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Early and Midterm Results after Coronary Artery Bypass Grafting with and without Cardiopulmonary Bypass: Which Patient Population Benefits the Most?

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ABSTRACT

Background: We present our early and midterm results with off-pump coronary artery bypass grafting (OPCAB) on the beating heart and with conventional coronary artery bypass grafting (CABG) and compare patient outcomes for both procedures.

Methods: Between November 1997 and April 2001, OPCAB was performed in 330 patients. The results were compared with those of a matched population of 330 patients who had undergone CABG during the same period. Specific postoperative outcomes were evaluated for patient subgroups with multimorbidity, with impaired ventricular function, of an older age, and of a young age without comorbidities. Midterm results and quality-of-life (QOL) scores for patients were obtained by follow-up.

Results: In the overall series, OPCAB resulted in significantly shorter surgery times (P = .008), ventilation times (P < .001), intensive care unit (ICU) stays (P < .001), and hospital stays (P = .006). OPCAB also resulted in less postoperative inotropic medication (P = .041), lower transfusion rates (P < .001), fewer postoperative myocardial infarctions (P = .038), and lower hospital mortality rates (P = .024). Among the patient subgroups, patients with multimorbidities were the only subgroup to show a significant reduction in hospital mortality after OPCAB surgery (P = .048). Times of postoperative ventilation, ICU stay, and hospitalization were significantly reduced for all patient subgroups (P < .05). After mean follow-up times of 43.8 months (OPCAB) and 44.8 months (CABG), QOL scores, midterm complication rates, and mortality rates were not significantly different among the groups.

Conclusion: OPCAB surgery improved postoperative recovery for the entire patient population without compromising midterm outcome. Compared with conventional CABG, high-risk patients with multimorbidity particularly profit from avoiding cardiopulmonary bypass and show significantly lower hospital mortality.

INTRODUCTION

Off-pump coronary artery bypass grafting (OPCAB) on the beating heart has emerged as a feasible alternative for conventional coronary artery bypass grafting (CABG) in recent years [Jansen 1998]. The use of cardiopulmonary bypass (CPB) is known to be associated with postoperative neurologic [Taylor 1998], pulmonary [Asimakopoulos 1999], and renal [Ascione 1999] dysfunction, as well as with coagulation disorders [Kirk 2001]. CPB also requires aortic cannulation and cross-clamping, which may lead to atheromatous macroemboli [Hartmann 1996]. Avoidance of CPB is likely to prevent these adverse side effects. Moreover, in selected patients the operation may be performed via a left anterior thoracotomy or a substernal incision, which makes sternotomy unnecessary [Diegeler 1998]. Thus, beating heart surgery now challenges on-pump CABG as the gold standard for coronary artery revascularization [Cartier 2000]. The development of new heart positioning and epicardial stabilization techniques has facilitated anastomosis suturing on the beating heart and widened the applicability of OPCAB surgery for patients with 3-vessel disease [Hart 2000]. The feasibility of beating heart surgery in high-risk patients [Stamou 2001], for acute myocardial infarction [Locker 2000], for critical left main stem disease [Yeatman 2001], and in the elderly [Koutlas 2000] has been demonstrated recently. However, it is still uncertain which patient population benefits the most from avoiding CPB [Hart 2001].

Beating heart surgery is technically more demanding, and its feasibility depends on the coronary anatomy and on the hemodynamic consequences of posterior wall exposure [Grundeman 1999]. Thus, in most institutions this procedure is performed only in selected patients. Furthermore, operating on a moving field may compromise the quality of the distal anastomoses and increase operation-related complications. The question remains whether midterm results can also meet

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Table 1. Preoperative Patient Demographics*

Variable	OPCAB (n = 330)	CABG (n = 330)	*P*
Age, y	64.6 ± 9.9	65.3 ± 9.9	.36
Male/female sex, n	250/80	250/80	1.00
Priority, n			.99
Elective	294	289	
Urgent	25	28	
Emergency	11	13	
CCS class, n			.22
I	24 (7.3%)	31 (9.4%)	
II	86 (26.1%)	73 (22.1%)	
III	169 (51.2%)	159 (48.2%)	
IV	51 (15.4%)	67 (20.3%)	
Previous MI, n	157 (47.6%)	134 (31.5%)	.079
Previous CVA, n	20 (6.1%)	21 (6.4%)	1.00
Diabetes, n	97 (29.4%)	76 (23.0%)	.077
Renal insufficiency, n	46 (13.9%)	50 (15.2%)	.74
COPD, n	41 (12.4%)	29 (8.8%)	.132
PVD, n	40 (12.1%)	46 (20.3%)	.56
Previous PTCA or stent, n	123 (37.3%)	134 (40.6%)	.38
Previous bypass surgery, n	42 (12.7%)	35 (10.6%)	.40
Multimorbidity, n	60 (18.2%)	52 (15.8%)	.46
Ejection fraction, %	61.2 ± 12.0	60.7 ± 10.8	.55

*Data are expressed as the mean ± SD where applicable. OPCAB indicates off-pump coronary artery bypass graft; CABG, coronary artery bypass graft; CCS class, Canadian Cardiovascular Society classification; MI, myocardial infarction; CVA, cerebrovascular accident; COPD, chronic obstructive pulmonary disease; PVD, peripheral vascular disease; PTCA, percutaneous transluminal coronary angioplasty.

the promising expectations regarding improvement in health-related quality of life (QOL), in the relief of cardiac symptoms, and in the frequency of reinterventions.

This retrospective study compares early and midterm outcomes after off-pump and on-pump surgeries and analyzes the specific outcomes of both procedures for different patient subgroups.

MATERIALS AND METHODS

Between November 1997 and August 2001, 330 OPCAB procedures were performed at the University of Munich. Patients were compared with a computer-matched control group of 330 patients undergoing conventional CABG with CPB at the same institution during the same period; these data were derived from the local cardiac surgical database. The 2 groups were equally matched according to age, sex, ejection fraction, Canadian Cardiovascular Society (CCS) classification, comorbidities, priority of surgery, and number of bypass grafts. OPCAB patients who had to be converted intraoperatively to CPB were statistically treated as OPCAB patients. The baseline characteristics were similar for the matched groups (Table 1). Multimorbidity was defined as the impairment of 3 or more organ systems and was found in 60 (18.2%) OPCAB and 52 (15.8%) CABG patients. Patient selection was carried out according to specific anatomic criteria, coronary artery morphology, and the severity of comorbidities. Thus, indications for OPCAB surgery at our institution were (1) single- or double-vessel revascularization, (2) multivessel revascularization in high-risk patients with several comorbidities, and (3) patient request for a minimally invasive surgical procedure [Detter 2002].

Various preoperative, intraoperative, and postoperative variables were studied for the groups as a whole, as well as within various subgroups to determine outcome differences. These subgroups included a high-risk population with multimorbidity, patients with impaired ventricular function (left ventricular ejection fraction less than or equal to 35%), elderly patients (≥75 years), and young and healthy patients. This last group was defined as patients aged ≤65 years with no history of myocardial infarction, no diabetes mellitus, no peripheral vascular disease, no chronic obstructive pulmonary disease, and no renal impairment. Postoperative blood loss was measured as total drainage from the chest tube.

OPCAB Using the Beating Heart Technique

The patient was positioned on a water-heated mattress in the operation room. Two-channel electrocardiography (ECG) was applied and continuously monitored for ST-segment change. Monitoring included a Swan-Ganz catheter for hemodynamic measurements and transesophageal echocardiography for the detection of changes in regional wall motion during the entire surgical procedure. Continuous mixed venous saturation measurement was used routinely. All patients underwent operations through a median sternotomy. Heparin was given with a dose of 100 IU/kg body weight before the division of the internal mammary artery to accomplish an activated coagulation time of greater than 250 seconds. Half of the amount of heparin was reversed via the use of protamine after the completion of the anastomoses. The OPCAB surgical technique has already been described in detail [Detter 2001]. In brief, pericardial traction sutures were placed between the left pulmonary veins and the inferior vena cava to expose the different coronary vessels and to avoid hemodynamic compromise and rhythm disturbances. Coronary artery stabilization was accomplished with a commercially available stabilization system. Temporary interruption of coronary blood flow was achieved either by 4-0 or 5-0 polypropylene sutures (Ethicon, Somerville, NJ, USA) that were snared over a pledget or by the use of vessel loops. Usually, the territory of the left anterior descending coronary artery (LAD) was revascularized first to minimize heart manipulation. Preconditioning was not performed routinely. An intracoronary shunt was inserted when necessary if ECG changes or arrhythmias occurred. A humidified carbon dioxide blower was used to improve visualization.

CABG Using Cardiopulmonary Bypass

Coronary artery bypass grafting was performed through a median sternotomy in all patients. CPB was established by cannulating the ascending aorta and the right atrium with standard techniques. Antegrade crystalloid or blood cardioplegia was used for myocardial protection. Heparin was given with a dose of 400 IU/kg body weight to accomplish an

Table 2. Intraoperative and Postoperative Data*

Variable	OPCAB	CABG	*P*
Grafts per patient, n	1.61 ± 0.64	1.66 ± 0.49	.32
Surgery time, min	183 ± 58	197 ± 78	.008
Time on CPB, min	—	77 ± 39	
Cross-clamp time, min	—	41 ± 20	
Use of inotropes, n	102 (30.9%)	128 (38.8%)	.041
Postoperative ventilation, h	11.0 ± 16.3	20.9 ± 22.9	<.001
Transfusion patients, n	108 (32.7%)	172 (52.1%)	<.001
Blood transfusion/patient, mL	647 ± 727	1163 ± 1345	<.001
Blood loss, mL	894 ± 586	1032 ± 601	.005
ICU stay, h	32.8 ± 19.3	43.9 ± 35.9	<.001
Hospital stay, d	8.4 ± 5.6	9.6 ± 5.2	.006

*Data are expressed as the mean ± SD where applicable. OPCAB indicates off-pump coronary artery bypass graft; CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; ICU, intensive care unit.

activated coagulation time of greater than 400 seconds. The body temperature was lowered to 28°C to 32°C. The effect of heparin was reversed by the use of protamine after the completion of the anastomoses.

Quality Control and Assessment Criteria

Graft patency and bypass flow rates were analyzed intraoperatively in all cases with an ultrasound-based flowmeter. Postoperative ECG was performed. Serial samples were taken for determinations of creatine kinase (CK) and CK-MB. Enzyme levels were determined every 6 hours up to 72 hours postoperatively in any patient, and peak levels were assessed. Myocardial infarction was defined as either an increase in CK-MB enzyme levels above 50 IU/L or a new Q wave in postoperative ECG.

Follow-up and QOL Assessment

A questionnaire containing the SF-36 form for QOL evaluation and questions regarding relief of symptoms, freedom from myocardial infarction, reintervention, and overall survival was distributed to all patients who had been operated on 3 or more years before. QOL was scored on physical and mental health summary scales in the 8 categories of physical functioning, role limitations due to physical health, role limitations due to emotional problems, energy/fatigue, emotional well-being, social functioning, bodily pain, and general health. The responses validly reflected the actual patient health status [Ware 1998].

Statistical Analysis

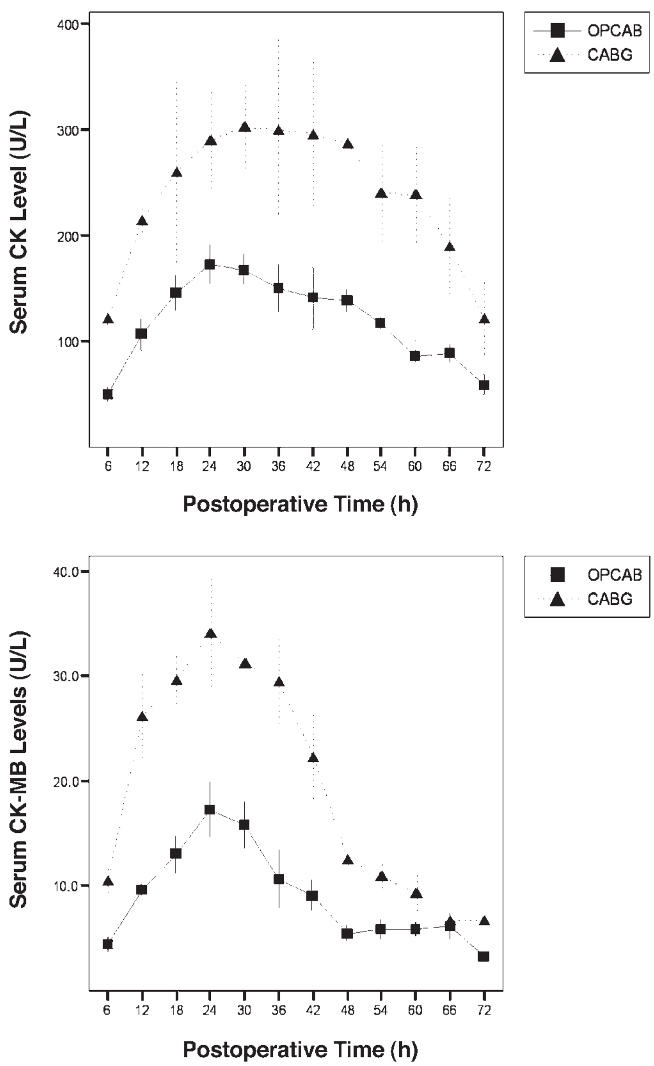
Continuous data were analyzed with the unpaired Student *t* test for 2 groups and with analysis of variance for more than 2 groups, and categorical data were analyzed as appropriate with the chi-square test or with the Fisher exact test. Values were expressed as the mean ± SD. *P* values less than .05 were considered statistically significant. Statistical analysis was performed with the SPSS statistical software package, version 10.0 for Windows (SPSS, Chicago, IL, USA).

RESULTS

Early Results

Intraoperative data are summarized in Table 2. The mean numbers of grafts performed per patient in the OPCAB and CABG groups were 1.61 ± 0.64 and 1.66 ± 0.49, respectively. Surgery time was significantly shorter in the OPCAB group with a mean of 183 ± 58 minutes versus 197 ± 78 minutes in the CABG group (*P* = .008). In the CABG group, the mean CPB and the mean aortic cross-clamp times were 77 ± 39 minutes and 41 ± 20 minutes, respectively.

Postoperative inotropic support was necessary in 30.9% of OPCAB patients and in 38.8% of CABG patients and thus was significantly less frequent after off-pump procedures (*P* = .041). Enzyme levels of CK and CK-MB were analyzed for detection of perioperative ischemia, and the results are depicted in the Figure. Peak postoperative serum



Serum creatine kinase (CK) and CK-MB levels during the first 72 postoperative hours after off-pump coronary artery bypass (OPCAB) surgery (■) and coronary artery bypass graft (CABG) surgery (▲).

Table 3. Postoperative Complications*

Variable	OPCAB Patients, n	CABG Patients, n	*P*
Conversion to CPB	13 (3.9%)	—	
Low output	2 (0.6%)	10 (3.0%)	.037
Reexploration for bleeding	16 (4.8%)	18 (5.5%)	.86
Reoperation after graft failure	4 (1.2%)	4 (1.2%)	1.00
Wound infection	9 (2.6%)	8 (2.3%)	1.00
Myocardial infarction	5 (1.5%)	15 (4.5%)	.038
Cerebrovascular events	0	0	1.00
Hospital mortality	5 (1.5%)	16 (4.8%)	.024

*Abbreviations are expanded in the footnote to Table 2.

CK levels averaged 172 ± 174 U/L in the OPCAB group and 303 ± 384 U/L in the CABG group ($P < .001$), and the corresponding peak CK-MB levels were 17.3 ± 24.8 U/L and 34.2 ± 51.8 U/L ($P < .001$). Postoperative blood loss was significantly less in the OPCAB group (894 ± 586 mL versus 1032 ± 601 mL; $P = .005$), leading to significantly fewer cases of perioperative blood transfusion requirements (32.7% versus 52.1%; $P < .001$) compared with the on-pump group. Both the time to extubation (11.0 ± 16.3 hours versus 20.9 ± 22.9 hours; $P < .001$) and the time of intensive care unit (ICU) stay (32.8 ± 19.3 hours versus 43.9 ± 35.9 hours; $P < .001$) were significantly reduced for the OPCAB group. The postoperative hospitalization time was 8.4 ± 5.6 days in the OPCAB group and 9.6 ± 5.2 days in the CABG group. Thus, hospitalization times were significantly longer after CABG procedures ($P = .006$) (Table 2).

Postoperative complications are summarized in Table 3. Rates of complications requiring reexploration for bleeding (OPCAB, 4.8%; CABG, 5.5%; $P = .86$) or reoperation for graft failure (1.2% in each group) or involving wound infection (OPCAB, 2.6%; CABG, 2.3%; $P = 1.0$) or cerebrovascular events (none in either group) showed no differences between the groups. There were significantly fewer myocardial infarctions after off-pump surgery than after on-pump procedures (1.5% versus 4.5%; $P = .038$). The hospital mortality was 1.5% in the OPCAB group and 4.8% in the CABG group ($P = .024$). Five early deaths occurred in the OPCAB group. A 51-year-old man and an 85-year-old man with previous aortic valve replacement and bypass surgery underwent single revascularization of the left internal mammary artery (LIMA) to the LAD. As proven by autopsy, both patients died because of myocardial infarction after occlusion of the circumflex artery, and the LIMA-to-LAD bypass graft was patent. A 75-year-old patient suffered from postoperative myocardial infarction after occlusion of a LIMA-to-LAD graft. Although the patient underwent immediate reoperation with a saphenous vein graft to the LAD, he died from cardiac failure on the first postoperative day. A 69-year-old patient with a history of ventricular arrhythmia died on the 26th postoperative day because of ventricular fibrillation. Mesenterial ischemia led to the death of an 83-year-old patient after off-pump revascularization. In the CABG group, there were 5 deaths due to multiorgan failure, 2 cases each of mesenterial ischemia and respiratory insufficiency, and 1 of aortic dissection. Nine patients died of cardiac failure, and 2 patients died of multiorgan failure.

Thirteen conversions to CPB (3.9%) occurred in the OPCAB group because of intramyocardial target vessels in 6 cases, arrhythmia with hemodynamic compromise in 5 cases, insufficient epicardial stabilization at the lateral wall in 1 case, and the need for revision of the distal anastomosis in another case. Of these 13 patients, there were 2 (15.4%) with multimorbidity, and most patients (53.8%) were in CCS class III. The outcomes of patients after conversion to CPB are summarized in Table 4. The mean CPB and aortic cross-clamp times were 69.6 ± 21.7 minutes and 35.4 ± 15.7 minutes, respectively. Two patients (15.4%) suffered low cardiac output postoperatively, and 7 patients (53.8%) depended on postoperative inotropic support. Two patients (15.4%) suffered perioperative myocardial infarction. Of these patients, 1 (7.7%) had to undergo early bypass revision on the first postoperative day because of hemodynamic instability. Hospital mortality was 0% in this conversion group.

In 92 (27.8%) of the 330 OPCAB patients, routine postoperative angiography was performed. In the 151 studied bypass grafts, a total graft patency rate of 96.7% and a stenosis-free patency rate of 94.0% were observed. Catheter intervention was necessary in 7 cases.

The data for the patient subgroups are summarized in Table 5. For all subgroups examined, surgery time, postoperative ventilation, and ICU stay were significantly shorter in

Table 4. Patients with Conversion to Cardiopulmonary Bypass*

Variable	OPCAB Patients
Patients, n	13
Preoperative	
LVEF, %	65.8 ± 5.1
CCS class, n	
I	1 (7.7%)
II	3 (23.1%)
III	7 (53.8%)
IV	2 (15.4%)
Multimorbidity, n	2 (15.4%)
Intraoperative	
Intramyocardial target vessel, n	6
Arrhythmia with hemodynamic compromise, n	5
Insufficient stabilization, n	1
Bypass revision, n	1
Time on CPB, min	69.6 ± 21.7
Cross-clamp time, min	35.4 ± 15.7
Postoperative	
Low cardiac output, n	2 (15.4%)
Reoperation because of graft failure, n	1 (7.7%)
Myocardial infarction, n	2 (15.4%)
Hospital mortality, n	0

*Data are expressed as the mean ± SD where applicable. LVEF indicates left ventricular ejection fraction; other abbreviations are expanded in the footnotes to Tables 1 and 2.

Table 5. Data by Patient Subgroup*

	High-Risk Patients with Multimorbidity			Patients with Impaired Ventricular Function		
Variable	OPCAB (n = 60)	CABG (n = 52)	*P*	OPCAB (n = 29)	CABG (n = 31)	*P*
Surgery time, min	190.4 ± 45.7	222.4 ± 85.6	.015	190.5 ± 52.2	226.6 ± 61.3	.017
Conversion to CPB, n	0	—		0	—	
Postoperative ventilation, h	13.5 ± 6.9	20.3 ± 17.7	.009	12.7 ± 6.9	31.4 ± 11.9	<.001
Patients with transfusions, n	32 (53.3%)	40 (76.9%)	.011	14 (48.3%)	20 (64.5%)	.30
PRBC/patient, mL	632 ± 617	998 ± 1004	.02	626 ± 863	651 ± 548	.89
Blood loss, mL	1065 ± 438	1414 ± 979	.02	190.5 ± 52.2	226.6 ± 61.3	.017
ICU stay, h	38.2 ± 20.5	47.1 ± 24.7	.040	31.1 ± 12.9	41.9 ± 11.9	.006
Postoperative hospitalization, d	9.9 ± 3.1	12.7 ± 3.2	.001	8.5 ± 4.6	10.6 ± 2.7	.036
Hospital mortality, n	1 (1.7%)	6 (11.5%)	.048	0	4 (12.9%)	.11
	Elderly Patients			**Young and Healthy Patients**		
Variable	OPCAB (n = 53)	CABG (n = 66)	*P*	OPCAB (n = 36)	CABG (n = 50)	*P*
Surgery time, min	196.4 ± 57.2	223.7 ± 79.3	.039	177.4 ± 56.5	206.5 ± 53.7	.017
Conversion to CPB, n	4 (7.5%)	—		2 (5.6%)	—	
Postoperative ventilation, h	18.2 ± 17.0	26.9 ± 22.4	.024	10.2 ± 5.8	15.8 ± 7.0	<.001
Patients with transfusions, n	32 (60.4%)	40 (60.6%)	1.00	12 (33.3%)	33 (66.7%)	.004
PRBC/patient, mL	688 ± 612	760 ± 945	.63	314 ± 383	595 ± 443	.003
Blood loss, mL	1047 ± 846	1021 ± 363	.83	1049 ± 344	1318 ± 493	.006
ICU stay, h	42.0 ± 17.0	53.9 ± 36.6	.032	29.6 ± 14.9	41.2 ± 26.2	.019
Postoperative hospitalization, d	9.6 ± 5.6	9.7 ± 5.4	.92	7.2 ± 2.3	8.8 ± 2.7	.005
Hospital mortality, n	4 (7.5%)	6 (9.1%)	.44	0	0	1.0

*Data are expressed as the mean ± SD where applicable. PRBC indicates packed red blood cells; other abbreviations are expanded in the footnote to Table 2.

the OPCAB group ($P < .05$). For the high-risk patients with multimorbidity, the blood losses, transfusion requirements, and postoperative hospitalization times were determined to be lower ($P < .05$). This was the only subgroup to show significantly lower hospital mortality after the beating heart procedure ($P = .048$). Remarkable is the advanced outcome of young OPCAB patients without comorbidities after beating heart revascularization. In this subgroup, even blood losses and transfusion requirements were lower, and postoperative hospitalization times were significantly shorter after off-pump surgery ($P < .05$). No hospital mortality was noticed in this population for either procedure.

Midterm Results

All patients who had been operated on more than 3 years before were included in the midterm follow-up. Follow-up was 94.4% and 95.9% complete, and the periods averaged 43.8 ± 5.1 months and 44.8 ± 8.6 months in the OPCAB and CABG groups, respectively, and were not significantly different. Regarding health-related QOL at the end of the follow-up period, no differences were obtained for all 8 categories (Table 6). Recurrent dyspnea was reported by 13 OPCAB patients (9.6%) and 22 CABG patients (15.4%), and recurrence of angina was present in 18 patients (13.3%) after off-pump and in 26 patients (18.2%) after on-pump surgery. The differences in both instances were not significant. Myocardial infarction occurred in 2 patients (1.5%) and in 4 patients (2.8%) after off- and on-pump surgery, respectively, and the differences were not significant. Catheter intervention was necessary in 19 patients of each group, and reoperation was necessary in 2 OPCAB patients (1.5%) and in 5 CABG patients (3.5%). These differences were not significant. Six OPCAB patients (4.4%) died during follow-up from cancer and infection in 1 case each and from cardiac failure in 2 cases. The causes of death in 2 cases are unknown. Nine patients (6.3%) died in the CABG group: 4 died from cardiac failure, 2 from multiorgan failure, and 2 from infection. The cause of death in 1 case remains unknown. Thus, follow-up did not reveal differences between the groups with regard to symptom relief, necessity of reintervention, and midterm mortality (Table 7).

DISCUSSION

With its elimination of the need for CPB thus reducing the systemic inflammatory response, beating heart surgery has theoretical advantages over on-pump procedures [Wan 1999]. To prove this hypothesis, we compared a matched patient population of 660 patients who underwent isolated coronary artery bypass surgery with and without the use of CPB. In this study, we could demonstrate a shorter overall surgery time as well as a shorter ICU and hospital stay in the OPCAB group. In contrast, the results of Bull and colleagues demonstrated a time reduction for the operative procedure but failed to show differences in the lengths of ICU and hospital stays [Bull 2001]. Our objective is to adjust the length of ICU and hospital stay to the individual patient's postoperative status rather than to routine protocols as implemented in other institutions. Thus, OPCAB surgery facilitates patient

Table 6. Quality of Life Scores at the End of Follow-up*

Variable	OPCAB	CABG	*P*
Physical functioning	70.3 ± 24.8	68.9 ± 29.1	.68
Role limitations due to physical health	56.8 ± 43.8	55.4 ± 46.4	.80
Role limitations due to emotional problems	68.7 ± 43.4	72.9 ± 41.9	.42
Energy/fatigue	57.7 ± 21.2	57.3 ± 21.8	.86
Emotional well-being	74.2 ± 19.8	74.5 ± 19.8	.91
Social functioning	81.8 ± 21.9	81.5 ± 22.5	.91
Pain	75.9 ± 25.9	80.9 ± 25.1	.10
General health	61.3 ± 16.2	58.4 ± 17.1	.16

*Data are expressed as the mean ± SD. Abbreviations are expanded in the footnote to Table 2.

recovery and decreases the use of limited and expensive hospital resources. Lancey and colleagues revealed a significant reduction of total costs with the OPCAB procedure without increasing the operative risks [Lancey 2000].

Conventional bypass surgery using CPB activates the complement and fibrinolytic cascade and contributes to postoperative bleeding complications [Woodman 1990]. Our study agrees with those of others who also noticed reduced blood losses and thus a reduced frequency of transfusion requirements with beating heart surgery [Cartier 2000]. Elimination of blood transfusion reduces the risk for infections and increases patient satisfaction.

Regarding the early postoperative outcomes, we demonstrated a significantly reduced requirement for postoperative inotropic support and a reduced incidence of low cardiac output and perioperative myocardial infarction after the OPCAB procedure. This finding correlates with the lower serum levels of the myocardial enzymes CK and CK-MB during the first 72 postoperative hours. Suggesting a lower degree of myocardial injury with off-pump surgery, our findings agree with prior observations of less myocardial enzyme release (a parameter for myocardial damage) in the OPCAB group [Koh 1999]. The regional warm ischemia of the beating heart caused by snaring of the diseased coronary arteries seems to cause considerably less myocardial injury than global cold ischemia induced by cardioplegic arrest [Czerny 2000]. Because deaths related to myocardial damage were significantly reduced with the OPCAB procedure, avoiding myocardial damage should be of particular interest.

During CPB, fluid shifts and damaging inflammatory effects are likely to compromise lung function [Yokoyama 2000]. In our study, OPCAB patients showed a significantly reduced mechanical ventilation time, indicating minor pulmonary injury during the beating heart procedure.

Overall, hospital mortality was significantly reduced in the OPCAB group. In agreement with the results of other workers who reported improved clinical outcomes after off-pump surgery [Arom 2000], our data suggest that off-pump surgery is a safe alternative to conventional on-pump CABG and reduces postoperative mortality.

The incidences of postoperative complications, such as bleeding requiring reexploration, graft failure requiring reoperation, wound infection, and cerebrovascular events, were not different between the groups. Because the rates of these complications were low for both groups, the demonstration of significant differences require huge patient numbers, such as those of the multicenter study of Cleveland and colleagues, which did reveal a significant reduction in the postoperative complications rate [Cleveland 2001].

Conversions to CPB were rare in the OPCAB group, occurring in 3.9%. Patients who had to undergo conversion did not show more severe comorbidities or a higher CCS class and thus could hardly have been distinguished preoperatively. However, conversions because of arrhythmia with hemodynamic compromise might have been prevented with the use of intracoronary shunts. Heart positioners now facilitate lateral wall and back wall revascularization, and thus difficulties in cardiac positioning have been reduced.

Because beating heart surgery has become a feasible alternative to on-pump CABG in many institutions, the patient subgroups that will benefit the most from this alternative procedure need to be defined. Recent studies have reported excellent outcomes after beating heart surgery for the elderly [Al-Ruzzeh 2001], for patients with impaired ventricular function [Bouchart 2001], and for high-risk patients [Yokoyama 2000]. Our data agree with those reports and support the findings of satisfying outcomes after beating heart surgery in high-risk patients with multimorbidity. In this patient subgroup, shorter ventilation times, shorter ICU and hospital stays, reduced blood losses and transfusion rates, and even a lower hospital mortality rate could be demonstrated in this study.

Although a reduction in the rate of early mortality could not be demonstrated in other subgroups, this study outlines the excellent postoperative recovery of OPCAB patients, because postoperative ventilation and ICU stays were significantly reduced across all patient subgroups. Thus, even for young patients without severe comorbidities, off-pump surgery is a recommendable alternative to conventional CABG procedures.

QOL scores serve as a tool to describe the patient's actual physical and mental well-being [Ware 1998]. At the end of our follow-up, no differences in subjective health estimation could be demonstrated. Furthermore, no differences in the

Table 7. Follow-up*

Variable	OPCAB (n = 143)	CABG (n = 149)	*P*
Follow-up complete, n	135 (94.4%)	143 (95.9%)	.59
Follow-up time, mo	43.8 ± 5.1	44.8 ± 8.6	.28
Recurrent dyspnea, n	13 (9.6%)	22 (15.4%)	.15
Recurrence of angina, n	18 (13.3%)	26 (18.2%)	.33
Catheter intervention, n	19 (14.1%)	19 (13.3%)	1.00
Myocardial infarction, n	2 (1.5%)	4 (2.8%)	.68
Reoperation, n	2 (1.5%)	5 (3.5%)	.45
Midterm mortality, n	6 (4.4%)	9 (6.3%)	.60

*Data are expressed as the mean ± SD where applicable. Abbreviations are expanded in the footnote to Table 2.

recurrence of symptoms, necessity for catheter intervention or reoperation, and midterm mortality were noticed during follow-up. Thus, OPCAB lowers in-hospital morbidity without compromising midterm outcome, compared with conventional on-pump coronary surgery. This study highlights the excellent midterm results after OPCAB surgery and demonstrates that, although it is technically more demanding when performed on the beating heart, there is no increase in cardiac-related complications during midterm follow-up.

A limitation of this study is that the patient population was retrospectively matched and not randomized. Furthermore, this group of patients was a selected group who underwent OPCAB surgery with a low number of grafts per patient. This approach introduces the possibility of selection bias. To overcome this limitation, we recommend a prospectively randomized trial.

In summary, OPCAB surgery with its excellent early and midterm results has emerged as a feasible alternative to on-pump coronary artery bypass surgery. High-risk patients with multimorbidity especially draw major benefit from avoiding the adverse side effects of CPB. The results of the present study are encouraging and support the use of OPCAB surgery for all patient populations.

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