Bilateral internal thoracic artery grafting with and without cardiopulmonary bypass: Six-year clinical outcome

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Objectives: We sought to evaluate whether early and late results in patients who underwent off-pump or on-pump myocardial revascularization with bilateral internal thoracic artery grafting were similar.

Methods: From November 1994 through December 2001, 1835 patients underwent isolated myocardial revascularization with bilateral internal thoracic artery grafting. By applying propensity score pairwise matching, 1194 patients were selected and operated on either off pump (n = 597) or on pump (n = 597).

Results: The overall 30-day mortality was 1.5% (1.2% in the off-pump group and 1.8% in the on-pump group, $P = .342$). There was no difference for all the other complications between the 2 groups. Mean follow-up was 5.2 ± 1.8 years. Forty-two patients died over the follow-up period (22 in the off-pump group and 20 in the on-pump group), 15 of them of cardiac causes (7 in the off-pump group and 8 in the on-pump group). Six-year outcomes (freedom from death, cardiac death, acute myocardial infarction and reoperation in all or in the grafted area, target cardiac events, and any other event) were similar for both categories. After a mean of 30.7 ± 20.1 months, 202 patients had a postoperative angiography showing similar results.

Conclusions: Our results with extensive arterial revascularization clearly show that with the technical improvements achieved in the most recent years, off-pump operations can be performed safely with the same quality of late results as those obtained with on-pump operations.

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Received for publication Sept 23, 2004; revisions received Nov 20, 2004; accepted for publication Nov 30, 2004.

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J Thorac Cardiovasc Surg 2005;130:340-5

0022-5223/$30.00

doi:10.1016/j.jtcvs.2004.11.053

Early results after myocardial revascularization without cardiopulmonary bypass (CPB) show, in the great majority of reports, a decrease in postoperative morbidity[1-8] and sometimes also in mortality in the general surgical population[4-8] or in subgroups of high-risk patients.[9,10] Long-term outcome is not yet well established, even though in the last 2 years some reports appeared showing basically similar results in the 2 groups of patients.[1,2,4,11,12] The better long-term outcome with bilateral internal thoracic artery (BITA) grafting over other myocardial revascularization strategies has been recently reported.[13-17] We analyzed retrospectively our results with on-pump and off-pump isolated coronary artery bypass grafting in which BITA grafting was used to evaluate whether off-pump coronary artery bypass grafting sacrifices a long-term benefit for a more attractive and fashionable strategy.

Material and Methods

From November 1994 through December 2001, 1835 patients underwent isolated myocardial revascularization with BITA grafting. These patients were included in other previous publications of ours. Use of our database was authorized by the University of Chieti Institutional Review Board (Ethical Committee). By applying propensity score pairwise matching, 1194 patients were selected and operated on either off pump (n = 597) or on pump (n = 597). The

TABLE 1. Preoperative data

	Off pump (n = 597)	On pump (n = 597)	*P* value
Age (y)	62.7 ± 9.2	62.4 ± 8.6	.552
≥75 y	52 (8.7%)	37 (6.2%)	.098
Female sex	84 (14.1%)	82 (13.7%)	.867
Diabetes	133 (22.3%)	150 (25.1%)	.247
Preoperative AMI	275 (46.1%)	296 (49.6%)	.224
ECV	135 (22.6%)	142 (23.8%)	.631
Redo	10 (1.7%)	20 (3.4%)	.064
Unstable angina	182 (30.5%)	159 (26.6%)	.141
Urgency	113 (18.9%)	112 (18.8%)	.941
LM	98 (16.4%)	118 (19.8%)	.133
2-Vessel disease	359 (60.1%)	371 (62.1%)	.543
3-Vessel disease	238 (39.9%)	226 (37.9%)	.543
EF (%)	58.8 ± 12.2	57.8 ± 18.8	.345
≤35%	24 (4.0%)	27 (4.5%)	.668
Logistic EuroSCORE	4.3%	4.1%	.458

AMI, Acute myocardial infarction; *ECV*, extracardiac vasculopathy; *LM*, left main; *EF*, ejection fraction.

TABLE 2. Technical details

	Off pump (n = 597)	On pump (n = 597)	*P* value
Anastomoses per patient	2.7 ± 0.8	2.8 ± 0.9	.156
Arterial anastomoses per patient	2.3 ± 0.6	2.4 ± 0.7	.123
BITA anastomoses per patient	2.2 ± 0.5	2.3 ± 0.6	.105
BITA Y grafts	251 (42.0%)	203 (34.0%)	.004
BITA sequential grafts	114 (19.1%)	180 (30.2%)	<.001
Isolated BITA	313 (52.4%)	351 (58.8%)	.027
TAMR	364 (61.0%)	426 (71.4%)	<.001
RA	32 (5.4%)	20 (3.4%)	.089
RGEA	30 (5.0%)	67 (11.2%)	.001
IEA	4 (0.7%)	3 (0.5%)	.726
SVG	221 (37.0%)	156 (26.1%)	<.001
Incompleteness of MR	88 (14.7%)	87 (14.6%)	.935

BITA, Bilateral internal thoracic artery; *TAMR*, total arterial myocardial revascularization; *RA*, radial artery; *RGEA*, right gastroepiploic artery; *IEA*, inferior epigastric artery; *SVG*, saphenous vein graft(s); *MR*, myocardial revascularization.

2 groups showed similar preoperative characteristics (Table 1). Thirty-nine (6.2%) patients who were converted from off-pump to on-pump operations were analyzed as part of the off-pump group (intention to treat).

Patient Selection

Allocation to an off-pump operation was determined on the basis of vessel size (>1.2 mm) and the absence of diffuse coronary calcifications. In the presence of mechanical instability, electric instability, or both, the patient was selected preferably for an on-pump operation. The final decision depended on the basal status and the expertise of the surgeon responsible for the operation.

Surgical Technique

On-pump operation. CPB was instituted by means of cannulation of the ascending aorta and right atrium. A standard circuit with a hollow-fiber membrane oxygenator and a roller pump was used. Body temperature was kept at 37°C. Myocardial protection was achieved by means of intermittent antegrade warm blood cardioplegia.

Off-pump operation. The method of exposure and stabilization of the target coronary vessel was previously reported.[18] In the most recent years, apical suction was used to expose, in particular, the lateral and inferior wall (Xpose; Guidant Corp, Cupertino, Calif). Stabilization was achieved with a pressure (Acces Ultima System, Guidant Corp) or suction (Axius Vacuum 2 System, Guidant Corp) stabilizer. The target vessel was occluded with a 4-0 Prolene suture, passed on a small piece of silicon tubing, and then gently snared.

Quality control of the anastomosis. Since January 1996, at the end of the procedure, the quality of the anastomosis was checked with a transit-time Doppler flow device (Transit Time Flowmeter; Medi-Stim ASA, Oslo, Norway). In 2001, an intraoperative imaging system (SPY System; Novadaq Technologies Inc, Mississauga, Ontario Canada) was added.

Clinical Data Collection, Monitoring, and Definition

A set of perioperative data is collected prospectively for all patients undergoing coronary artery bypass grafting at our institution. The following were recorded and defined. Mortality included death from any cause. Cardiac mortality included any death from cardiac causes and sudden deaths. Cerebrovascular events (CVEs) were defined as global or focal neurologic deficits diagnosed by a neurologist and confirmed with a brain computed tomographic scan. Acute myocardial infarction (AMI) was defined as enzymatic increase, electrocardiographic signs of necrosis, new akinetic segments at echocardiography, and non–potassium-related ventricular arrhythmias. Early major events were defined as the sum of death from any cause, CVE, AMI, low output syndrome (need for an intra-aortic balloon pump, inotropic drugs, or both for >12 hours), need for mechanical ventilation for more than 24 hours, acute renal failure (postoperative blood creatinine level of ≥2.0 mg% when the preoperative value was normal [≤1.4] and 1 mg higher when abnormal), and gastrointestinal complications. Early negative primary end points were defined as death from any cause, AMI, and CVE. *Target cardiac event* was defined as cardiac deaths, AMI in grafted areas, and redo-percutaneous transluminal coronary angioplasty (PTCA) in grafted areas; *any event* was defined as death from any cause, AMI in any territory, and redo-PTCA in any territory.

Follow-up

All the patients were followed up in our outpatient clinic 3, 6 and 12 months after surgical intervention and thereafter at yearly intervals. The most recent information was obtained by calling the patients or the referring cardiologists. Follow-up was 100% complete on December 31, 2003.

TABLE 3. Target coronary vessels

	Off pump	On pump	*P* value
Patients	597	597	
BITA anastomoses	1335	1396	
LAD	596 (44.6)	599 (42.9)	.392
Diagonal	121 (9.1)	134 (9.6)	.702
Cx system	530 (39.7)	575 (41.1)	.480
RCA system	88 (6.5)	88 (6.3)	.891

BITA, Bilateral internal thoracic artery; *LAD*, left descending artery; *Cx*, circumflex artery; *RCA*, right coronary artery.

TABLE 4. Early clinical outcome

	Off pump (n = 597)	On pump (n = 597)	*P* value
Deaths	7 (1.2%)	11 (1.8%)	.342
Cardiac deaths	3 (0.5%)	7 (1.2%)	.204
CVE	5 (0.8%)	4 (0.7%)	1.000
AMI	6 (1.0%)	4 (0.7%)	.525
ENPEP	16 (2.7%)	15 (2.5%)	.856
EME	30 (5.0%)	34 (5.7%)	.607
ICU stay (h)	13.9 ± 16.5	18.1 ± 21.6	<.001
In-hospital stay (d)	4.4 ± 2.6	5.2 ± 2.6	<.001

CVE, Cerebrovascular events; *AMI*, acute myocardial infarction; *ENPEP*, early negative primary end points; *EME*, early major events; *ICU*, intensive care unit.

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Statistical Analysis

Results are expressed as mean values ± standard deviation. Statistical analysis comparing 2 groups was performed with unpaired 2-tailed *t* tests for the means or χ^2 tests for categoric variables. Stepwise logistic regression was used to realize a model to calculate the propensity score.[19] Variables included in the stepwise logistic regression analysis were preoperative (age, age ≥75 years, female sex, body weight, history of hypertension, history of smoking, hypercholesterolemia, chronic renal failure, chronic hepatic failure, chronic obstructive pulmonary disease, unstable angina, chronic heart failure, AMI <24 hours, preoperative intra-aortic balloon pumping, previous atrial fibrillation, urgency, diabetes [insulin or oral treatment], redo, ventricular arrhythmias, extracoronary vasculopathy, previous cerebrovascular accident, previous AMI, left main disease, number of diseased vessels, ejection fraction, ejection fraction ≤35%, inotropes, or nitroglycerin ever) or perioperative (surgeon, use of CPB, simultaneous carotid surgery, number of anastomoses, number of arterial anastomoses, or target coronary vessels grafted by BITA). The definition of the variables was previously reported.[5] The goodness of the model was evaluated by using the Hosmer and Lemeshow goodness-of-fit statistic and residual analysis. Each off-pump patient was matched with the on-pump patient with the closest propensity score. Variables at the basis of the model are shown in Appendix 1. Stepwise logistic regression was used to select the independent variables that could predict the end points of this study and included all the univariate variables with a *P* value of .2 or less. Six-year actuarial results were obtained with the Kaplan-Meier method and listed in the tables as percentages. Statistical significance was calculated with the log-rank test. Cox analysis was used to evaluate the independent risk factors for reduced late events. SPSS software (Chicago, Ill) was used.

Results

The average number of total anastomoses, which included arterial anastomoses and anastomoses performed with BITA grafting, was similar in both groups. Although more BITA Y grafts were achieved in the off-pump group, a significantly higher number of sequential grafts were performed in the on-pump group (Table 2). Target coronary vessels grafted by means of BITA grafting were similar and are shown in Table 3.

Early Clinical Outcome

Overall 30-day mortality was 1.5% (1.2% in the off-pump group and 1.8% in the on-pump group, $P = .342$). There was no difference for AMI, CVE, early negative primary end point, and early major event incidence between the 2 groups. The duration of postoperative in-hospital stay (both in the intensive care unit and in the ward) was longer for the on-pump group (Table 4).

Late Clinical Outcome

Mean follow up was 5.2 ± 1.8 years (range, 2.0-9.1 years; 5.1 ± 1.7 years in the off-pump group and 5.3 ± 2.0 years in the on-pump group, $P = .063$). The number of patients at risk after 1, 3, and 6 years was, respectively, 582, 480, and 239 in the off-pump group and 577, 518, and 273 in the on-pump group.

Freedom from death. After a mean of 1.3 ± 1.4 years, 42 patients died (22 in the off-pump group and 20 in the on-pump group), 15 of them of cardiac causes (7 in the off-pump group and 8 in the on-pump group). One-, 3-, and 6-year freedom from death from any cause was 97.3% ± 0.7%, 95.4% ± 0.9%, and 95.0% ± 0.9% in the off-pump group and 96.7% ± 0.7%, 95.4% ± 0.9%, and 94.5% ± 0.9% in the on-pump group ($P = .88$, Figure 1). Freedom from cardiac death was 99.2% ± 0.4%, 98.3% ± 0.5%, and 98.3% ± 0.5%, respectively, in the off-pump group and 98.0% ± 0.6%, 97.6% ± 0.6%, and 97.4% ± 0.7% in the on-pump group ($P = .32$).

Freedom from AMI. Six patients (2 in the off-pump group and 4 in the on-pump group) experienced a new AMI, 4 in the grafted area (1 in the off-pump group and 3 in the on-pump group). One-, 3-, and 6-year freedom from AMI was 99.0% ± 0.4%, 98.6% ± 0.5%, and 98.6% ± 0.5%, respectively, in the off-pump group and 99.0% ± 0.4%, 98.8% ± 0.5%, and 98.6% ± 0.5% in the on-pump group ($P = .98$). Freedom from AMI in grafted areas was 99.2% ± 0.4%, 99.2% ± 0.4%, and 99.0% ± 0.6%, respectively,

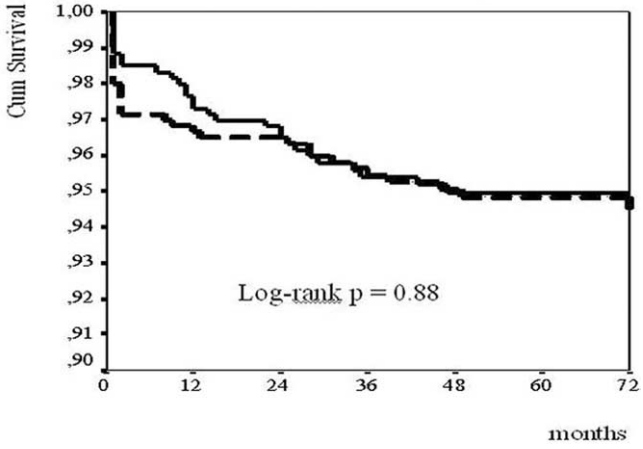

Figure 1. Six-year actuarial freedom from death of any cause according to off-pump *(solid line)* or on-pump *(dashed line)* coronary surgery.

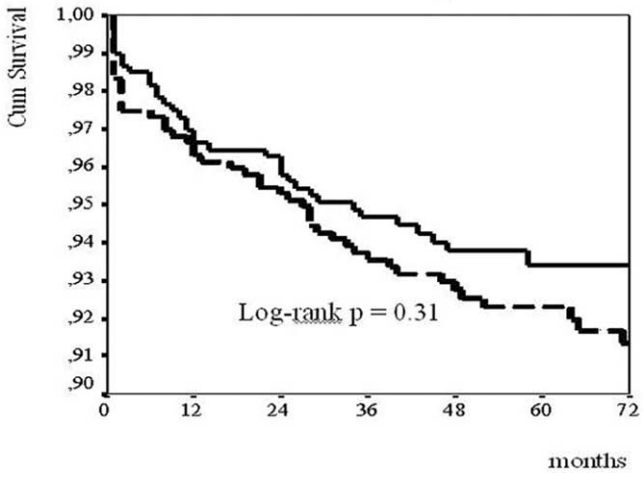

Figure 2. Six-year actuarial freedom from any event according to off-pump *(solid line)* or on-pump *(dashed line)* coronary surgery.

in the off-pump group and 99.0% ± 0.4%, 98.8% ± 0.5%, and 98.8% ± 0.5% in the on-pump group ($P = .79$).

Freedom from redo-PTCA. Twenty-six patients (9 in the off-pump group and 17 in the on-pump group) needed a further myocardial revascularization, 18 of them in the grafted area (6 in the off-pump group and 12 in the on-pump group). Seven needed a surgical revascularization (3 in the off-pump group and 4 in the on-pump group), whereas the remaining 19 (6 in the off-pump group and 13 in the on-pump group) were treated in the interventional laboratory. One-, 3-, and 6-year freedom from redo-PTCA was 99.2% ± 0.4%, 99.0% ± 0.4%, and 98.1% ± 0.6%, respectively, in the off-pump group and 99.5% ± 0.2%, 98.1% ± 0.6%, and 96.4% ± 0.9% in the on-pump group ($P = .21$). Freedom from redo-PTCA in grafted areas was 99.2% ± 0.4%, 99.2% ± 0.4%, and 99.0% ± 0.4%, respectively, in the off-pump group and 99.7% ± 0.2%, 98.2% ± 0.6%, and 97.6% ± 0.7% in the on-pump group ($P = .20$). An on-pump operation was not an independent variable by means of Cox analysis.

Freedom from target cardiac events. Cardiac death, AMI, and redo-PTCA in grafted areas occurred in 32 patients (11 in the off-pump group and 21 in the on-pump group). One-, 3-, and 6-year freedom from target cardiac events was 98.5% ± 0.5%, 97.8% ± 0.6%, and 97.8% ± 0.6%, respectively, in the off-pump group and 98.0% ± 0.6%, 96.2% ± 0.8%, and 95.3% ± 0.9% in the on-pump group ($P = .07$). An on-pump operation was not an independent variable by means of Cox analysis.

Freedom from any event. Death from any cause, AMI, and redo-PTCA occurred in 68 patients (30 in the off-pump group and 38 in the on-pump group). One-, 3-, and 6-year freedom from any event was 96.6% ± 0.7%, 94.7% ± 0.9%, and 93.4% ± 1.1%, respectively, in the off-pump group and 96.3% ± 0.8%, 93.6% ± 1.0%, and 91.3% ± 1.2% in the on-pump group ($P = .31$, Figure 2).

Outcome of patients converted from off-pump to on-pump operations. Thirty-day mortality (10.3% vs 1.2%, $P = .002$) and morbidity (30.8% vs 4.5%, $P < .001$) of 39 patients converted from off-pump to on-pump operations were significantly higher if compared with those of the remaining 1155 patients. This subgroup of patients had lower 6-year freedom from AMI (94.9% ± 3.5% vs 98.7% ± 0.5%, $P = .028$) and from AMI in the grafted areas (94.9% ± 3.5% vs 99.0% ± 0.3%, $P = .028$).

Angiographic Controls

After a mean of 30.7 ± 20.1 months, 202 patients had a postoperative angiography, 103 in the off-pump group and 91 in the on-pump group. In 112 of them (68 in the off-pump group and 44 in the on-pump group), return of angina was suspected. Results are shown in Table 5. Only 2 off-pump cases had a B-grade anastomotic stenosis.[20]

Discussion

Many retrospective or randomized studies have focused on early results after myocardial revascularization without CPB.[1-8] Many benefits were identified both in the clinical and in the neurocognitive fields,[1-8,21] often in high-risk patients.[9,10] However, not all reports confirmed these findings.[22,23] Even if there is still no general agreement, we can reasonably conclude that off-pump operations are related to lower postoperative morbidity, even though some studies were also able to demonstrate a reduction in early mortality.[4-8] On the contrary, reports about long-term results are few. Gundry and colleagues[24] described a 7-year follow-up

TABLE 5. Angiographic results

	Off pump (n = 103)	On pump (n = 91)	*P* value
Follow-up	28.4 ± 15.3	33.3 ± 28.9	.135
LITA	123/127 (96.8%)	94/101 (93.0%)	.311
RITA	108/118 (91.5%)	95/109 (87.2%)	.403
BITA	231/245 (94.3%)	189/210 (90.0%)	.124
Y graft	32/35 (91.4%)	22/25 (80.0%)	.506
RGEA	10/11 (90.9%)	4/4 (100%)	.318
RA	9/9 (100%)	6/6 (100%)	1.000
IEA	2/2 (100%)	—	—
SVG	40/44 (90.9%)	2/4 (50.0%)	.115

LITA, Left internal thoracic artery; *RITA*, right internal thoracic artery; *BITA*, bilateral internal thoracic artery, grade A according to Fitzgibbon classification[20]; *RGEA*, right gastroepiploic artery; *RA*, radial artery; *IEA*, inferior epigastric artery; *SVG*, saphenous vein graft(s).

experience with patients who underwent off-pump operations. They found that although survival was the same, more than 20% of the off-pump patients needed a second procedure compared with only 7% in the on-pump group. They concluded that the price to pay for off-pump revascularization was much higher; indeed, they showed a 3-fold rate of reoperation. This study is related to early surgical experiences, when there were neither stabilizers nor exposure devices, and off-pump myocardial revascularization had unpredictable results. Angelini and associates[1] did not find any differences at midterm follow-up, suggesting that the early benefits in morbidity obtained with off-pump operations were not at the expense of high-quality clinical outcomes. Similar 1-year follow-up data were presented by Nathoe and coworkers.[2] Sabik and colleagues[12] reported 4-year clinical results in 2 groups of patients who were also the subjects of a previous study.[3] They showed, as did we,[4,11] similar clinical results in the 2 groups. Although off-pump patients had fewer distal anastomoses (2.8 ± 1.0 vs 3.5 ± 1.1, $P < .001$) and a higher incidence of incomplete revascularization (31% vs 18%), they did not experience more late ischemia-related events or need for further coronary operations compared with on-pump patients. In a previous study[11] we showed similar 4-year clinical results, first month excluded, in 2 groups of patients with multivessel disease operated on without or with CPB (906 and 896 patients, respectively). Early results in these patients were previously reported by us.[5] In a more recent report,[4] in which propensity score analysis was used, again the 5-year outcome was similar. However, a significant benefit in freedom from AMI in grafted areas was found, very likely related to lower creatine kinase MB release in off-pump compared with on-pump patients. The same outcome was also identified in high-risk patients 5 years after surgical intervention.[9]

In this study we tested the hypothesis that with use of a more extensive arterial revascularization, such as BITA grafting, the same quality of results could be reached with and without CPB. Recent long-term results with BITA grafting[1-17] emphasized the benefit of such vessels in patients who needed myocardial revascularization. With the advent of off-pump techniques, we did not change our policy of extensive arterial grafting.[25] As a consequence, evaluation of long-term BITA grafting results with both strategies after a reasonable period of time was necessary because the increased technical difficulty could jeopardize the quality of off-pump anastomoses, with a consequent reduction of the quality of long-term results. Our study shows that there is no difference in clinical outcome. Furthermore, in grafted areas overall freedom from redo-PTCA was similar, even though the absolute number of patients who needed further revascularization was greater in the on-pump group. Even though this is indirect evidence, we feel comfortable in stating that the quality of distal anastomoses is equal with both off-pump and on-pump techniques.

This aspect of off-pump operations has been debated for a long time. In a recent study Kim and associates[26] found that although the left internal thoracic artery patency rate was the same, the saphenous vein graft patency rate was lower in patients operated on off pump, very likely because of increased and uncontrolled hypercoagulability after off-pump procedures. Khan and coworkers[27] showed a better 3-month patency rate in patients undergoing on-pump versus off-pump operations (98% vs 88%, $P = .002$), questioning the long-term efficacy of off-pump operations on the basis of this reduced early patency rate. These results are difficult to explain. The authors did not report their previous experience with off-pump procedures and did not use apical suction to expose the lateral and inferior walls. Shunts were not used routinely, and even though their effect on limiting myocardial ischemia can be discussed, it is certain that in less-experienced hands shunts act as tutors to avoid anastomotic problems. We never designed a randomized study. However, in many articles we reported our early and late patency rates in off-pump patients,[25,28-30] and as in the present study (Table 5), patency rates were similar in both groups.

We believe that in the field of coronary surgery, we need to assure patients with the best early but also late results possible. To reach this goal, it is our duty to choose worldwide accepted strategies that provide the longest survival with the lowest complication rate. As a consequence, BITA grafting, if indicated, should not to be denied to anyone. Changing strategy to reach better early results with the risk of jeopardizing the long-term outcome is not ethical. Our results show that extensive arterial revascularization can

provide the same long-term results independently from the use of off-pump or on-pump techniques.

A limitation of the present study is that it is not randomized. Moreover, our center has been dedicated to off-pump operations for a long time, and we have reached a particular expertise in this field. Nevertheless, we think that the present study, together with others, clearly shows that thanks to the technical improvements achieved in the most recent years, off-pump operations can be performed safely and with the same quality of late results obtained as seen with on-pump operations.

References

1. Angelini GD, Taylor FC, Reeves BC, Ascione R. Early and midterm outcome after off-pump and on-pump surgery in Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomized controlled trials. *Lancet.* 2002;359:1194-9.
2. Nathoe HM, van Dijk D, Jansen EW, et al. A comparison of on-pump and off-pump coronary bypass surgery in low-risk patients. *N Engl J Med.* 2003;348:394-402.
3. Sabik JF, Gillinov AM, Blackstone EH, et al. Does off-pump coronary surgery reduce morbidity and mortality? *J Thorac Cardiovasc Surg.* 2002;124:698-707.
4. Calafiore AM, Di Mauro M, Canosa C, et al. Myocardial revascularization with and without cardiopulmonary bypass: advantages, disadvantages and similarities. *Eur J Cardiothorac Surg.* 2003;24:953-60.
5. Calafiore AM, Di Mauro M, Contini M, et al. Myocardial revascularisation with and without cardiopulmonary bypass in multivessel disease: impact of the strategy on early. *Ann Thorac Surg.* 2001;72:456-62.
6. Al-Ruzzeh S, Ambler G, Asimakopoulos G, et al. Off-pump coronary artery bypass (OPCAB) surgery reduces risk-stratified morbidity and mortality: a United Kingdom Multi-Center Comparative Analysis of Early Clinical Outcome. *Circulation.* 2003;108(suppl):II1-8.
7. Cleveland JC Jr, Shroyer ALW, Chen AY, Peterson E, Grover FL. Off-pump coronary artery bypass grafting decreases risk-adjusted mortality and morbidity. *Ann Thorac Surg.* 2001;72:1282-9.
8. Plomondon ME, Cleveland JC Jr, Ludwig ST, et al. Off-pump coronary artery bypass is associated with improved risk-adjusted outcomes. *Ann Thorac Surg.* 2001;72:114-9.
9. Calafiore AM, Di Mauro M, Canosa C, et al. Early and late outcome of myocardial revascularization with and without cardiopulmonary bypass in high risk patients (Euroscore ≥6) *Eur J Thorac Cardiovasc. Surg.* 2003;23:360-7.
10. Mack MJ, Pfister A, Bachand D, et al. Comparison of coronary bypass surgery with and without cardiopulmonary bypass in patients with multivessel disease. *J Thorac Cardiovasc Surg.* 2004;127:167-73.
11. Calafiore AM, Di Mauro M, Canosa C, Cirmeni S, Iacò AL, Contini M, et al. Myocardial revascularization with and without cardiopulmonary bypass in multivessel disease: impact of strategy on midterm outcome. *Ann Thorac Surg.* 2003;76:32-6.
12. Sabik JF, Blackstone EH, Lytle BW, Houghtaling PL, Gillinov AM, Cosgrove DM. Equivalent midterm outcomes after off-pump and on-pump coronary surgery. *J Thorac Cardiovasc Surg.* 2004;127:142-8.
13. Lytle BW, Blackstone EH, Loop FD, et al. Two internal thoracic artery grafts are better than one. *J Thorac Cardiovasc Surg.* 1999;117:855-72.
14. Berreklouw E, Rademakers PP, Koster JM, van Leur L, van der Wielen BJW, Wsters P. Better ischemic event-free survival after two internal thoracic artery grafts:13 years of follow up. *Ann Thorac Surg.* 2001;72:1535-41.
15. Pick AW, Orszulak TA, Anderson BJ, Schaff HV. Single versus bilateral internal mammary artery grafts: 10-year outcome analysis. *Ann Thorac Surg.* 1997;64:599-605.
16. Endo M, Tomizawa Y, Nishida H. Bilateral versus unilateral internal mammary revascularization in patients with diabetes. *Circulation.* 2003;108:1343-9.
17. Calafiore AM, Di Mauro M, Canosa C, et al. Myocardial revascularization with and without cardiopulmonary bypass: advantages, disadvantages and similarities. *Eur J Cardiothorac Surg.* 2003;24:953-60.
18. Calafiore AM, Di Giammarco G, Teodori G, Mazzei V, Vitolla G. Recent advances in multivessel coronary grafting without cardiopulmonary bypass. *Heart Surg Forum.* 1998;1:20-5.
19. Rosenbaum PR, Rubin DB. The central role of the propensity score in observational studies for causal effects. *Biometrika.* 1983;70:41-55.
20. Fitzgibbon GM, Kafka HP, Leach AJ. Coronary bypass graft fate and patient outcome: angiographic follow-up of 5,065 grafts related to survival and re-operation in 1,388 patients during 25 years. *J Am Coll Cardiol.* 1996;28:616-26.
21. Diegeler A, Hirsch R, Schneider F, et al. Neuromonitoring and neurocognitive outcome in off-pump versus conventional coronary bypass operation. *Ann Thorac Surg.* 2000;69:1162-6.
22. van Dijk D, Nierich AP, Jansen WL, et al. Early outcome after off-pump versus on-pump coronary bypass surgery. Results from a randomised study. *Circulation.* 2001;104:1761-6.
23. Bull DA, Neumayer LA, James C, et al. Coronary artery bypass grafting with cardiopulmonary bypass versus off-pump cardiopulmonary bypass grafting: does eliminating the pump reduce morbidity and cost? *Ann Thorac Surg.* 2001;71:170-5.
24. Gundry SR, Romano MA, Shattuck OH, Razzouk AJ, Bailey LL. Seven-year follow-up of coronary artery bypasses performed with and without cardiopulmonary bypass. *J Thorac Cardiovasc Surg.* 1998;115:1273-8
25. Calafiore AM, Teodori G, Di Giammarco G, et al. Multiple arterial conduits without cardiopulmonary bypass: early angiographic results. *Ann Thorac Surg.* 1999;67:450-6.
26. Kim KB, Lim C, Lee C, et al. Off-pump coronary artery bypass may decrease the patency of saphenous vein grafts. *Ann Thorac Surg.* 2001;72(suppl):S1033-7.
27. Khan NE, De Souza A, Mister R, et al. A randomized comparison of off-pump and on-pump multivessel coronary-artery bypass surgery. *N Engl J Med.* 2004;350:21-8.
28. Contini M, Di Mauro M, Vitolla G, et al. Off-pump myocardial revascularization using arterial conduits without cardiopulmonary bypass. *J Card Surg.* 2000;15:251-5.
29. Contini M, Iaco A, Iovino T, et al. Current results in off pump surgery. *Eur J Cardiothorac Surg.* 1999;16(suppl 1):S69-72.
30. Calafiore AM, Di Giammarco G, Deodori G, et al. Midterm results after minimally invasive coronary surgery (last operation). *J Thorac Cardiovasc Surg.* 1998;115:763-71.

APPENDIX 1. Variables included in the propensity score model

Variable	B value	*P* value
Age	−0.016	.007
Diabetes	0.13	.318
ECV	−0.22	.282
Female sex	0.19	.495
No. of anastomoses	0.66	<.0001
Previous AMI	0.16	.025
Urgency	0.39	.073
Chronic renal failure (cr ≥2.0)	−0.48	.040
Left main disease	0.10	.339
Redo	1.99	<.0001
X^{2}*	Degrees of freedom*	*P* value*
6.6	8	.85

ECV, Extracardiac vasculopathy; *AMI,* acute myocardial infarction; *cr,* creatinine. *Goodness-of-fit test.