Impact of multiple arterial grafts in off-pump and on-pump coronary artery bypass surgery

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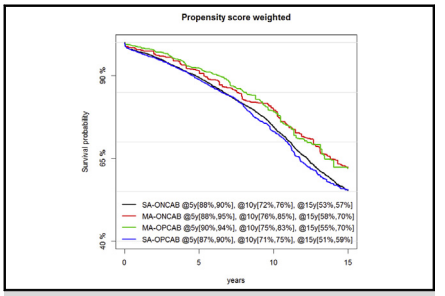
ABSTRACT

Objectives: There is growing concern that off-pump coronary artery bypass (OPCAB) is associated with reduced long-term survival compared with traditional on-pump coronary artery bypass (ONCAB); however, most of available comparisons between OPCAB and ONCAB focus on single-artery (SA) revascularization. We sought to investigate the impact of using multiple arterial (MA) conduits in the comparison between OPCAB versus ONCAB by performing a single-center, long-term propensity score base analysis.

Methods: The study population included 5195 SA-ONCAB, 1208 MA-ONCAB, 4412 SA-OPCAB, and 1818 MA-OPCAB procedures. Late survival was available for all cases (100%). Inverse propensity score weighting and a time-segmented Cox model were used for multiple treatments comparison.

Results: No significant differences were found between the 4 groups in terms of 30-day mortality, postoperative cerebrovascular accident, and renal replacement therapy. After a mean follow-up time of 8.2 ± 4.7 years, in the propensity score−weighted sample, survival probabilities at 10 years were 74.5 ± 0.4, 79.7 ± 0.4, 73.4 ± 0.5, and 79.0 ± 0.5 in the SA-ONCAB, MA-ONCAB, SA-OPCAB, and MA-OPCAB groups respectively. Propensity-weighted analysis confirmed that MA-OPCAB (hazard ratio, 0.81; 95% confidence interval, 0.69-0.98) and MA-ONCAB (hazard ratio, 0.81; 95% confidence interval, 0.65-0.99) were associated with a lower late mortality compared with standard SA-ONCAB.

Conclusions: OPCAB with multiple arterial grafts is as safe as the conventional ONCAB and achieves excellent long term survival rates which are superior to those observed after standard SA-ONCAB and comparable with MA-ONCAB. (J Thorac Cardiovasc Surg 2017;153:300-9)



Survival rate in the propensity score weighted MA and SA OPCAB and ONCAB surgery groups (±standard errors at 5, 10, and 15 years are reported for each propensity score weighted group).

Central Message

Multiarterial grafting is associated with improved late survival after on- and off-pump coronary artery bypass grafting. Off-pump surgery is associated with similar survival as on-pump surgery, when we controlled for the extent of arterial revascularization.

Perspective

There is growing concern that off-pump coronary artery bypass is associated with reduced long-term survival compared with traditional on-pump surgery; however, most available comparisons focus on single artery revascularization. We found that off-pump multiple arterial grafting is superior to standard on pump single arterial revascularization. Therefore, multiple arterial grafting should be the standard strategy in randomized studies comparing off-pump with on-pump surgery.

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There is growing concern that off-pump coronary artery bypass (OPCAB) is associated with reduced long-term graft patency of saphenous vein grafts (SVGs),[1-4] and this might translate into inferior long-term survival compared with

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Abbreviations and Acronyms

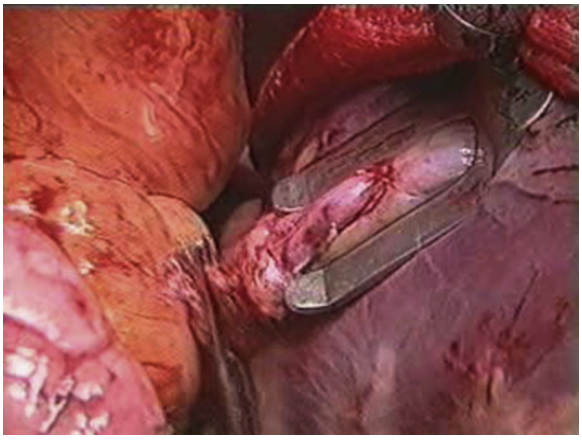
BITA = bilateral internal thoracic artery
CABG = coronary artery bypass grafting
CI = confidence interval
CVA = cerebrovascular accident
HR = hazard ratio
IABP = intra-aortic balloon pump
IR = incomplete revascularization
LITA = left internal thoracic artery
LEVG = left ventricular ejection fraction
MA = multiple arterial
ONCAB = on-pump coronary artery bypass
OPCAB = off-pump coronary artery bypass
PS = propensity score
RA = radial artery
RRT = renal replacement therapy
SA = single arterial
SVG = saphenous vein graft

traditional on-pump coronary artery bypass (ONCAB).[5] In contrast, OPCAB has been associated with arterial graft patency rates comparable with those after ONCAB.[4] Technical issues, the learning curve, and the inflammatory and prothrombotic state in patients undergoing OPCAB have been suggested as an explanation for the reported inferior graft patency rate. There is also evidence that patients operated on-pump have significantly greater saphenous graft mean flow in comparison with patients operated off-pump, with no difference in these parameters for arterial grafts.[6]

As a consequence, the use of multiple arterial (MA) grafts, including the bilateral internal thoracic arteries (BITAs)[7,8] and the radial artery (RA), instead of SVGs[7,9] in OPCAB recently has gained popularity.[10-12] Most of available comparisons between OPCAB and ONCAB, however, focus on single-arterial (SA) revascularization.[13-18] We sought to investigate the impact of using MA conduits in the comparison between OPCAB versus ONCAB by performing a single-center, long-term propensity score (PS) base comparison. We also investigated the effects of incomplete revascularization (IR) after each of the treatment strategies.

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 analyzed prospectively collected data from The National Institute for Cardiovascular Outcomes Research NACSA registry on June 1, 2015, for all isolated first-time coronary artery bypass grafting (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 updated regularly as required. To summarize, duplicate records and nonadult 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.



VIDEO 1. Use of the radial artery during off-pump coronary artery bypass. Video available at: http://www.jtcvsonline.org/article/S0022-5223(16)31492-1/addons.

Further details and definition of variables are available at http://www.ucl.ac.uk/nicor/audits/adultcardiac/datasets. Among 15,119 isolated first-time CABG cases performed at our institution during the study period, we selected subjects who met the following criteria: first-time isolated CABG; multivessel coronary disease and/or left main disease; requiring at least 2 grafts; and CABG performed via the following 4 strategies: on-pump single left internal thoracic artery (LITA) grafting plus additional SVGs (SA-ONCAB, reference group); on-pump MA grafting (by using LITA plus right internal thoracic artery and/or RA) with or without additional SVGs (MA-ONCAB); off-pump single internal thoracic artery grafting plus additional SVGs (SA-OPCAB); and off-pump MA grafting (by using LITA plus right internal thoracic artery and/or RA) with or without additional SVGs (MA-OPCAB, Video 1).

In the present series, the surgical strategy was based on individual surgeon preference and expertise. In the present series, the RA was considered only in case of target stenosis ≥75% and it was used a free graft proximally connected to the ascending aorta. The internal thoracic artery was used as a pedicle graft that remained proximally connected to its respective subclavian artery (in situ) or as a free graft proximally connected to other internal thoracic artery.

Pretreatment Variables and Study End Points

The effect of MA conduits and OPCAB was adjusted for the following pretreatment variables, including age, sex, body mass index; Canadian Cardiovascular Society grade III or IV; New York Heart Association grade III or IV; previous myocardial infarction and myocardial infarction within 30 days, previous percutaneous coronary intervention; diabetes mellitus on oral treatment or on insulin; chronic obstructive pulmonary disease; current smoking; serum creatinine ≥200 mmol/L, previous cerebrovascular accident (CVA); peripheral vascular disease; preoperative atrial fibrillation; left main disease; 3-vessel disease; left ventricular ejection fraction (LVEF) between 30% and 49%; LVEF less than 30%; nonelective admission, emergent/salvage operation; cardiogenic shock; preoperative intra-aortic balloon pump (IABP); and year of surgery. Logistic European System for Cardiac Operative Risk Evaluation was used as measure of overall risk profile but not included in the PS model.

The short-term outcomes investigated were the incidence of re-exploration for bleeding, need for sternal wound reconstruction, postoperative CVA (defined as any confirmed neurologic deficit of abrupt onset that did not resolve within 24 hours), postoperative renal replacement

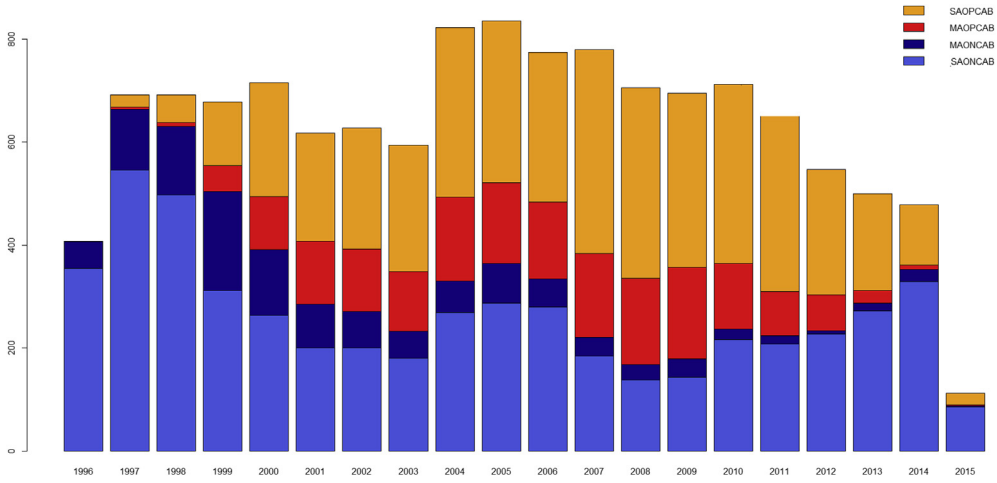


FIGURE 1. Number of MA and SA OPCAB and ONCAB surgery during the study period. *SA*, Single arterial; *OPCAB*, off-pump coronary artery bypass; *MA*, multiple arterial; *ONCAB*, on-pump coronary artery bypass.

therapy (RRT), need for postoperative IABP, and early mortality (within 30 days). We also reported, as short-term outcomes, IR, defined as at least one diseased primary arterial territory not grafted. Long-term outcome investigated was all-cause late mortality. Information about postdischarge mortality tracking was available for all patients (100%) and was obtained by linking the institutional database with the National General Register Office.

Statistical Analysis

For baseline characteristics, variables are summarized as mean for continuous variables and percentage for categorical variables. The χ^2 test was used to test unadjusted association between treatment variable and outcomes. Multiple imputation ($m = 3$) was used to address missing data (165 patients). The Rubin method[19] was used to combine results from each of m imputed data sets.

Inverse probability (PS) of treatment weighting for modeling causal effects was used for multiple treatments comparison.[20] A generalized boosted model was implemented to estimate multinomial PS with adjustment for pretreatment covariates, and the PS was assumed as the probability that an individual with pretreatment characteristics X receives treatment t (twang R package; The R Project for Statistical Computing, Vienna, Austria).The average treatment effect on the population was used to answer the question of how, on average, the outcome of interest would change if everyone in the population of interest had been assigned to a particular treatment relative to if they had all received another single treatment.

To estimate the average treatment effect on the population, we gave treated patients weight $w_i = 1/(1 - p(x_i))$, where p(xi) is the PS, and reference patients $w_i = 1/p(x_i)$. SA-ONCAB was considered as the reference group in all comparisons. The absolute standardized mean difference was used as a balance metric to summarize the difference between 2 univariate distributions of a single pretreatment variable. A value $\geq$0.20 was considered as an indicator of imbalance.[21]

Although all subjects are retained by the use of inverse probability (PS) of treatment weighting, weighted means can have greater sampling variance than unweighted means from a sample of equal size. To account for such observation, we calculated the effective sample size, which gives an estimate of the number of comparison participants that are comparable with the treatment group.[20] We then estimated the treatment effect estimates by using weighted logistic regression models for postoperative complications and weighted time-segmented Cox models for early (within 30 days) and late (beyond 30 days) mortality. These models contained only a treatment indicator. Finally, we estimated the treatment effect within subgroups according to the presence of IR, total arterial revascularization, and era of surgery. R version 3.1.2 (The R Project for Statistical Computing; October 31, 2014) was used for all statistical analyses.

RESULTS

Study Population

The study population included 5195 SA-ONCABs, 1208 MA-ONCABs, 4412 SA-OPCABs, and 1818 MA-OPCABs (Figure 1). Preoperative variable distribution in the 4 groups is summarized in Table 1. In the unweighted population, SA-ONCAB and SA-OPCAB groups tended to present a greater burden of comorbidities compared with MA-ONCAB and MA-OPCAB. In particular, patients undergoing SA-ONCAB and SA-OPCAB were more likely to older, female, and present New York Heart Association III-IV functional class, chronic obstructive pulmonary disease, and LVEF $\leq$30%. SA-ONCAB cases were more likely to have 3-vessel disease compared with the other groups (Table E1). After PS weighting, the 4 groups were comparable for all pretreatment variables (absolute mean standardized difference $<$ 0.20, Table 2, Table E2, Figure E1). Although the original MA-ONCAB and MA-OPCAB groups had 1208 and 1818 cases, respectively, the PS estimates effectively used only 388 and 739 of the comparison cases with a significant loss of sample size, which indicates that many of the original cases were not useful for isolating the treatment effect.

Intraoperative Data

Intraoperative data are summarized in Table 3. Among patients receiving MA conduits, BITA was used more often during ONCAB, whereas RA was used more often during OPCAB. The overall rate of total arterial revascularization, however, was comparable between ONCAB and OPCAB. Overall, numbers of grafts were lower among OPCAB cases. Both circumflex artery and right coronary

TABLE 1. Pretreatment variables in the unweighted population

	SA-ONCAB, n = 5194		MA-ONCAB, n = 1208		SA-OPCAB, n = 4412		MA-OPCAB, n = 1818		Max
	n	%	n	%	n	%	n	%	ASMD
Age, y, SD	68 ± 8		57 ± 8		69 ± 9		61 ± 9		121%
Female	935	18	109	9	838	19	218	12	26%
CCS III-IV	1610	31	290	24	1324	30	382	21	21%
NYHA III-IV	2701	52	580	48	1985	45	782	43	18%
MI within 30 d	987	19	145	12	971	22	345	19	26%
PCI	208	4	36	3	265	6	109	6	15%
DM orally treated	571	11	72	6	485	11	164	9	18%
DM on insulin	364	7	60	5	353	8	109	6	12%
Current smoking	623	12	217	18	529	12	273	15	18%
Creatinine ≥200 mmol/L	156	3	12	1	132	3	18	1	16%
COPD	416	8	36	3	353	8	91	5	2%
CVA	208	4	36	3	176	4	36	2	11%
PVD	571	11	72	6	485	11	127	7	15%
Atrial fibrillation	208	4	24	2	176	4	36	2	8%
3-vessel disease	4155	80	870	72	3044	69	1218	67	3%
Left main disease	1299	25	242	20	1279	29	509	28	21%
LVEF between 30% and 49%	1195	23	205	17	1015	23	291	16	17%
LVEF ≤30%	312	6	36	3	221	5	18	1	21%
Cardiogenic shock	52	1	0	0	0	0	0	0	11%
Preoperative IABP	104	2	0	0	44	1	0	0	12%
Nonelective admission	2545	49	507	42	2162	49	745	41	16%
Emergent/salvage	52	1	0	0	44	1	18	1	1%
BMI	28 ± 5		28 ± 4		28 ± 4		28 ± 4		19%
Year of surgery	2004 ± 6		2002 ± 4		2007 ± 4		2006 ± 4		92%
Logistic EuroSCORE	4.3 ± 4.8		2.1 ± 2.2		4.5 ± 4.8		2.5 ± 2.8		

SA, Single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *ASMD*, absolute standardized mean difference; *SD*, standard deviation; *CCS*, Canadian Cardiovascular Society; *NYHA*, New York Heart Association; *MI*, myocardial infarction; *PCI*, percutaneous coronary intervention; *DM*, diabetes mellitus; *COPD*, chronic obstructive pulmonary disease; *CVA*, cerebrovascular accident; *PVD*, peripheral vascular disease; *LVEF*, left ventricular ejection fraction; *IABP*, intra-aortic balloon pump; *BMI*, body mass index; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation.

artery territories were less likely to be grafted during OPCAB, but this was more evident among SA-OPCAB cases. The overall incidence of IR was greater among OPCAB in particular after SA-OPCAB; however, the majority of MA-OPCAB cases received complete revascularization (91.3%), and the absolute increase in IR rate in the MA-OPCAB group was marginal compared with SA-ONCAB (+2.9%) and MA-ONCAB (+3.5%).

Short-Term Outcomes

Observed 30-days mortality and rate of postoperative complications are summarized in Table 4. Unadjusted treatment effect estimates on outcomes of interest are summarized in Table 5. Overall crude 30-day mortality rate was 152 (1.2%) with a significant trend towards a reduced mortality with MA-ONCAB and MA-OPCAB compared with standard SA-ONCAB. The crude incidences of postoperative CVA, IABP, and RRT were significantly lower in MA-OPCAB. SA-OPCAB and MA-OPCAB were associated with a reduced rate of re-exploration for bleeding; however, this observed trend towards a reduced morbidity and early mortality in the MA-OPCAB group was correlated to the greater burden of comorbidities observed in SA-ONCAB and SA-OPCAB groups rather than a real treatment effect. In fact, after PS weighting (Table 5), no significant differences were found between the 4 groups in terms of 30-day mortality, postoperative CVA, and RRT; however, OPCAB still remained associated with a trend towards reduced incidence of postoperative IABP and re-exploration for bleeding. In the PS-weighted analysis, OPCAB remained associated with a 2-fold increased risk of IR regardless of the use of MA grafts.

Long-Term Survival

After a mean follow-up time of 8.2 ± 4.7 years, there were 1583 (30%), 195 (16%), 1103 (25%), and 269 (15%) deaths in the SA-ONCAB, MA-ONCAB, SA-OPCAB, and MA-OPCAB groups, respectively. In the unweighted sample, survival probabilities at 10 were 72.4 ± 0.7, 89.3 ± 0.9, 69.7 ± 0.9, and 83.7 ± 0.1 and in the SA-ONCAB, MA-ONCAB, SA-OPCAB, and MA-OPCAB groups, respectively. In the PS-weighted sample, survival probabilities at 10 years were 74.5 ± 0.4, 79.7 ± 0.4, 73.4 ± 0.5, and 79.0 ± 0.5 in the SA-ONCAB, MA-ONCAB, SA-OPCAB, and MA-OPCAB groups, respectively (Figure 2, left). In the unweighted

TABLE 2. Pretreatment variables in the PS-weighted population

	SA-ONCAB ESS = 3972		MA-ONCAB ESS = 388		SA-OPCAB ESS = 2567		MA-OPCAB ESS = 739		Max ASMD
	n	%	n	%	n	%	n	%	
Age, y, SD	66 ± 10		65 ± 10		66 ± 9		65 ± 9		14%
Female	675	17	58	15	410	16	118	16	6%
NYHA III-IV	1906	48	186	48	1206	47	339	46	4%
CCS III-IV	1151	29	116	30	744	29	199	27	8%
MI within 30 d	794	20	69	18	487	19	147	20	4%
PCI	198	5	19	5	128	5	44	6	4%
DM orally treated	397	10	38	10	282	11	73	10	2%
DM on insulin	278	7	19	5	179	7	44	6	10%
Current smoking	556	14	46	12	333	13	88	12	5%
Creatinine ≥200 mmol/L	79	2	3	1	51	2	7	1	10%
COPD	278	7	27	7	179	7	44	6	5%
CVA	158	4	15	4	102	4	14	2	10%
PVD	397	10	31	8	256	10	59	8	7%
Atrial fibrillation	119	3	15	4	77	3	22	3	6%
3-vessel disease	2939	74	279	72	1848	72	524	71	8%
Left main disease	1032	26	100	26	693	27	192	26	2%
LVEF between 30% and 49%	873	22	89	23	539	21	147	20	8%
LVEF ≤30%	198	5	23	6	102	4	22	3	16%
Cardiogenic shock	0	0	0	0	0	0	0	0	7%
Preoperative IABP	39	1	0	0	25	1	7	1	9%
Nonelective admission	1866	47	182	47	1232	48	332	45	6%
Emergent/salvage	39	1	3	1	25	1	7	1	6%
BMI	28 ± 4		28 ± 4		28 ± 4		28 ± 4		8%
Year of surgery	2005 ± 4		2005 ± 6		2006 ± 6		2005 ± 8		13%
Logistic EuroSCORE	3.9 ± 3.8		3.7 ± 5.9		3.9 ± 3.6		3.6 ± 4.1		

SA, Single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *ASMD*, absolute standardized mean difference; *ESS*, effective sample size; *SD*, standard deviation; *NYHA*, New York Heart Association; *CCS*, Canadian Cardiovascular Society; *MI*, myocardial infarction; *PCI*, percutaneous coronary intervention; *DM*, diabetes mellitus; *COPD*, chronic obstructive pulmonary disease; *CVA*, cerebrovascular accident; *PVD*, peripheral vascular disease; *LVEF*, left ventricular ejection fraction; *IABP*, intra-aortic balloon pump; *BMI*, body mass index; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation.

sample, SA-OPCAB was associated with a lower survival compared with the standard SA-ONCAB whereas MA-ONCAB and MA-OPCAB were associated with better late survival (Table 4). PS-weighted analysis (Figure 2, right) confirmed that MA-OPCAB and MA-ONCAB were associated with a relative 20% risk reduction in late mortality compared with standard SA-ONCAB, whereas PS-weighted SA-OPCAB did not significantly increase the risk of late death (Table 4).

When the analysis was restricted to subjects who had complete revascularization, MA-OPCAB (adjusted hazard ratio [HR], 0.80; 95% confidence interval [CI], 0.65-0.97; $P = .02$) and MA-ONCAB (adjusted HR, 0.80; 95% CI, 0.63-0.99; $P = .04$) but not SA-OPCAB (adjusted HR, 1.05; 95% CI, 0.94-1.17; $P = .39$) were associated with a reduced risk of late death compared with SA-ONCAB. In contrast, among subjects with IR, we found that neither MA-OPCAB (adjusted HR, 0.95; 95% CI, 0.62-1.46; $P = .82$) or MA-ONCAB (adjusted HR, 1.06; 95% CI, 0.60-1.90; $P = .83$) or SA-OPCAB (adjusted HR, 1.07; 95% CI, 0.77-1.48; $P = .69$) were associated with better long-term survival compared with SA-ONCAB (Figure E2). We could not demonstrate a superiority in terms of late survival by using total arterial OPCAB (adjusted HR, 0.77; 95% CI, 0.60-0.98) instead of MA-OPCAB with additional SVGs (adjusted HR, 0.71; 95% CI, 0.57-0.89) or by using total arterial ONCAB (adjusted HR, 0.84; 95% CI, 0.64-1.09) instead of MA-ONCAB with additional SVGs (adjusted HR, 0.57; 95% CI, 0.42-0.78) over the standard SA-ONCAB strategy (Figure E3). The incidence of IR among total arterial-OPCAB and total arterial-ONCAB, however, was particularly high (20% and 12%, respectively) compared with MA-OPCAB with additional SVGs (0%) and MA-ONCAB with additional SVGs (0.4%), and this aspect might have caused an underestimation of the effect of total arterial revascularization.

The effect of era of surgery also was investigated (Figure E4). Compared with SA-ONCAB, MA-OPCAB was associated with reduced late mortality during the era 1996-2004 (adjusted HR, 0.83; 95% CI, 0.64-0.99) and 2005-2009 (adjusted HR, 0.73; 95% CI, 0.55-0.96) whereas

TABLE 3. Intraoperative data

	SA-ONCAB, n = 5194		MA-ONCAB, n = 1208		SA-OPCAB, n = 4412		MA-OPCAB, n = 1818		
	n	%	n	%	n	%	n	%	χ^2 *P* value
MA configuration									
BITA	–	–	420	34.8	–	–	335	18.4	<.0001
RA			617	51.1			1384	76.2	
BITA + RA			171	14.1			99	5.4	
Total arterial Revascularization									
No			708	58.6			1031	56.7	.31
Yes			500	41.4			787	43.3	
Number of grafts									
1	1	0.0	1	0.1	0	0.0	0	0.0	<.0001
2	1004	19.3	330	27.3	1662	37.7	645	35.5	
3	3020	58.1	609	50.4	2383	54.0	913	50.2	
4	1106	21.3	249	20.6	357	8.1	252	13.9	
5	62	1.2	19	1.6	9	0.2	8	0.4	
6	1	0.0	0	0.0	1	0.0	0	0.0	
Mean grafts/pt	3.04 ± 0.67		2.96 ± 0.74		2.71 ± 0.62		2.79 ± 0.68		<.0001
LAD territory grafted									
No	89	1.7	22	1.8	89	2.0	43	2.4	.3
Yes	5105	98.3	1186	98.2	4323	98.0	1775	97.6	
RCA territory grafted									
No	1265	24.4	316	26.2	1406	31.9	609	33.5	<.0001
Yes	3929	75.6	892	73.8	3006	68.1	1209	66.5	
CX territory grafted									
No	655	12.6	208	17.2	1031	23.4	323	17.8	<.0001
Yes	4539	87.4	1000	82.8	3381	76.6	1495	82.2	
Diagonal branch grafted									
No	3887	74.8	915	75.7	3607	81.8	1428	78.5	<.0001
Yes	1307	25.2	293	24.3	805	18.2	390	21.5	
Sequential anastomosis									
No	4956	95.4	1130	93.5	4097	92.9	1694	93.2	<.0001
Yes	238	4.6	78	6.5	315	7.1	124	6.8	

SA, Single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *BITA*, bilateral internal thoracic arteries; *RA*, radial artery; *LAD*, left anterior descending artery; *RCA*, right coronary artery; *CX*, circumflex artery.

the 2 strategies were comparable after 2010, and this is explained partially by the relatively short follow-up duration (<5 years). Compared with standard SA-ONCAB, MA-OPCAB also did not increase early mortality across eras (1996-2004: HR, 0.88; 95% CI, 0.25-3.01; after 2010 MA-OPCAB: HR, 0.28; 95% CI, 0.03-2.15, respectively).

DISCUSSION

The main finding of the present study is that MA-OPCAB can be performed with a very low operative mortality and morbidity. Complete revascularization with MA-OPCAB was achieved in the majority of patients (92.3%). MA-OPCAB with complete revascularization was associated with excellent long-term survival rates that are at least comparable with those observed after MA-ONCAB and significantly superior to those observed after SA-ONCAB. SA-OPCAB was associated with poorer long-term survival compared with SA-ONCAB, although this difference was no longer statistically significant after risk adjustment. Among cases with IR, we could not identify any difference between ONCAB and OPCAB in terms of late survival regardless the use of MA grafts, although this analysis was largely underpowered.

In the present analysis we used all-cause mortality to assess long-term treatment effect. All-cause mortality 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.[22] The 4 groups were compared by the use of inverse PS weighting. One of the advantages of this technique over standard pairwise propensity matching is the possibility of simultaneous comparisons between multiple treatments. Moreover, all the individuals in the study can be used for the outcomes evaluation, whereas a large number of subjects may not be used in a propensity matching.

TABLE 4. Incidence of postoperative outcomes

	SA-ONCAB, n = 5194		MA-ONCAB, n = 1208		SA-OPCAB, n = 4412		MA-OPCAB, n = 1818		χ^2
	n	%	n	%	n	%	n	%	*P* value
Mortality within 30 d									
No	5125	98.7	1201	99.4	4344	98.5	1810	99.6	.0005
Yes	69	1.3	7	0.6	68	1.5	8	0.4	
Postoperative CVA									
No	5112	98.4	1197	99.1	4348	98.5	1808	99.4	.005
Yes	82	1.6	11	0.9	64	1.5	10	0.6	
Postoperative IABP									
No	5023	96.7	1188	98.3	4318	97.9	1796	98.8	<.0001
Yes	171	3.3	20	1.7	94	2.1	22	1.2	
Postoperative RRT									
No	5075	97.7	1192	98.7	4299	97.4	1799	99.0	.003
Yes	119	2.3	16	1.3	113	2.6	19	1.0	
Sternal wound reconstruction									
No	5157	99.3	1204	99.7	4376	99.2	1808	99.4	.3
Yes	37	0.7	4	0.3	36	0.8	10	0.6	
Re-exploration									
No	5021	96.7	1164	96.4	4312	97.7	1786	98.2	.0001
Yes	173	3.3	44	3.6	100	2.3	32	1.8	
IR									
No	4888	94.1	1145	94.8	3898	88.3	1659	91.3	<.0001
Yes	306	5.9	63	5.2	514	11.7	159	8.7	

SA, Single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *CVA*, cerebrovascular accident; *IABP*, intra-aortic balloon pump; *RRT*, renal replacement therapy; *IR*, incomplete revascularization.

Whether OPCAB surgery is superior to traditional ONCAB surgery remains one of the most controversial areas of cardiac surgery. In North America, OPCAB procedures peaked at 25% in 2004 and have decreased steadily since that time.[23] Among possible explanations, there is growing concern that OPCAB is associated with reduced long-term graft patency, thus resulting in inferior long-term survival compared with traditional ONCAB as observed by some authors.[5] However, meta-analyses of currently available randomized controlled trials on graft patency have shown that OPCAB increases the incidence of SVG graft occlusion only but does not affect internal thoracic artery and RA graft patency compared with ONCAB.[4] As a consequence, recent reports advocate for a more extensive use of arterial grafts during OPCAB to improve OPCAB results.

Suzuki and colleagues[10] recently reported on 260 cases undergoing OPCAB with SVG and 520 cases of OPCAB with total arterial revascularization; total arterial OPCAB was protective in terms of late cardiac events (HR, 0.5; 95% CI, 0.31-0.84; $P = .007$). In a previous study, Kinoshita and colleagues[11] compared off-pump skeletonized single (n = 236) versus bilateral (n = 300) internal thoracic artery grafting in high-risk cases (European System for Cardiac Operative Risk Evaluation ≥5). After a mean follow-up of 3.2 years, BITA grafting was significantly associated with a lower risk of overall death (hazard ratio, 0.56; 95% CI, 0.32-0.87; $P = .009$). Navia and colleagues[12] recently compared 1447 OPCAB cases with BITA grafting versus and 253 OPCAB with received LITA and RA grafting. They found that the 2 strategies were comparable in terms of late mortality ($P = .65$), although BITA grafting was associated with lower postoperative reintervention/readmission-free survival ($P = .03$).

Available randomized comparative studies on long-term survival after OPCAB versus ONCAB, however, included mainly procedure with LITA to left anterior descending artery and small number of other arterial grafts.[13-18] Therefore, the impact of MA grafts on long-term survival after OPCAB versus ONCAB still needs to be determined. To date, few studies focused on early outcomes after MA-OPCAB versus MA-ONCAB. Kobayashi and colleagues[24] reported on 167 consecutive unselected patients assigned randomly to undergo MA-OPCAB (n = 81) or MA-ONCAB (n = 86), and they found that the incidence of perioperative complications was similar. In the BITA arm of the Arterial Revascularization Trial (ART),[25] OPCAB and ONCAB were found comparable in terms of 1-year outcomes.

The completeness of revascularization has been a major concern in OPCAB. Because OPCAB with arterial grafts is thought to be technically demanding, IR might limit its benefit on long-term survival.[26] In a recently published large series, Omer and colleagues[27] reported a 29% rate

TABLE 5. PS-weighted estimates (SA-ONCAB as a reference group)

	Treatment group	Crude ES (95% CI)	Crude *P* value	PS-weighted ES (95% CI)	PS-weighted *P* value
Mortality within 30 d	MA-ONCAB	0.43 (0.20-0.94)	.03	0.96 (0.28-3.22)	.95
	SA-OPCAB	1.16 (0.83-1.62)	.38	0.96 (0.67-1.39)	.86
	MA-OPCAB	0.33 (0.16-0.69)	.03	0.44 (0.18-1.08)	.07
Postoperative CVA	MA-ONCAB	0.57 (0.30-1.08)	.08	1.84 (0.72-4.70)	.20
	SA-OPCAB	0.92 (0.66-1.28)	.60	1.08 (0.72-1.63)	.70
	MA-OPCAB	0.35 (0.18-0.67)	.001	0.90 (0.38-2.11)	.81
Postoperative IABP	MA-ONCAB	0.49 (0.31-0.79)	.003	1.67 (0.88-3.15)	.11
	SA-OPCAB	0.64 (0.50-0.83)	<.0001	0.69 (0.51-0.92)	.01
	MA-OPCAB	0.36 (0.23-0.56)	<.0001	0.70 (0.41-1.20)	.20
Postoperative RRT	MA-ONCAB	0.57 (0.34-0.97)	.03	1.23 (0.55-2.76)	.61
	SA-OPCAB	1.12 (0.86-1.46)	.39	1.15 (0.86-1.54)	.34
	MA-OPCAB	0.45 (0.28-0.73)	.001	0.82 (0.41-1.63)	.57
Sternal wound reconstruction	MA-ONCAB	0.46 (0.16-1.30)	.14	2.33 (0.64-8.39)	.20
	SA-OPCAB	1.15 (0.72-1.82)	.46	1.10 (0.50-2.40)	.59
	MA-OPCAB	0.77 (0.38-1.55)	.56	0.87 (0.54-1.41)	.81
Re-exploration	MA-ONCAB	1.10 (0.78-1.54)	.59	1.18 (0.68-2.03)	.55
	SA-OPCAB	0.67 (0.52-0.86)	<.0001	0.66 (0.51-0.87)	.002
	MA-OPCAB	0.52 (0.36-0.76)	<.0001	0.78 (0.49-1.24)	.28
IR	MA-ONCAB	0.88 (0.66-1.15)	.36	1.002 (0.61-1.65)	.99
	SA-OPCAB	2.11 (1.82-2.44)	<.0001	2.39 (2.01-2.86)	<.0001
	MA-OPCAB	1.53 (1.25-1.86)	<.0001	2.04 (1.54-2.68)	<.0001
Late mortality (beyond 30 d)	MA-ONCAB	0.36 (0.31-0.42)	<.0001	0.81 (0.649-0.99)	.04
	SA-OPCAB	1.14 (1.05-1.24)	.001	1.07 (0.96-1.19)	.20
	MA-OPCAB	0.56 (0.49-0.64)	<.0001	0.81 (0.69-0.98)	.03

ES, Effect size; *CI*, confidence interval; *PS*, propensity score; *MA*, multiple arteries; *ONCAB*, on-pump coronary artery bypass; *SA*, single artery; *OPCAB*, off-pump coronary artery bypass; *CVA*, cerebrovascular accident; *IABP*, intra-aortic balloon pump; *RRT*, renal replacement therapy; *IR*, incomplete revascularization.

of IR in 6367 OPCAB cases compared with 11.0% in 34,772 ONCAB cases. In the present series, however, the rate of IR in the MA-OPCAB group was relatively low and only marginally greater than MA-ONCAB (8.7% vs 5.2%). These findings confirmed that complete revascularization can be achieved in MA-OPCAB in the majority of cases, and this conclusion is supported by previous reports.

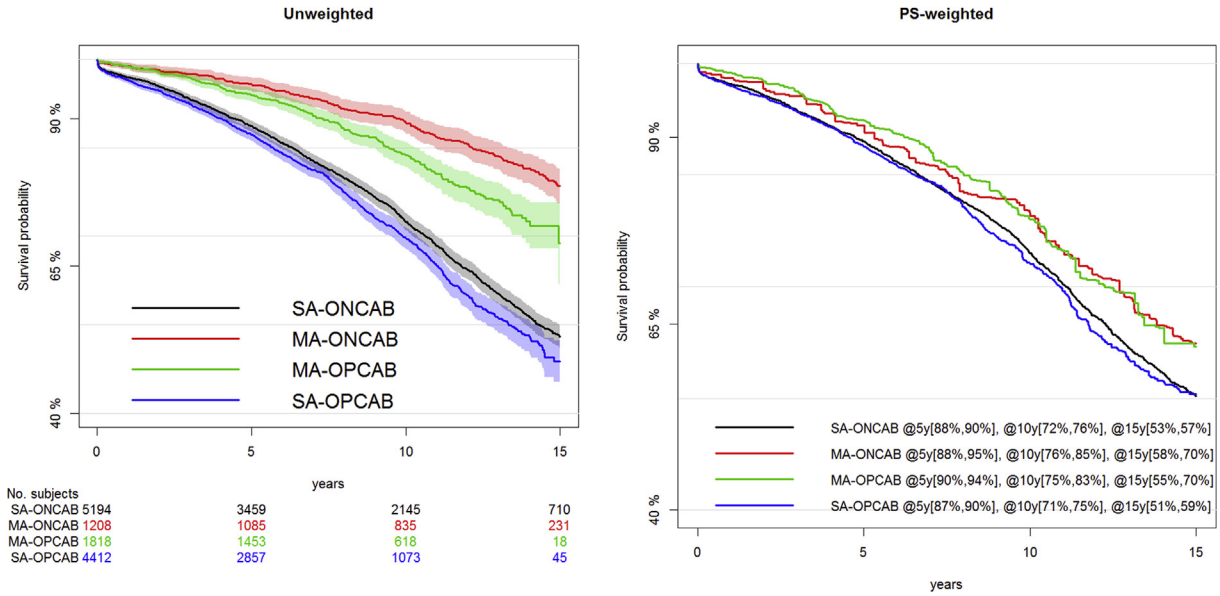


FIGURE 2. Survival rate in the unweighted (*left*) and propensity score weighted (*right*) MA and SA OPCAB and ONCAB surgery groups (±standard errors at 5, 10, and 15 years are reported for each propensity score weighted group). *SA*, Single arterial; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arterial; *OPCAB*, off-pump coronary artery bypass; *PS*, propensity score.

In their randomized trial, Kobayashi and colleagues[24] found that completeness of revascularization (completed grafts/planned grafts) was 98% in both MA-OPCAB and MA-ONCAB groups. In the BITA arm of the ART,[24] OPCAB and ONCAB groups showed comparable number of grafts per patient. Of note, in a recent report on the Veterans Affairs Continuous Improvement in Cardiac Surgery Program[26] 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 with that observed in 34,772 ONCAB cases (11.0%). A possible explanation for the relatively low IR rate observed in our MA-OPCAB series is the high OPCAB volume at our center performed by experienced surgeons during the study period. The high OPCAB volume also can partially account for the quasi-equipoise between OPCAB and ONCAB in patients receiving a single arterial graft, thus confirming a central role of surgeon experience in determining outcomes after myocardial revascularization without cardiopulmonary bypass.[27]

Limitations

Although the data were collected prospectively, the main limitation is the retrospective analysis. It is possible that patients receiving MA conduits were younger and healthier. Propensity technique can adjust only for measurable and included variables, and we cannot exclude a selection bias based on a nonmeasurable "eye-balling." Moreover, we were unable to provide specific causes of death (cardiac vs noncardiac) 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 equipoise between OPCAB and ONCAB on long-term survival.

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 centers. These results might be true only for cardiac surgeons and anesthesiologists who are fully accustomed to OPCAB. Furthermore, patients might have been selected for MA grafting OPCAB only when complete revascularization was deemed possible. The use of MA grafts has declined in recent years. In our healthcare system, there is an increasing demand for reducing resource use, and this might influence surgeons in adopting MA grafting, which is more time consuming. It also can be speculated that the use of the RA often was preferred over a second internal thoracic artery as anticipated to be less time consuming and technically demanding. The decrease in the number of OPCAB procedures in recent years in our center can be explained with the appointment of 2 young surgeons with no previous training in this technique, the retirement of one of the most senior OPCAB surgeon, and the part-time position of the senior surgeon who first introduced the technique.

In conclusion, multiarterial grafting was associated with improved late survival after on- and off-pump CABG. Off-pump was associated consistently with a lower risk of need for IABP postoperatively and re-exploration, and it was associated with similar 10-year survival as on-pump surgery when we controlled for the extent of arterial revascularization. Complete revascularization during OPCAB is achievable in the majority of cases, and it should still be the main goal while performing OPCAB surgery to optimize outcomes after surgical revascularization.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: off-pump coronary artery bypass grafting, multiple arterial grafting, survival, propensity score

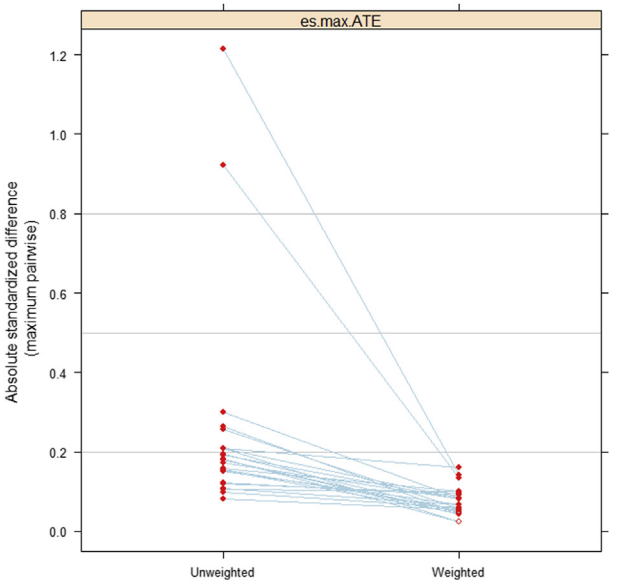

FIGURE E1. Change in maximum absolute standardized mean differences before and after propensity score weighting. *ATE*, Average treatment effect on the population.

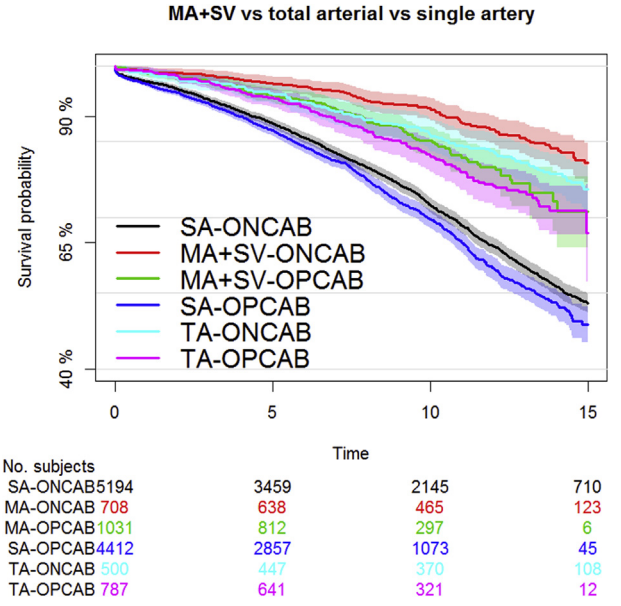

FIGURE E3. Survival rate in the unweighted MA plus SV, TA, and SA OPCAB and ONCAB surgery groups. *MA*, Multiple arterial; *SV*, saphenous vein; *SA*, single arterial; *ONCAB*, on-pump coronary artery bypass; *OPCAB*, off-pump coronary artery bypass; *TA*, total arterial.

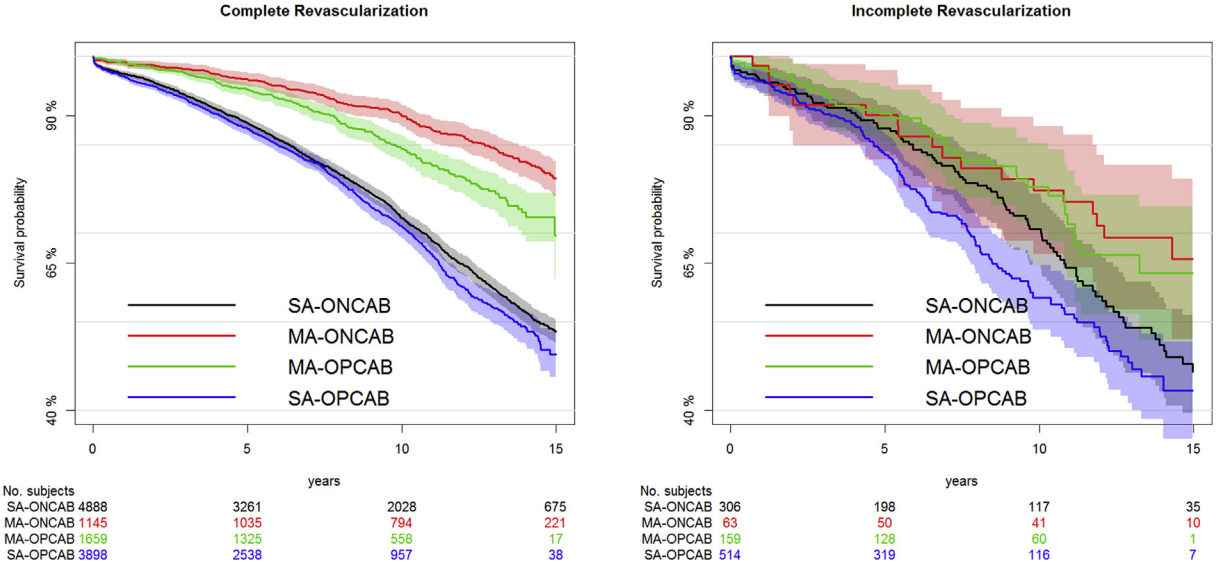

FIGURE E2. Survival rate in the unweighted MA- and SA-OPCAB and ONCAB surgery groups according to completeness of revascularization. *SA*, Single arterial; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arterial; *OPCAB*, off-pump coronary artery bypass.

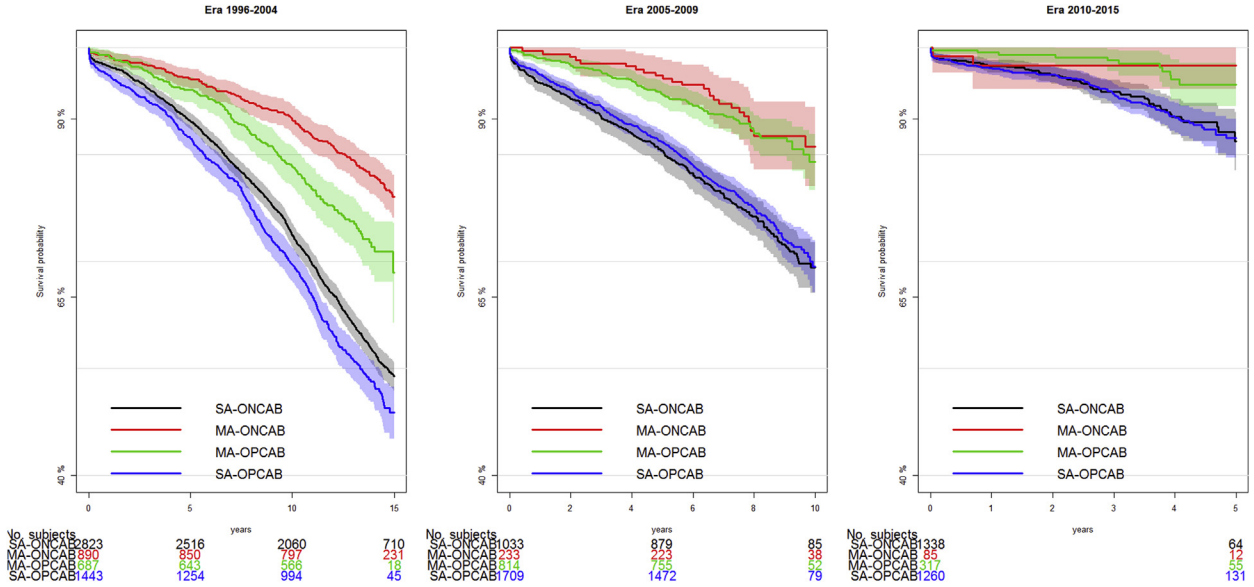

FIGURE E4. Survival rate in the unweighted MA- and SA-OPCAB and ONCAB surgery groups across eras of surgery. *SA*, Single arterial; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arterial; *OPCAB*, off-pump coronary artery bypass.

TABLE E1. ASMD for each variable among groups comparison in the unweighted population

Variable	Group 1	Group 2	ASMD	Group 1	Group 2	ASMD
Age	SA-ONCAB	MA-ONCAB	110%	MA-ONCAB	MA-OPCAB	42%
Female	SA-ONCAB	MA-ONCAB	25%	MA-ONCAB	MA-OPCAB	7%
NYHA III-IV	SA-ONCAB	MA-ONCAB	7%	MA-ONCAB	MA-OPCAB	11%
CCS III-IV	SA-ONCAB	MA-ONCAB	14%	MA-ONCAB	MA-OPCAB	7%
MI within 30 d	SA-ONCAB	MA-ONCAB	18%	MA-ONCAB	MA-OPCAB	18%
PCI	SA-ONCAB	MA-ONCAB	7%	MA-ONCAB	MA-OPCAB	15%
DM orally treated	SA-ONCAB	MA-ONCAB	16%	MA-ONCAB	MA-OPCAB	11%
DM on insulin	SA-ONCAB	MA-ONCAB	9%	MA-ONCAB	MA-OPCAB	2%
Current smoking	SA-ONCAB	MA-ONCAB	17%	MA-ONCAB	MA-OPCAB	8%
Creatinine $\geq$200 mmol/L	SA-ONCAB	MA-ONCAB	14%	MA-ONCAB	MA-OPCAB	0%
COPD	SA-ONCAB	MA-ONCAB	18%	MA-ONCAB	MA-OPCAB	5%
CVA	SA-ONCAB	MA-ONCAB	7%	MA-ONCAB	MA-OPCAB	2%
PVD	SA-ONCAB	MA-ONCAB	14%	MA-ONCAB	MA-OPCAB	2%
Atrial fibrillation	SA-ONCAB	MA-ONCAB	8%	MA-ONCAB	MA-OPCAB	0%
3-vessel disease	SA-ONCAB	MA-ONCAB	19%	MA-ONCAB	MA-OPCAB	11%
Left main disease	SA-ONCAB	MA-ONCAB	12%	MA-ONCAB	MA-OPCAB	18%
LVEF between 30% and 49%	SA-ONCAB	MA-ONCAB	15%	MA-ONCAB	MA-OPCAB	2%
LVEF $\leq$30%	SA-ONCAB	MA-ONCAB	15%	MA-ONCAB	MA-OPCAB	6%
Cardiogenic shock	SA-ONCAB	MA-ONCAB	11%	MA-ONCAB	MA-OPCAB	1%
Preoperative IABP	SA-ONCAB	MA-ONCAB	12%	MA-ONCAB	MA-OPCAB	2%
Nonelective admission	SA-ONCAB	MA-ONCAB	15%	MA-ONCAB	MA-OPCAB	1%
Emergent/salvage	SA-ONCAB	MA-ONCAB	10%	MA-ONCAB	MA-OPCAB	1%
BMI	SA-ONCAB	MA-ONCAB	12%	MA-ONCAB	MA-OPCAB	7%
Year of surgery	SA-ONCAB	MA-ONCAB	44%	MA-ONCAB	MA-OPCAB	77%
Age	SA-ONCAB	MA-OPCAB	68%	MA-ONCAB	SA-OPCAB	121%
Female	SA-ONCAB	MA-OPCAB	18%	MA-ONCAB	SA-OPCAB	26%
NYHA III-IV	SA-ONCAB	MA-OPCAB	18%	MA-ONCAB	SA-OPCAB	7%
CCS III-IV	SA-ONCAB	MA-OPCAB	21%	MA-ONCAB	SA-OPCAB	12%
MI within 30 d	SA-ONCAB	MA-OPCAB	0%	MA-ONCAB	SA-OPCAB	26%
PCI	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	15%
DM orally treated	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	18%
DM on insulin	SA-ONCAB	MA-OPCAB	7%	MA-ONCAB	SA-OPCAB	12%
Current smoking	SA-ONCAB	MA-OPCAB	9%	MA-ONCAB	SA-OPCAB	18%
Creatinine $\geq$200 mmol/L	SA-ONCAB	MA-OPCAB	14%	MA-ONCAB	SA-OPCAB	16%
COPD	SA-ONCAB	MA-OPCAB	13%	MA-ONCAB	SA-OPCAB	20%
CVA	SA-ONCAB	MA-OPCAB	10%	MA-ONCAB	SA-OPCAB	8%
PVD	SA-ONCAB	MA-OPCAB	12%	MA-ONCAB	SA-OPCAB	15%
Atrial fibrillation	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	8%
3-vessel disease	SA-ONCAB	MA-OPCAB	30%	MA-ONCAB	SA-OPCAB	7%
Left main disease	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	21%
LVEF between 30% and 49%	SA-ONCAB	MA-OPCAB	17%	MA-ONCAB	SA-OPCAB	15%
LVEF $\leq$30%	SA-ONCAB	MA-OPCAB	21%	MA-ONCAB	SA-OPCAB	11%
Cardiogenic shock	SA-ONCAB	MA-OPCAB	10%	MA-ONCAB	SA-OPCAB	4%
Preoperative IABP	SA-ONCAB	MA-OPCAB	10%	MA-ONCAB	SA-OPCAB	11%
Nonelective admission	SA-ONCAB	MA-OPCAB	16%	MA-ONCAB	SA-OPCAB	13%
Emergent/salvage	SA-ONCAB	MA-OPCAB	9%	MA-ONCAB	SA-OPCAB	6%
BMI	SA-ONCAB	MA-OPCAB	19%	MA-ONCAB	SA-OPCAB	2%
Year of surgery	SA-ONCAB	MA-OPCAB	33%	MA-ONCAB	SA-OPCAB	92%
Age	SA-ONCAB	SA-OPCAB	12%	MA-OPCAB	SA-OPCAB	79%
Female	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	18%
NYHA III-IV	SA-ONCAB	SA-OPCAB	14%	MA-OPCAB	SA-OPCAB	4%
CCS III-IV	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	20%
MI within 30 d	SA-ONCAB	SA-OPCAB	8%	MA-OPCAB	SA-OPCAB	8%
PCI	SA-ONCAB	SA-OPCAB	8%	MA-OPCAB	SA-OPCAB	0%
DM orally treated	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	7%

(Continued)

TABLE E1. Continued

Variable	Group 1	Group 2	ASMD	Group 1	Group 2	ASMD
DM on insulin	SA-ONCAB	SA-OPCAB	3%	MA-OPCAB	SA-OPCAB	10%
Current smoking	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	10%
Creatinine$\geq$ 200 mmol/L	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	16%
COPD	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	15%
CVA	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	11%
PVD	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	13%
Atrial fibrillation	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	8%
3-vessel disease	SA-ONCAB	SA-OPCAB	26%	MA-OPCAB	SA-OPCAB	4%
Left main disease	SA-ONCAB	SA-OPCAB	9%	MA-OPCAB	SA-OPCAB	3%
LVEF between 30% and 49%	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	17%
LVEF $\leq$30%	SA-ONCAB	SA-OPCAB	5%	MA-OPCAB	SA-OPCAB	16%
Cardiogenic shock	SA-ONCAB	SA-OPCAB	7%	MA-OPCAB	SA-OPCAB	3%
Preoperative IABP	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	9%
Nonelective admission	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	14%
Emergent/salvage	SA-ONCAB	SA-OPCAB	4%	MA-OPCAB	SA-OPCAB	4%
BMI	SA-ONCAB	SA-OPCAB	10%	MA-OPCAB	SA-OPCAB	9%
Year of surgery	SA-ONCAB	SA-OPCAB	48%	MA-OPCAB	SA-OPCAB	15%

ASMD, Absolute standardized mean difference; *SA*, single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *NYHA*, New York Heart Association; *CCS*, Canadian Cardiovascular Society; *MI*, myocardial infarction; *PCI*, percutaneous coronary intervention; *DM*, diabetes mellitus; *COPD*, chronic obstructive pulmonary disease; *CVA*, cerebrovascular accident; *PVD*, peripheral vascular disease; *LVEF*, left ventricular ejection fraction; *IABP*, intra-aortic balloon pump; *BMI*, body mass index.

TABLE E2. ASMD for each variable among groups comparison after inverse propensity score weighting

Variable	Group 1	Group 2	ASMD	Group 1	Group 2	ASMD
Age	SA-ONCAB	MA-ONCAB	11%	MA-ONCAB	MA-OPCAB	1%
Female	SA-ONCAB	MA-ONCAB	6%	MA-ONCAB	MA-OPCAB	2%
NYHA III-IV	SA-ONCAB	MA-ONCAB	0%	MA-ONCAB	MA-OPCAB	4%
CCS III-IV	SA-ONCAB	MA-ONCAB	4%	MA-ONCAB	MA-OPCAB	8%
MI within 30 d	SA-ONCAB	MA-ONCAB	4%	MA-ONCAB	MA-OPCAB	4%
PCI	SA-ONCAB	MA-ONCAB	0%	MA-ONCAB	MA-OPCAB	4%
DM orally treated	SA-ONCAB	MA-ONCAB	1%	MA-ONCAB	MA-OPCAB	2%
DM on insulin	SA-ONCAB	MA-ONCAB	10%	MA-ONCAB	MA-OPCAB	6%
Current smoking	SA-ONCAB	MA-ONCAB	5%	MA-ONCAB	MA-OPCAB	0%
Creatinine $\geq$200 mmol/L	SA-ONCAB	MA-ONCAB	10%	MA-ONCAB	MA-OPCAB	4%
COPD	SA-ONCAB	MA-ONCAB	0%	MA-ONCAB	MA-OPCAB	5%
CVA	SA-ONCAB	MA-ONCAB	2%	MA-ONCAB	MA-OPCAB	10%
PVD	SA-ONCAB	MA-ONCAB	5%	MA-ONCAB	MA-OPCAB	1%
Atrial fibrillation	SA-ONCAB	MA-ONCAB	4%	MA-ONCAB	MA-OPCAB	4%
3-vessel disease	SA-ONCAB	MA-ONCAB	6%	MA-ONCAB	MA-OPCAB	2%
Left main disease	SA-ONCAB	MA-ONCAB	0%	MA-ONCAB	MA-OPCAB	1%
LVEF between 30% and 49%	SA-ONCAB	MA-ONCAB	3%	MA-ONCAB	MA-OPCAB	8%
LVEF $\leq$30%	SA-ONCAB	MA-ONCAB	7%	MA-ONCAB	MA-OPCAB	16%
Cardiogenic shock	SA-ONCAB	MA-ONCAB	7%	MA-ONCAB	MA-OPCAB	2%
Preoperative IABP	SA-ONCAB	MA-ONCAB	9%	MA-ONCAB	MA-OPCAB	4%
Nonelective admission	SA-ONCAB	MA-ONCAB	1%	MA-ONCAB	MA-OPCAB	4%
Emergent/salvage	SA-ONCAB	MA-ONCAB	5%	MA-ONCAB	MA-OPCAB	1%
BMI	SA-ONCAB	MA-ONCAB	5%	MA-ONCAB	MA-OPCAB	3%
Year of surgery	SA-ONCAB	MA-ONCAB	5%	MA-ONCAB	MA-OPCAB	13%
Age	SA-ONCAB	MA-OPCAB	10%	MA-ONCAB	SA-OPCAB	14%
Female	SA-ONCAB	MA-OPCAB	4%	MA-ONCAB	SA-OPCAB	4%
NYHA III-IV	SA-ONCAB	MA-OPCAB	4%	MA-ONCAB	SA-OPCAB	2%
CCS III-IV	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	3%
MI within 30 d	SA-ONCAB	MA-OPCAB	0%	MA-ONCAB	SA-OPCAB	3%
PCI	SA-ONCAB	MA-OPCAB	4%	MA-ONCAB	SA-OPCAB	0%
DM orally treated	SA-ONCAB	MA-OPCAB	0%	MA-ONCAB	SA-OPCAB	2%
DM on insulin	SA-ONCAB	MA-OPCAB	4%	MA-ONCAB	SA-OPCAB	9%
Current smoking	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	3%
Creatinine $\geq$200 mmol/L	SA-ONCAB	MA-OPCAB	6%	MA-ONCAB	SA-OPCAB	9%
COPD	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	1%
CVA	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	1%
PVD	SA-ONCAB	MA-OPCAB	7%	MA-ONCAB	SA-OPCAB	5%
Atrial fibrillation	SA-ONCAB	MA-OPCAB	0%	MA-ONCAB	SA-OPCAB	6%
3-vessel disease	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	0%
Left main disease	SA-ONCAB	MA-OPCAB	1%	MA-ONCAB	SA-OPCAB	1%
LVEF between 30% and 49%	SA-ONCAB	MA-OPCAB	6%	MA-ONCAB	SA-OPCAB	4%
LVEF $\leq$30%	SA-ONCAB	MA-OPCAB	9%	MA-ONCAB	SA-OPCAB	8%
Cardiogenic shock	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	4%
Preoperative IABP	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	9%
Nonelective admission	SA-ONCAB	MA-OPCAB	5%	MA-ONCAB	SA-OPCAB	1%
Emergent/salvage	SA-ONCAB	MA-OPCAB	6%	MA-ONCAB	SA-OPCAB	2%
BMI	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	5%
Year of surgery	SA-ONCAB	MA-OPCAB	8%	MA-ONCAB	SA-OPCAB	13%
Age	SA-ONCAB	SA-OPCAB	3%	MA-OPCAB	SA-OPCAB	13%
Female	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	2%
NYHA III-IV	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	2%
CCS III-IV	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	6%
MI within 30 d	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	1%
PCI	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	4%
DM orally treated	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	0%

(Continued)

TABLE E2. Continued

Variable	Group 1	Group 2	ASMD	Group 1	Group 2	ASMD
DM on insulin	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	4%
Current smoking	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	3%
Creatinine ≥200 mmol/L	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	6%
COPD	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	4%
CVA	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	9%
PVD	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	6%
Atrial fibrillation	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	1%
3-vessel disease	SA-ONCAB	SA-OPCAB	6%	MA-OPCAB	SA-OPCAB	2%
Left main disease	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	2%
LVEF between 30% and 49%	SA-ONCAB	SA-OPCAB	1%	MA-OPCAB	SA-OPCAB	5%
LVEF ≤30%	SA-ONCAB	SA-OPCAB	2%	MA-OPCAB	SA-OPCAB	8%
Cardiogenic shock	SA-ONCAB	SA-OPCAB	3%	MA-OPCAB	SA-OPCAB	2%
Preoperative IABP	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	5%
Nonelective admission	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	6%
Emergent/salvage	SA-ONCAB	SA-OPCAB	3%	MA-OPCAB	SA-OPCAB	3%
BMI	SA-ONCAB	SA-OPCAB	0%	MA-OPCAB	SA-OPCAB	8%
Year of surgery	SA-ONCAB	SA-OPCAB	8%	MA-OPCAB	SA-OPCAB	1%

ASMD, Absolute standardized mean difference; *SA*, single artery; *ONCAB*, on-pump coronary artery bypass; *MA*, multiple arteries; *OPCAB*, off-pump coronary artery bypass; *NYHA*, New York Heart Association; *CCS*, Canadian Cardiovascular Society; *MI*, myocardial infarction; *PCI*, percutaneous coronary intervention; *DM*, diabetes mellitus; *COPD*, chronic obstructive pulmonary disease; *CVA*, cerebrovascular accident; *PVD*, peripheral vascular disease; *LVEF*, left ventricular ejection fraction; *IABP*, intra-aortic balloon pump; *BMI*, body mass index.