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ORIGINAL ARTICLE

Use of cardiopulmonary pump support during coronary artery bypass grafting in the high-risk: a meta-analysis

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Abstract
Background Data from randomized trials evaluating the efficacy of on- versus off-pump coronary artery bypass grafting remain inconclusive, particularly in high-risk populations.
Aims The aim of this study is to compare the outcomes associated with on- versus off-pump coronary artery bypass grafting among high-risk patients.
Methods We performed a meta-analysis of randomized control trials comparing on- versus off-pump coronary artery bypass grafting, focusing on high-risk populations. Studies focusing on "high-risk" features: European System of Cardiac Operative Risk Evaluation (EuroSCORE) ≥ 5, age > 70 years, preexisting renal insufficiency, history of stroke(s), and the presence of left ventricular dysfunction were included. MEDLINE, Scopus, and Embase were searched for all publications between January 1, 2000 and August 1, 2016, using the following terms: *on-pump*, *off-pump*, *coronary artery bypass*, *high-risk*, *left ventricular dysfunction*, *elderly*, *aged*, and *renal insufficiency*. Endpoints included cardiovascular and all-cause mortality, non-fatal myocardial infarction, stroke, need for revascularization, renal failure, and length of hospital stay.
Results Nine studies incorporating 11,374 patients with a mean age of 70 years were selected. There was no statistical difference in cardiovascular mortality, all-cause mortality, non-fatal myocardial infarction, and renal failure between the two groups. There was a decrease in further revascularization at 1 year with on-pump (OR 0.67 (0.50–0.89)). However, there was an increase in length of hospital stay by 2.24 days ($p = 0.03$) among the on-pump group with no difference in stroke (OR 1.34 (1.00–1.80)).
Conclusions On-pump is associated with a decreased risk of additional revascularization by 1 year. However, this appears to be a cost of longer hospitalization.

Keywords Coronary artery bypass surgery · High-risk · Off-pump · On-pump

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Introduction

Coronary artery bypass grafting (CABG) remains among the most commonly performed surgical procedures with over 400,000 performed in the USA alone [1]. However, significant concerns have been raised about the safety of the procedure in the elderly and patients with significant comorbidities [2, 3]. Prior studies have suggested a higher incidence of neuro-cognitive dysfunction, residual myocardial ischemia, renal dysfunction, and pulmonary damage [4–17]. Much of these effects have been attributed to the induction of cardiac arrest, employing the use of the cardiopulmonary bypass machine and aortic cannulation [9]. These concerns have prompted an uptake in the use of the off-pump CABG (OPCAB) technique [4, 5, 16].

Encouraging early data coupled with a significant technical development in stabilizing equipment led to the rapid rise of the OPCAB technique with > 25% of all CABGs in the early 2000s in the USA being performed via this approach [18]. However, multiple randomized trials have suggested no or limited benefit over conventional CABG (CCAB) [3–5, 13, 16–18]. Furthermore, emerging evidence determining the role of OPCAB in high-risk patients remains unclear [4, 5, 19]. An early meta-analysis by Panesar et al. of non-randomized studies of elderly patients (> 70 years), undergoing OPCAB or CCAB, showed that the off-pump technique was associated with a significantly lower incidence of death, stroke, and the development of atrial fibrillation among this more vulnerable population [19]. Yet, in a more recent analysis of randomized studies incorporating broad populations, an increase in long-term mortality in association with the off-pump method (compared to the on-pump technique) was observed [2]. Current practice guidelines from the American College of Cardiology/American Heart Association in collaboration with multiple Thoracic Surgical Societies reflect this controversy, as no specific recommendation(s) regarding the choice of on- versus off-pump CABG is given, but leave the decision to the primary operator [20]. Due to the conflicting evidence surrounding the use of on-pump versus off-pump CABG, especially in the high-risk, we embarked on a meta-analysis of available randomized trials to determine the role of OPCAB revascularization, particularly among high-risk patients undergoing CABG.

Methods

We selected randomized controlled trials comparing CCAB and OPCAB with a focus on high-risk patients. The MEDLINE database (National Library of Medicine), Scopus, and Embase databases were searched to identify potential studies involving the use of OPCAB. Two cardiovascular investigators independently conducted a literature review of studies involving CCAB and OPCAB in high-risk patients between January 1, 2000 and August 1, 2016. The publications were filtered for randomized controlled trials, controlled clinical trials, and adult human subjects with focus on studies performed on high-risk patient populations. The publications were screened on the basis of titles and abstracts. Potentially relevant publications were retrieved for review. To ensure that the search was complete, reference lists from relevant articles were reviewed. Search terms for literature review included the following: on-pump, off-pump, coronary artery bypass, high risk, left ventricular dysfunction, elderly, aged, and renal insufficiency.

We aimed to perform an inclusive analysis of randomized controlled trials comparing on-pump versus off-pump coronary bypass graft in high-risk patients. After review of the available literature, we limited our inclusion criteria to studies with a significant focus on patients with at least one high-risk feature. These high-risk features are a mean European System of Cardiac Operative Risk Evaluation score (EuroSCORE) of ≥ 5, a mean age > 70 years, the presence of renal insufficiency, a history of prior strokes, the presence of left ventricular dysfunction (ejection fraction < 0.40), and/or the need for emergent coronary bypass as previously defined [21]. Patient characteristics and main features of each study are included in Tables 1 and 2. All patients from each selected study were included. We excluded trials in which patients enrolled were selected based on the lack of these high-risk features. The Comparison of On-pump and Off-pump Coronary Bypass Surgery in Low-Risk Patients study (OCTOPUS), which was a study of low-risk patients exemplified the type of trial that we wished to exclude [31]. Since we wanted to perform an inclusive study, we did not limit studies based on the follow-up period or the number of patients in the study. All studies that met the inclusion criteria were further examined for adequate blinding, randomization, and reported outcome events. Nearly all the trials reported all-cause and cardiovascular (CV) mortality, cerebrovascular events (CVA), non-fatal myocardial infarction (MI), revascularization, and renal insufficiency. Selected studies reported 1-year outcome data for death and revascularization. Each trial commented on the high expertise of surgeons in both groups. The average experience level varied between trials, from 2 to 5 years of experience. Figure 1 shows a PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) diagram of the results of our literature review [32].

For the review, we chose the reported outcomes of all-cause mortality at 30 days and at 1 year, CV mortality, perioperative non-fatal MI and non-fatal MI at 1 year, CVA, repeat revascularization at 30 days and at 1 year, and renal failure. These outcomes were reported in most studies included in our review. Long-term outcomes were only reported in a few studies. Although the definitions of MI, CVA, and renal failure differ slightly between the trials, we employed the original definitions from each trial. This was because the statistical analysis mainly required the ability to compare treatment differences between active and control groups within each trial. This is followed by combining the differences and variances from each study.

The statistical methods used in this review are very similar to those described previously by Møller et al. [33]. Analyses were performed by calculating odds ratios (OR) using a random effects model. The OR for all-cause mortality, cardiovascular mortality, non-fatal MI, cerebrovascular events, the development of renal failure, and need for repeat revascularization were calculated along with the 95% confidence intervals

Table 1 Baseline characteristics of each randomized controlled trial

Characteristic	Sajja et al. [22]	Fattouch et al. [23]	Shroyer et al. [24]	Møller et al. [25]	Houlind et al. [26]	Lamy et al. [27]	Lemma et al. [28]	Diegeler et al. [29]	Erkut et al. [30]
Age	61	62	63	76	75	68	74	79	67
Sex, female (on/off) (%)	10/13	23/39	1/1	36/35	22/24	18/20	32/29	32/30	33/49
Diabetes (%)	56	40	44	18	20	47	43	15	35
Hypertension (%)	72	65	87	51	71	76	83	NR	50
Previous MI (%)	NR	29	NR	57	28	35	74	37	NR
Previous stroke (%)	NR	NR	8	15	5	8	10	9	10
Previous revascularization (%)[a]	NR	NR	NR	NR	NR	NR	NR	23	27
Peripheral vascular disease (%)	NR	NR	16	NR	14	8	36	33	19
NYHA class	NR	NR	NR	II-III	III	NR	II	NR	III-IV
Ejection fraction (%)	42%[c]	43%	41%[d]	58%[c]	33%[c]	30%[c]	56%[c]	33%[c]	27%[e]
EuroSCORE	NR	NR	NR	6.9	5	NR[b]	8	8.3	NR
Current smoking (%)	41	59	8	19	50	NR	26	NR	73

*Previous revascularization – mostly PCI; **Exact values are not reported; Reported as mean cohort EF; +Reported as EF < 50%; ++Reported as EF < 55%. Abbreviations: EuroSCORE = European System of Cardiac Operative Risk Evaluation score, MI = myocardial infarction, NR = no report, NYHA = New York heart association, ON = on-pump, OFF = off-pump.

(CIs); reductions in risks are presented as percent 1-RR. Tests of heterogeneity between studies were done with index of heterogeneity ($I2 = [(Q - df) / Q] / 100\%$, where Q is the chi-squared statistic and df is its degrees of freedom). This describes the percentage of the variability in effect estimates that is caused by heterogeneity rather than sampling error (chance). $I2$ lies between 0 (no heterogeneity) and 100% (maximal heterogeneity). To assess the publication bias and other types of bias, funnel plots were created in which a trial's OR was logarithmic transformed and plotted against the standard error [34]. All analyses were performed with RevMan Analyses version 4.2.7 [35].

The overall quality of the trials was assessed by analysis of the data given in the protocol and design publications, in addition to the main publications presenting the results of the trials. We found no consistent visual or statistical evidence of publication bias, as assessed graphically using a funnel plot of the logarithm of effect size versus the standard error for each trial, and mathematically using an adjusted rank correlation test, according to the method of Begg and Mazumdar [36].

Results

As outlined in Fig. 1, a total of 64 publications were screened, of which 9 articles met the inclusion criteria for a total of 11,374 patients, all of which were included in the meta-analysis [23–30]. Individual trial populations varied from 116 to 4752 patients. The follow-up period ranged from 15 days to 36 months, with mean average follow up of 10 months among included studies. Trial names, acronyms, designs, and main baseline characteristics of patients are summarized in Tables 1 and 2. Each trial included a homogenous patient population with a specific high-risk feature as mentioned in the previous tables (except the CABG Off or On Pump Revascularization Study (CORONARY) which included a rather heterogeneous patient population with mixed high-risk features) [29]. The percentage of patients with specific high-risk characteristics and these findings are shown in Table 1. There was no difference in the mean ages of patients included between the two groups (69 +/− 8 and 70 +/− 7 years, for CCAB and OPCAB, respectively). The percentage of females included differed among studies, ranging from 1 to 49%, but this did not differ significantly between the individual groups within each study. Most studies reported preoperative New York Heart Association (NYHA) classification with a mean classification of NYHA class III and mean EuroSCORE of 7.7 +/− 0.7. Also, the CCAB cohort had an increased mean number of grafts placed compared to the OPCAB group, 3.1 and 2.9, respectively. This difference was statistically significant in half of the studies.

There was no statistically significant difference in overall CV (OR 0.82; 95% CI 0.38–1.73) and all-cause mortality (OR 1.06; 95% CI 0.81–1.37) between the two groups. There were no statistically significant differences in the development of perioperative non-fatal MIs (OR 1.17; CI, 0.78–1.75) and renal failure (OR 1.40; CI 0.98–1.99), respectively. There was a trend toward increased perioperative stroke in the CCAB group

Table 2 Main features of randomized controlled trials included and event rates

	Sajja et al. [22]	Fattouch et al. [23]*	Shroyer et al. [24]	Møller et al. [25]	Houlind et al. [26]	Lamy et al. [27]	Lemma et al. [28]	Diegeler et al. [29]	Erkut et al. [30]*
High-risk features	Non-dialysis dependent renal insufficiency with a GFR of 60 or less, elective CABG	Patients who presents with STEMI who are not candidate for primary PCI or fibrinolytic therapy, primary PCI failure and persistent symptoms, LM stenosis, or three-vessel disease	Urgent or elective CABG-only procedures	First time isolated CABG, > 54 years old, EuroSCORE greater than or equal to five, had three-vessel disease	Patients age 70 years or older admitted for non-emergent surgery revascularization	Eligible if with one or more of following: age of 70 years or more, presence of peripheral arterial disease,cerebrovascular disease, or carotid stenosis of 70% or more, or renal insufficiency. Patient ages 60–69 accepted if presence of diabetes, urgent revascularization, LVEF of 35% or less, or recent history of smoking (< 1 year)	Age > 18 years old, patients with a EuroSCORE of six or more referred for urgent or elective isolated CABG	First time CABG, at least 75 years or older	Patients with an LV ejection fraction between 25 and 35
Number of patients	116	128	2203	339	900	4752	411	2394	131
Population size—on-pump/off-pump	60/56	65/63	1099/1104	163/176	450/450	2377/2375	203/208	1207/1187	66/65
Follow up, months	0.5 (15 days)	36	12	1	6	12	1	12	11
Event rates (ON/OFF)									
Short term[b]									
All-cause mortality	3/0	5/1	13/18	11/6	8/7	59/60	7/4	34/31	14/2
CV mortality	NR	5/1	14/29	NR	NR	59/60	NR	NR	NR
Non-fatal—MI	NR	NR	NR	15/9	25/37	170/158	6/4	20/18	11/1
Renal failure	33/17	NR	9/10	20/21	NR	27/28	10/5	37/29	11/2
Stroke	1/0	4/3 NR	14/8	6/7	18/10	27/24	1/0	32/26	4/2
Long term									
All-cause mortality	3/0	NR[d]	30/43	11/6	46/48	119/122	27/12[c]	83/95	14/2
CV mortality	NR	5/1[e]	14/29	3/1	NR	96/99	NR	24/36	NR
Revascularization by 1 year	NR	NR	36/49	NR	NR	20/33	NR	NR	NR

Overall numbers are taken from available trial data; +Events at 30 days (or in-hospital); ++All-cause mortality at 1 month was separated from perioperative morality; **All-cause mortality post-index hospitalization was not reported; $No cardiac-related late deaths occurred post-index hospitalization; ***All-cause mortality post-index hospitalization was not reported. Abbreviations: CABG = coronary artery bypass graft, CORONARY = CABG Off or On Pump Revascularization Study, CV = cardiovascular, DOORS = Danish On-Pump Off-Pump Randomization Study, EuroSCORE = European System of Cardiac Operative Risk Evaluation score, GFR = glomerular filtration rate, 31 GOPCABE = German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients, LM = left main, LV = left ventricle, LVEF = left ventricular ejection fraction, MI = myocardial infarction, NR = No report, PCI = percutaneous coronary intervention, ROOBY = Randomized On/Off Bypass Study Group, STEMI = ST segment elevation myocardial infarction.

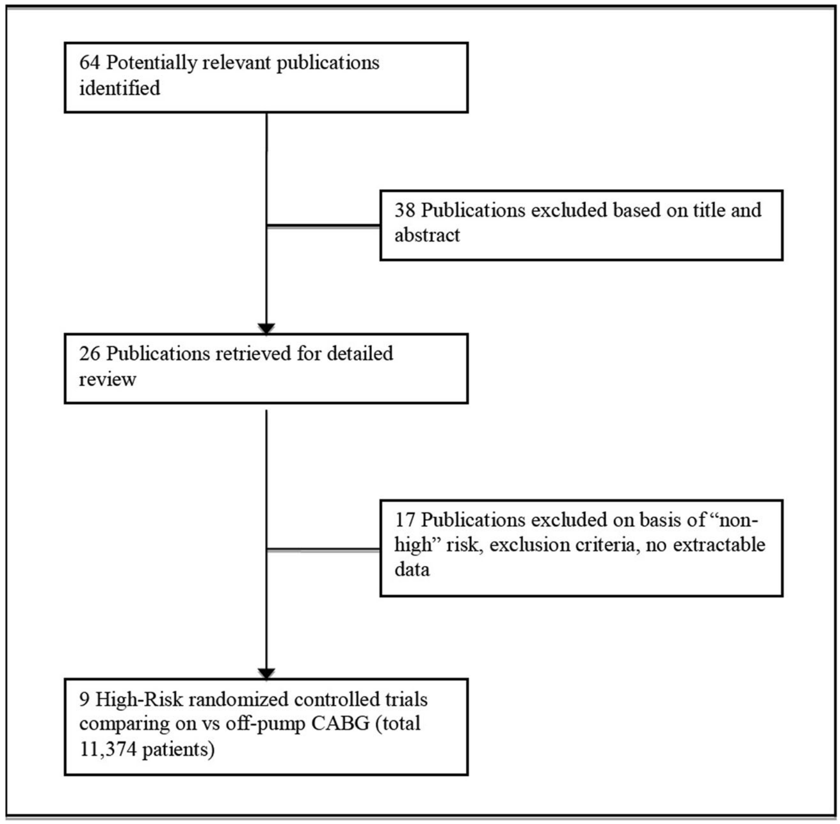


Fig. 1 Study flow diagram illustrating the search strategy and result of literature review for on-pump versus off-pump cardiopulmonary bypass in high-risk patients

(OR 1.34; CI 1.00–1.80) with a number needed to harm of 217. The hospital length of stay was also increased by 2.24 days more in CCAB ($p = 0.03$). CCAB was associated with a decrease in late revascularization (OR 0.67; CI, 0.50–0.89) with a number needed to treat of 122. Study results are summarized in Fig. 2 and described in further detail as follows.

There was no difference in early (perioperative or generally within 30 days) mortality between the groups (OR 1.34; CI, 0.90–2.00). Only limited data were reported regarding the need for perioperative revascularizations and intra-aortic balloon pump (IABP) support. These outcomes did not differ significantly between groups. Three trials reported all-cause mortality at 1 year, but no difference was seen between the two groups (OR 0.90; CI, 0.63–1.28) [27, 30]. Three studies reported late outcomes (1 year) for non-fatal MI with no difference (OR 1.11; CI, 0.92–1.35).

Discussion

This meta-analysis comparing the use of CCAB to OPCAB in over 11,000 predominantly high surgical risk subjects demonstrated a significantly reduced need for future revascularization with CCAB, but an increased post-bypass length of hospital stay associated with the CCAB method. Among those treated with OPCAB, there was a strong trend toward an increase risk of stroke. However, there was no difference between the two groups in the reduction of early adverse outcomes, including perioperative mortality, the development of acute renal failure, perioperative revascularization, and the need for IABP support. Furthermore, no statistically significant difference was found in the other endpoints including overall all-cause mortality, CV mortality, and non-fatal MI. The lack of statistically significant differences in several markers of early events was most likely driven by a lack of power in the individual trials considered in the meta-analysis. Together, these findings suggest potential early benefit to the selection of OPCAB compared to CCAB, while in the long-term outcomes appear comparable or even improved with CCAB among higher risk patients.

In recent years, an increased focus has been placed on the reevaluation of the merits of pump support coronary surgical revascularization, particularly among high-risk groups [4, 5, 23, 25, 28]. Panesar et al. had previously demonstrated less favorable outcomes with pump support use in the elderly [19]. More recently, Møller et al. added to these concerns with publication of the results of the Best Bypass Surgery Trial [25]. These studies, focusing on populations with average ages above the seventh decade of life, are accompanied by data among other high-risk groups [19, 23, 25, 28]. Examining these cohorts, it is plausible to postulate a direct association with the dramatic shifts in vascular hemodynamics induced by the induction of cardiac arrest and aortic cannulation [6, 9]. This is particularly important when considering the

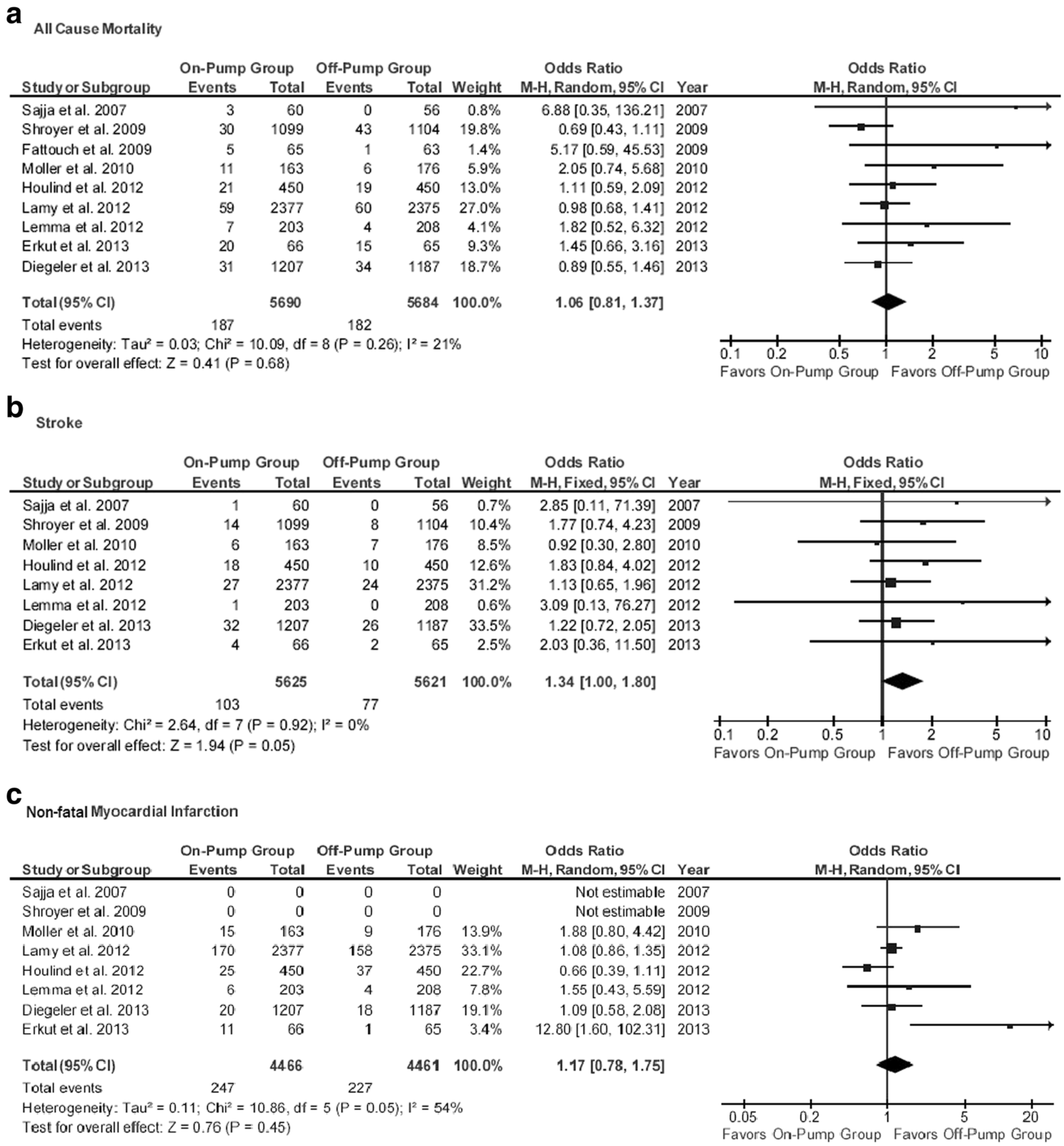


Fig. 2 Comparison of outcomes from studies employing the off-pump or the on-pump CABG techniques in high-risk patient populations. **a** All-cause mortality. **b** Stroke. **c** Non-fatal myocardial infarction (MI). **d** Development or worsening of renal failure. **e** Revascularization at 1 year. **f** Hospital length of stay

generally increase in aortic atherosclerotic burden and change in vasomotor tone seen in both the elderly and those with vascular disease beyond the coronary bed [9].

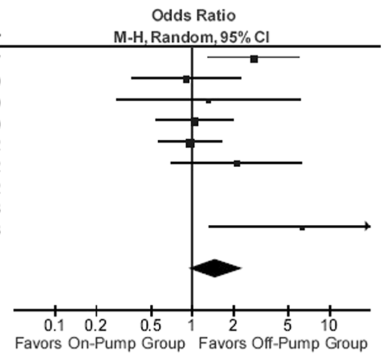
The current report revealed a decreased incidence of stroke or vascular event(s), an outcome supported by recent findings from the US Nationwide Inpatient Sample database suggesting decreased stroke rates in the high-risk with the OPCAB technique [37]. This is also supported by the theoretical advantage of the avoidance of aortic cross-clamping with the OPCAB technique [6]. It can also be theorized that the overall procedure time and aortic cross-clamp time may be longer in the "high-risk" as compared to lower risk groups due more comorbid disease (including probable hemodynamic stability) [9]. It may also reasonable to suggest that although not well documented, the incidence of hypotension during surgery in this cohort (older age, history of prior strokes, renal failure, and higher EuroSCORE) was higher—a known risk factor for cerebral injury. Similarly, this may explain the trend toward decreased renal failure (permanent or transient) in the OPCAB arm [22, 37–40].

Despite the benefits noted in the perioperative period, there was a clear trend toward decreased comparative efficacy of the

d Renal Failure

Study or Subgroup	On-Pump Group Events	On-Pump Group Total	Off-Pump Group Events	Off-Pump Group Total	Weight	Odds Ratio M-H, Random, 95% CI	Year
Sajja et al. 2007	33	60	17	56	17.3%	2.80 [1.31, 6.02]	2007
Shroyer et al. 2009	9	1099	10	1104	14.4%	0.90 [0.37, 2.23]	2009
Fattouch et al. 2009	4	65	3	63	6.9%	1.31 [0.28, 6.11]	2009
Moller et al. 2010	20	163	21	176	19.9%	1.03 [0.54, 1.98]	2010
Lamy et al. 2012	27	2377	28	2375	23.2%	0.96 [0.57, 1.64]	2012
Lemma et al. 2012	10	203	5	208	11.4%	2.10 [0.71, 6.27]	2012
Houlind et al. 2012	0	0	0	0		Not estimable	2012
Diegeler et al. 2013	0	0	0	0		Not estimable	2013
Erkut et al. 2013	11	66	2	65	6.8%	6.30 [1.34, 29.67]	2013
Total (95% CI)		**4033**		**4047**	**100.0%**	**1.48 [0.94, 2.32]**	
Total events	114		86				

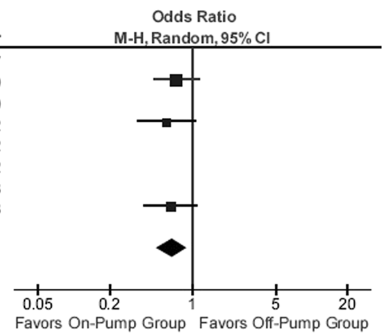
Heterogeneity: Tau² = 0.16; Chi² = 10.95, df = 6 (P = 0.09); I² = 45%
Test for overall effect: Z = 1.69 (P = 0.09)



e Revascularization 1-year

Study or Subgroup	On-Pump Group Events	On-Pump Group Total	Off-Pump Group Events	Off-Pump Group Total	Weight	Odds Ratio M-H, Random, 95% CI	Year
Sajja et al. 2007	0	0	0	0		Not estimable	2007
Shroyer et al. 2009	36	1099	49	1104	43.1%	0.73 [0.47, 1.13]	2009
Moller et al. 2010	0	0	0	0		Not estimable	2010
Lamy et al. 2012	20	2377	33	2375	26.6%	0.60 [0.34, 1.05]	2012
Houlind et al. 2012	0	0	0	0		Not estimable	2012
Lemma et al. 2012	0	0	0	0		Not estimable	2012
Erkut et al. 2013	0	0	0	0		Not estimable	2013
Diegeler et al. 2013	24	1207	36	1187	30.3%	0.65 [0.38, 1.09]	2013
Total (95% CI)		**4683**		**4666**	**100.0%**	**0.67 [0.50, 0.89]**	
Total events	80		118				

Heterogeneity: Tau² = 0.00; Chi² = 0.30, df = 2 (P = 0.86); I² = 0%
Test for overall effect: Z = 2.74 (P = 0.006)



f Length of Hospital Stay

Study or Subgroup	Conventional Mean	Conventional SD	Conventional Total	Non-Conventional Mean	Non-Conventional SD	Non-Conventional Total	Weight	Mean Difference IV, Random, 95% CI
Shroyer et al. 2009	7.8	6.1	1099	8.2	8.8	1104	21.2%	-0.40 [-1.03, 0.23]
Moller et al. 2010	7	0	163	7	0	176		Not estimable
Diegeler et al. 2013	12	0	1207	11	0	1187		Not estimable
Lamy et al. 2012	10.2	10	2377	10.1	8.6	2375	21.4%	0.10 [-0.43, 0.63]
Houlind et al. 2012	8.1	7.2	450	7.6	8	450	20.5%	0.50 [-0.49, 1.49]
Fattouch et al. 2009	12.4	5.7	65	8.3	1.7	63	19.3%	4.10 [2.65, 5.55]
Erkut et al. 2013	15	7	66	7	4	65	17.7%	8.00 [6.05, 9.95]
Total (95% CI)			**5427**			**5420**	**100.0%**	**2.24 [0.34, 4.14]**

Heterogeneity: Tau² = 4.32; Chi² = 90.62, df = 4 (P < 0.00001); I² = 96%
Test for overall effect: Z = 2.32 (P = 0.02)

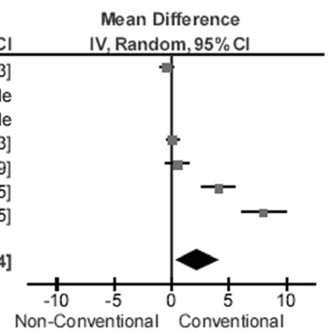


Fig. 2 continued.

OPCAB, particularly after accounting for repeat revascularization and late mortality. This was borne out by the lack of difference in overall (combined early and late) survival between the groups. Similar results were noted by Feng et al. [41]. Specifically, OPCAB offered no reduction in the 1-year all-cause mortality in their lower risk cohort (OR, 1.00; 95% CI, 0.75 to 1.33; p = 1.00). Yet, further examination of the findings of the present analysis may shed light on a potential explanation. Specifically, within this higher-risk cohort, there was an increase in the need for late revascularization(s) among the OPCAB group, suggesting less complete revascularization. Prior reviews of patients undergoing either the OPCABG or the CCAB methods of CABG have hinted toward a correlation in the need for repeat revascularization and the number of successful grafts placed. The OPCAB technique has been associated with 0.1–0.3 fewer grafts implanted in the largest trials and meta-analysis, which, although not clearly elucidated, may at least be in part related to differences in OPCAB referral patterns based on coronary disease complexity [24, 42–44]. This same difference was appreciated in our analysis of the high-risk cohort.

Several studies of among broad patient populations have reported health economic analyses at time periods up to 1 year post-bypass favoring OPCAB [31, 45–47]. Most of these analyses also factor hospital length of stay as a mainstay in the assessment of economic burden. They also report similar gains in quality of life with OPCAB compared to CCAB, despite the lower cost. In light of this, we postulate that similar gains with OPCAB would be noted in this higher-risk cohort considering the differences in hospital length of stay.

One of the limitations of this study is the difficulty to adjust for the impact of incorporating patients with potentially differing comorbidities despite their global higher risk status. Also, the included studies were inherently unable to engage in full randomization of clinical personnel, as the surgeons had to be aware of the use of the cardiopulmonary bypass machine. This organizational prerequisite often resulted in an interval randomization and surgery, during which logistic and medical requirements could override the randomization assignments. However, nearly all studies demonstrated no effect of these additional considerations on outcomes, when per-protocol analyses were later performed. Further, it should be noted that a significant proportion of the available data studying this population is derived from the three largest studies evaluating this population (Randomized On/Off Bypass Study Group trial, CORONARY, and the German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients trial, respectively) [24, 27, 29]. Due to smaller available sample size(s), a subgroup analysis based on specific baseline high-risk feature was not included in this analysis. These same trials were the only groups to report repeat revascularization at 1-year outcomes. Additionally, the meta-analysis did not have enough power to detect differences in outcomes based on the type of graft employed. There is limited and inconsistent direct comment of the completeness of revascularization across studies (except for the mention of the overall number bypass grafts placed). Similarly, this was likely the case in regard to the trend toward reduction in acute renal failure. Further, due to reporting variations across the studies, non-cardiac causes were difficult to accurately adjudicate. Additionally, although not well reported, it is reasonable to conceive that a significant number of the late deaths may have been secondary to "non-cardiac" causes in this relatively older cohort. Finally, it should be stated that there is general publication bias favoring the OPCAB technique.

Conclusions

Off-pump CABG in higher-risk patients is associated with a reduced length of hospitalization but appears to be associated with an increased need for future revascularization. All other outcomes, including cardiovascular and overall all-cause mortality, appear to be comparable to more traditional on-pump CABG performed on cardiopulmonary bypass support.

Compliance with ethical standards No relevant disclosures.

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