original article

Myocardial protection and early outcome of different coronary surgical techniques for diabetic patients with triple vessels

Yu Lei, Tianxiang Gu, Enyi Shi, Chun Wang, Fang Qin

From the Department of Cardiac Surgery, China Medical University, Shenyang, China

Correspondence: Dr. Tianziang Gu · Department of Cardiac Surgery, China Medical University, First Affiliated Hospital, Shenyang, China · T: 86-24-83283455. F: 86-24-83283455 · cmuyulei@aliyun.com

Ann Saudi Med 2014; 34(5): 375-382

DOI: 10.5144/0256-4947.2014.375

BACKGROUND AND OBJECTIVES: For patients with diabetes and triple-vessel disease, coronary artery bypass grafting (CABG) surgery is a well-established procedure, but cardiopulmonary bypass support may also lead to severe complications to these patients. The aim of this study was to compare myocardial protection and early outcomes in patients with diabetes and triple-vessel disease following different coronary surgical techniques.

DESIGN AND SETTINGS: Prospective randomized trial of patients treated at the First Affiliated Hospital of China Medical University over a 3-year period (2011- 2013).

METHODS: In a single-center randomized trial, 668 patients with diabetes and triple-vessel disease were randomly assigned to off-pump (OPCAB) (number [n]=222), on-pump beating heart (OnP-BH) (n=223), and conventional CABG (OnP) (n=223) between January 2011 and October 2013. Myocardial injury was assessed by measuring the serial release of cardiac troponin I (cTnI) preoperatively, 1 hour, 12 hours, 24 hours, and 72 hours postoperatively. The early outcomes were compared among these 3 groups.

RESULTS: Preoperative characteristics of the patients in all 3 groups were similar. No significant difference was found regarding the number of anastomoses, the use of the internal thoracic artery, postoperative new-onset atrial fibrillation, hemodialysis, stroke, reoperation for bleeding, and infective complications in the 3 groups ($P>.05$). The complete revascularization, postoperative drainage loss, intra-aortic balloon pump support, blood requirements, postoperative myocardial infarction, pulmonary complications, gastrointestinal complications, inotropic requirements >24 hours, ventilation >24 hours, intensive care unit stay >24 hours, and in-hospital stay >7 days were significantly lower in the OPCAB group than in the other 2 groups ($P<.05$). In-hospital mortality was lower in the OPCAB group than in the other 2 groups, but no statistical difference was observed ($P>.05$). Preoperative cTnI in the 3 groups was similar ($P>.05$); however, the lowest cTnI value was noted in the OPCAB group, followed by the OnP group, and it was highest in the OnP-BH group 1 hour, 12 hours, 24 hours, and 72 hours postoperatively ($P<.05$).

CONCLUSION: OPCAB is superior to the OnP-BH and OnP techniques in terms of postoperative complications and myocardial protection in patients with diabetes and triple-vessel disease. Myocardial injury in the OnP-BH group was significantly higher than that in the OnP group.

Diabetes mellitus (DM) is a well-known risk factor for the development of coronary artery disease (CAD).[1] Affected patients often present with advanced and more diffuse disease, involving multiple vessels and rapidly progressive CAD when compared to nondiabetic patients.[2] Particularly, percutaneous coronary interventions (PCIs), including angioplasty and stent placement, have been reported to carry a higher risk for restenosis and recurrent symptoms. In diabetic patients with severe multivessel disease, coronary artery bypass grafting (CABG) was repeatedly proven to be superior to PCIs in terms of the risk of myocardial infarction (MI), cardiac death, and the need for repeat revascularization.[3,4] However, to date, diabetes has been recognized as an important factor in determining postoperative outcomes after CABG,[5] and the best treatment strategy for diabetic patients with multivessel disease remains controversial.

Conventional CABG (OnP) is one of the most commonly performed procedures, and it is a very well-established treatment for CAD. This procedure, in combination with cardiac arrest, allows for the performance of coronary artery anastomosis in a steady, bloodless surgical field.[6] Nevertheless, significant morbidity remains, mostly because of the whole-body response to the nonphysiologic nature of on-pump, leading to a propagation of systemic inflammatory response syndrome, such as cytokines and complements.[7,8] Currently, the optimal method for intraoperative myocardial protection is blood cardioplegia, but this is still associated with low cardiac output syndrome in 10% of cases.[9] Over the last decade, interest has reemerged in off-pump (OPCAB) surgery, which avoids cardiopulmonary bypass (CPB), cardioplegic arrest and, consequently, the global ischemic time. Recently, the Randomized On/Off Bypass (ROOBY) and 2 CORONARY trials indicated that 30-day and 1-year outcomes would be no different between OnP and OPCAB.[10-12] However, a study consisting of 21 640 patients that compared OnP and OPCAB concluded that OPCAB was associated with less morbidity, a shorter-length hospital stay, and similar mortality rates when compared with on-pump procedures, suggesting that OPCAB can be a safe and effective alternative to OnP.[13] In recent years, a hybrid procedure of on-pump beating heart (OnP-BH), but without cardioplegic arrest, might confer some of the advantages of the OPCAB in some higher-risk patients.[14,15]

Yet, to date, very little data exist as part of a clinical trial to validate the OnP, OnP-BH, and OPCAB techniques simultaneously. In this randomized controlled trial, we set to evaluate the 3 surgical techniques by assessing their impact on myocardial protection and early outcomes in patients with DM and triple-vessel disease.

METHODS

Patient selection

This study was approved by the Institutional Review Board of China Medical University and was in compliance with the Health Insurance Portability and Accountability Act Regulations and the Declaration of Helsinki. We used the CONSORT checklist[16] for the design and conduct of this study.

The definition of diabetes is based on the following World Health Organization diagnostic criteria issued in 1999: fasting plasma glucose ≥7.0 mmol/L (126 mg/dL); or 2-hour plasma glucose ≤11.1 mmol/L (200 mg/dL).[17] After receiving written consent from the diabetic patients with triple-vessel disease (number [n]=668), the patients participated voluntarily in OnP (n=223), OnP-BH (n=223), or OPCAB (n=222) in our hospital from January 2011-October 2013. All of the operations were performed by the same surgical team. Among the OPCAB group, conversions to on-pump surgery occurred in 5 patients (2.25%) because of hemodynamic instability. Among the OnP group, 1 patient (0.45%) had his operation converted from on-pump to OPCAB because of heavily calcified aortas. All of these patients were still included in the intention-to-treat analysis.

Exclusion criteria included an inability to provide informed consent, emergency or urgent operation, combined cardiac procedures, cardiac reoperation, a history of renal insufficiency (creatinine [Cr] >2 mg/dL), or stroke within 1 month. Preoperative and perioperative data were collected. Data were collected prospectively during the patient's admission as part of routine clinical practice and were subsequently entered into our cardiac surgery registry. Myocardial injury was assessed by measuring the serial release of cardiac troponin I (cTnI) preoperatively and 1 hour, 12 hours, 24 hours, and 72 hours postoperatively.

Randomization

Before being able to randomize patients, the surgeon had to enter a preoperative plan including which coronary arteries were to be grafted, the conduit type, and whether a single, sequential, or Y-graft was planned. Having done this, the patient was subsequently randomized to OnP, OnP-BH, or OPCAB. Randomization was performed by chance the day prior to surgery using randomization envelopes. Patients were ascribed their unique patient identifier the evening before surgery. The surgical team was only unblinded to the surgical procedure once the patient had been anesthetized. The postoperative care team was blinded according to detailed protocols. Events were, however, evaluated by an independent committee composed of 2 physicians with relevant medical background in the field of cardiac surgery.

Surgical technique

Median sternotomy was used as the surgical access in all cases. The aim of the surgery was to obtain complete revascularization using the left internal mammary artery and saphenous vein grafts, where possible. The anesthetic technique was standardized in the 3 groups; all patients received a standard anesthetic protocol comprising scopolamine, fentanyl, pancuronium, etomidate, and propofol. Procedures were performed using CPB in the OnP and OnP-BH groups. CPB was established by aortic inflow cannulation and right atrium outflow cannulation with a single 2-stage cannula. The heparin dose was 300 U/kg in the CPB groups to achieve an activated clotting time >400 seconds and 100 U/kg in the OPCAB group. All patients were placed on CPB, during which the mean arterial pressure was maintained between 60 mm Hg and 70 mm Hg, with pharmacological manipulation as necessary. A membrane oxygenator and alpha-stat control of acid-base management were used. In the OnP group, myocardial protection was obtained with 1 L of cold blood cardioplegia delivered antegradely and repeated every 30 minutes as necessary. In the OnP-BH group, we used our OPCAB technique, as previously described,[18] except for the intracoronary shunt. In the OPCAB group, the target vessels were exposed and controlled with a silastic sling. The chosen devices for coronary artery stabilization were the Medtronic Octopus apical suction positioning device and apical suction positioning device (Medtronic, Inc., Minneapolis, MN, USA), with the mean arterial pressure always >60 mm Hg throughout the surgery to maintain hemodynamic stability. The target vessel was then opened and an intracoronary shunt (Medtronic, Inc.) was put in to maintain distal perfusion during the performance of anastomosis. Visualization of the operative field was achieved with a carbon dioxide surgical blower system. All proximal anastomoses were performed with the use of a side-biting aortic clamp.

Postoperative management

When hypotension occurred after the operation, infusions of extracellular fluid type were used and inotropic agents (epinephrine, norepinephrine, or both) were given to maintain an adequate blood pressure or heart rate. All postoperative cardiac surgery patients were taken to a dedicated cardiac intensive care unit (ICU). Glycolic control during the operation and ICU stay was achieved by continuous intravenous insulin infusion, and in the following days. The insulin drip was titrated on the basis of the most recent finger-stick glucose measurement to maintain blood glucose levels between 150 mg/dL and 200 mg/dL. Each patient was required to meet standard criteria before extubation. Patients were generally transferred from the cardiac ICU if they were considered clinically at risk for decreased oxygen delivery. Oral routine medications included daily aspirin and the resumption of cholesterol-lowering agents, beta-blockers, and angiotensin-converting enzyme inhibitors, as appropriate.

Data management and statistical analysis

The data were managed and analyzed by SPSS software version 16 (SPSS, Inc., Chicago, IL, USA). All continuous variables were shown as the mean (standard deviation). Continuous variables were compared by Student *t* test. Postoperative complications and some preoperative risk factors were compared using the chi-square carried out using analysis of variance (CG1) for continuous variables and the chi-square test for categorical variables. Differences in cTnI among the 3 groups were analyzed with multiple analyses of variance for repeated measures followed by the Student–Newman–Keuls post hoc test. *P* values were used to evaluate the significance of the differences: $P<.05$ was considered significant.

RESULTS

Preoperative characteristics

Table 1 shows the preoperative characteristics of the 3 groups. There were no significant preoperative differences among the 3 groups with regard to age, sex, hypertension, chronic obstructive pulmonary disease, previous MI, peripheral artery disease, history of smoking, dyslipidemia, previous stroke, previous PCIs, carotid stenosis >50%, body mass index, serum creatinine, New York Heart Association class III-IV ejection fraction, and atrial fibrillation ($P>.05$).

Perioperative data

Table 2 shows the perioperative data from the 3 groups. No significant difference was found regarding the number of anastomoses, the use of internal thoracic artery, and postoperative new-onset atrial fibrillation in the 3 groups ($P>.05$). The incidence of hemodialysis, stroke (new acute focal neurologic deficit with signs and symptoms lasting greater than 24 hours, and neurologic events including transient ischemic attack and stroke), reoperation for bleeding, and infective complications were less among the OPCAB group, but the difference did not reach statistical significance (P=.527, P=.243, P=.415, and P=.097, respectively). The complete revascularization (P=.007), postoperative drainage loss ($P<.001$), intra-aortic balloon pump (IABP) support (P=.040), blood requirements ($P<.001$), postoperative MI (creatinine kinase [CK]-MB release >80 IU/mL, regardless of concomitant changes in electrocardiogram or impaired hemodynamics) (P=.017), pulmonary

Table 1. Clinical characteristics of the patients.

Variables	OPCAB (n=222)	OnP-BH (n=223)	OnP (n=223)	*P*	OPCAB versus OnP-BH, *P*	OPCAB versus OnP, *P*	OnP-BH versus OnP, *P*
Mean age Years (SD)	64.79 (8.03)	63.65 (8.21)	64.94 (8.08)	.215	.140	.845	.096
Sex ratio (M/F)	135/87	133/90	139/84	.843	.877	.816	.627
Hypertension (%)	140 (63.1%)	155 (69.5%)	146 (65.5%)	.348	.181	.666	.419
COPD (%)	20 (9.0%)	18 (8.1%)	23 (10.3%)	.712	.854	.760	.512
Previous MI (%)	54(24.3%)	45 (20.2%)	49 (22.0%)	.573	.349	.634	.728
Peripheral artery disease (%)	35 (15.8%)	26 (11.7%)	29 (13.0%)	.437	.262	.487	.773
History of smoking (%)	113 (50.9%)	124 (55.6%)	131 (58.7%)	.246	.368	.117	.566
Dyslipidemia (%)	150 (67.6%)	140 (62.8%)	136 (61.0%)	.326	.337	.177	.770
Previous stroke (%)	55 (24.8%)	62 (27.8%)	65 (29.1%)	.570	.537	.351	.834
Previous PCI (%)	33 (14.9%)	35 (15.7%)	30 (13.5%)	.794	.911	.771	.591
Ejection fraction Mean (SD)	50.38 (11.06)	50.20 (11.24)	51.63 (11.36)	.371	.864	.240	.182
BMI (kg/m^2)	23.01 (3.37)	22.74 (3.44)	22.48 (4.11)	.275	.399	.137	.469
Serum creatinine (mg/dL)	1.03 (0.27)	0.98 (0.35)	1.01 (0.33)	.165	.064	.428	.320
NYHA class III-IV (%)	108 (48.6%)	115 (51.6%)	101 (45.3%)	.414	.538	.478	.185
AF (%)	21 (9.5%)	18 (8.1%)	17 (7.6%)	.767	.605	.488	.860
Carotid stenosis >50%	89 (40.1%)	95 (42.6%)	99 (44.4%)	.653	.591	.358	.702

OPCAB: off-pump coronary artery bypass grafting; n: number; OnP-BH: on-pump beating heart; OnP: conventional coronary artery bypass grafting. SD: standard deviation; M: male; F: female; COPD: chronic obstructive pulmonary disease; MI: myocardial infarction; PCI: percutaneous coronary intervention; BMI: body mass index; NYHA: New York Heart Association; AF: atrial fibrillation.

complications (*P*=.002), gastrointestinal complications (*P*=.025), inotropic requirements >24 hours (*P*<.001), ventilation >24 hours (*P*<.001), ICU stay >24 hours (*P*<.001), and in-hospital stay >7 days (P<.001) were significantly lower in the OPCAB group than in the other 2 groups. The perioperative characteristics were very similar between the OnP-BH and OnP groups, except for blood requirements (*P*=.008). In-hospital mortality was lower in the OPCAB group than in the other 2 groups, but no statistical difference was observed (OPCAB, n=2, 0.9%; OnP-BH, n=4, 1.2%; OnP, n=7, 3.1%).

Table 3 indicates the cTnI values from all 3 groups. No significant differences in preoperative values were observed among these groups. Each independent technique showed a marked rise of cTnI from baseline to 12 hours and a decrease from 12 hours to 72 hours postoperatively. Furthermore, the lowest cTnI was in the OPCAB group, followed by the OnP group, and the highest value was in the OnP-BH group, 1 hour, 12 hours, 24 hours, and 72 hours postoperatively (*P*<.05).

Table 2. Perioperative data.

Variables	OPCAB (n=222)	OnP-BH (n=223)	OnP (n=223)	*P*	OPCAB versus OnP-BH, *P*	OPCAB versus OnP, *P*	OnP-BH versus OnP, *P*
Number of anastomoses/patient	3.18 (0.64)	3.21 (0.66)	3.22 (0.61)	.868	.727	.606	.881
Use of internal thoracic artery (%)	217 (97.7%)	213 (95.5%)	214 (96.0%)	.409	.192	.281	.815
Complete revascularization (%)	205 (92.3%)	217 (97.3%)	218 (97.8%)	.007	.018	.008	.760
Drainage loss (mL)	532.3 (160.1)	664.8 (415.7)	685.9 (277.9)	<.001	<.001	<.001	.529
IABP support (%)	5 (2.3%)	16 (7.2%)	15 (6.7%)	.040	.014	.023	.852
Blood requirements (%)	43 (19.4%)	105 (47.1%)	134 (60.1%)	<.001	<.001	<.001	.008
New-onset AF (%)	32 (14.4%)	28 (12.6%)	30 (13.5%)	.848	.663	.876	.888
Postoperative MI (%)	4 (1.8%)	17 (7.6%)	13 (5.8%)	.017	.004	.027	.450
Pulmonary complications (%)	15 (6.8%)	35 (15.7%)	36 (16.1%)	.002	.005	.003	1.000
Hemodialysis (%)	2 (0.9%)	4 (1.8%)	5 (2.2%)	.527	.414	.256	.736
Stroke (%)	2 (0.9%)	6 (2.7%)	7 (3.1%)	.243	.155	.094	.778
Reoperation for bleeding (%)	1 (0.5%)	3 (1.3%)	4 (1.8%)	.415	.317	.179	.703
Gastrointestinal complications (%)	5 (2.3%)	16 (7.2%)	17 (7.6%)	.025	.014	.009	.856
Infective complications (%)	9 (4.1%)	18 (8.1%)	20 (9.0%)	.097	.076	.036	.734
Inotropic requirements >24 hours (%)	41 (18.5%)	112 (50.25)	126 (56.5%)	<.001	<.001	<.001	.217
Ventilation >24 hours (%)	31 (14%)	88 (39.5%)	97 (43.5%)	<.001	<.001	<.001	.442
ICU stay >24 hours (%)	35 (15.8%)	95 (42.6%)	111 (49.8%)	<.001	<.001	<.001	.154
In-hospital stay >7 days (%)	26 (11.7%)	75 (33.6%)	82 (36.8%)	<.001	<.001	<.001	.552
In-hospital mortality (%)	2 (0.9%)	4 (1.2%)	7 (3.1%)	.228	.414	.094	.360

OPCAB: off-pump coronary artery bypass grafting; n: number; OnP-BH: on-pump beating heart; OnP: conventional coronary artery bypass grafting; IABP: intra-aortic balloon pump; AF: atrial fibrillation; MI: myocardial infarction; ICU: intensive care unit.

DISCUSSION

Coronary artery lesions in diabetic patients are frequently complex, owing to their small size and diffuse involvement with atherosclerosis.[19] Therefore, many diabetic patients with coronary heart disease have multivessel disease or severely stenosed vessels. In diabetic patients with severe multivessel disease, CABG was repeatedly proven to be superior to PCIs in terms of the risk of MI, cardiac death, and the need for repeat revascularization. Nevertheless, OnP can also lead to severe complications, as demonstrated in prospective studies that show a 1% to 3% incidence rate of ischemic and hemorrhagic insults after CABG.[20,21] This risk is particularly high for patients with DM.

The largest trial that has compared OnP with OPCAB was the ROOBY trial,[10] which enrolled 2203 patients from the Veterans Affairs medical system. However, the trial did not have sufficient power to accurately assess moderate, but clinically important, differences in the rates of death, MI, stroke, and renal failure. Furthermore, the cited research remains controversial because more than 50% of procedures were performed

Table 3. Comparing cTnI of the patients in the 3 groups by repeated measures ANOVA.

cTnI (ng/mL)	n	Pre-op	1 h	12 h	24 h	72 h
OPCAB	222	0.10 (0.33)	0.34 (0.40)[a]	1.02 (1.84)[a]	0.88 (1.72)[a]	0.51 (1.25)[a]
OnP-BH	223	0.10 (0.35)	0.81 (0.71)[ac]	4.66 (7.23)[ac]	3.67 (6.62)[ac]	2.37 (4.23)[ac]
OnP	223	0.12 (0.33)	0.48 (0.44)[ab]	2.49 (4.03)[ab]	1.76 (3.18)[ab]	1.22 (2.09)[ab]

Values are given as the mean±SD.

[a]*P*<.05 compared with Pre-op; [b]*P*<.05 compared with the OPCAB group; [c]*P*<.05 compared with the OnP group.

cTnI: cardiac troponin I; ANOVA: analysis of variance; n: number; Pre-op: preoperative; OPCAB: off-pump coronary artery bypass grafting; OnP-BH: on-pump beating heart; OnP: conventional coronary artery bypass grafting; SD: standard deviation.

by surgeons with low to moderate experience. Another limitation of this study was the very high conversion rate from off-pump to on-pump surgery. Lamy et al[11,12] overcame some of the limitations of the previous studies and conducted a larger trial (CORONARY) in a wider range of hospital settings, with specific requirements for surgical experience. The researchers concluded that 30-day and 1-year outcomes would be no different between OnP and OPCAB. In their study, each operation was performed by a surgeon with expertise in the specific type of surgery that the patient was assigned to receive. Expertise was defined as having more than 2 years of experience and having completed more than 100 procedures involving the specific technique. Surgeons who met these criteria for each type of operation, separately, were considered to have expertise in both techniques and were allowed to perform both types of CABG during the trial. However, in our opinion, the training process for OPCAB is extremely important to achieve proficiency in technically demanding procedures. Although it was a study that consisted of 21640 patients, had compared OnP and OPCAB, and had concluded that OPCAB was associated with less morbidity, a shorter-length hospital stay, and similar mortality rates when compared with the on-pump procedures,[13] this study is subject to the limitations inherent in any nonrandomized retrospective observational study. It is also affected by the fact that the OPCAB techniques were used in only 9% of CABG procedures in this multicenter analysis, and that individual surgeon experience can influence the results of OPCAB. Moreover, the trials detailed herein did not discuss the effect of DM for different coronary surgical techniques. OnP-BH is an attractive technique that keeps a heartbeat with the aid of CPB, but without aortic cross clamping or cardioplegic arrest. The avoidance of cardioplegic arrest can eliminate intraoperative global myocardial ischemia, which might contribute to myocardial protection.[22] The beating heart can preserve native coronary blood flow, which might reduce myocardial injury.[23] Perrault et al[22] described OnP-BH coronary operations as an acceptable trade-off between conventional CABG and OPCAB in high-risk patients. However, for patients with DM and multivessel disease, who often present with diffuse coronary disease when compared with nondiabetic patients, intraoperative myocardial protection may be different for different coronary surgical techniques.

In a very recent study by Emmert et al[24] that included 1015 DM patients, OPCAB offers a lower mortality rate and superior postoperative outcomes in diabetic patients with multivessel disease. Nevertheless, that investigation was limited by quite a long study period and by the fact that most on-pump CABG patients were treated during the early part of the study, whereas the majority of off-pump CABG patients were included during the latter part of the study period, and they had 2 groups of surgeons with different operating skills. Our results are in general agreement with an earlier report on the beneficial outcome effects of off-pump CABG in DM patients conducted by Renner et al.[25] However, the limitations of their study include that it was a nonrandomized, retrospective, observational study; moreover, the differences in preoperative IABP use, repeat CABG procedure and urgent operations were likely to influence perioperative mortality. To the best of our knowledge, the present randomized investigation simultaneously validated the OnP, OnP-BH, and OPCAB techniques for the first time, and it observed lower incidences of postoperative complications in DM patients with triple-vessel disease undergoing OPCAB.

However, there is much criticism about OPCAB because of the potential for incomplete revascularization and the worsening quality of vascular anastomosis. Findings about the inferior patency rate of conduit-performed OPCAB were reported from numerous randomized studies comparing the angiographic results of OnP and OPCAB, especially when the grafts were made from the great saphenous vein.[26] An observed trend toward a higher mean number of coronary anastomoses and 1-year rates of graft patency in the OnP group when compared to the OPCAB group was reported.[10] However, a randomized trial concluded that off-pump and on-pump CABG were associated with similar early and late graft patency, incidence rates of recurrent or residual MI, the need for reintervention, and long-term survival.[27] Although we observed slightly fewer anastomoses in the OPCAB group than in the other 2 groups, no statistical difference was observed (OPCAB, 3.18 [0.64]; OnP-BH, 3.21 [0.66]; OnP, 3.22 [0.61]). However, complete revascularization was less in the OPCAB group than in the other 2 groups in our study (*P*=.007). On the contrary, in-hospital mortality was lower in the OPCAB group than in the other two groups, but the difference failed to reach statistical significance (OPCAB, n=2, 0.9%; OnP-BH, n=4, 1.2%; OnP, n=7, 3.1%).

Our study observed that the lowest cTnI level was in the OPCAB group, followed by the OnP group, and the highest level was in the OnP-BH group, 1 hour, 12 hours, 24 hours, and 72 hours postoperatively. Most of the available evidence arises from studies in which CPB, cardioplegic arrest, and surgical trauma were concomitantly used. Although cardioplegic arrest was not used in the OnP-BH group, by contrast, the degree of myocardial injury was the most serious. So it could be argued that the observed changes in myocardial injury were due to CPB and surgical trauma alone. Recently, Pegg et al[28] reported a small randomized trial of 50 patients with impaired left ventricular function to compare OnP-BH versus OnP; the authors found that the incidence of new irreversible myocardial injury was significantly higher in OnP-BH than in OnP. In their study, the mean perfusion pressure during CPB was about 60 mm Hg, but clearly it may be much lower distally due to significant proximal coronary stenosis. Our results are in general agreement with their report on the mechanism of myocardial injury, because the present study suggests that the combination of bypass may still not be adequate to perfuse the distal coronary territories, especially in patients with DM and triple-vessel disease, who often present with diffuse coronary disease leading to inadequate coronary perfusion to distal myocardial territories.

In high-risk patient cohorts, the benefits of avoiding CPB and aortic manipulation may be more apparent than in lower-risk patients. However, one of the main limitations of OPCAB is the occasional need to convert to on-pump. This occurrence is associated with a significantly increased risk of mortality and postoperative morbidity, and it negates any potential benefit of OPCAB. Several authors have, however, reported that hemodynamic collapse and emergent conversion to CPB from off-pump CABG is associated with a poor prognosis.[29] In our study, as previously reported, 5 patients (2.25%) converted to on-pump surgery. Certain maneuvers may avoid some of the potentially deleterious hemodynamic consequences during OPCAB that may lead to conversion. At our institution, certain intraoperative techniques can facilitate OPCAB even during challenging cases. The sequence of grafting (left internal thoracic artery to left anterior descending artery anastomosis prior to the other anastomoses may maintain cardiac performance), the timing of proximal anastomoses, grafting collateralized vessels first, the use of a cardiac stabilizing device in combination with an apical suction positioning device, the use of intracoronary shunts, trials of temporary regional ischemia before arteriotomy, the judicious use of inotropic agents, and minimizing compression during cardiac positioning can all be used to result in a successful OPCAB procedure.

Although the early outcomes of our trial are encouraging, it is important to recognize that we stipulated a high level of expertise for participating surgeons. Therefore, surgeons, particularly trainees or inexperienced surgeons who are early in the learning curve, may choose to tailor their surgical approach according to the expected technical difficulties and potential benefits for each patient. In our clinical routine, we completed more than 50% of cases of OPCAB. The entire cardiac surgical staff is therefore highly familiar with this technique. Less experienced centers and centers still in the process of establishing OPCAB programs should start out with standard patients with good target vessels. Subsequently, the experience gained can thus be transferred to high-risk cases, aiming for excellent results in that challenging population.

Study limitations

The single-surgeon, single-center nature of the trial design limits the generalizability of the surgical outcomes, as both the center and the surgeon have greater than average experience and interest in OPCAB. Furthermore, we are not able to study graft patency in the 3 groups, though this is a crucial outcome when evaluating the 3 surgical techniques. The present report does not include data on long-term morbidity and mortality. However, further follow-up and angiographic control of graft patency are planned and are in the process of being performed. Finally, an estimation of glucose control (glycosylated hemoglobin) before surgery and its impact on the postoperative infection rate would be interesting to investigate.

In conclusion, these findings are important because this is, to our knowledge, the first randomized study to evaluate the 3 surgical techniques by assessing their impact on myocardial protection and early outcomes in patients with DM and triple-vessel disease. The results of this study are counterintuitive, but they clearly document higher levels of myocardial injury and worse early outcomes in response to revascularization in OnP-BH patients. The OnP-BH technique is theoretically elegant in its conception; however, these issues need to be resolved before this hybrid technique is suitable for use in patients with DM and triple-vessel disease. OPCAB is superior to both the OnP-BH and OnP techniques for treating patients with DM and triple-vessel disease.

REFERENCES

1. Haffner SM, Lehto S, Rönnemaa T, Pyörälä K, Laakso M. Mortality from coronary heart disease in subjects with type 2 diabetes and in nondiabetic subjects with and without prior myocardial infarction. N Engl J Med. 1998;339(4):229–234.

2. Goraya TY, Leibson CL, Palumbo PJ, et al. Coronary atherosclerosis in diabetes mellitus: a population-based autopsy study. J Am Coll Cardiol. 2002;40(5):946–953.

3. Serruys PW, Morice MC, Kappetein AP, et al; SYNTAX Investigators. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. N Engl J Med. 2009;360(10):961–972.

4. Deb S, Wijeysundera HC, Ko DT, Tsubota H, Hill S, Fremes SE. Coronary artery bypass graft surgery vs percutaneous interventions in coronary revascularization: a systematic review. JAMA. 2013;310(19):2086–2095.

5. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA guidelines for coronary artery bypass graft surgery: executive summary and recommendations : A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to revise the 1991 guidelines for coronary artery bypass graft surgery). Circulation. 1999;100(13):1464–1480.

6. Shennib H, Lee AG, Akin J. Safe and effective method of stabilization for coronary artery bypass grafting on the beating heart. Ann Thorac Surg. 1997;63(4):988–992.

7. Savaris N, Polanczyk C, Clausell N. Cytokines and troponin-I in cardiac dysfunction after coronary artery grafting with cardiopulmonary bypass. Arq Bras Cardiol. 2001;77(2):107–119.

8. Butler J, Rocker GM, Westaby S. Inflammatory response to cardiopulmonary bypass. Ann Thorac Surg. 1993;55(2):552–559.

9. Flack JE 3rd, Cook JR, May SJ, et al. Does cardioplegia type affect outcome and survival in patients with advanced left ventricular dysfunction? Results from the CABG Patch Trial. Circulation. 2000;102(19 Suppl 3):III84–III89.

10. Shroyer AL, Grover FL, Hattler B, et al; Veterans Affairs Randomized On/Off Bypass (ROOBY) Study Group. On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med. 2009;361(19):1827–1837.

11. Lamy A, Devereaux PJ, Prabhakaran D, et al; CORONARY Investigators. Effects of off-pump and on-pump coronary-artery bypass grafting at 1 year. N Engl J Med. 2013;368(13):1179–1188.

12. Lamy A, Devereaux PJ, Prabhakaran D, et al; CORONARY Investigators. Off-pump or on-pump coronary-artery bypass grafting at 30 days. N Engl J Med. 2012;366(16):1489–1497.

13. Brewer R, Theurer PF, Cogan CM, Bell GF, Prager RL, Paone G; Membership of the Michigan Society of Thoracic and Cardiovascular Surgeons. Morbidity but not mortality is decreased after off-pump coronary artery bypass surgery. Ann Thorac Surg. 2014;97(3):831–836.

14. Miyahara K, Matsuura A, Takemura H, et al. On-pump beating-heart coronary artery bypass grafting after acute myocardial infarction has lower mortality and morbidity. J Thorac Cardiovasc Surg. 2008;135(3):521–526.

15. Tsai YT, Lin FY, Lai CH, Lin YC, Lin CY, Tsai CS. On-pump beating-heart coronary artery bypass provides efficacious short- and long-term outcomes in hemodialysis patients. Nephrol Dial Transplant. 2012;27(5):2059–2065.

16. CONSORT [webpage on the Internet]. CONSORT: Transparent reporting of trials. Ottawa, ON: The CONSORT Group; 2014. Available from: http://www.consort-statement.org/#12[a]. Accessed [AUTHOR: Please provide an access date in the following format: January 1, 2014.]

17. World Health Organization. Definition, Diagnosis and Classification of Diabetes Mellitus and its Complications: Report of a WHO Consultation. Part 1: Diagnosis and Classification of Diabetes Mellitus. Geneva, Switzerland: World Health Organization; 1999.

18. Yu L, Gu T, Shi E, Jiang C. Surgery for chronic total occlusion of the left main coronary artery. Ann Saudi Med. 2012;32(2):156–161.

19. Banning AP, Westaby S, Morice MC, et al. Diabetic and nondiabetic patients with left main and/or 3-vessel coronary artery disease: comparison of outcomes with cardiac surgery and paclitaxel-eluting stents. J Am Coll Cardiol. 2010;55(11):1067–1075.

20. Afilalo J, Rasti M, Ohayon SM, Shimony A, Eisenberg MJ. Off-pump vs. on-pump coronary artery bypass surgery: an updated meta-analysis and meta-regression of randomized trials. Eur Heart J. 2012;33(10):1257–1267.

21. Sedrakyan A, Wu AW, Parashar A, Bass EB, Treasure T. Off-pump surgery is associated with reduced occurrence of stroke and other morbidity as compared with traditional coronary artery bypass grafting: a meta-analysis of systematically reviewed trials. Stroke. 2006;37(11):2759–2769.

22. Perrault LP, Menasché P, Peynet J, et al. On-pump, beating-heart coronary artery operations in high-risk patients: an acceptable trade-off? Ann Thorac Surg. 1997;64(5):1368–1373.

23. Rastan AJ, Bittner HB, Gummert JF, et al. On-pump beating heart versus off-pump coronary artery bypass surgery-evidence of pump-induced myocardial injury. Eur J Cardiothorac Surg. 2005;27(6):1057–1064.

24. Emmert MY, Salzberg SP, Seifert B, et al. Is off-pump superior to conventional coronary artery bypass grafting in diabetic patients with multivessel disease? Eur J Cardiothorac Surg. 2011;40(1):233–239.

25. Renner A, Zittermann A, Aboud A, et al. Coronary revascularization in diabetic patients: off-pump versus on-pump surgery. Ann Thorac Surg. 2013;96(2):528–534.

26. Takagi H, Matsui M, Umemoto T. Lower graft patency after off-pump than on-pump coronary artery bypass grafting: an updated meta-analysis of randomized trials. J Thorac Cardiovasc Surg. 2010;140(3):e45–e47.

27. Puskas JD, Williams WH, O'Donnell R, et al. Off-pump and on-pump coronary artery bypass grafting are associated with similar graft patency, myocardial ischemia, and freedom from reintervention: long-term follow-up of a randomized trial. Ann Thorac Surg. 2011;91(6):1836–1842; discussion 1842–1843.

28. Pegg TJ, Selvanayagam JB, Francis JM, et al. A randomized trial of on-pump beating heart and conventional cardioplegic arrest in coronary artery bypass surgery patients with impaired left ventricular function using cardiac magnetic resonance imaging and biochemical markers. Circulation. 2008;118(21):2130–2138.

29. Patel NC, Patel NU, Loulmet DF, McCabe JC, Subramanian VA. Emergency conversion to cardiopulmonary bypass during attempted off-pump revascularization results in increased morbidity and mortality. J Thorac Cardiovasc Surg. 2004;128(5):655–661.