Off-pump coronary artery bypass and avoidance of hypothermic cardiac arrest improves early left ventricular function in patients with systolic dysfunction

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Abstract

Objective: Off-pump coronary artery bypass surgery (OPCAB) and beating-heart coronary artery bypass grafting (BH-CAB) performed with cardiopulmonary bypass support are used with increasing frequency in the treatment of coronary artery occlusive disease. The utility of OPCAB and BH-CAB in treating high-risk patients has been studied, but the effects of these procedures on ventricular function have not been thoroughly investigated.

Methods: Data were collected from a database encompassing all patients who underwent isolated coronary revascularization performed by a single surgeon between August 2002 and March 2007. All procedures (n = 507) began as OPCAB operations, but 99 were converted to BH-CAB during surgery. Each patient’s ejection fraction (EF) was measured preoperatively and postoperatively (median, 5.0 days after surgery).

Results: We found that although the BH-CAB patients tended to be in worse health and to have a lower preoperative EF than the OPCAB patients, both groups of patients had similar improvements in postoperative EF (6.8% vs 5.4%; p = 0.65). In addition, multivariable linear regression showed that a lower preoperative EF, age ≥70 years, and cardiomegaly predicted less postoperative EF improvement after coronary revascularization by either OPCAB or BH-CAB.

Conclusions: Both OPCAB and BH-CAB procedures produce significant and similar short-term improvement in EF in patients with coronary disease. This change in EF may account for the subjective clinical improvements seen early after both procedures.

Keywords: Cardiac function; Coronary artery bypass graft surgery; CABG; Off-pump surgery

1. Introduction

Off-pump coronary artery bypass surgery (OPCAB) and beating-heart coronary artery bypass grafting (BH-CAB) grafting performed with cardiopulmonary bypass (CPB) support have become much more common in the surgical treatment of coronary artery occlusive disease. Although studies have been published regarding the utility of these two techniques in high-risk patients, such as those with renal dysfunction and those at higher risk for neurologic events, the effects of OPCAB and BH-CAB on ventricular function have been only cursory investigated [1—4].

We examined improvements in ejection fraction (EF) in more than 500 consecutive patients, all of whom underwent OPCAB or BH-CAB for coronary revascularization. Our hypothesis was that both OPCAB and BH-CAB would provide effective myocardial preservation because neither procedure involves ischemic cardiac arrest, and that early postoperative ventricular function would, therefore, improve (i.e., the beneficial effects of revascularization would not be confounded by the effects of ischemic cardiac arrest).

2. Materials and methods

2.1. Patients

Prospectively collected observational data were obtained from a database encompassing all patients who underwent coronary revascularization performed by a single surgeon. The Institutional Review Board at the University of Texas–Houston approved the data collection for use in research. The requirement for patient consent was waived because no identifying data were recorded.
Between August 2002 and March 2007, coronary revascularization with either OPCAB or BH-CAB was performed on 507 consecutive patients. No patient had hypothermic cardiac arrest or aortic cross-clamping. This series included emergent cases, redo operations, and hemodynamically unstable patients. Twenty-six patients were excluded because their EF data were not available; hence, the final cohort consisted of 481 patients.

The following preoperative data were recorded for each patient: operative priority (urgent, emergent, or elective); age (<70 or ≥70 years); sex; history of smoking, myocardial infarction (MI) (at any time, within the previous 7 days, or within the previous 48 h), non-transmural MI, and stroke; and the presence or absence of chronic obstructive pulmonary disease (COPD) requiring inhalant therapy, diabetes, hypertension, angina, congestive heart failure (CHF), and cardiomegaly (i.e., increased cardiac diameter observed on preoperative radiography).

2.2. Preoperative and postoperative assessment of ejection fraction

EF was measured preoperatively and postoperatively (median, 5 days after surgery), whenever possible, with multiple gated acquisition (MUGA) nuclear scanning (Table 1). Echocardiographic and MUGA scans were obtained within 5 days before operation in all cases. Of the 481 patients included in the study, 377 (78%) had preoperative assessment of EF by MUGA nuclear scanning; the remaining 104 patients (22%) did not undergo MUGA nuclear scanning because they were hemodynamically unstable, or were receiving intravenous nitroglycerin, or were intubated preoperatively. In these patients, EF was assessed either by echocardiogram or by left ventriculogram during cardiac catheterization.

Ninety-one percent of patients were assessed postoperatively by MUGA scan; these scans were obtained within 3–10 days after operation in 79%, within the subsequent 3 months in 9%, and after 3 months in 2%. In the remaining 10% of patients, postoperative MUGA scans were not obtained because of dye allergy, patient refusal, or the presence of chest tubes, which are considered a contraindication to nuclear scanning in our institution; these patients underwent echocardiography instead (at a median of 8 days after surgery).

2.3. Assessment of cardiac enzyme release

After each operation, the patient’s creatine kinase-MB (CK-MB) index was measured every 8 h for 24 h. Troponin I release was measured initially, but our institution switched to measuring troponin T release halfway through the trial; hence, troponin I and troponin T release values were not included in the analysis.

2.4. Surgical technique

All elective coronary artery revascularizations were begun with the intent to perform OPCAB. If hemodynamic instability unrelated to changes in cardiac position developed, or if electrocardiographic (ECG) changes compatible with ischemia in the left anterior descending (LAD) coronary artery territory developed that did not resolve with insertion of a ‘flow-through’ shunt, the patient was converted to BH-CAB. In patients with hemodynamic instability or ongoing ischemia, cases were initiated with CPB support (i.e., they began as BH-CAB procedures).

Conduits for bypass were harvested initially. Radial arteries and saphenous veins were harvested before or during sternotomy. Internal mammary artery conduits, bilateral when appropriate, were then harvested. All patients received 2 mg kg⁻¹ heparin intravenously. Each patient’s activated clotting time was kept above 400 s throughout the operation; the activated clotting time was checked every 30–40 min, and additional doses of intravenous heparin were given as necessary.

Proximal anastomoses were performed first. In the first portion of the study period, proximal anastomoses were performed by placing a partial occluding clamp on the ascending aorta; in the latter portion of the study period, the Heartstring device (Maquet Cardiovascular, Wayne, NJ, USA) was used, obviating the need to occlude the ascending aorta. In patients who were hemodynamically unstable or had active ongoing ischemia, an aortic cannula and a single venous cannula were placed after completion of the proximal anastomoses so that CPB could be initiated when and if necessary. In patients who were hemodynamically stable, these cannulas were not placed. The left internal mammary artery to LAD anastomosis was performed first. Standard stabilization techniques were employed; either Guidant or Medtronic (Minneapolis, MN, USA) off-pump stabilizers were used. Control of the LAD was achieved by placing 4/0 Prolene figure-of-eight sutures proximal and distal to the planned anastomotic site. After appropriate positioning, the snares were tightened, and an arteriotomy was created in the LAD. If ECG changes were noted or hypotension unrelated to cardiac positioning developed, a mechanical flow-through transluminal shunt was employed, and the snares were loosened. In the absence of any such changes, no shunt was employed.

Once the anastomoses were completed and the territory of the LAD was reperfused, the right coronary artery system was grafted, if indicated. Both axial stabilization and pressure stabilization were employed. If the main right coronary artery trunk was bypassed, a prophylactic flow-through shunt was used because of the difficulty of detecting myocardial ischemia when the right coronary artery is occluded. As with the LAD, while the shunt was being placed and removed, 4/0 Prolene snare was placed proximal and distal to the site of the anastomosis for vascular control. When the posterior descending artery or posterolateral...
artery was grafted, a prophylactic shunt was used only when ECG or blood pressure changes developed. After the LAD and right coronary system had been bypassed, the circumflex system was grafted. The heart was retracted upward and laterally by using axial succion to expose the lateral circumflex marginal vessels. Snares of 4/0 Prolene were placed at the base of the chosen marginal arteries. Then, shunting was used electively, if hypotension or ECG changes developed. After all distal anastomoses were completed, the heart was returned to its native position.

Sixty of the 99 BH-CAB cases were initiated with CPB because of ongoing ischemia that manifested as STE elevations on ECG, or as ongoing chest pain, or as hemodynamic instability at the initiation of surgery. Thirty-nine of the 99 BH-CAB cases were converted from OPCAB because of intraoperative hemodynamic instability or ECG changes. In the conversions, CPB was initiated because hypotension developed that seemed to be related to cardiac ischemia and did not respond to changes in cardiac position or volume loading. CPB was also used when ECG changes developed and persisted despite the use of a transliminal flow-through shunt. CPB was performed through a single cannula placed in the ascending aorta and a single venous cannula placed in the right atrium. Hypothermic cardiac arrest with aortic cross-clamping was not used in any case. When CPB was used, weaning from CPB occurred after all distal anastomoses were complete.

2.5. Statistical analyses

Because a test of normality showed that the EF data were not normally distributed, Wilcoxon signed-ranks tests were performed to examine differences between preoperative and postoperative EF within groups. In addition, locally weighted scatterplot smoothing (LOWESS) curves were generated to examine changes in EF. Finally, multivariable stepwise linear regression with backward selection was performed to determine which, if any, of the eight prospectively collected demographic factors independently predicted changes in EF. Data were analyzed by using PASW Statistics 17.0 (SPSS Inc., Chicago, IL, USA) and S-PLUS 6.2 (Insightful Corp., Palo Alto, CA, USA).

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

3. Results

In several respects, the BH-CAB patients were in worse health than the OPCAB patients (Table 2): the BH-CAB patients were far more likely than the OPCAB patients to have cardiomegaly or a history of CHF, or to have had an MI in the previous 48 h. In addition, 36.9% (31/84) of BH-CAB patients had a preoperative EF less than 40%, whereas only 18.1% (72/397) of the OPCAB patients did (p < 0.001). Finally, BH-CAB cases were more than 4 times as likely to be emergent or salvage operations as OPCAB cases were.

Myocardial damage as assessed by peak CK-MB index was not significantly different between the OPCAB and BH-CAB groups (Table 3). Mean peak CK-MB index was 5.3 for both groups (p = 0.27).

In the 481 patients in whom both preoperative and postoperative EF was assessed, EF improved from a mean of 52.2% preoperatively to 57.9% postoperatively (p < 0.001). Mean EF increased from 53.5% to 58.9% (p < 0.001) in the 397 OPCAB patients and from 46.3% to 53.1% in the 84 BH-CAB patients (Table 4). Operative mortality was 0.8% (4/481) for the entire study cohort.

The addition of CPB did not influence the improvement in EF; the mean EF improvement was similar in the OPCAB patients (5.4%) and the BH-CAB patients (6.8%) (p = 0.65). The LOWESS curves were used to characterize the relationship between postoperative and preoperative EF, which was very similar for OPCAB and BH-CAB patients (Fig. 1). Improvement in EF was particularly dramatic for those patients with a preoperative EF less than 40% (Table 4). This was true for both OPCAB and BH-CAB patients. Nearly all patients with a preoperative EF less than 40% improved after coronary revascularization. For patients with a preoperative EF greater than 40%, there was less room for postoperative improvement, and the LOWESS lines flattened out at this point (Fig. 2).

Multivariable linear regression of the eight prospectively collected demographic factors (Table 5) showed that sex, presence or absence of COPD, presence or absence of diabetes, history of MI, stable versus unstable angina, and history of CHF did not predict postoperative change in EF. However, a low preoperative EF, age ≥ 70 years, and cardiomegaly predicted a lower EF after coronary revascularization by either OPCAB or BH-CAB.

Table 2. Patient demographics and medical history.

<table>
<thead>
<tr>
<th></th>
<th>OPCAB (n = 397)</th>
<th>BH-CAB (n = 84)</th>
<th>p</th>
<th>Total (N = 481)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ≥ 70</td>
<td>152 (38%)</td>
<td>28 (34%)</td>
<td>0.134</td>
<td>180 (37%)</td>
</tr>
<tr>
<td>Female</td>
<td>156 (40%)</td>
<td>41 (50%)</td>
<td>0.188</td>
<td>197 (40%)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>152 (40%)</td>
<td>29 (35%)</td>
<td>0.247</td>
<td>181 (38%)</td>
</tr>
<tr>
<td>COPD</td>
<td>153 (41%)</td>
<td>37 (45%)</td>
<td>0.270</td>
<td>190 (40%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>156 (40%)</td>
<td>32 (38%)</td>
<td>0.150</td>
<td>188 (39%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>139 (36%)</td>
<td>32 (38%)</td>
<td>0.270</td>
<td>171 (35%)</td>
</tr>
<tr>
<td>History of MI</td>
<td>261 (67%)</td>
<td>65 (78%)</td>
<td>0.034</td>
<td>326 (68%)</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>152 (40%)</td>
<td>37 (45%)</td>
<td>0.253</td>
<td>189 (39%)</td>
</tr>
<tr>
<td>History of CHF</td>
<td>113 (29%)</td>
<td>32 (38%)</td>
<td>0.003</td>
<td>145 (30%)</td>
</tr>
<tr>
<td>History of stroke</td>
<td>40 (10%)</td>
<td>10 (12%)</td>
<td>0.819</td>
<td>50 (10%)</td>
</tr>
<tr>
<td>Cardiomegaly</td>
<td>21 (5%)</td>
<td>40 (48%)</td>
<td>0.001</td>
<td>61 (13%)</td>
</tr>
<tr>
<td>Operative priority</td>
<td>0.003</td>
<td>&lt;</td>
<td>0.003</td>
<td>&lt;</td>
</tr>
<tr>
<td>Elective</td>
<td>82 (21%)</td>
<td>17 (21%)</td>
<td>0.89</td>
<td>99 (20%)</td>
</tr>
<tr>
<td>Urgent</td>
<td>75 (32%)</td>
<td>45 (35%)</td>
<td>0.33</td>
<td>120 (25%)</td>
</tr>
<tr>
<td>Emergent/salvage</td>
<td>7 (1%)</td>
<td>8 (10%)</td>
<td>0.65</td>
<td>15 (3%)</td>
</tr>
</tbody>
</table>

BH-CAB grafting: beating-heart coronary artery bypass; CHF: congestive heart failure; COPD: chronic obstructive pulmonary disease; MI: myocardial infarction; OPCAB: off-pump coronary artery bypass surgery.

Table 3. Peak CK-MB index in all patients.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Peak CK-MB</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPCAB</td>
<td>377</td>
<td>5.3 ± 2.7 (4.8)</td>
<td>0.226</td>
</tr>
<tr>
<td>BH-CAB</td>
<td>79</td>
<td>5.7 ± 3.2 (5.4)</td>
<td>0.65</td>
</tr>
<tr>
<td>All patients</td>
<td>456</td>
<td>5.3 ± 2.8 (4.9)</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD (median). BH-CAB grafting: beating-heart coronary artery bypass; CK-MB: creatine kinase MB; OPCAB: off-pump coronary artery bypass surgery.
4. Discussion

Both OPCAB and BH-CAB surgery avoid ischemic cardiac arrest during coronary artery revascularization. Despite enthusiasm for these techniques on the part of surgeons who use them frequently, widespread adoption has been slower than anticipated [5]. This is due, in part, to a lack of definitive evidence that either technique produces better outcomes than OPCAB. However, many observational studies and meta-analyses indicate that OPCAB may reduce mortality and morbidity rates [6,7]. Likewise, beating-heart techniques may be associated with reduced rates of postoperative renal dysfunction, perioperative stroke, and mortality, although these conclusions are controversial [6—9]. In a recent randomized study, OPCAB and on-pump techniques seemed to produce equivalent results, although OPCAB was associated with a somewhat lower graft patency rate (however, this study can be criticized for the lack of surgeon experience with the OPCAB technique) [10].

The OPCAB and BH-CAB patients had a different demographic profile. The BH-CAB patients tended to have had an MI within the previous 48 h, and they were more likely to have CHF (although neither of these factors was significant at the \( p < 0.0001 \) level). Despite this difference, there was no difference in perioperative CK release between the two groups. One explanation for this might be that the liberal use of CPB support is important for adequate myocardial protection.

Practitioners of OPCAB and BH-CAB often cite rapid recovery as a potential benefit, but the evidence for such recovery is anecdotal. The magnitude of this benefit is challenging to quantify. Furthermore, the mechanisms underlying the faster recovery of OPCAB and BH-CAB patients, if it is indeed faster, have yet to be elucidated. We concentrated on one potential parameter that might be important: cardiac function and its improvement during the first several days after surgery.

Table 4. Preoperative and postoperative ejection fraction.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Preoperative EF (mean ± SD)</th>
<th>Postoperative EF (mean ± SD)</th>
<th>Difference (mean ± SD)</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>481</td>
<td>52.2 ± 15.4 (55)</td>
<td>57.9 ± 12.4 (61)</td>
<td>5.6 ± 11.3 (4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>OPCAB</td>
<td>397</td>
<td>53.5 ± 14.5 (57)</td>
<td>59.0 ± 11.6 (62)</td>
<td>5.4 ± 10.9 (4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BH-CAB</td>
<td>84</td>
<td>46.3 ± 18.1 (50)</td>
<td>53.1 ± 14.2 (50)</td>
<td>6.7 ± 13.2 (5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Patients with preoperative EF &lt; 40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPCAB</td>
<td>72</td>
<td>28.8 ± 7.0 (31)</td>
<td>43.7 ± 13.1 (43)</td>
<td>14.9 ± 11.6 (14)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BH-CAB</td>
<td>31</td>
<td>25.6 ± 6.3 (27)</td>
<td>42.1 ± 13.7 (42)</td>
<td>16.4 ± 13.8 (17)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>All</td>
<td>103</td>
<td>27.8 ± 6.9 (30)</td>
<td>43.2 ± 13.2 (43)</td>
<td>15.4 ± 12.2 (14)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD (median). 'Difference' indicates postoperative EF minus preoperative EF. \( p \) values were generated by Wilcoxon signed-ranks tests.

BH-CAB grafting: beating-heart coronary artery bypass; EF: ejection fraction; OPCAB: off-pump coronary artery bypass surgery.

Table 5. Significant independent predictors of improvement in ejection fraction after OPCAB or BH-CAB coronary revascularization.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>4.031</td>
<td>0.000</td>
</tr>
<tr>
<td>Preoperative EF &lt; 40%</td>
<td>-14.261</td>
<td>0.000</td>
</tr>
<tr>
<td>Age ( \geq ) 70 years</td>
<td>-2.303</td>
<td>0.028</td>
</tr>
<tr>
<td>Cardiomegaly</td>
<td>-3.943</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Coefficients and \( p \) values were computed by linear regression. BH-CAB grafting: beating-heart coronary artery bypass; EF: ejection fraction; OPCAB: off-pump coronary artery bypass surgery.
Cardiac function improves in the short term after OPCAB or BH-CAB procedures. These improvements may account for the subjective clinical improvements seen early after both procedures. Further prospective randomized studies and comparison with both on-pump coronary revascularization and percutaneous techniques will be of interest.

Acknowledgment

Stephen N. Palmer contributed to the editing of the article.

References

[8] Hernandez Jr F, Brown JR, Likosky DS, Clough RA, Hess AL, Roth RM, Ross CS, Whitten CM, O’Connor GT, Kiemper JD. Neurocognitive outcomes of Substantial improvements in EF are seen as early as 3—5 days after surgical revascularization with off-pump techniques. The magnitude of improvement with OPCAB or BH-CAB is similar. Presumably, these improvements are produced by improved myocardial oxygen supply to previously ischemic areas of myocardium, in the absence of any detrimental effects on the remainder of well-perfused myocardium. Our avoidance of ischemic myocardial arrest (and possibly the resultant myocardial edema) might be the most important factor in the early improvement we observed in myocardial function.

Prediction of improvement in EF after cardiac surgery has been controversial. Various imaging techniques, such as dobutamine stress echocardiography, adenosine thallium nuclear scanning, and positron emission tomography (PET) scanning, have been used to predict which patients might have higher EF after coronary revascularization [15,17]. Such imaging techniques were not used in our study. The magnitude of improvement in EF was not significantly different after OPCAB versus BH-CAB; the LOWESS lines were similar for both techniques. Our data do not address whether the addition of a period of ischemic cardiac arrest would influence either of these curves.

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