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Off-Pump Coronary Bypass Surgery Is Safe in Patients with a Low Ejection Fraction (≤25%)

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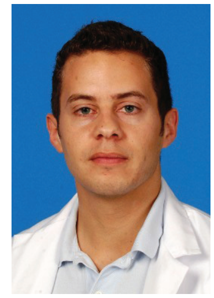

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ABSTRACT

Background: A severely decreased ejection fraction (EF) of ≤25% is an established risk factor for a worse outcome after heart surgery and therefore has been incorporated into the EuroSCORE risk-stratification model. We compare clinical outcomes after off-pump coronary artery bypass grafting (OPCAB) and on-pump coronary artery bypass grafting in patients with a severely compromised EF.

Methods: We compared 112 patients with a low EF (≤25%) who underwent myocardial revascularization between 2003 and 2008. Forty-four patients underwent OPCAB (group A), and 68 patients underwent on-pump surgery (group B). We compared demographics, intraoperative parameters, intraoperative outcomes, and the completeness of revascularization for the 2 groups.

Results: Demographic and EuroSCORE data were comparable for groups A and B. The 2 groups appeared to be similar with respect to mortality rate during the first 30 days (2.2% and 8.8%, respectively; $P = .11$) and the rate of major complications such as stroke (2.2% and 2.9%, respectively; $P = 0.83$). The patients in group A had fewer pulmonary complications (7% versus 25%, $P < .01$), received fewer blood transfusions (15.9% versus 47.0%, $P < .01$), required fewer postoperative pacing procedures (atrial, 11.4% versus 39.7%; ventricular, 13.6% versus 47.1%; $P < .01$), and had fewer wound infections (2.2% versus 16.1%, $P = .02$). The numbers of diseased vessels were comparable, and although the OPCAB patients received more arterial grafts (1.05 ± 0.43 versus 0.84 ± 0.37, $P < .01$), the total number of grafts per patient was lower among these patients (2.50 ± 0.88 versus 3.53 ± 0.92, $P = .03$). Similarly, complete revascularization was achieved less frequently within this group (80% versus 94%, $P = .02$).

Conclusions: A standardized OPCAB approach in patients with a severely decreased EF is safe and may benefit this subset of patients with respect to fewer postoperative complications. Although complete revascularization is the optimal approach for these patients, they benefit from avoiding cardiopulmonary bypass.

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INTRODUCTION

Surgical treatment of patients with coronary artery disease and a severely decreased left ventricular ejection fraction (EF) remains a particular challenge. Recent data indicate an increased perioperative mortality and high morbidity among these high-risk patients [Christakis 1992; O'Connor 1992], which are reflected in an increased EuroSCORE (http://www.euroscore.org), an established scoring system for preoperative risk stratification of patients undergoing cardiac surgery. The compromised outcomes of these high-risk patients may be partly associated with the deleterious effect of cardiopulmonary bypass (CPB) and with the effects of cardioplegic solutions on the heart [Wan 2004; Nesher 2006].

Minimally invasive techniques have led to the development of off-pump coronary artery bypass grafting (OPCAB). This approach permits complete myocardial revascularization while avoiding CPB, which may be of particular benefit to high-risk patients with an impaired cardiac function.

As practiced today, however, the use of OPCAB varies from site to site. Off-pump procedures involve repeated dislocation of the heart, especially when the circumflex territory is addressed. Additionally, the occurrence of extended periods of hypotension and decreased cardiac output may lead to compromised hemodynamics and cardiac decompensation [Brown 1999]. For this reason, surgeons have thus far been cautious about exposing patients with a severely decreased EF to these techniques, which may put patients at risk for emergent conversion to CPB and damage to other organs. On the other hand, current data have demonstrated that OPCAB is generally associated with fewer major complications and a decrease in the risk-adjusted mortality rate [Cleveland 2001; Puskas 2003; Hannan 2007; Puskas 2008]. In addition, Chamberlain and colleagues recently demonstrated safety, feasibility, and reduced morbidity in 332 high-risk patients who underwent off-pump surgery for myocardial revascularization [Chamberlain 2002]. Furthermore, Shennib et al evaluated

77 patients with a low EF (<35%) and found OPCAB to be safe and efficacious in these high-risk patients, but at a cost of a slightly less complete revascularization [Shennib 2002]. We found it worthwhile to compare OPCAB and on-pump results for mortality and morbidity in patients with a severely impaired EF (≤25%).

MATERIALS AND METHODS

From 2003 to 2008, 112 patients with a severely decreased EF (≤25%) underwent isolated OPCAB at our institution for symptomatic multivessel disease. After informed consent was obtained and following review by our institutional review board, we compared 44 OPCAB patients (group A) to 68 on-pump patients (group B). The EF was documented with transthoracic echocardiography before surgery and was confirmed intraoperatively by transesophageal echocardiography. The mean age (±SD) of the patients at the time of surgery was 65.5 ± 9.8 years. The EuroSCORE risk-stratification system was used for preoperative risk stratification. Preoperative medications included angiotensin-converting enzyme inhibitors, beta-blockers, diuretics, calcium channel blockers, aspirin, heparin, and warfarin. The patients' operations were performed by a heterogeneous group of 6 surgeons with variable experience and a ratio of OPCAB to on-pump procedures in their practice of 30% to 50%. Table 1 summarizes the demographic and preoperative data.

We performed on-pump coronary revascularization with state-of-the-art techniques, which are meticulously described elsewhere. After aortic cross-clamping, we used cold blood–based antegrade and/or retrograde cardioplegia supplemented with a solution of potassium, magnesium, and procaine.

OPCAB surgery was performed according to internationally established techniques. In brief, following sternotomy and pericardiotomy, 150 IU heparin was administered to achieve an activated clotting time of 250 to 300 seconds. The left internal mammary artery (LIMA) was harvested before the pericardiotomy. Next, a deep pericardial stitch was placed with 0 silk sutures, through which gauze was passed for exposure purposes. Cannulation purse-string sutures were placed in the aorta and the right atrium as a standby measure in case of conversion to CPB. Epicardial pacemaker wires were inserted, the heart was filled with an adequate volume, and the operating table was broken for variably "head down" manipulations in the Trendelenburg position. In cases of an enlarged heart, a vertical pericardiotomy and right pleurotomy were carried out to permit extended exposure of the heart without hemodynamic compromise. For distal anastomoses, the target vessel was occluded proximally to the anastomotic site with silicone-supported tourniquets. The anastomotic area was stabilized with either the Octopus® stabilizer or the Starfish® heart suction stabilizer (Medtronic, Minneapolis, MN, USA). Intracoronary shunts were used whenever possible, and a blower/mister device was used. Proximal anastomoses were performed with the aid of multiple side-biting clamps.

Hemodynamic optimization was attempted in all patients by fluid resuscitation, Trendelenburg positioning, atrial pacing, and inotrope administration. When this conservative approach was insufficient, an intra-aortic balloon pump (IABP) was inserted intraoperatively. Transesophageal echocardiography and a pulmonary artery catheter (Swan-Ganz catheter) were used to assess any hemodynamic compromise. Surgical revascularization was started by LIMA grafting to the left anterior descending coronary artery (LAD). Then, the right coronary system was approached, and, finally, revascularization of the circumflex territory was performed. In patients with left main disease, the LAD and circumflex arteries were always grafted, regardless of the degree of stenosis. All other vessels with significant lesions (>70% stenosis) were identified preoperatively and selected as targets for revascularization.

The evaluated parameters included patient demographics, intraoperative variables, and postoperative outcomes. Preoperative patient characteristics included cardiovascular risk factors and comorbidities, such as previous cerebrovascular accidents, cerebrovascular disease, obesity, chronic obstructive pulmonary disease, and renal failure. Cardiac-related preoperative conditions were as follows: past myocardial infarction (MI); MI within the 3 months prior to surgery; previous cardiogenic shock; congestive heart failure; angina pectoris; arrhythmias; EF; number of diseased coronary vessels; previous coronary artery bypass grafting (CABG); elective, urgent, or emergent presentation; previous percutaneous transluminal coronary angioplasty; previous stent implantation; previous thrombolysis; and the logistic EuroSCORE. Intraoperative variables included the following: CPB data, the number of arterial and venous grafts, and the total number of distal anastomoses. The completeness of revascularization was assessed with the aid of a revascularization index (RI), which was defined as the total number of distal grafts divided by the number of the affected coronary vessels revealed in the coronary angiogram. Postoperative variables were as follows: operative and early postoperative mortality (≤30 days), stroke, need for IABP implantation, requirement for pacing, inotrope use, use of antiarrhythmic medication, reintubation, cardiac arrest, advanced-stage heart atrioventricular block, atrial fibrillation, postoperative MI, postoperative creatine kinase activity, creatine kinase MB isoenzyme activity at 12 hours postoperatively, total blood product requirements, pulmonary complications (pleural effusions, pneumonia, postoperative ventilation time, and prolonged-ventilation time), dialysis requirement, wound infections, and the cumulative length of stay in the intensive care unit (ICU) and the high-dependency unit (HDU).

Analysis of descriptive statistics was performed. Continuous data are presented as the mean ± SD. Categorical or dichotomous data are presented as frequencies and percentages. The OPCAB and on-pump CABG groups (data sets were normally distributed) were compared to assess postoperative outcomes for patients with a severely compromised EF (≤25%). Differences between the groups in numerical variables were compared with the Student *t* test for independent. Dichotomous variables were compared with the chi-square test with Fisher exact adjustment. Statistical significance was assumed for P values <.05.

Table 1. Patient Demographics and Preoperative Characteristics*

Parameter	Group A (Off-Pump; n = 44)	Group B (On-Pump; n = 68)	*P*
Male sex, n	41 (93%)	60 (88%)	.63
Age, y	60.4 ± 9.7	59.3 ± 10.2	.74
Race, n			
Chinese	30 (68%)	41 (60%)	.79
Malay	12 (27%)	15 (22%)	.98
Indian	2 (5%)	10 (15%)	.09
Caucasian	0 (0%)	2 (3%)	.24
History of smoking, n	16 (36%)	28 (41%)	.61
Diabetes, n	26 (59%)	36 (53%)	.52
History of CAD, n	3 (7%)	10 (15%)	.20
Hypercholesterolemia, n	33 (75%)	53 (78%)	.72
Hypertension, n	31 (70%)	49 (72%)	.85
Past cerebrovascular accident, n	5 (11%)	5 (7%)	.46
Cerebrovascular disease, n	4 (9%)	1 (1%)	.06
COPD, n	1 (2%)	4 (6%)	.35
Preoperative dialysis, n	3 (7%)	8 (12%)	.39
Preoperative IABP, n	9 (20%)	16 (24%)	.70
MI within 90 days before surgery, n	33 (75%)	42 (62%)	.11
Preceding cardiogenic shock, n	7 (16%)	6 (9%)	.25
Cardiomegaly, n	6 (14%)	10 (15%)	.87
Angina pectoris, n	26 (59%)	48 (70%)	.20
Past resuscitation, n	1 (2%)	2 (3%)	.81
Arrhythmias, n	3 (7%)	7 (10%)	.53
EF, %	24.8 ± 4.7	23.9 ± 4.9	.32
No. of diseased coronary vessels	2.75 ± 0.57	2.91 ± 0.33	.15
Previous CABG, n	0 (0%)	1 (1%)	.42
Presentation, n			
Elective	31 (70%)	46 (68%)	.75
Urgent	1 (2%)	8 (12%)	.07
Emergency	12 (28%)	14 (20%)	.41
Previous intervention, n			
PTCA	5 (11%)	10 (15%)	.61
Stent	0 (0%)	2 (3%)	.25
Thrombolysis	4 (9%)	2 (3%)	.16
EuroSCORE	6.9 ± 4.1	6.7 ± 4.1	.77

*Data are presented as the mean ± SD where indicated. CAD indicates coronary artery disease; COPD, chronic obstructive pulmonary disease; IABP, intra-aortic balloon pump; MI, myocardial infarction; EF, ejection fraction; CABG, coronary artery bypass grafting; PTCA, percutaneous transluminal coronary angioplasty.

RESULTS

A univariate analysis of preoperative patient characteristics showed a homogeneous distribution between the groups. Patients in groups A and B were comparable with respect to age, sex, cardiovascular risk factors, and comorbidities, such as peripheral artery disease and chronic obstructive pulmonary disease. The mean EuroSCORE in group A was 6.9 ± 4.1, versus 6.7 ± 4.1 in group B (P = .77). In addition, groups A and B had similar frequencies of recent MI (within

Table 2. Intraoperative Data*

Parameter	Group A (Off-Pump; n = 44)	Group B (On-Pump; n = 68)	*P*
CPB conversion, n	0	—	—
CPB time, min	—	105 ± 35	—
Cross-clamp time, min	—	54 ± 21	—
Operation time, min	228 ± 66	234 ± 52	.63
No. of arterial grafts/patient	1.05 ± 0.43	0.83 ± 0.37	<.01
LIMA use, n	43 (97%)	59 (87%)	.04
Radial artery use, n	3 (7%)	3 (4%)	.58
Total arterial revascularization, n	10 (23%)	2 (3%)	<.01
No. of SVGs/patient	1.45 ± 1.04	2.69 ± 0.98	<.01
Use of SVG, n	34 (72%)	66 (97%)	<.01
No. of grafts/patient	2.50 ± 0.88	3.53 ± 0.92	.03
No. of diseased vessels	2.75 ± 0.57	2.91 ± 0.33	.15
Completeness of revascularization, n	35 (80%)	64 (94%)	.02
Revascularization index	1.01 ± 0.32	1.23 ± 0.30	.03
Intraoperative MI, n	0 (0%)	1 (1.5%)	.42
IABP use, n	0 (0%)	7 (10%)	.03

*Data are presented as the mean ± SD where indicated. CPB indicates cardiopulmonary bypass; LIMA, left internal mammary artery; SVG, saphenous vein graft; MI, myocardial infarction; IABP, intra-aortic balloon pump.

the last 90 days) (75% and 62%, respectively; *P* = .11), preceding cardiogenic shock (16% and 9%, respectively; *P* = .25), and preoperative implantation of an IABP (20% and 24%, respectively; *P* = .70) (Table 1).

Groups A and B had comparable numbers of diseased vessels per patient (2.75 ± 0.57 and 2.91 ± 0.33, respectively; *P* = .15). Patients in group A received significantly more arterial grafts (1.05 ± 0.43 versus 0.83 ± 0.37, *P* < .01) because of more frequent use of the LIMA (97% versus 87%, *P* = .04). On the other hand, group A patients received significantly fewer saphenous vein grafts (1.45 ± 1.04 versus 2.69 ± 0.98, *P* < .01), and the total number of grafts was lower among the patients who underwent OPCAB surgery (2.50 ± 0.88 versus 3.53 ± 0.92, *P* = .03). Totally arterial revascularization was performed significantly more frequently in group A (23% versus 3%, *P* < .01). Completeness of revascularization was achieved in 80% of the patients in group A, versus 94% of the patients in group B (*P* = .02), and the RI was significantly higher in patients who underwent surgery with the on-pump approach (1.01 ± 0.32 versus 1.23 ± 0.30, *P* = .03). OPCAB patients did not require an intraoperative IABP (0% versus 10.3%, *P* = .03). Groups A and B had similar mean operation times (228 ± 66 minutes and 234 ± 52 minutes, respectively; *P* = .63). In group B, the mean CPB time was 105 ± 35 minutes, and the mean cross-clamp time was 54 ± 21 minutes. Among the patients who underwent OPCAB surgery, no conversion to CPB was necessary (Table 2).

Groups A and B appeared to be comparable with respect to mortality within the first 30 days (2.2% and 8.8%, respectively; *P* = .11) and major complications such as stroke (2.2% and 2.9%, respectively; *P* = .83; total stroke rate for entire series, 2.6% [n = 3]). In contrast, patients who underwent OPCAB surgery had significantly fewer pulmonary complications (7% versus 25%, *P* < .01), had shorter ventilation times (17.7 ± 18.9 hours versus 54.5 ± 136.4 hours, *P* = .03), and required prolonged ventilation (>24 hours) less frequently (4.5% versus 17.6%, *P* = .04). Moreover, OPCAB patients presented with wound infections less frequently (2.2% versus 16.1%, *P* = .02); less frequently required blood transfusions (15.9% versus 47.0%, *P* < .01), inotrope use (29.6% versus 69.1%, *P* < .01), and postoperative pacing (atrial, 11.4% versus 39.7%; ventricular, 13.6% versus 47.1%; *P* < .01); and had shorter cumulative stays in the ICU plus HDU (75 ± 117 hours versus 144 ± 237 hours, *P* = .04). Finally, patients who underwent off-pump surgery were less likely to be readmitted for surgical revision or complications, including pericardial/pleural effusion or wound infection (4.5% versus 17.6%, *P* = .04) (Table 3).

DISCUSSION

The major finding of this study is that OPCAB is safe and feasible in high-risk patients with a severely decreased EF who require myocardial revascularization. The mortality rate, as well as the rate of major complications such as stroke and renal failure, appears to be similar to that of the patients who underwent on-pump surgery. Furthermore, our results reveal that OPCAB patients had significantly fewer postoperative pulmonary complications and appeared to have a more uneventful postoperative course. This conclusion is clearly supported by the significantly lower requirements for postoperative pacing, blood transfusions, and inotropes, which

Table 3. Postoperative Outcomes*

Parameter	Group A (Off-Pump; n = 44)	Group B (On-Pump; n = 68)	*P*
Mortality, n	1 (2.2%)	6 (8.8%)	.11
Requirements, n			
Atrial pacing	5 (11.4%)	27 (39.7%)	<.01
Ventricular pacing	6 (13.6%)	32 (47.1%)	<.01
Inotrope use	13 (29.5%)	47 (69.1%)	<.01
Cardiac arrest, n	0 (0%)	1 (1.5%)	.42
Advanced-stage heart AV block, n	1 (2.2%)	2 (2.9%)	.83
Atrial fibrillation, n	7 (15.9%)	10 (14.7%)	.86
Postoperative IABP, n	0 (0%)	7 (10.3%)	.03
Blood transfusions, n	7 (15.9%)	32 (47.0%)	<.01
Pulmonary complications, n	3 (7.0%)	17 (25%)	<.01
Wound infections, n	1 (2.2%)	11 (16.1%)	<.01
Renal failure/dysfunction, n	2 (4.5%)	11 (16.1%)	.06
Dialysis, n	1 (2.2%)	6 (8.8%)	.16
Stroke, n	1 (2.2%)	2 (2.9%)	.83
Ventilation time, h	17.7 ± 18.9	54.5 ± 136.4	.03
Prolonged ventilation (>24 h), n	2 (4.5%)	12 (17.6%)	.04
Cumulative ICU + HDU length of stay, h	75 ± 117	144 ± 237	.04
CK, U/L	428 ± 425	635 ± 453	.11
CK-MB, U/L	16 ± 29	21 ± 27	.53

*Data are presented as the mean ± SD where indicated. AV indicates atrioventricular; IABP, intra-aortic balloon pump; ICU, intensive care unit; HDU, high-dependency unit; CK, creatine kinase; CK-MB, creatine kinase isoenzyme MB.

led to significantly shorter overall stays in the ICU and the HDU. In addition, the rate of readmission due to cardiac and noncardiac complications was much lower among the patients who underwent off-pump surgery.

Our findings are supported by Stamou and associates, who recently reviewed 513 high-risk patients. As many as 228 of these patients had an EF <34% and underwent either on-pump CABG (n = 102) or OPCAB (n = 126) [Stamou 2005]. They found that OPCAB patients had a lower mortality rate and a comparable event-free survival rate. They concluded that OPCAB can be performed in high-risk patients with a reasonably low morbidity and a lower mortality. Furthermore, these investigators suggested that OPCAB could even be the better operative strategy in this subset of patients [Stamou 2005]. Compared with this study, our series has fewer patients. On the other hand, Stamou et al did not focus specifically on the outcomes of patients with a low EF, but rather on patients with a generally high-risk profile (including such comorbidity factors as renal failure, recent MI, cerebrovascular disease, and advanced age [Stamou 2005].

More similarly to our study, Arom and colleagues compared 45 OPCAB and 132 on-pump patients who had EFs ≤30%. The authors suggested that OPCAB is safe and reasonable in patients with an impaired cardiac function, that it is appropriate and applicable, but that these results come at the cost of a less complete revascularization [Arom 2000]. These findings were confirmed by the recent results of Darwazah and colleagues [2006], who reviewed the results for 66 OPCAB and 84 on-pump patients who had an EF <35%. They found that OPCAB produce a better clinical outcome and a lower mortality rate, but at the cost of a smaller number of distal grafts [Darwazah 2006].

The superior postoperative outcomes for OPCAB may be explained mainly by the avoidance of CPB, which is well known to have deleterious effects on postoperative cardiac performance [Wan 2004; Weerasinghe 2005]. Pathophysiologically, these effects are reflected in the increased degree of myocardial injury [Koh 1999; Krejca 1999] and inflammatory reactions [Wan 2004] after CPB, particularly if the CPB time is prolonged [Moshkovitz 1997]. In this situation, the activation of various inflammatory mediators may hinder myocardial performance, especially if it was already severely decreased [Stamou 2001]. Furthermore, the changes in the ventricular geometry of the empty heart that occur during CPB seem to contribute to impeding the coronary collateral flow that supplies potentially ischemic areas of the myocardium [Stamou 2001]. Additionally, Akins et al demonstrated a better preservation of normal septal movement among off-pump patients, whereas on-pump CABG frequently produces paradoxical movement of the interventricular septum

[Akins 1984]. For this reason, we and others [Shennib 2002; Stamou 2005] believe that these high-risk patients with an already severely impaired EF might disproportionately benefit from a standardized OPCAB approach with regard to a less complicated postoperative course.

On the other hand, the benefits of the OPCAB approach seem to come at the cost of a less complete revascularization, which has been suggested to be a crucial predictor of long-term outcome [Puskas 2003; Lattouf 2008]. Recent data have shown, however, that the completeness of revascularization is still limited and remains an important problem in OPCAB as it is performed today [Stamou 2005; Virani 2005; Darwazah 2006; Lattouf 2008]. One important reason involves the temporary stabilization and repetitive dislocation of the heart during OPCAB procedures, especially when the circumflex territory is addressed. These maneuvers can cause severe arrhythmia, low cardiac output, and extended periods of hypotension that may end in cardiac decompensation, forcing the surgeon to convert emergently to CPB. Therefore, the surgeon tries to avoid these dangerous maneuvers, particularly in high-risk patients, even if it is at the cost of less complete revascularization.

In contrast, the feasibility of complete revascularization in OPCAB has been described recently by Puskas and colleagues, who prospectively compared 200 unselected patients who underwent either OPCAB or conventional on-pump surgery. Their analysis revealed that compared with on-pump surgery, OPCAB achieved a similar completeness of revascularization [Puskas 2003]. Compared with the patients in our series, the patients described in these investigators' report were unselected, with a mainly normal EF. They were not high-risk patients with a severely decreased EF.

Although the RI in the OPCAB patients was still significantly lower than that of the on-pump patients, we were able to achieve a reasonable mean RI of 1.01 for off-pump patients and accomplished complete revascularization in at least 80% of these patients, a slightly higher rate than the international average for this subset of patients [Virani 2005; Darwazah 2006]. In addition, we also demonstrated an increased use of arterial grafts and a higher frequency of totally arterial revascularization among our OPCAB patients, which might have had a compensating effect on the overall less complete revascularization for the patients who underwent off-pump surgery. Another reason for less complete revascularization might be explained by the variable surgeon experience and by an overall lower rate of performance of OPCAB procedures. Depending on the surgeon, the OPCAB approach at our institution accounts for 30% to 50% of all coronary bypass procedures, whereas in the United States, for example, only approximately 20% of all coronary bypass procedures are performed in an off-pump fashion [Lattouf 2008].

In summary, the OPCAB approach in patients with a severely decreased EF is safely applicable and may benefit this subset of patients with respect to fewer pulmonary complications and an overall more uncomplicated postoperative clinical course. Although complete revascularization is optimal, this goal may be partially abandoned so that CPB can be avoided. The augmented use of arterial grafts may balance the compromise of a less complete revascularization and may contribute to an improved long-term outcome.

This study is limited, of course, by its retrospective, nonrandomized nature. Our results lack the force of numbers, and certainly a higher level of significance might have been obtained had we analyzed a larger cohort of patients. The ideal approach would consist of a prospective, randomized clinical trial; however, such trials thus far are available only for OPCAB patients with a relatively low-risk profile [Puskas 2003]. Next, one might argue that the total time in the ICU and HDU seems very high. As mentioned above, we have provided the cumulative number of hours, because the ICU stay in our institution is usually followed by an HDU stay before the patient is transferred to the normal ward. To some extent, this standardized procedure may lead to an extended total length of stay, particularly given that transfers to the normal wards are limited on weekends. Although the difference was not significant, it became apparent that patients in group A more frequently had cerebrovascular disease. To some degree, this difference may have influenced the surgeon's choice to perform off-pump surgery, because CPB is a well-established risk factor for neurologic events [Murkin 1999] and cross-clamping of the aorta poses an additional risk for cerebral embolization if a beating heart approach is not performed [Taylor 1998].

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