

Minimally Invasive Direct Coronary Artery Bypass Grafting (MIDCAB) and Off-Pump Coronary Artery Bypass Grafting (OPCAB): Two Techniques for Beating Heart Surgery

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Christian Detter, MD, Hermann Reichenspurner, MD, PhD, Dieter H. Boehm, MD, Michael Thalhammer, MD, Panajotis Raptis, MD, Albert Schütz, MD, Bruno Reichart, MD

Department of Cardiac Surgery, University Hospital Grosshadern, Ludwig-Maximilian-University, Munich, Germany

ABSTRACT

Objective: Coronary bypass surgery can be performed less invasively by avoiding cardiopulmonary bypass (CPB). We present our experiences with beating heart bypass surgery performed through a minithoracotomy or sternotomy.

Methods: From May 1997 to September 1999, 340 patients were included in a prospective study. Of these patients, 111 (group 1) underwent minimally invasive direct coronary artery bypass grafting (MIDCAB) through an antero-lateral minithoracotomy, and 229 (group 2) had off-pump coronary artery bypass grafting (OPCAB) through a full sternotomy. A pressure stabilizer was used for MIDCAB and a suction stabilizer for OPCAB surgery. Early postoperative angiography was performed on 48% of patients in group 1 and 45% of those in group 2. Statistical analysis was applied to compare the variables from both groups and a probability value of less than 0.05 was considered significant.

Results: In all MIDCAB grafts, revascularization was performed by a single left internal mammary artery (LIMA) graft to the left anterior descending coronary artery (LAD). This procedure was completed in 96.4% of patients without CPB. Conversion to sternotomy was necessary for one patient (0.9%). In the OPCAB group, an average of 1.7 grafts per patient were revascularized, of which 98 were single, 99 double, and 32 triple. Of the OPCAB group, 12% of patients were redo operations and 17% had severe comorbidities. Conversion to CPB was necessary for 10 patients (4.4%) because of hemodynamic instability. No cerebrovascular accident (CVA) was seen in any group. There were no hospital deaths in the MIDCAB group, but there were three deaths (1.3%) in the OPCAB group. Age, previous bypass surgery, and severe comorbidities did not influence early mortality.

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Address correspondence and reprint requests to: Dr. Christian Detter, Department of Cardiovascular Surgery, University Hospital Eppendorf, Martinistr. 52, 20246 Hamburg, Germany, Phone: +49 40 42803 440, Fax: +49 40 42803 4931, Email: detter@ube.uni-hamburg.de

Early postoperative reoperation due to graft failure was necessary for three patients (2.7%) after MIDCAB and for three patients (1.3%) after OPCAB. Confirmed by angiography, the early postoperative total graft patency rate was 96.2% in the MIDCAB group and 96.6% in the OPCAB group; the perfect patency rate (no stenosis greater than 50%) was 92.4% and 93.1%, respectively.

Conclusions: Coronary bypass surgery without the use of CPB is feasible and safe, and offers good early results. Nevertheless, MIDCAB grafting is a challenging technique and should only be performed in selected patients with favorable coronary anatomy. On the other hand, with the sternotomy approach, exposure of all vessels was well tolerated and made complete revascularization feasible. OPCAB can be performed safely even on high-risk patients.

INTRODUCTION

Coronary bypass surgery can be performed less invasively by avoiding the negative physiological impact of cardiopulmonary bypass (CPB). As early as 1967, Kolessov performed off-pump coronary artery bypass grafting (CABG) through a left thoracotomy [Kolessov 1967]. Since then, different minimally invasive techniques for myocardial revascularization on a beating heart have been introduced as an alternative to standard CABG in selected patients [Buffolo 1990, Benetti 1991, Pfister 1992, Buffolo 1996]. Recently, minimally invasive direct coronary artery bypass grafting (MIDCAB) has become widely used [Acuff 1996, Calafiore 1996, Calafiore 1997, Subramanian 1997a, Subramanian 1997b] as an approach for revascularization of the left anterior descending coronary artery (LAD) using the left internal mammary artery (LIMA). With the development of new coronary stabilizers and exposure techniques, indication for this approach has extended from one-vessel to multi-vessel revascularization with off-pump coronary artery bypass grafting (OPCAB) through a median sternotomy [Borst 1996, Jansen 1998, Baumgartner 1999]. Despite widespread acceptance, concerns have been raised regarding the ability to perform an accurate coronary anastomosis on a beating heart through a limited or standard access.

We present our experiences with CABG on a beating heart through a left minithoracotomy or a median sternotomy.

Table 1. Preoperative Demographics.

Variable	MIDCAB	OPCAB
Patients (n)	111	229
Age (year) (mean \pm SD)	61.4 \pm 10.1	63.5 \pm 10.5
Sex (male/female)	81/30	175/54
CCS class		
I	14 (12.5%)	10 (4.4%)
II	44 (39.6%)	54 (23.6%)
III	53 (47.8%)	131 (57.2%)
IV	0	34 (14.8%)
Previous MI	34 (30.6%)	131 (57.2%)
Previous CVA	5 (4.5%)	13 (5.7%)
Diabetes	2 (1.8%)	25 (10.9%)
Renal insufficiency	2 (1.8%)	27 (11.8%)
COPD	3 (2.7%)	34 (14.8%)
PVD	0	22 (9.6%)
Other comorbidities	5 (4.5%)	26 (11.4%)
Previous PTCA or stent	48 (43.2%)	81 (35.4%)
Previous bypass surgery	4 (3.6%)	27 (11.8%)
EF (mean)	61.4 \pm 10.1	54.5 \pm 13.6

MIDCAB = minimally invasive direct coronary artery bypass grafting; OPCAB = off-pump coronary artery bypass grafting; SD = standard deviation; 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; EF = ejection fraction.

MATERIALS AND METHODS

From May 1997 to September 1999, a prospective study was undertaken on 340 patients who underwent CABG without CPB at the University of Munich. All patients had been advised about the procedure and agreed to this method of operation. Of the 340 patients, 111 underwent MIDCAB through an antero-lateral minithoracotomy. The mean age of patients at the time of surgery was 61.4 \pm 10.1 years; 81 patients were male and 30 were female. In all patients, a LIMA to LAD procedure was carried out. The majority of patients had single-vessel disease, but 22 patients had two-vessel disease and eight had three-vessel disease. Most of the patients were in the Canadian Cardiovascular Society (CCS) class II or III category.

Since 1998, all MIDCAB patients underwent electron beam tomography (EBT) for preoperative visualization of the topographical structures and relationship of the LIMA, LAD, and intercostal spaces [Gulbins 1998]. This permits potential technical difficulties to be detected and an individual plan for the operation to be developed.

During the same time, 229 patients had OPCAB surgery through a full median sternotomy. The mean age of these patients at the time of surgery was 63.5 \pm 10.5 years; 175 patients were male and 54 were female. This cohort received between one and three bypasses. Of this group, 27 patients (11.8%) had previous bypass surgery and 39 (17.0%) had severe comorbidities. These included chronic renal failure, cerebrovascular disease, peripheral vascular dis-

ease, and chronic obstructive pulmonary disease ($FEV_1 < 20\%$ of predicted). Several patients had an overlap of different comorbidities. Preoperative demographics of the study population are depicted in Table 1 (●).

Anesthesiological Management

All patients received anesthesia under a standardized protocol, including intubation with a double-lumen endotracheal tube to allow right single-lung ventilation in MIDCAB procedures and regular single-lumen intubation in OPCAB surgery. The patient was positioned on a water-heated mattress in the operating room. A two-channel electrocardiograph (ECG) was applied and continuously monitored for ST-segment change. Monitoring included a Swan-Ganz catheter for hemodynamic measurements and transesophageal echocardiography (TEE) for detection of changes in regional wall motion during the whole surgical procedure. Continuous mixed venous saturation measurement was used in all patients. Heparin was given with a dose of 100 IU/kg of body weight prior to the division of the internal mammary artery (IMA) to accomplish an activated coagulation time of greater than 250 seconds. Half of the amount of heparin was reversed by the use of protamine after completion of the anastomoses.

Beating Heart Techniques

MIDCAB

The patient was placed in a supine position with the left shoulder being elevated by 30 degrees. A left anterolateral minithoracotomy (5 to 8 cm, median of 7.5 cm) was performed, penetrating the fourth intercostal space without resecting a rib. The LIMA was harvested, under direct vision in all cases, proximally up to the first rib and distally to below the sixth rib with a commercially available thoracic retractor (ThoraLift, US Surgical Corp., Norwalk, CT). The artery was treated with external administration of diluted papaverine. After preparation of the LAD, the vessel was surrounded proximally and distally to the region of the anastomosis with 4-0 or 5-0 polypropylene sutures (Ethicon, Somerville, NJ) that were snared over a piece of pledget for temporary interruption of blood flow. After initial occlusion of the LAD, the ECG and regional wall motion controlled by TEE were checked for signs of major myocardial ischemia. In case of ischemia, preconditioning was performed with five minutes of occlusion, followed by a five-minute period of reperfusion. A pressure stabilizer (CardioThoracic Systems, Cupertino, CA) was employed to achieve local immobilization of the target vessel. The anastomosis between the LIMA and the LAD was performed on the beating heart using one running 7-0 or 8-0 polypropylene suture under direct vision. A carbon dioxide/saline blower was used to clear blood from the operative field. A chest tube was placed in the left pleural space before closure of the incision.

In three patients (2.7%), the procedure was converted to a Port-Access CABG (Heartport Inc., Redwood City, CA), including femoral arterial and venous access for CPB and the use of a transfemoral endoaortic occlusion catheter for aortic occlusion, root venting, and application of antegrade cardioplegia. This technique allows CABG to be done through the

Table 2. Operative Procedures.

Procedure	MIDCAB	OPCAB
LAD	111	83
RCA		15
LAD + DIAG		37
LAD + MARG / CX		18
LAD + RCA / PDA		44
LAD + DIAG + MARG		7
LAD + DIAG + RCA		15
LAD + MARG / CX + RCA		10

LAD = left anterior descending coronary artery; DIAG = diagonal branch; MARG = marginal branch of the circumflex artery; CX = circumflex artery; RCA = right coronary artery; PDA = posterior descending coronary artery.

same left anterolateral minithoracotomy with extracorporeal circulation and cardioplegic arrest.

Off-pump Coronary Artery Bypass Grafting (OPCAB)

All OPCAB operations were approached through a standard median sternotomy. For multi-vessel beating heart revascularization, the Octopus 1 (suction stabilizer and, after February 1999 the Octopus 2 (stabilizer (Medtronic GmbH, Düsseldorf, Germany) were used. After harvesting of the LIMA (n = 206), the RIMA (n = 22), and the greater saphenous vein (n = 164), the pericardium was opened and the target coronary arteries were identified and dissected from the surrounding tissue for evaluation of the technical suitability of a beating heart procedure. Usually, revascularization started with distal left-sided vessels: the circumflex artery or the marginal branch, followed by the diagonal branch, the LAD, and the right coronary artery. Deep pericardial traction sutures were placed on the left side for exposure of the LAD and in line with the left superior pulmonary vein and the inferior vena cava for grafting of the circumflex artery and branches. To enhance exposure of the circumflex artery, the table was rotated to the right and into the Trendelenburg position (Figure 1). The coronary arteries were surrounded with 4.0 or 5.0 polypropylene sutures as described above. Suction was then applied (-400 mmHg) for stabilization of the corresponding vessels. The distal coronary anastomoses were performed using 7.0 or 8.0 polypropylene for the IMA and 7.0 polypropylene for distal vein anastomosis. Then, the aorta was partially clamped and the proximal anastomoses were made with running 6.0 polypropylene sutures. The inferior vena cava was temporarily clamped in order to lower the arterial pressure for the clamping procedure. The chest was then closed in a routine fashion after inserting one pericardial chest drain.

Quality Control and Assessment Criteria

Graft patency and bypass flow rates were analyzed intraoperatively, using a Doppler flow probe in all cases. Postoperative ECG was performed and serial myocardial fractions of creatine kinase (CK-MB) were determined every six hours at the intensive care unit and on post-op day 3, day 5, and before discharge for all patients. Myocardial infarction was

defined as either an increase in CK-MB enzyme levels above 50 IU/L or Q-wave in the postoperative ECG. The early postoperative graft patency rate was confirmed by angiography in 47.7% of MIDCAB patients (53/111) and in 45.0% of OPCAB patients (103/229).

Statistical Analysis

Continuous data was analyzed using the Mann-Whitney U test or an unpaired Student's t-test, and categorical data was analyzed using the Chi-square test. Values were expressed as mean \pm standard deviation or as median and range. Probability values (p) of less than 0.05 were considered significant. Statistical analysis was performed using the SPSS statistical software package 9.0 for Windows (SPSS Inc., Chicago, IL).

RESULTS

MIDCAB

In all 111 patients of the MIDCAB group, revascularization was performed by a single LIMA graft to the LAD. The operative data for the two groups are listed in Table 2. The average coronary artery occlusion time was 20.5 ± 6.1 minutes. Mean duration of the procedure was 142 ± 58 minutes (Table 3). MIDCAB was completed in 107 patients (96.4%) without CPB. In three patients (2.7%), the procedure was converted to a Port-Access CABG because of an intramyocardial LAD in two cases and an insufficient length of the LIMA in one case, necessitating the use of a saphenous vein graft. Conversion to sternotomy was necessary for one patient (0.9%) because of signs of ischemia in the ECG. The patient was operated on with CPB, receiving an additional saphenous vein graft. Myocardial infarction, defined as either an increase in CK-MB enzyme levels above 50 IU/L or Q-wave in the postoperative ECG, occurred in three patients (2.7%). There was no neurologic complication. Early postoperative reoperation due to graft occlusion was necessary in two patients and due to graft stenosis in one patient at 5, 9, and 10 days after surgery, respectively. There were no early deaths in this patient group.

OPCAB

In the OPCAB group, an average of 1.71 ± 0.6 grafts per patient was performed. Of the 229 patients, 98 (42.8%) had single, 99 (43.2%) double, and 32 (14.0%) triple graft revascularization. The total number of bypass grafts was 392. Arterial grafts were used in 216 patients (94.3%) with a

Table 3. Intraoperative and Postoperative Data.

Variable	MIDCAB	OPCAB
Surgery time (min)	142 ± 58	175 ± 43
Coronary artery occlusion time (min)	20.5 ± 6.1 (10-39)	14.4 ± 6.4 (8-36)
Postoperative ventilation (h)	6.2 ± 3.1	9.5 ± 5.2
ICU stay (h)	22.3 ± 6.2	28.9 ± 14.1

ICU = intensive care unit.

Table 4. Postoperative Complications.

Variable	MIDCAB	OPCAB
Conversion		
To CPB	4 (3.6%)	10 (4.4%)
To Sternotomy	1 (0.9%)	-
To Port-Access	3 (2.7%)	-
Reexploration for bleeding	1 (0.9%)	4 (1.7%)
Wound infection	1 (0.9%)	2 (0.9%)
Reoperation due to graft failure	3 (2.7%)	3 (1.3%)
Myocardial infarction	3 (2.7%)	6 (2.6%)
Hospital mortality	0	3 (1.3%)

CPB = cardiopulmonary bypass.

LIMA graft in 206 patients, a RIMA graft in 22 patients, and a bilateral IMA graft in 12 patients. Additionally, 164 vein grafts were performed. The operative data is listed in Table 2 (●). Average anastomosis time was 14.4 ± 6.4 minutes in the sternotomy group. Mean surgery time was 175 ± 43 minutes (Table 3, ●). Twelve percent of the patients had redo operations and 17% had two or more severe comorbidities. In 10 patients (4.4%), the procedure was converted to include CPB intraoperatively because of hemodynamic insufficiency during exposure of the target vessel or severe bradycardia during occlusion of the right coronary artery. No cerebrovascular accident was diagnosed. Myocardial infarction occurred in six patients (2.6%), and early postoperative reoperation due to occlusion of the bypass graft was necessary for three patients (1.3%). There were three hospital deaths (1.3%) in the OPCAB group. One patient died two days after reoperation due to occlusion of a bypass graft. The other two patients died due to myocardial infarction following occlusion of the non-grafted branches of the circumflex artery, while the performed LIMA-LAD bypass graft was patent; in both patients, no significant stenosis of the circumflex artery was recorded in the preoperative coronary angiography. Age, previous bypass surgery, and severe comorbidities were not statistically significant influences on early mortality. All postoperative complications are listed in Table 4 (●).

Assessment of Graft Patency

MIDCAB

In the MIDCAB group, 53 patients (47.7%) had a follow-up angiography. The early postoperative total graft patency rate was 96.2% and the perfect patency rate (no stenosis greater than 50%) was 92.4%. Four patients had significant anastomotic stenoses, which were treated successfully with percutaneous transluminal coronary angioplasty (PTCA) in three patients and reoperation 10 days after surgery in one patient.

OPCAB

At postoperative angiography in the OPCAB group (45.0%), the studies revealed patent anastomoses in 96.6% and stenosis-free patency in 93.7%. Ten patients required PTCA because of significant anastomotic stenoses. All postoperative angiographic results are listed in Table 5 (●).

DISCUSSION

New techniques for less invasive treatment of coronary artery disease are presently under evaluation. One modification is the omission of CPB. Since many researchers have reported good results with beating heart surgery, interest in these techniques has increased worldwide. A number of these researchers' reports are listed below in the References section. The MIDCAB procedure is currently used for revascularization of the LAD or diagonal artery with the LIMA on a beating heart through an anterolateral minithoracotomy [Acuff 1996, Calafiore 1996, Calafiore 1997, Subramanian 1997a, Subramanian 1997b]. This technique was standardized when stabilizers became commercially available for local immobilization of the target coronary arteries [Borst 1996], which is a crucial factor for achieving favorable results.

In the present study, the coronary arteries could be easily reached through the limited incision, and good immobilization could be achieved with pressure stabilizers. Thus, the MIDCAB procedure was completed in 96.4% without CPB. Nevertheless, conversion to sternotomy was necessary in one patient because of myocardial ischemia. In three patients, the procedure was converted to a Port-Access CABG because of an intramyocardial LAD or an insufficient length of the LIMA. Here, the Port-Access method can be highly recommended as a backup procedure instead of conversion to full sternotomy and regular CPB [Reichenspurner 1998]. Because technical difficulties may occur in patients with an intramyocardial LAD or an enlarged left ventricle and subsequent lateral positioning of the LAD, we used electron beam tomography (EBT) for preoperative visualization of the topographical structures in the MIDCAB patients [Gulbins 1998]. With this method, the topography and relationship of the LIMA, LAD, and intercostal spaces can be visualized, which permits individual planning of the operation. Since introduction of this modification, there have been no recorded conversions due to inadequate visualization.

In MIDCAB procedures, temporary LAD occlusion was well tolerated in all but one patient. This patient had ventricular fibrillation during occlusion of the LAD. While ECG showed normal ST-segments, acinesia of the anterior wall of the left ventricle was recorded in the transesophageal echocardiogram (TEE). Therefore, we believe that TEE is an extremely helpful tool in detecting early myocardial ischemia and should be a major requirement when perform-

Table 5. Postoperative angiography

Variable	MIDCAB	OPCAB
Postoperative angiography	53/111 (47.7%)	103/229 (45.0%)
Studied bypass grafts	53/111	175/389
Total graft patency	51/53 (96.2%)	169/175 (96.6%)
Stenosis-free patency	49/53 (92.4%)	164/175 (93.7%)
PTCA	3/53 (5.7%)	10/175 (5.7%)

PTCA = percutaneous transluminal coronary angioplasty.

ing a MIDCAB procedure. Nevertheless, after defibrillation and insertion of an intracoronary shunt, the anastomosis was finished through the same incision without conversion. The patient had an uneventful postoperative course without myocardial infarction, as indicated by normal postoperative enzymes and ECG. The use of intracoronary shunts may help alleviate this complication [Rivetti 1998].

With the development of new coronary stabilizers and exposure techniques, the indication for off-pump bypass surgery extended from one-vessel to multi-vessel revascularization with OPCAB through a median sternotomy [Borst 1996, Jansen 1998, Baumgartner 1999]. This approach allows the surgeon to offer the benefit of avoiding CPB to a much larger group of patients. With the suction stabilizer, exposure of the anterior, inferior, and posterior wall was well tolerated, making complete revascularization, including grafting of the circumflex artery, feasible. Nevertheless, conversion to CPB was recorded in 10 OPCAB patients (4.4%) because of hemodynamic insufficiency during exposure of the target vessel or severe bradycardia during occlusion of the right coronary artery. Eight of these patients had poor left ventricular function after major preoperative myocardial infarction. Here, the OPCAB procedure provides more safety, because conversion to CPB is fast and easy to perform.

Excellent long-term results using a LIMA graft to the LAD have been reported in conventional coronary bypass surgery [Loop 1986]. However, CABG on the beating heart is more difficult in terms of technical skills. Therefore, quality control by angiography is very important for analyzing the early graft patency rate. At angiographic follow-up, the total patency rate of the anastomoses performed was 96.2% through a limited incision and 96.6% through a full sternotomy. This is comparable with results described in the literature, which is reported to be between 90% and 99% [Calafiore 1997, Subramanian 1997a, Jansen 1998, Mack 1999]. The perfect graft patency was 92.4% in MIDCAB and 93.7% in OPCAB procedures. This reflects the quality of the anastomoses performed without the use of CPB and compares favorably with conventional CABG procedures [Mack 1999]. If myocardial ischemia occurs, coronary angioplasty or early postoperative reoperation may be needed, but the incidence of this complication was low in both groups.

Questions remain as to which patients benefit from beating heart surgery and which patients should be operated upon through a limited access approach or a standard median sternotomy. Avoiding CPB seems to be the most important benefit of less invasive CABG [Benetti 1991, Buffolo 1996]. CPB causes cerebral microemboli, which may lead to neuropsychological and neurological deficits [Moody 1995]. Adverse cerebral outcomes after coronary bypass surgery are relatively common and are associated with a substantial increase in mortality [Roach 1996]. In addition, when aortic cross-clamping is avoided, the risk of atheromatous emboli is further reduced. Therefore, less invasive CABG may be considered for patients with associated disease and elderly patients [Jansen 1997]. These high-risk patients may benefit the most from OPCAB compared to surgery with standard CPB [Baumgartner 1999]. In our series, no stroke and no

other major cerebrovascular event was observed. In addition, age, previous bypass surgery, and severe comorbidities did not influence early mortality.

Although both beating heart techniques have shown excellent results with low rates of early complications, low hospital mortality, and early graft patency rates comparable to conventional CABG with CPB [Mack 1999], the selection of the right technique for the right patient remains the key to less invasive beating heart coronary revascularization. Although excellent results have been reported with single LIMA grafting to the LAD via a left anterior small thoracotomy without CPB [Calafiore 1996], MIDCAB is a challenging technique that requires optimal monitoring and management. If an intramyocardial vessel of small diameter or diffuse calcification is present, this procedure may not be possible and conversion to sternotomy or to a Port-Access CABG with CPB may be necessary. MIDCAB should only be performed in selected patients with favorable coronary anatomy.

Using the sternotomy approach, exposure of all vessels is feasible. Thus, multivessel disease can also be treated without CPB. The mortality rate in our OPCAB patients was low (1.3%) and well comparable to other reported rates [Jansen 1998, Baumgartner 1999]. Early mortality was due to occlusion of a bypass graft in only one patient (0.4%) and was 0.4% in redo operations. Additionally, severe comorbidities did not increase early mortality. Thus, OPCAB can be performed safely even in high-risk patients. Indeed, high-risk patients may be likely to benefit the most from beating heart surgery compared to standard CPB. Additionally, this technique has the advantage of looking for the optimal location of the vessel for the anastomosis and, in case of hemodynamic instability, conversion to CPB is fast and easy to perform. Therefore we prefer the OPCAB technique through a full sternotomy in high-risk patients or in patients with an unfavorable coronary anatomy, even for single-vessel disease.

CONCLUSION

Coronary bypass surgery without using cardiopulmonary bypass is feasible and safe, and offers good early results. The MIDCAB procedure is an ideal technique for single-graft revascularization to the LAD. Nevertheless, MIDCAB is a challenging technique and should only be performed on patients with favorable coronary anatomy. In selected patients, excellent results can be achieved, as documented by the low complication and high graft patency rates. With the development of new coronary stabilizers and exposure techniques, the indication for off-pump bypass surgery has extended from one-vessel to multi-vessel revascularization with OPCAB. Through a sternotomy approach, exposure of all vessels is well tolerated, making complete revascularization feasible. This approach allows the surgeon to offer the benefit of avoiding CPB to a much larger group of patients. Because severe comorbidities and redo operations were not found to significantly increase early mortality, OPCAB can be performed safely without significant perioperative morbidity or mortality even in high-risk patients.

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