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On-Pump Beating Heart Surgery Offers an Alternative for Unstable Patients Undergoing Coronary Artery Bypass Grafting

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ABSTRACT

Background: Cardiac surgery has expanded the available approaches to aortocoronary artery bypass grafting to include approaches from minimally invasive surgery to full sternotomy. The heart can be arrested, left beating, or assisted with a right ventricular assist device or cardiopulmonary bypass pump. We have examined the 4 surgical modes that we use routinely in our large multisurgeon practice to determine our selection biases and the outcomes of the different techniques.

Methods: Of the 4733 coronary artery bypass grafting (CABG) patients we studied from January 2000 through December 2002, 2332 (49.3%) operations were done on-pump on the arrested heart, 1908 (40.3%) were performed off-pump, 364 (7.7%) were performed on-pump on the beating heart, and 129 (2.7%) were performed with right heart assist. The preoperative risk factors, operative variables, and postoperative outcomes of the groups were analyzed.

Results: Patients selected for on-pump beating heart procedures tended to be sicker with the highest predicted risk of death. We also selected patients who were in cardiogenic shock, in resuscitation, in emergent or salvage status, on dialysis, and with preoperative intra-aortic balloon pump (IABP) use for on-pump beating heart procedures at higher than expected rates. Patients with renal failure with or without dialysis, and those having a history of cerebrovascular accident tended not to be chosen for on-pump arrested heart procedures. Off-pump beating heart procedures were avoided for patients with cardiogenic shock or resuscitation, in emergent or salvage status, and with preoperative IABP use. The mortality rate in these patients was slightly worse in the on-pump beating heart group (4.4%) than in the on-pump arrested heart (3.5%) and off-pump (2.3%) groups (analysis of variance [ANOVA], $P = .04$). Atrial fibrillation occurred more frequently in both the on-pump beating heart (20.1%) and on-pump arrested heart (23.8%) groups (ANOVA, $P < .001$). The on-pump groups had higher rates of blood product use and reoperation for bleeding and a prolonged ventilation rate, compared with the other procedures. On-pump patients had a statistically longer length of stay than either off-pump or right heart–assisted patients ($P < .05$) and required longer times on the ventilator and in the intensive care unit.

Conclusions: Normothermic cardiopulmonary bypass with a beating heart is safe and efficacious and may be the method of choice for patients in cardiogenic shock, requiring resuscitation, or with previous CABG surgery, recent myocardial infarction, a low ejection fraction, or unstable arrhythmias.

INTRODUCTION

In the past, most coronary artery bypass grafting (CABG) was carried out through a median sternotomy with the patient on cardiopulmonary bypass (CPB) and with an arrested heart (ONCAB). However, current clinical practice offers at least 4 types of procedures from which the surgeon can choose: (1) CABG with CPB and on an arrested heart (arrested-ONCAB), (2) CABG with CPB but with an empty beating heart (beating-ONCAB), (3) off-pump CABG (OPCAB), and (4) CABG with right heart assist (RHA-CAB).

Arrested-ONCAB has a long and proven track record of relief of ischemia and is associated with an acceptable long-term graft patency rate. It allows the surgeon excellent visualization of a motionless field. However, this procedure employs CPB, manipulation of the aorta for cannulation, cross-clamping and proximal anastomosis, global ischemia, and usually hypothermia—all of which have associated morbidities.

Beating-ONCAB also allows the surgeon excellent visualization of the displaced heart with the hemodynamic stability afforded by CPB. Aortic manipulation is less than in arrested-ONCAB, because an aortic cross-clamp is not employed. Global myocardial ischemia and cardioplegic arrest are avoided, and the degree of hypothermia is moderate. There is some motion of the heart, but regional stabilization is easily achieved with modern devices.

OPCAB avoids the use of CPB with its associated morbidities. It also maintains normothermia and minimizes aortic manipulation. OPCAB maneuvers have been demonstrated to result in lower overall mortality and morbidities, especially in high-risk groups. Blood product use and mechanical ventilation are less, and hospital stays are shorter

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[Kim 2002, Aldea 2003, Bhatti 2003, Jazayeri 2003]. However, the annual report of the Society of Thoracic Surgeons (STS) for 2002 notes that only 22% of isolated CABG procedures are OPCAB procedures. It is likely that many surgeons are uncomfortable with this technique. Hemodynamic instability can be a problem during cardiac displacement, especially in the unstable patient, and visualization of the target vessel can be difficult. Additionally, OPCAB has yet to demonstrate long-term graft patency rates that are equivalent to those of ONCAB.

RHA-CAB attempts to achieve the benefits of OPCAB while ameliorating the hemodynamic effects of cardiac displacement that are largely attributable to right heart compression [Mathison 2000]. Although an oxygenator is not employed, an extracorporeal circuit is used. Studies have shown that the levels of inflammatory markers are lower than when full CPB is used [Caputo 2002]. This methodology, like OPCAB, suffers from the lack of a long track record. Additionally, we have observed that the potential for significant iatrogenic pulmonary edema exists if right-side flow rates are not carefully controlled.

The surgeon must select the appropriate procedure for each patient; however, the criteria for selection are currently ill defined. Our large single-group practice is rich with diverse practice patterns, and all 4 of these techniques are used. We have analyzed our practice patterns to determine if there are certain populations to which each of these techniques tends to be applied and to determine the associated outcomes in these groups.

MATERIALS AND METHODS

Patient Population

This study is a retrospective review of prospectively collected data entered into a customized STS-approved database at the Cardiopulmonary Research Science and Technology Institute (CRSTI). CRSTI collects data for all surgical patients in our practice from the preoperative period up to 30 days after surgery or the discharge date. These patient data are gathered from 16 surgeons who vary in their practice styles but who all carry out procedures both on and off pump. Of the CABG surgeries carried out on 4733 patients from January 2000 to December 2002, 2332 (49.3%) were arrested-ONCAB heart procedures, 1908 (40.3%) were OPCAB, 364 (7.7%) were beating-ONCAB, and 129 (2.7%) were RHA-CAB. This patient information was analyzed for preoperative risk factors, operative variables, and postoperative outcomes.

Data Analysis

After data export from the database, all results were analyzed with SAS software, version 8.2 (SAS Institute, Cary, NC, USA). Categorical variable data for the treatment groups were compared as proportions with chi-square statistics. A P value of .05 or less was considered statistically significant.

Continuous variable data were summarized (mean ± SD) and compared among groups by analysis of variance. Variables with significant P values in the F test were then subjected to post hoc testing using the Scheffé test. This conservative test minimizes type I errors in pairwise comparisons. Statistically significant differences are noted for each analysis, with statistical significance based on a P level of <.05.

Calculation of Selection Bias

Preoperative risk data were reanalyzed to examine the proportions of patients being selected for each of the 4 surgical technique groups. We then compared these values to an expected value derived from the initial distribution of patients among the 4 groups. For example, because 7.7% of the patients received their bypass surgeries using beating-ONCAB procedures, 7.7% of all patients for each tested parameter are expected to fall in this group if no selection bias is present. However, the data for the patients on dialysis show that the measured value was 8 (14.5%) of 55 patients, which is 88% higher than the expected proportion. For any group, a bias of 0% means that the variable has the expected proportion of patients, and a drop of –100% means that no patients were selected into that group.

RESULTS

Preoperative Risk Factors

The preoperative risk factors analyzed for the 4 procedures are shown in Table 1.

The data in Table 2 show that although the mean age is very nearly the same for all of the groups (with only the arrested-ONCAB and OPCAB groups being statistically different), the patients with the largest STS predicted risk of mortality (PROM) tended to be selected for beating-ONCAB. These patients also have the lowest mean ejection fractions in the study.

Patient Selection Biases

The selection of patients for each of the 4 surgical groups was not random. The data in Table 3 show the relative change in this variation for each of the measured preoperative variables. The incidence of each variable is calculated, and the fraction occurring in each patient group is then presented as a change from the expected value. A drop of –100% means that no patients were selected, whereas 0% means that the proportion was equal to the expected value, based on the numbers of patients in each group.

Some trends become evident with the analysis of the patient distribution in the 4 groups. A large fraction of patients in resuscitation and cardiogenic shock had surgery using the beating-ONCAB technique. Forty-five percent of all patients with renal disease and 71% of dialysis patients having CABG underwent OPCAB operations. As expected, there was a 62% increase in the preference to use arrested-ONCAB for patients with salvage status. The proportion of previous CABG patients who had redo surgery using beating-ONCAB was higher than expected, and previous valve patients underwent operations using beating-ONCAB and RHA-CAB at rates that were higher than expected. We also note that patients with preoperative intra-aortic balloon pump use tended to receive surgery using beating-ONCAB and arrested-ONCAB procedures at greater-than-expected frequencies.

Table 1. Preoperative Risk Factors*

Category	RHA-CAB, n (%)	Beating-ONCAB, n (%)	OPCAB, n (%)	Arrested-ONCAB, n (%)	P
No. of cases	129 (2.7)	364 (7.7)	1908 (40.3)	2332 (49.3)	
Female sex	33 (25.6)	92 (25.3)	585 (30.7)	557 (23.9)	<.001
Smoker	38 (29.5)	91 (25.0)	423 (22.2)	582 (25.0)	.008
Diabetes	39 (30.2)	115 (31.7)	620 (32.5)	741 (31.8)	NS
Renal failure	3 (2.3)	16 (4.4)	99 (5.2)	51 (2.2)	<.001
Dialysis	2 (1.6)	8 (2.2)	38 (2.0)	7 (0.3)	<.001
Hypertension	82 (63.6)	254 (70.0)	1360 (71.4)	1698 (73.0)	NS (.08)
Cerebrovascular accident	13 (10.1)	33 (9.1)	126 (6.6)	110 (4.7)	<.001
Lung disease	24 (18.6)	42 (11.5)	270 (14.2)	274 (11.7)	.02
Peripheral vascular disease	14 (10.9)	44 (12.1)	224 (11.8)	284 (12.2)	NS
Cerebral vascular disease	20 (15.5)	52 (14.3)	201 (10.5)	223 (9.6)	.01
Previous CAB	3 (2.3)	43 (11.8)	158 (8.3)	177 (7.6)	.004
Previous valve	2 (1.6)	2 (0.6)	7 (0.4)	8 (0.3)	NS
Myocardial infarction	53 (41.1)	196 (54.3)	797 (41.8)	1026 (44.0)	<.001
Congestive heart failure	11 (8.5)	59 (16.5)	242 (12.7)	268 (11.6)	.03
Angina	87 (67.4)	333 (91.5)	1670 (87.6)	2146 (92.0)	<.001
Angina type					
Stable	73 (83.9)	208 (62.5)	1233 (73.9)	1434 (66.9)	<.001
Unstable	14 (16.1)	125 (37.5)	436 (26.1)	711 (33.2)	
Cardiogenic shock	0 (0.0)	12 (3.3)	11 (0.6)	38 (1.6)	<.001
Resuscitation	0 (0.0)	10 (2.8)	6 (0.3)	19 (0.8)	<.001
Arrhythmia	6 (4.7)	47 (13.0)	140 (7.3)	186 (8.0)	.002
3-Vessel disease	105 (81.4)	308 (85.1)	1297 (68.0)	1962 (84.2)	<.001
Left main >50%	23 (17.8)	75 (20.8)	359 (18.9)	594 (25.7)	<.001
Status					
Elective	69 (53.5)	122 (33.5)	896 (47.0)	905 (38.8)	<.001
Urgent	60 (46.5)	225 (61.8)	981 (51.5)	1342 (57.6)	
Emergent	0 (0.0)	15 (4.1)	28 (1.5)	72 (3.1)	
Salvage	0 (0.0)	2 (0.6)	1 (0.1)	12 (0.5)	
Preoperative IABP	3 (2.3)	51 (14.0)	62 (3.3)	264 (11.3)	<.001

*RHA-CAB indicates right heart assist coronary artery bypass; beating-ONCAB, on-pump coronary artery bypass on the beating heart; OPCAB, off-pump coronary artery bypass on the beating heart; arrested-ONCAB, on-pump coronary artery bypass on the arrested heart; NS, not significant; CAB, coronary artery bypass; IABP, intra-aortic balloon pump.

Selected variables are shown graphically in Figure 1, illustrating that parameters related to the severity of disease were preferentially selected by the surgeons in deciding to use particular surgical techniques.

Outcomes and Complications

Table 4 shows the results of the surgeries on the patient populations. The lengths of stay (in days) were greatest in the two on-pump groups (beating-ONCAB and arrested-ONCAB) and

Table 2. Patient Age, Ejection Fraction (EF), and Projected Risk of Mortality (PROM) as Preoperative Risk Factors for the 4 Surgical Groups*

Continuous Variables (ANOVA)	RHA-CAB	Beating-ONCAB	OPCAB	Arrested-ONCAB	P
Age, y	64.4 ± 10.3	63.4 ± 10.3	64.0 ± 11.3	63.0 ± 10.5	†
EF, %	48.1 ± 13.2	45.6 ± 12.5	51.0 ± 13.1	50.7 ± 12.1	‡
PROM	0.0240 ± 0.0320	0.0373 ± 0.0611	0.0306 ± 0.0405	0.0293 ± 0.0469	§

*Data are presented as the mean ± SD. ANOVA indicates analysis of variance. Other abbreviations are expanded in the footnote to Table 1.

†Post hoc testing of age results indicates that arrested-ONCAB is statistically different ($P < .05$) from OPCAB. No other comparisons are statistically significant.

‡Post hoc testing of EF results indicates that beating-ONCAB is statistically different ($P < .05$) from arrested-ONCAB and OPCAB. No other comparisons are statistically significant.

§Post hoc testing of PROM results indicates that beating-ONCAB is statistically different ($P < .05$) from RHA-CAB and from arrested-ONCAB. No other comparisons are statistically significant.

Table 3. Percentage Changes in Parameter Values Relative to Expected Values*

	RHA–CAB	Beating–ONCAB	OPCAB	Arrested–ONCAB
Female sex	−4%	−6%	15%	−11%
Smoker	23%	4%	−7%	4%
Diabetes	−6%	−1%	2%	−1%
Renal failure	−35%	23%	45%	−39%
Dialysis	33%	89%	71%	−74%
Hypertension	−11%	−3%	−1%	2%
Cerebrovascular accident	69%	52%	11%	−21%
Lung disease	44%	−10%	10%	−9%
Peripheral vascular disease	−9%	1%	−2%	2%
Cerebral vascular disease	48%	36%	1%	−9%
Previous CAB	−71%	47%	3%	−6%
Previous valve	286%	37%	−9%	−15%
Myocardial infarction	−6%	23%	−5%	0%
Congestive heart failure	−30%	32%	4%	−6%
Angina	−25%	2%	−2%	3%
Angina type				
Stable	−9%	−8%	4%	−1%
Unstable	−60%	26%	−16%	12%
Cardiogenic shock	−100%	156%	−55%	26%
Resuscitation	−100%	272%	−57%	10%
Arrhythmia	−42%	61%	−8%	0%
3-Vessel disease	5%	9%	−12%	8%
Left main >50%	−20%	−7%	−15%	15%
Status				
Elective	27%	−20%	12%	−8%
Urgent	−16%	12%	−7%	4%
Emergent	−100%	70%	−40%	27%
Salvage	−100%	73%	−83%	62%
Preoperative IABP	−71%	75%	−60%	41%

*Abbreviations are expanded in the footnote to Table 1.

least in the RHA-CAB–supported patients. The number of anastomoses (distal arteries plus distal veins) averaged 3.3 to 3.5 in all groups except the OPCAB group, where it was only 2.9, although the risks table shows that the OPCAB group tended to have slightly less 3-vessel disease than expected (Table 1). The decrease in the number of anastomoses is statistically significant.

Furthermore, pump use tends to increase ventilator times and the lengths of intensive care unit stays.

Table 5 shows the results of the categorical variable analysis for the surgical groups. The data do not have matched groups, and unmatched groups are obtained when the patients are selected as we have indicated. The use of CPB pumps, either with or without cardioplegia, is associated with an increased incidence of postoperative atrial fibrillation, blood product use, renal failure, prolonged ventilation, and a need for reoperation for continued bleeding. Beating-ONCAB has an increased rate of cardiac arrest, and arrested-ONCAB shows a higher rate of pneumonia. There was also a significantly more frequent need for intra-aortic balloon pump use during or after surgery in the beating-ONCAB and arrested-ONCAB groups.

The observed mortality rates are higher than predicted for both on-pump groups and are lower than predicted for the OPCAB and RHA-CAB groups, with all differences being statistically significant (Table 6). The observed-expected (O/E) ratios are also shown. Risk-adjusted mortality rates are not available, because the national value supplied by the STS is not broken down into on-pump and off-pump groupings.

DISCUSSION

The observational nature of this study does not allow any conclusions to be drawn concerning the superiority of one technique over another. These groups are not matched, because one of the objectives was to learn which patients were being selected preferentially for each technique. Therefore, we eliminated from this analysis any surgeons who were not actively performing any surgeries off pump, the reasoning being that if these surgeons were not comfortable with beating heart techniques, they would never select a patient for an OPCAB or a beating-ONCAB procedure. The cases presented here encompass the experience of the 16 surgeons

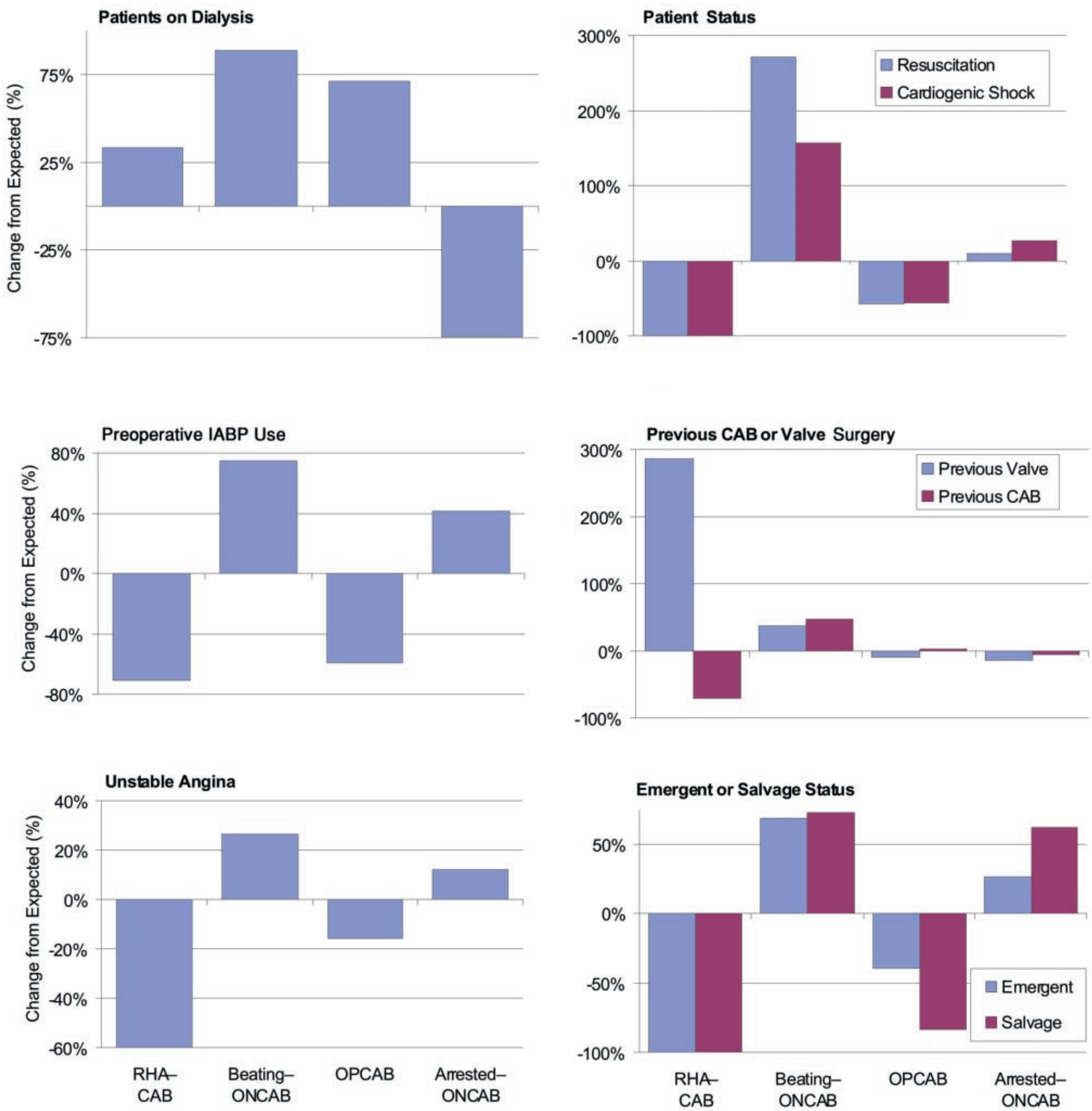

Figure 1. Surgical procedure preferences. IABP indicates intra-aortic balloon pump; CAB, coronary artery bypass; RHA-CAB, right heart assist coronary artery bypass; beating-ONCAB, on-pump coronary artery bypass on the beating heart; OPCAB, off-pump coronary artery bypass on the beating heart; arrested-ONCAB, on-pump coronary artery bypass on the arrested heart.

who use an on-pump or off-pump procedure as appropriate. Furthermore, we should note that a single surgeon did almost all of the RHA-CAB procedures. Although these data are included mostly to examine the outcomes, one should be careful about drawing conclusions about which patients were selected into this group, because most of the surgeons did not have this technique available to use.

Determination of Selection Bias

Although we cannot define clear criteria for selection into each method, some interesting trends emerged. It appears that our sickest patients underwent operations with beating-ONCAB techniques. These patients had the highest PROM, often were unstable, and had cardiogenic shock, resuscitation, arrhythmias, an emergent or salvage status, a previous

Table 4. Outcomes of Surgery*

Continuous Variables (ANOVA)	RHA-CAB	Beating-ONCAB	OPCAB	Arrested-ONCAB	*P*
Length of stay, d	4.2 ± 3.5	7.8 ± 8.1	5.8 ± 4.8	7.5 ± 6.8	†
Distal arteries, n	1.22 ± 0.70	0.93 ± 0.49	1.23 ± 0.74	1.10 ± 0.70	‡
Distal veins, n	2.23 ± 0.84	2.36 ± 1.05	1.67 ± 1.11	2.37 ± 1.04	§
Total anastomoses, n	3.45 ± 0.81	3.29 ± 1.03	2.90 ± 1.13	3.47 ± 1.00	‖
Cross-clamp time, min	0	0	0	56.9 ± 20.5	N/A
Perfusion time, min	38.9 ± 22.4	102.3 ± 39.5	0	103.0 ± 36.0	¶
Ventilator time, h	4.9 ± 6.9	24.8 ± 55.3	10.6 ± 45.4	24.9 ± 84.3	#
ICU stay, d	1.1 ± 1.3	3.4 ± 6.7	2.0 ± 3.6	3.1 ± 4.7	**

*Data are presented as the mean ± SD. ANOVA indicates analysis of variance; N/A, not applicable; ICU, intensive care unit. Other abbreviations are expanded in the footnote to Table 1.

†Differences between RHA-CAB and OPCAB and between beating-ONCAB and arrested-ONCAB are not statistically significant. All other comparisons are statistically significant ($P < .05$).

‡Differences between RHA-CAB and OPCAB and between RHA-CAB and arrested-ONCAB are not statistically significant. All other comparisons are statistically significant ($P < .05$).

§OPCAB is statistically different from all other groups ($P < .05$). No other comparisons are statistically significant.

‖Differences between arrested-ONCAB and beating-ONCAB, arrested-ONCAB and OPCAB, and RHA-CAB and OPCAB are statistically significant ($P < .05$). All other comparisons are not statistically significant.

¶Beating-ONCAB is not statistically different from arrested-ONCAB. All other comparisons are statistically significant ($P < .05$).

#Differences between arrested-ONCAB and OPCAB, arrested-ONCAB and RHA-CAB, and beating-ONCAB and OPCAB are statistically significant ($P < .05$). All other comparisons are not statistically significant.

**Differences between beating-ONCAB and OPCAB, beating-ONCAB and RHA-CAB, arrested-ONCAB and OPCAB, and arrested-ONCAB and RHA-CAB are statistically significant ($P < .05$). All other comparisons are not statistically significant.

CABG, myocardial infarction, or cerebrovascular accidents. Patients with renal insufficiency tended to be selected for OPCAB or beating-ONCAB.

Outcome Differences

Table 5 shows a statistically significant difference in the observed mortality rates for the 4 groups. This finding is not surprising given that the PROMs were different for these groups. The beating-ONCAB group had both the highest predicted (3.7%) and the highest observed (4.4%) mortality rates, although the O/E ratio does not differ from that for arrested-ONCAB. Indeed, the beating-ONCAB mortality rate compares favorably with the 13.7% rate observed by Perrault et al [1997] in a group of 37 high-risk beating-ONCAB patients. It is important to remember that these groups are not matched, and the mortality of this group might have been even higher had a different technique for revascularization been selected for these patients. For example, beating-ONCAB may afford better protection to the heart and less ischemia than arrested-ONCAB. Other investigators have maintained that arresting the heart provides protection that is inferior to allowing it to beat while on CPB. In his discussion of the report by Ascione and coworkers [1999], Buffolo states, ". . . what we call myocardial protection, is not really myocardial protection; it is some kind of myocardial aggression. When I have to operate the patient on pump, I use the empty beating heart technique."

There is other objective evidence that the arrested heart may not be as well protected from ischemia as the empty beating heart. Krejca et al [1999] found troponin T levels to be higher in arrested-ONCAB than in beating-ONCAB or OPCAB. In their study, Perrault et al [1997] and Szmagala et al [1998] also measured post-bypass troponin I levels. Furthermore, these investigators took pre-bypass and post-bypass right atrial biopsies and processed them with Northern blotting techniques to evaluate expression levels of messenger RNA (mRNA) coding for cardioprotective heat-shock protein 70 (HSP 70). They found that the troponin levels in the arrested-ONCAB group were twice as high as in the beating-ONCAB group and that the cardioprotective HSP 70 mRNA levels were increased in the beating-ONCAB group but not in the arrested-ONCAB group.

Previous studies have shown OPCAB to have a lower mortality rate than ONCAB [Demaria 2002, Mack 2002, Shennib 2002]. It is interesting that the observed mortality rate was significantly higher than predicted (O/E ratio >1) in both of the groups that used CPB, regardless of whether the heart was arrested, and was lower than predicted (O/E ratio <1) in the OPCAB group. This finding suggests that the avoidance of arresting the heart does not fully ameliorate the higher mortality rate associated with the use of CPB. Furthermore, although RHA-CAB uses extracorporeal circulation but without an oxygenator, the mortality rate of this group was lower than predicted, suggesting that the presence of the oxygenator is an important contributor to the morbidity of CPB.

Other interesting differences also emerged between the two groups that used CPB and the two that did not. Beating-ONCAB and arrested-ONCAB had significantly higher rates of blood product use, higher rates of return to the operating room for bleeding complications, prolonged ventilation times, and longer lengths of stay in the hospital. This finding again suggests that the presence of the oxygenator contributes to these morbidities. Similar findings have previously been reported. Caputo et al [2002] compared OPCAB with

Table 5. Outcomes and Morbidities*

Factor	RHA-CAB, n (%)	Beating-ONCAB, n (%)	OPCAB, n (%)	Arrested ONCAB, n (%)	*P*
Mortality rate	2 (1.6)	16 (4.4)	44 (2.3)	82 (3.5)	.04
Atrial fibrillation	8 (6.2)	73 (20.1)	266 (13.9)	554 (23.8)	<.001
Cardiac arrest	0 (0)	9 (2.5)	21 (1.1)	26 (1.1)	NS
Blood products	21 (16.3)	212 (59.2)	516 (27.2)	1210 (52.3)	<.001
Coma (24 h)	0 (0)	1 (0.3)	7 (0.4)	14 (0.6)	NS
Renal failure	2 (1.6)	33 (9.1)	45 (2.4)	106 (4.6)	<.001
Dialysis required	0 (0)	4 (1.1)	15 (0.8)	25 (1.1)	NS
Gastrointestinal disorder	0 (0)	10 (2.8)	30 (1.6)	38 (1.6)	NS
Myocardial infarction	2 (1.6)	3 (0.8)	10 (0.5)	24 (1.0)	NS
Intraoperative or postoperative IABP	0 (0)	15 (4.1)	7 (0.4)	74 (3.2)	.03
Graft occlusion	0 (0)	3 (0.8)	3 (0.2)	9 (0.4)	NS
Multisystem failure	0 (0)	3 (0.8)	13 (0.7)	15 (0.6)	NS
Pneumonia	0 (0)	6 (1.7)	31 (1.6)	79 (3.4)	<.001
Reoperation for bleeding	2 (1.6)	13 (3.6)	32 (1.7)	78 (3.3)	.004
Readmit in 30 d	7 (5.4)	21 (5.9)	134 (7.1)	146 (6.3)	NS
Septicemia	0 (0)	1 (0.3)	8 (0.4)	20 (0.9)	NS
Sternal deep infection	0 (0)	2 (0.6)	4 (0.2)	9 (0.4)	NS
Stroke, permanent	1 (0.8)	5 (1.4)	15 (0.8)	28 (1.2)	NS
Stroke, transient	1 (0.8)	2 (0.6)	3 (0.2)	8 (0.3)	NS
Tamponade	0 (0)	1 (0.3)	4 (0.2)	13 (0.6)	NS
Ventilation, prolonged	3 (2.3)	45 (12.4)	83 (4.4)	288 (12.4)	<.001

*Abbreviations are expanded in the footnote to Table 1.

RHA-CAB and arrested-ONCAB. These workers found that the level of blood product use for RHA-CAB was intermediate between the levels for OPCAB and arrested-ONCAB. However, levels of inflammation markers (interleukin 6, interleukin 8, C3a, C5a) were significantly higher in arrested-ONCAB patients, but marker levels in OPCAB and RHA-CAB patients were not different.

Similar to the results found in other studies [Potger 2002, Sabik 2002, Shennib 2002], we found that fewer grafts were placed in the OPCAB group. This finding may be purely a matter of selection bias, because there were also significantly fewer patients with triple-vessel disease in this group (see Table 1). Some critics may argue that OPCAB patients are undergoing incomplete revascularization. The long-term markers of incomplete revascularization are recurrent angina, a need for reintervention, and a decrease in late survival rate [Bell 1992, Jones 1996, Scott 2000], outcomes that are pending long-term follow-up of OPCAB procedures. However, a Turkish study published by Tasdemir et al [1998] identified 3 early markers of incomplete revascularization. In leaving left lateral vessels intentionally ungrafted in their study, these investigators argued that the benefits of OPCAB to the easily approachable anterior and inferior vessels outweighed the risks of incomplete revascularization. They found that the incompletely revascularized patients had higher rates of operative mortality, perioperative myocardial infarction, and low output syndrome. None of these early markers of incomplete revascularization were present in our OPCAB group.

Avoidance of arresting the heart did not protect against postoperative atrial fibrillation. Both arrested-ONCAB and beating-ONCAB groups had higher rates of atrial fibrillation.

Finally, a previous study has warned that warm CPB is associated with an increased rate of perioperative stroke [Martin 1994]. It is important to note that our technique of beating-ONCAB involves allowing the patient temperature to drift lower with no active warming until the patient is ready to be weaned from CPB. Using this technique, we had no increased rate of stroke in our tepid beating-ONCAB group, compared with our cold arrested-ONCAB group.

CONCLUSIONS

Beating-ONCAB was found to be safe and was often used for our sickest, most unstable patients.

Avoidance of cold CPB and cardiac arrest does not protect against the increased bleeding, lengths of hospital stay, and ventilator times that have repeatedly been shown to be greater in ONCAB than in OPCAB.

Tepid CPB may be as protective against stroke as cold CPB.

Table 6. Expected and Observed Mortality*

	Mortality			
	Observed	Expected	O/E Ratio	*P*
RHA-CAB	0.016	0.0240	0.67	.005
Beating-ONCAB	0.044	0.0373	1.18	.04
OPCAB	0.023	0.0306	0.75	<.001
Arrested-ONCAB	0.035	0.0293	1.19	<.001

*O/E indicates observed/expected. Other abbreviations are expanded in the footnote to Table 1.

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