROC}^{P})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality, %</td>
<td>1.6</td>
<td>10.3</td>
<td>3.0</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Re-operation for bleeding, %</td>
<td>1.5</td>
<td>6.6</td>
<td>2.4</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Renal failure, %</td>
<td>6.9</td>
<td>18.9</td>
<td>5.4</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Stroke, %</td>
<td>1.0</td>
<td>6.6</td>
<td>2.5</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary failure, %</td>
<td>3.7</td>
<td>16.7</td>
<td>6.5</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gastrointestinal problem, %</td>
<td>1.4</td>
<td>3.0</td>
<td>1.8</td>
<td>0.011</td>
<td>0.082</td>
</tr>
</tbody>
</table>

**TABLE 2. Unadjusted Mortality and Morbidity by Subgroups**

<table>
<thead>
<tr>
<th>Group</th>
<th>N*</th>
<th>Observed Mortality</th>
<th>Expected Mortality</th>
<th>O/E Ratio</th>
<th>ROC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayesian model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPB</td>
<td>62 634</td>
<td>3.0%</td>
<td>3.2%</td>
<td>0.95 (0.91, 0.99)</td>
<td>0.77 (0.76, 0.78)</td>
</tr>
<tr>
<td>ITT off-pump</td>
<td>7880</td>
<td>2.1%</td>
<td>2.9%</td>
<td>0.72 (0.61, 0.85)</td>
<td>0.79 (0.76, 0.83)</td>
</tr>
<tr>
<td>OPCAB</td>
<td>7424</td>
<td>1.6%</td>
<td>2.8%</td>
<td>0.57 (0.46, 0.72)</td>
<td>0.80 (0.76, 0.84)</td>
</tr>
<tr>
<td>CONVERT</td>
<td>456</td>
<td>9.9%</td>
<td>4.5%</td>
<td>2.18 (1.82, 2.61)</td>
<td>0.71 (0.62, 0.79)</td>
</tr>
<tr>
<td>Total</td>
<td>70 514</td>
<td>2.9%</td>
<td>3.2%</td>
<td>0.93 (0.89, 0.96)</td>
<td>0.77 (0.76, 0.78)</td>
</tr>
<tr>
<td>Logistic regression model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPB</td>
<td>61 788</td>
<td>3.0%</td>
<td>2.5%</td>
<td>1.20 (1.16, 1.25)</td>
<td>0.77 (0.76, 0.78)</td>
</tr>
<tr>
<td>ITT off-pump</td>
<td>7805</td>
<td>2.1%</td>
<td>2.3%</td>
<td>0.92 (0.79, 1.08)</td>
<td>0.79 (0.76, 0.83)</td>
</tr>
<tr>
<td>OPCAB</td>
<td>7350</td>
<td>1.6%</td>
<td>2.2%</td>
<td>0.74 (0.60, 0.90)</td>
<td>0.81 (0.77, 0.84)</td>
</tr>
<tr>
<td>CONVERT</td>
<td>455</td>
<td>9.9%</td>
<td>3.6%</td>
<td>2.77 (2.35, 3.27)</td>
<td>0.68 (0.60, 0.77)</td>
</tr>
<tr>
<td>Total</td>
<td>69 593</td>
<td>2.9%</td>
<td>2.5%</td>
<td>1.18 (1.13, 1.22)</td>
<td>0.77 (0.76, 0.78)</td>
</tr>
</tbody>
</table>

*N*Numbers differ between analytic methods, because Bayesian model uses all patients but logistic regression model uses any complete-data patients.
Risk of Off-Pump Conversion to On-Pump

Because the CONVERT patients have worse risk-adjusted mortality than the OPCAB and CPB patients, a logistic regression risk model was developed to predict which ITT off-pump patients would be converted to on-pump (Table 4). Of the 7880 ITT off-pump cases, 7714 (98%) cases had complete data on all risk factors and could be used in the model. The c statistic of the model was 0.758.

Discussion

The off-pump CABG procedure is purported to have economic and clinical benefits. Cleveland et al5 reported with the Society of Thoracic Surgeons (STS) data of 118 140 CABG-only procedures that off-pump CABG was associated with decreased mortality and morbidity, including stroke or coma, ventilator use of 24 hours or more, renal failure, deep sternal infection, and re-operation for bleeding. Other authors1–4,6 also conclude that a successful off-pump CABG reduces operative mortality and postoperative morbidity.

Previous studies found that the patients who convert from off-pump CABG to on-pump CABG have worse outcome than completed OPCAB.7–12 But most have been small series, single-center experiences or used only univariate analysis. Our study has a large cohort of patients across multiple centers and risk-adjusted mortality was compared between groups.

In our study, the OPCAB patients had significantly reduced mortality by both Bayesian and logistic regression risk-adjustment methods (upper 95% confidence limit of the O/E ratio <1) compared with the predicted mortality. And the O/E ratio of the OPCAB patients was also less than the O/E ratio for the CPB patients by both risk models (Figure 1). However, the subset of CONVERT patients who were not able to be completed off-pump had much higher rates of mortality and morbidity (Table 2). Despite the fact that the CONVERT patients were at higher risk, after risk adjustment by both Bayesian and logistic methods, the O/E ratio of their mortality was still 2- to 3-times that of the OPCAB patients. Although the risk models were developed by 2 different methods and based on different patient population, the results agree remarkably.

We attempted to characterize the CONVERT patients using logistic regression models. The model indicates that the priority of operation, left ventricular hypertrophy, previous CABG, and cerebrovascular disease are the independent risk factors for conversion from off-pump to on-pump. Edgerton et al developed a logistic regression model and found surgeon previous off-pump experience, previous CABG, and congestive heart failure are the risk factors of conversion.8

The ITT off-pump group had better outcomes than the CPB group, even though the CONVERT patients had a much worse outcome. If we could identify the patients with a high risk of converting from off-pump to on-pump and do their CABG on-pump, we would further lower the OPCAB mortality.

**TABLE 4. Logistic Regression Model for the Probability of Conversion from Off-Pump to On-Pump**

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Odds Ratio</th>
<th>95% CI for Odds Ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salvage</td>
<td>7.21</td>
<td>(2.29, 22.76)</td>
<td>0.001</td>
</tr>
<tr>
<td>Left ventricular hypertrophy</td>
<td>3.74</td>
<td>(2.93, 4.77)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CCS class 3/4</td>
<td>3.52</td>
<td>(2.82, 4.40)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous coronary artery surgery</td>
<td>1.96</td>
<td>(1.37, 2.79)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Urgency/emergency</td>
<td>1.76</td>
<td>(1.43, 2.18)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>History of cerebrovascular disease</td>
<td>1.76</td>
<td>(1.31, 2.38)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prior myocardial infarction</td>
<td>1.31</td>
<td>(1.07, 1.61)</td>
<td>0.010</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.29</td>
<td>(1.04, 1.60)</td>
<td>0.022</td>
</tr>
<tr>
<td>Body surface area</td>
<td>0.46</td>
<td>(0.29, 0.71)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Bayesian Versus Logistic Regression Risk Models

Each type of model has its strengths. The Bayesian model is not limited by missing data, whereas the logistic regression model only can use the data with all risk factors available (unless imputation methods are used). The logistic regression model adjusts for the correlations between risk factors, whereas the Bayesian model does not, and thus tends to over predict the risk. The initial STS CABG risk models were developed with Bayesian methods and then converted to logistic regression methods.\(^ {19–21}\) Currently, logistic regression methods are widely used for cardiac surgery risk models.\(^ {22–24}\) Bayesian models have been used since the establishment of the MCR database and are updated each year. However, because the MCR data are quite complete and \(\sim 98\%\) of the patients have all risk factors to assess the risk of aborted off-pump CABG, it was natural to apply logistic regression methods as well. And this provides an opportunity to compare the results from these 2 methods.

Limitations of This Study

One limitation of this study is that we did not have the specific reason for conversion from a planned off-pump strategy to an on-pump procedure. In addition, we were unable to determine the relative experiences of each surgeon or team with regard to OPCAB techniques. Some studies have suggested that surgeons early in their OPCAB experience are more likely to have patients having CON- VERT.\(^7,8,11\) Additionally, they have noted that hemodynamic and electrical instability requiring conversion are more likely to be associated with poor outcomes than when conversion is performed in elective and stable patients.\(^7\) The MCR database does not contain patient or surgeon-specific identifiers because of privacy concerns similar to those of the STS database.

Conclusion

Although the off-pump patients in general have better short-term outcomes than on-pump CABG patients, it is important to realize that if the patient cannot be completed off-pump, significantly worse outcomes can be expected. The aborted off-pump CABG patients have significantly higher risks of operative mortality and morbidity than those which are completed off-pump. Examining the differences among hospitals with varying caseloads shows that it is possible for large serials of patients to be performed off-pump with a very low percentage of on-pump conversion. The model developed in this study may help the surgeon in selecting off-pump patients to maximize the percentage of patients who are able to have completion off-pump. The risk model suggests preferentially selecting on-pump CABG strategy for patients in salvage priority with preoperative hemodynamic instability, left ventricular hypertrophy, and history of CABG.

Facilities Contributing to the Merged Cardiac Registry

California
Santa Rosa Memorial Hospital, Santa Rosa; Cottage Health System, Santa Barbara; Dameron Hospital Association, Stockton; Pomona Valley Hospital, Pomona; Good Samaritan Hospital, San Jose; Los Robles Regional Medical Center, Thousand Oaks; Hoag Memorial Hospital, Newport Beach; Encino-Tarzana Regional Medical Center, Tarzana; St. Agnes Medical Center, Fresno; TENET Healthcare Corporation, Lakewood; California Pacific Medical Center, San Francisco; Marin General Hospital, Greenbrae; Alvarado Hospital Medical Center, San Diego; Covina Valley Health, Covina; Kaweah Delta Health Care District, Visalia; UCSD Medical Center, San Diego; Washington Hospital, Fremont; Palomar Pomerado Health, Escondido.

Oregon
Legacy Emanuel Hospital, Portland; Legacy Good Samaritan, Portland; Providence Portland Med Center, Portland; Providence St. Vincent Medical Center, Portland; Rogue Valley Medical Center, Medford; Sacred Heart Hospital, Eugene; Salem Hospital, Salem; St. Charles Hospital, Bend; Tuality Community Hospital, Hillsboro.

Washington
SW Washington Medical Center, Vancouver; Swedish Hospital, Seattle.

Florida
Cardiac Surgical Associates of SW Florida, Fort Myers; St. Joseph’s Hospital, Tampa; Tampa General Hospital, Tampa.

Alabama

Georgia
St. Joseph’s Hospital, Atlanta.

Ohio
Cardiac, Vascular, and Thoracic Surgeons, Inc, Cincinnati.

Pennsylvania
Shaffer Cardiovascular Associates, Lemoynce.

Wisconsin
Wausau Hospital, Wausau.

References


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