International Journal of Cardiology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Long-term survival after off-pump versus on-pump coronary artery bypass graft surgery. Does completeness of revascularization play a role?

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ARTICLE INFO

Article history:
Received 6 December 2016
Accepted 17 April 2017
Available online xxxx

Keywords:
Off-pump coronary artery bypass grafting
Long-term survival
Incomplete revascularization

ABSTRACT

Background: We sought to compare the incidence of incomplete revascularization (IR) and long-term survival (up to 20 years) after off-pump (OPCAB) versus on-pump (ONCAB) coronary artery bypass in a high OPCAB volume centre where OPCAB was introduced in 1996 and has become the preferred strategy over the years.
Methods and results: From 1996 to 2015 a total of 7,427 OPCAB and 7128 ONCAB procedures were performed at Bristol Heart Institute, United Kingdom. We obtained 5423 propensity matched pairs for final comparison. Mixed effect Cox model accounting for clustering due to different surgeon was used to investigate the treatment effect on mortality.
Results: OPCAB was associated with higher rate of incomplete revascularization 13.3% versus 6.7%; $P < 0.0001$). Mean follow-up time was 7.8 ± 4.6 year [max 17.3]. At 12 years OPCAB was associated with a marginal but significant + 3% increase in overall mortality (67.4%[95%CI 65.8–69.1] vs 64.4%[95%CI 62.7–66.2]; stratified log-rank P = 0.03). When compared to ONCAB with complete revascularization, OPCAB with IR (HR 1.74;95%CI 1.53–1.99; P < 0.001) and ONCAB with IR (HR 1.29; 95%CI 1.06–1.57; P = 0.01) but not OPCAB with complete revascularization (HR 1.02;95%CI 0.94–1.11; P = 0.63) were associated with increased risk of late mortality.
Conclusion: Despite completeness of revascularization was achieved in the majority of OPCAB cases, OPCAB remained associated with a significantly higher rate of incomplete revascularization. This translated into a marginal but significant reduction in late survival rates after OPCAB when compared to ONCAB.

1. Introduction

Despite the potential advantages of avoiding cardiopulmonary bypass, there is continued debate as to whether off-pump coronary artery bypass grafting surgery (OPCAB) provides any benefit over on-pump coronary revascularization (ONCAB). In North America, OPCAB procedures peaked at 25% in 2004 but have declined steadily since that time [1] and currently this technique is used in fewer than 1 in 5 patients who undergo surgical coronary revascularization. The reasons for this decline are speculative but may be partly related to both individual center and surgeon dissatisfaction with the procedure and the results of clinical trials [2–4]. In fact, the perceived benefits of OPCAB in terms of perioperative mortality and morbidity including stroke and renal failure were not realized in the majority of studies comparing the two strategy [2–4]. Furthermore the long-term effects of OPCAB on survival continue to be controversial [5–7]. A Cochrane Review on the subject [8] and more recent meta-analyses concluded that all-cause mortality rates with OPCAB were higher than rates with ONCAB [5]. In view of these concerns, it has been recently suggested that OPCAB should be abandoned [9]. OPCAB is a more technically demanding procedure and result in a high rate of incomplete revascularization (IR) which has been advocated as a major determinant of poorer long term survival reported by previous study [3]. However, the magnitude of the impact of OPCAB on IR and long term survival in the real world practice remains unclear as well as the extent of the learning curve effect on outcomes during OPCAB. Current comparisons present several limitations. Randomized controlled trials available were limited by relatively short long term follow-up and were largely underpowered to demonstrate a difference in long-term survival [10–11]. Moreover, the total off-pump experience was relatively small in the majority of them [12]. On the other hand, in observational series, ONCAB has usually been the first choice strategy [6,7] thus introducing a selection bias with patients at higher risk undergoing OPCAB.

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http://dx.doi.org/10.1016/j.ijcard.2017.04.087
0167-5273/

We sought to investigate the incidence of IR and long-term survival after OPCAB versus ONCAB by analysing prospectively collected data from a single institution where OPCAB was introduced in 1996 and has become the preferred strategy over the years for many surgeons. The emphasis of this study is large sample size, long term follow-up and high OPCAB volume to shed further light as to whether these techniques offer comparable results.

2. Methods

The study was conducted in accordance with the principles of the Declaration of Helsinki. The local audit committee approved the study, and the requirement for individual patient consent was waived. We retrospectively analysed prospectively collected data from The National Institute for Cardiovascular Outcomes Research (NICOR) registry on 1 June 2015 for all isolated first time CABG procedures performed at the Bristol Heart Institute, Bristol United Kingdom from 1996 to April 2015. Reproducible cleaning algorithms were applied to the database, which are regularly updated as required. Briefly, duplicate records and non-adult cardiac surgery entries were removed; transcriptional discrepancies harmonized; and clinical conflicts and extreme values corrected or removed. The data are returned regularly to the local units for validation.

Further details and definition of variables are available at http://www.ucl.ac.uk/nicor/audits/adultcardiac/datasets. During the study period, a total of 15,119 patients underwent first time isolated CABG; information regarding the strategy used (OPCAB versus ONCAB) was not available for 487 subjects and data on operating surgeon identification number (ID) was not available for further 80 subjects, thus leaving 14,552 for the final analysis. Of them 7427 received OPCAB and 7128 ONCAB surgery (Supplementary Figure 1). The rate of OPCAB has declined in the recent years due to changes in the staff composition with new attending surgeons who preferentially performed ONCAB replacing senior surgeons who preferentially performed OPCAB. Patients who were initially intended to undergo off-pump CABG but were converted to on-pump CABG intraoperatively ($n = 32$, 0.4% of off-pump patients) were regarded as having OPCAB. All procedures were performed by a total of 22 surgeons (Supplementary Table 1). Hybrid procedures were not included in the present series. In case of IR following either OPCAB or ONCAB, subsequent percutaneous coronary intervention was performed only in case of recurrent symptoms.

2.1. Surgical procedures and medication

The majority of patients were operated on through a median sternotomy, whereas some of the patients receiving single Internal thoracic arteries (ITAs) were dissected in either a pedicled or skeletonized fashion according to the surgeon preferences. All saphenous vein (SV) grafts were harvested by the open technique. The pedicled radial artery (RA) was harvested with the use of a harmonic scalpel or electrocautery in an open fashion. To prevent arterial graft spasm after harvesting, a vasodilatory cocktail was applied topically and injected intraluminally. In cases of on-pump strategy, intermittent, normotherimc antegrade blood cardioplegic infusion was the principal strategy for myocardial protection during aortic cross clamping. The left ITA was used to bypass the left anterior descending artery whenever possible. Choices of conduits and their configurations for other coronary territories were determined on the basis of conduit availability, number of distal targets, the target territory (right coronary vs. left circumflex territories), and the surgeon's preference. Statin medications and aspirin were routinely prescribed to all of the patients starting from postoperative day 1 or 2 and were continued indefinitely, if not contraindicated, through the 6- month interval outpatient clinic visits. The dose of statin medication was adjusted for a target low-density lipoprotein level of <100 mg/dl.

2.2. Study endpoints

All-cause mortality during follow-up was the primary endpoint. All-cause death is considered the most robust and unbiased index in cardiovascular research because no adjudication is required, thus avoiding inaccurate or biased documentation and clinical assessments. Information about post-discharge mortality tracking was available for all patients (100%) and was obtained by linking the institutional database with the National General Register Office. IR was defined as at least one diseased primary arterial territory. The rate of IR among individual surgeons and across different eras (Supplementary Material).

Other short-term outcomes analysed were: re-exploration for bleeding, need for sternal wound reconstruction, postoperative cerebrovascular accident (CVA) (defined as any confirmed neurologic deficit of abrupt onset that did not resolve within 24 h), postoperative dialysis, need for postoperative intra-aortic balloon pump (IABP) and early mortality (within 30 days).

2.2.1. Pre-treatment variables

The effect of OPCAB on outcomes of interest was adjusted for the following pre-treatment variables including: age, gender, body mass index (BMI); Canadian Cardiovascular Society (CCS) grade III or IV; New York Heart Association grade III or IV; previous myocardial infarction (MI) and MI within 30 days, previous percutaneous coronary intervention (PCI); diabetes mellitus (DM) on oral treatment or on insulin; chronic obstructive pulmonary disease (COPD); current smoking; serum creatinine ≥200 mmol/l, previous CVA; peripheral vascular disease (PVD); preoperative atrial fibrillation (AF); left main disease (LMD); number of vessel diseased; left ventricular ejection fraction (LVEF) between 30% and 49%; LVEF <30%; non elective admission, cardiogenic shock; preoperative IABP and eras of surgery; use of left and right internal thoracic arteries (LITA and RITA), radial artery (RA) and saphenous vein graft (SVG).

2.3. Statistical analysis

Categorical variables are presented as frequencies and percentages and continuous variables as mean ± standard deviation. Survival curves were constructed using Kaplan-Meier estimates and compared with the log-rank test. To reduce the effect of treatment selection bias and potential confounding, we adjusted for differences in baseline characteristics by propensity score (PS) matching.

A PS was generated for each patient from a multivariable logistic regression model based on pre-treatment covariates as independent variables with treatment type (OPCAB vs ONCAB) as a binary dependent variable [13]. The resulting propensity score represented the probability of a patient undergoing OPCAB (Supplementary Table 2). Pairs of patients undergoing OPCAB and OPCAB were derived using greedy 1:1 matching with a calliper of width of 0.2 standard deviation of the logit of the PS [13] (http://www.jstatsoft.org/v42/i08/). The quality of the match was assessed by comparing selected pre-treatment variables in propensity score– matched patient using the standardized mean difference (SMD), by which an absolute standardized difference of >10% is suggested to represent meaningful covariate imbalance. McNemar's test was used to assess the statistical significance of the risk difference in short term outcomes in the matched sample. The stratified log-rank test can be used to compare the equality of the survival curves in matched samples [14]. Finally to account for clustering effect due to individual surgeons, we used a mixed effect Cox model with individual surgeons as random effect [15] to investigate the effect of OPCAB on survival (http://CRAN.R-project.org/package=coxme). PS matching based subgroup analysis was conducted according to the completeness of revascularization. The effect of IR on late mortality was tested in a fully adjusted mixed proportional hazard model including the original sample. All p-values <0.05 were considered to indicate statistical significance. All statistical analysis was performed using R Statistical Software (version 3.2.3; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Before matching, patients undergoing OPCAB were more likely to be older, obese while, more likely to have prior PCI while ONCAB patients were more likely to have 3-vessel disease. OPCAB patients were more likely to receive RA graft and less likely SVG and RITA grafts (Table 1). PS matching selected 5423 pairs (Table 2) comparable for all variables (SMD < 0.10; Supplementary Fig. 2).

3.1. Intraoperative data and short term outcomes

Intraoperative data and short term outcomes are summarized in Table 3. After PS matching, OPCAB patients received a marginally but significantly lower number of grafts. In particular the number of patients receiving 4 or more grafts was higher in the ONCAB group. The circumflex artery was more likely to remain un-grafted during OPCAB. Overall, OPCAB was associated with ~2 fold increase in risk of IR (13.6% vs 6.9%). Overall mortality was comparable between the two groups (1.4%). OPCAB was associated with a lower incidence of postoperative complications. In particular OPCAB significantly reduced the risk of postoperative CVA, re-exploration and need for IABP.

3.2. Survival analysis

Mean follow-up time was 7.8 ± 4.6 year [max 17.3]. At 12 years OPCAB was associated with a marginal but significant 3% decrease in survival rates (67.4%[95%CI 65.8–69.1] vs 64.4%[95%CI 62.7–66.2]; stratified log-rank $P = 0.03$; Supplementary Table 3; Fig. 1 left). When the analysis was adjusted for clustering effect due to individual surgeon OPCAB was confirmed to be independently associated with a 11% increased risk of late death (HR 1.11; 95%CI 1.05–1.20; $P = 0.02$). Effect of individual surgeon on mortality was not significant ($P = 0.6$). Subjects undergoing OPCAB with IR (51.6%[95%CI 46.8–56.3) and ONCAB with IR (58.2%[95%CI 51.3–65.2) showed lower 12 year survival rates when compared to OPCAB with complete revascularization (CR) (66.5%[95%CI 64.7–68.4]) and ONCAB with CR (68.1%[95%CI 66.4–69.8]) (Fig. 1, right). When compared to ONCAB with CR, OPCAB with

Please cite this article as: U. Benedetto, et al., Long-term survival after off-pump versus on-pump coronary artery bypass graft surgery. Does completeness of revascularization play..., Int J Cardiol (2017), http://dx.doi.org/10.1016/j.ijcard.2017.04.087

IR (HR 1.74;95%CI 1.53–1.99; $P < 0.001$) and ONCAB with IR (HR 1.29; 95%CI 1.06–1.57; $P = 0.01$) but not OPCAB with CR (HR 1.02;95%CI 0.94–1.11; $P = 0.63$) were associated with increased risk of late mortality. To account for imbalance in risk factors distribution in subjects who received IR versus CR, we compared propensity matched OPCAB vs ONCAB according to the completeness of revascularization. Among, 6479 and 6625 subjects from the original sample who received CR with OPCAB and ONCAB respectively, we selected 4953 matched pairs (Supplementary Tables 4, 5). OPCAB with CR and ONCAB with CR showed comparable survival (HR 1.07;95%CI 0.98–1.16; $P = 0.11$; Supplementary Fig. 3). Among, 945 and 503 subjects from the original sample who received IR with OPCAB and ONCAB respectively we selected 4953 matched pairs (Supplementary Tables 6, 7). OPCAB with IR and was associated with lower survival rates when compared to ONCAB with IR (HR 1.29;95%CI1.03–1.61; $P = 0.03$; Supplementary Fig. 4). In a fully adjusted including IR as covariate, IR (HR 1.25;95%CI 1.14–1.38; $P < 0.001$) but not OPCAB (HR 1.06;95%CI 0.99;1.14;$P = 0.11$) was associated with increased risk of late death (Supplementary Table 8). For unmatched OPCAB and ONCAB subjects from the main analysis, baseline characteristics, operative outcomes and long term survival are reported in Supplementary Tables 9, 10 and Supplementary Fig. 5 respectively.

4. Discussion

The main finding of the present analysis was that completeness of revascularization was achieved in the majority of OPCAB cases but OPCAB still remained associated with a significantly higher rate of

Table 1
Characteristics of the unmatched population.

	ONCAB	OPCAB	P	SMD
n	7128	7424		
Age (mean (sd))	65.65 (9.31)	66.16 (9.56)	0.001	0.054
Female n(%)	1285 (18.0)	1364 (18.4)	0.604	0.009
BMI (mean (sd))	27.62 (4.45)	28.12 (4.42)	<0.001	0.113
CCS III–IV n(%)	3722 (52.2)	3355 (45.2)	<0.001	0.141
NYHA III–IV n(%)	2188 (30.7)	2070 (27.9)	<0.001	0.062
MI within 30 days n(%)	1265 (17.7)	1509 (20.3)	<0.001	0.066
PCI n(%)	305 (4.3)	535 (7.2)	<0.001	0.126
DM orally treated n(%)	727 (10.2)	788 (10.6)	0.428	0.014
DM on insulin n(%)	503 (7.1)	543 (7.3)	0.569	0.010
Smoking n(%)	951 (13.3)	958 (12.9)	0.449	0.013
Cr > 200 mmol/l n(%)	178 (2.5)	186 (2.5)	1.000	0.001
COPD n(%)	542 (7.6)	559 (7.5)	0.890	0.003
CVA n(%)	272 (3.8)	261 (3.5)	0.358	0.016
PVD n(%)	718 (10.1)	715 (9.6)	0.386	0.015
AF n(%)	253 (3.5)	242 (3.3)	0.359	0.016
NVD n (%)			<0.001	0.351
LAD only	278 (3.9)	768 (10.3)		
LAD plus CX or RCA	1493 (20.9)	2184 (29.4)		
LAD, CX and RCA	5357 (75.2)	4472 (60.2)		
LMD n(%)	1703 (23.9)	1924 (25.9)	0.005	0.047
LVEF 30–49% n(%)	1591 (22.3)	1500 (20.2)	0.002	0.052
LVEF <30% n(%)	425 (6.0)	307 (4.1)	<0.001	0.084
Preop IABP n(%)	111 (1.6)	101 (1.4)	0.357	0.016
Non-elective n(%)	3460 (48.5)	3374 (45.4)	<0.001	0.062
Preop shock n(%)	69 (1.0)	24 (0.3)	<0.001	0.081
RA n(%)	825 (11.6)	1562 (21.0)	<0.001	0.258
SV n(%)	6428 (90.2)	5835 (78.6)	<0.001	0.323
RITA n(%)	634 (8.9)	473 (6.4)	<0.001	0.095
LITA n(%)	6552 (91.9)	7054 (95.0)	<0.001	0.126
Year of surgery (mean (sd))	2003.59 (5.81)	2006.23 (4.19)	<0.001	0.520

OPCAB: off-pump coronary artery bypass; ONCAB: on-pump coronary artery bypass; SMD: standardized mean difference; BMI: body mass index; CCS: Canadian Cardiovascular Society; NYHA: New York Heart Association grade; MI: myocardial infarction; PCI: percutaneous coronary intervention; DM: diabetes mellitus; Cr: creatinine; COPD: chronic obstructive pulmonary disease; CVA: cerebrovascular accident; PVD: peripheral vascular disease; AF: atrial fibrillation; NVD: number of vessels diseased; LMD: left main disease; LVEF: left ventricular ejection fraction; IABP: intra-aortic balloon pump; RA: Radial Artery; SV: saphenous vein graft RITA: right internal thoracic artery; LITA: left internal thoracic artery.

Table 2
Intraoperative data in the propensity matched group.

	ONCAB	OPCAB	P	SMD
n	5423	5423		
Age (mean (sd))	66.27 (9.44)	66.14 (9.54)	0.476	0.014
Female n(%)	970 (17.9)	987 (18.2)	0.690	0.008
BMI (mean (sd))	27.97 (4.51)	28.02 (4.36)	0.510	0.013
CCS III–IV n(%)	2618 (48.3)	2521 (46.5)	0.065	0.036
NYHA III–IV n(%)	1593 (29.4)	1583 (29.2)	0.849	0.004
MI within 30 days n(%)	1108 (20.4)	1067 (19.7)	0.337	0.019
PCI n(%)	292 (5.4)	338 (6.2)	0.065	0.036
DM orally treated n(%)	566 (10.4)	586 (10.8)	0.554	0.012
DM on insulin n(%)	415 (7.7)	402 (7.4)	0.662	0.009
Smoking n(%)	725 (13.4)	735 (13.6)	0.800	0.005
Cr > 200 mmol/l n(%)	132 (2.4)	149 (2.7)	0.333	0.020
COPD n(%)	423 (7.8)	422 (7.8)	1.000	0.001
CVA n(%)	207 (3.8)	206 (3.8)	1.000	0.001
PVD n(%)	559 (10.3)	550 (10.1)	0.800	0.005
AF n(%)	179 (3.3)	187 (3.4)	0.710	0.008
NVD n (%)			<0.001	0.092
LAD only	274 (5.1)	370 (6.8)		
LAD plus CX or RCA	1344 (24.8)	1443 (26.6)		
LAD, CX and RCA	3805 (70.2)	3610 (66.6)		
LMD n(%)	1448 (26.7)	1426 (26.3)	0.648	0.009
LVEF 30–49% n(%)	1194 (22.0)	1157 (21.3)	0.402	0.017
LVEF <30% n(%)	261 (4.8)	256 (4.7)	0.857	0.004
Preop IABP n(%)	79 (1.5)	79 (1.5)	1.000	<0.001
Non-elective n(%)	2621 (48.3)	2555 (47.1)	0.211	0.024
Preop Shock n(%)	24 (0.4)	24 (0.4)	1.000	<0.001
RA n(%)	815 (15.0)	928 (17.1)	0.003	0.057
SV n(%)	4741 (87.4)	4614 (85.1)	<0.001	0.068
RITA n(%)	405 (7.5)	375 (6.9)	0.281	0.021
LITA n(%)	5093 (93.9)	5105 (94.1)	0.656	0.009
Year of surgery (mean (sd))	2005.31 (5.53)	2005.69 (4.20)	<0.001	0.077

OPCAB: off-pump coronary artery bypass; ONCAB: on-pump coronary artery bypass; SMD: standardized mean difference; BMI: body mass index; CCS: Canadian Cardiovascular Society; NYHA: New York Heart Association grade; MI: myocardial infarction; PCI: percutaneous coronary intervention; DM: diabetes mellitus; Cr: creatinine; COPD: chronic obstructive pulmonary disease; CVA: cerebrovascular accident; PVD: peripheral vascular disease; AF: atrial fibrillation; NVD: number of vessels diseased; LMD: left main disease; LVEF: left ventricular ejection fraction; IABP: intra-aortic balloon pump; RA: Radial Artery; SV: saphenous vein graft RITA: right internal thoracic artery; LITA: left internal thoracic artery.

Table 3
Intraoperative data and postoperative outcomes in the propensity matched group.

	ONCAB	OPCAB	P
n	5423	5423	
Intraoperative data			
IR n(%)	373 (6.9)	740 (13.6)	<0.001
Mean number of grafts/pt. (mean (sd))	2.85 (0.77)	2.61 (0.76)	<0.001
N of grafts n(%)			<0.001
1	230 (4.2)	407 (7.5)	
2	1337 (24.7)	1813 (33.4)	
3	2899 (53.5)	2709 (50.0)	
4	912 (16.8)	478 (8.8)	
5	44 (0.8)	15 (0.3)	
6	1 (0.0)	1 (0.0)	
Territory grafted			
LAD n(%)	5234 (96.5)	5253 (96.9)	0.334
RCA n(%)	3791 (69.9)	3484 (64.2)	<0.001
CX n(%)	4402 (81.2)	3868 (71.3)	<0.001
DIA n(%)	1185 (21.9)	1017 (18.8)	<0.001
Postoperative complications			
Re-exploration for bleeding, n(%)	176 (3.2)	128 (2.4)	0.006
Sternal wound reconstruction, n(%)	36 (0.7)	33 (0.6)	0.809
Cerebrovascular accident, n(%)	85 (1.6)	54 (1.0)	0.04
Dialysis n(%)	134 (2.5)	108 (2.0)	0.104
Postoperative IABP, n(%)	173 (3.2)	103 (1.9)	<0.001
Mortality at 30 days n(%)	77 (1.4)	74 (1.4)	0.870

OPCAB: off-pump coronary artery bypass; ONCAB: on-pump coronary artery bypass; IR: incomplete revascularization; LAD: left anterior descending artery; CX: circumflex artery; RCA: right coronary artery; DIA: diagonal branch; IABP: intra-aortic balloon pump.

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incomplete revascularization. IR was found to be a strong independent risk factor for late death and the excess of IR among OPCAB translated into a marginal but significant 3% increased risk of mortality at 12 years. In case of complete revascularization, OPCAB and ONCAB achieved comparable survival rates. However, the detrimental effect of incomplete revascularization on survival was more relevant in subjects undergoing OPCAB when compared to ONCAB. On the other hand, OPCAB was associated with a trend toward less operative complications including stroke and re-exploration for bleeding.

Despite the resurgence in OPCAB in the 1990s on the basis of the various purported advantages attributed to avoiding extracorporeal circulation, there is continued debate as to whether this technique provides any benefit over ONCAB. OPCAB has been consistently reported to be associated with higher rate of incomplete revascularization and concerns remain its potential detrimental effect on long-term outcomes. Kim et al. [6] recently reported on long term survival from high OPCAB volume Asian centre. By comparing 1070 PS matched OPCAB vs ONCAB pairs they found that OPCAB was associated with a 48% relative risk increase of late death ($P < 0.0001$) after a median follow-up 6.4 years. In a 2014 meta-analysis, Takagi et al. [5] pooled randomized controlled trials and adjusted observational studies of off-pump versus on-pump coronary bypass surgery that had reported long-term (>5-year) all-cause mortality as an outcome. Pooled analysis of 5 randomized trials (1486 patients) demonstrated a statistically non-significant 14% increase in mortality with off-pump relative to on-pump ($P = 0.39$) and pooled analysis of 17 observational studies (102,820 patients) demonstrated a statistically significant 7% increase in mortality with off-pump relative to on-pump CABG ($P = 0.0004$). Criticisms for current randomized trials comparing off-pump versus on-pump on long term survival include a possible bias toward including relatively low-risk patients, low off-pump experience of participating surgeons and relatively small sample. To address these issues, a large international trial that enrolled 4752 patients, CORONARY (CABG Off or On Pump Revascularization Study) [2], was recently conducted. A strict criterion was applied to include only experienced surgeons. The 5-year results showed no significant differences between the 2 groups with regard to death, nonfatal stroke, nonfatal myocardial infarction, or renal failure. However, no data are available on long term comparison.

The present is one of the largest series comparing OPCAB versus ONCAB with very long follow-up available. The patient population size was adequate to power the statistical analysis. We found that despite complete revascularization could be achieved in the majority of OPCAB cases, the rate of incomplete revascularization with OPCAB was significantly higher than ONCAB. This difference translated into a marginal but significant reduction of late survival rates with OPCAB. On the hand, OPCAB was associated with a significant reduction in the postoperative complications including stroke.

It should be emphasized that the IR rate in the present OPCAB series was particularly low (13.6%) than those reported by others and this might partially account for the marginal difference in late survival rates between the two strategies compared to other series [5,6]. In a recent report on the Veterans Affairs Continuous Improvement in Cardiac Surgery Program [16] involving 41,139 patients with left main and 3-vessel coronary artery disease, the IR rate among 6367 OPCAB cases was remarkably high (29%) compared to that observed in 34,772 ONCAB cases (11.0%). In accordance with previous reports [17], we found that incomplete revascularization was associated with poorer long term survival. In the SYNTAX (Synergy Between PCI With Taxus and Cardiac Surgery) trial [18], the rates of IR were 43.3% for PCI and 36.8% for the surgical revascularization. IR was found to be associated with poorer outcomes in the PCI arm but not in the surgical revascularization arm. However, it should be noticed that the SYNTAX trial analysis was limited by a very short follow-up (3 years). We also found that survival curves between OPCAB and ONCAB are superimposed up to 3–4 years and then start diverging thus suggesting a delayed effect of IR on survival. It has been reported that patients who undergo IR are more likely to present multiple comorbidities and unfavourable anatomy and this could bias the data in favour of complete revascularization [19]. It might be possible that the high rate of IR among some of the surgeons in the present series (Supplementary Table 1) is partially due to a selection bias with high risk patients operated on most senior and OPCAB experienced surgeons.

5. Limitations

Although the data were collected prospectively, the main limitation is the retrospective analysis. We were unable to provide specific causes of death (cardiac vs non-cardiac) as well as incidence of major cardiac adverse events including myocardial infarction and repeat revascularization and therefore, we can only speculate that the mechanism beyond the differences between OPCAB and ONCAB. Another limitation of this study is that OPCAB was performed by experienced surgeons and the results may not be the same with surgeons in their learning curve period or in low volume OPCAB centres. These results might be true only for

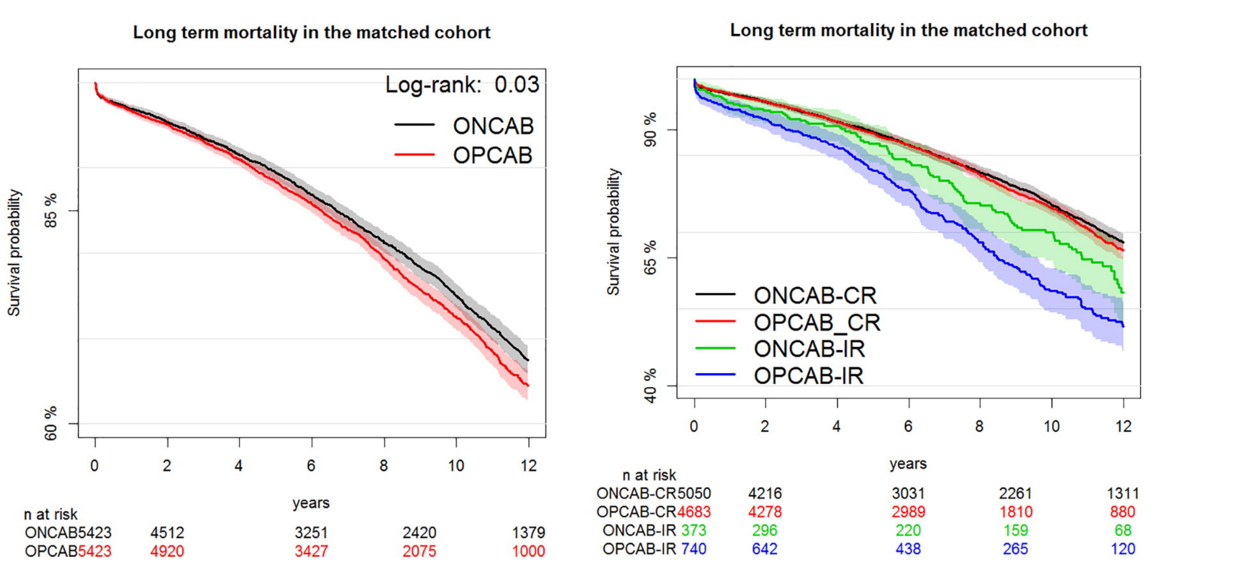

Fig. 1. Survival in off-pump coronary artery bypass (OPCAB, red) and on-pump coronary artery bypass (ONCAB) in the matched sample (left) and according to the completeness of revascularization (CR: complete revascularization; IR: incomplete revascularization, right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Please cite this article as: U. Benedetto, et al., Long-term survival after off-pump versus on-pump coronary artery bypass graft surgery. Does completeness of revascularization play..., Int J Cardiol (2017), http://dx.doi.org/10.1016/j.ijcard.2017.04.087

cardiac surgeons and anaesthesiologists who are fully accustomed to OPCAB.

6. Conclusions

OPCAB is a valuable technique that may reduce morbidities in the setting of high risk patients. Despite completeness of revascularization can be achieved in the majority of OPCAB cases, OPCAB remains associated with a significantly higher rate of incomplete revascularization that can ultimately translate into a marginal but significant reduction in late survival rates. When compared to ONCAB. In the light of these results, a 2-step hybrid approach might represent a valid option to reach the completeness of the myocardial revascularization.

Funding

This study was supported by the British Heart Foundation and the NIHR Bristol Cardiovascular Biomedical Research Unit (CH/92027/7163).

Conflict of interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ijcard.2017.04.087.

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