Ten-year outcomes after off-pump versus on-pump coronary artery bypass grafting: Insights from the Arterial Revascularization Trial

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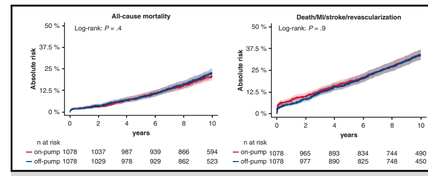
ABSTRACT

Objective: We performed a post hoc analysis of the Arterial Revascularization Trial to compare 10-year outcomes after off-pump versus on-pump surgery.

Methods: Among 3102 patients enrolled, 1252 (40% of total) and 1699 patients received off-pump and on-pump surgery (151 patients were excluded because of other reasons); 2792 patients (95%) completed 10-year follow-up. Propensity matching and mixed-effect Cox model were used to compare long-term outcomes. Interaction term analysis was used to determine whether bilateral internal thoracic artery grafting was a significant effect modifier.

Results: One thousand seventy-eight matched pairs were selected for comparison. A total of 27 patients (2.5%) in the off-pump group required conversion to on-pump surgery. The off-pump and on-pump groups received a similar number of grafts (3.2 ± 0.89 vs 3.1 ± 0.8; $P = .88$). At 10 years, when compared with on-pump, there was no significant difference in death (adjusted hazard ratio for off-pump, 1.1; 95% confidence interval, 0.84-1.4; $P = .54$) or the composite of death, myocardial infarction, stroke, and repeat revascularization (adjusted hazard ratio, 0.92; 95% confidence interval, 0.72-1.2; $P = .47$). However, off-pump surgery performed by low volume off-pump surgeons was associated with a significantly lower number of grafts, increased conversion rates, and increased cardiovascular death (hazard ratio, 2.39; 95% confidence interval, 1.28-4.47; $P = .006$) when compared with on-pump surgery performed by on–pump-only surgeons.

Conclusions: The findings showed that in the Arterial Revascularization Trial, off-pump and on-pump techniques achieved comparable long-term outcomes. However, when off-pump surgery was performed by low-volume surgeons, it was associated with a lower number of grafts, increased conversion, and a higher risk of cardiovascular death. (J Thorac Cardiovasc Surg 2020;■:1-9)



Cumulative outcome incidence in the matched sample in the off-pump versus on-pump groups.

CENTRAL MESSAGE

In experienced hands, off-pump surgery can achieve long-term outcomes comparable to those observed after on-pump surgery and can therefore be considered a valid alternative to on-pump surgery to reduce morbidity. The choice of bilateral versus single internal thoracic artery grafts should not influence the decision to adopt the off-pump technique.

PERSPECTIVE

Off-pump surgery in experienced hands can achieve long-term outcomes comparable to those observed after on-pump surgery; therefore, surgery off-pump should be considered a valid alternative to on-pump to reduce morbidity following coronary bypass surgery. The choice of bilateral versus single internal thoracic artery grafts should not influence the decision to adopt the off-pump technique.

See Commentary on page XXX.

ADULT

Whether off-pump coronary artery bypass graft (CABG) surgery is as safe and effective as on-pump surgery remains among the most controversial areas of cardiac surgery.[1] Some randomized controlled trials have found increased mortality following off-pump surgery,[1,2] but limited surgeon off-pump experience has been advocated to explain

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Abbreviations and Acronyms

ART = Arterial Revascularization Trial
BITA = bilateral internal thoracic artery
CABG = coronary artery bypass graft
MI = myocardial infarction
SITA = single internal thoracic artery

Scanning this QR code will take you to the article title page to access supplementary information.

these results.[2] On the other hand, off-pump has been shown to achieve results comparable to on-pump surgery when performed by experienced surgeons.[3,4] However, available randomized controlled trials are limited by relatively short follow-up duration (5 years) and differences in clinical outcomes may become evident with longer follow-up duration.[5]

Moreover, available data comparing off-pump and on-pump surgery were based on a single internal thoracic artery (SITA) graft supplemented by saphenous vein grafts.[2-4] There is growing concern that off-pump surgery is associated with a significantly higher graft failure rate when saphenous vein grafts but not arterial grafts are used.[6] Therefore, it has been suggested that a more extensive use of arterial grafts, including bilateral internal thoracic artery (BITA) grafts should be adopted during off-pump surgery.[6,7]

The Arterial Revascularization Trial (ART) was designed to compare 10-year survival after BITA versus SITA grafting and the final results have recently reported.[8] In the ART, the choice of off-pump versus on-pump was based on surgeon preference in accordance with their clinical expertise. As such, the ART may provide useful insights into the long-term effect of off-pump surgery when performed by surgeons who use it routinely in clinical practice. Moreover, the ART can provide further information regarding the role of BITA versus SITA grafting in patients undergoing off-pump surgery. We performed a post hoc analysis to compare 10-year outcomes after off-pump versus on-pump surgery and the effect of BITA versus SITA grafting.

MATERIALS AND METHODS

The present study is a post hoc retrospective analysis of 10-year outcomes of the ART. The study was approved by an institutional review committee and the subjects gave informed consent. The data that support the findings of this study are available from the corresponding author upon reasonable request. The study adheres to the principles set forth in the Declaration of Helsinki (http://www.wma.net/en/30publications/10policies/b3/index.html). In the ART, the choice of off-pump versus on-pump surgery was based on individual surgeon discretion in accordance with their routine clinical practice. The off-pump versus on-pump strategy adopted was available for all patients enrolled.

Among all patients enrolled in the ART (n = 3102 from 2004 to 2007), we excluded a total of 151 patients, including those who did not undergo surgery (n = 24), incomplete information regarding the use of cardiopulmonary bypass and myocardial protection strategy (n = 6), patients who received on-pump beating heart surgery (n = 23), and 98 patients who received crossclamp fibrillation. The present analysis compared 1252 patients who underwent off-pump surgery with 1699 patients who underwent on-pump with cardioplegic arrest. Off-pump surgery requiring intraoperative conversion to on-pump was included in the off-pump group in the primary analysis (Figure E1).

Trial Design

The ART was approved by the institutional review board of all participating centers, and informed consent was obtained from each participant. The protocol for the ART has been published elsewhere.[9] Briefly, the ART is a 2-arm, randomized multicenter trial conducted in 28 hospitals in 7 countries, with patients being randomized equally to SITA or BITA grafting. Eligible patients were those with multivessel coronary artery disease undergoing coronary artery bypass grafting, including patients requiring urgent treatment. Only patients requiring emergency treatment (refractory myocardial ischemia/cardiogenic shock) and patients requiring single grafts or redo surgery were excluded.

Follow-up

Questionnaires were sent to study participants by mail at 12 months and then every year after surgery. No clinic visits were planned apart from the routine clinical 6-week postoperative visit. Participants were sent stamped addressed envelopes to improve the return rates of postal questionnaires. Study coordinators contacted participants by telephone to alert them to the questionnaire's arrival and to ask them about medications, adverse events, and health services resource use. A total of 2792 patients (95%) completed 10-year follow-up. Median follow-up time was 10.0 years (interquartile range, 9.3-10.0 years).

Study Outcomes

The 2 strategies were compared in terms of hospital and 10-year outcomes. The primary end point was all-cause mortality. We also investigated the incidence cardiovascular death, nonfatal myocardial infarction (MI), nonfatal stroke, and repeat revascularization and a combined end point of death, MI, stroke, and repeat revascularization. Adverse events were adjudicated blind to surgical procedure by a member of the clinical event review committee.

Outcomes Definitions

Death was classified into cardiovascular and noncardiovascular, when possible, using autopsy reports and death certificates. Congestive heart failure, arrhythmia or MI, pulmonary embolus, and dissection were considered cardiovascular causes of death. MI was diagnosed when 2 of the following 3 criteria were present: unequivocal electrocardiogram changes, elevation of cardiac enzyme(s) above twice the upper limit of normal or diagnostic troponin increases, and chest pain typical for acute MI that lasted more than 20 minutes. Cerebro-vascular accident was defined as new neurologic deficit evidenced by clinical signs of paresis, plegia, or new cognitive dysfunction, including any mental status alteration lasting longer than 24 hours or evidence on computed tomography or magnetic resonance imaging scan of recent brain infarct (<6 months). Repeat revascularization was defined as coronary bypass surgery or percutaneous coronary intervention performed after trial procedure. Acute kidney injury was defined as a 0.3 mg/dL (≥26.5 μmol/L) creatinine increase from baseline within 48 hours of surgery.

TABLE 1. Baseline characteristics in the off-pump and on-pump group (matched sample)

Characteristic	Off-pump surgery (n = 1078)	On-pump surgery (n = 1078)	*P* value	Standardized mean difference
Age (y)	63.83 ± 8.88	63.97 ± 8.74	.71	0.02
Female	144 (13.4)	139 (12.9)	.79	0.01
Ethnicity			.08	0.09
White	1001 (92.9)	1023 (94.9)		
East Asian	1 (0.1)	4 (0.4)		
South Asian	63 (5.8)	41 (3.8)		
Afro-Caribbean	0 (0.0)	2 (0.2)		
African	0 (0.0)	4 (0.4)		
Other	13 (1.2)	4 (0.4)		
Body mass index	28.22 ± 4.18	28.33 ± 3.91	.51	0.02
Serum creatinine (mmol/L)	99.07 ± 20.02	97.86 ± 21.93	.18	0.05
Unstable angina	83 (7.7)	71 (6.6)	.35	0.04
Treated hypertension	813 (75.4)	824 (76.4)	.61	0.02
Treated hyperlipidemia	1012 (93.9)	1019 (94.5)	.58	0.03
Diabetes			.59	0.04
No	850 (78.8)	847 (78.6)		
Insulin dependent	51 (4.7)	61 (5.7)		
Noninsulin dependent	177 (16.4)	170 (15.8)		
Smoking			.31	0.05
Current smoker	157 (14.6)	136 (12.6)		
Ex-smoker	585 (54.3)	642 (59.6)		
Never	336 (31.2)	300 (27.8)		
COPD	28 (2.6)	30 (2.8)	.89	0.01
Asthma	53 (4.9)	53 (4.9)	1	<0.001
Extracardiac arteriopathy	72 (6.7)	68 (6.3)	.79	0.01
Stroke	29 (2.7)	23 (2.1)	.48	0.03
Myocardial infarction	435 (40.4)	450 (41.7)	.54	0.02
PCI	182 (16.9)	190 (17.6)	.69	0.02
History of AF	15 (1.4)	15 (1.4)	1	<0.001
LVEF*			.30	0.03
≥50%	842 (78.1)	811 (75.2)		
31%-49%	205 (19.0)	253 (23.5)		
≤30%	31 (2.9)	14 (1.3)		
APLT within 3 d	156 (14.5)	166 (15.4)	.58	0.02
RCA disease	695 (64.5)	703 (65.2)	.75	0.02
Mean vessel quality†	1.73 ± 0.59	1.69 ± 0.54	.11	0.07
Endarterectomy	12 (1.1)	14 (1.3)	.84	0.02
BITA	497 (46.1)	483 (44.8)	.57	0.03
Radial artery use	224 (20.8)	223 (20.7)	1	0.002
Saphenous vein graft	804 (74.6)	815 (75.6)	.61	0.02

Values are presented as mean ± standard deviation or n (%). *COPD*, Chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention; *AF*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; *APLT*, antiplatelet therapy; *RCA*, right coronary artery; *BITA*, bilateral internal thoracic arterial. *LVEF was categorized as good (≥50%), moderate (31%-49%), or poor (≤30%). †Quality was categorized as 1 = good, 2 = moderate, or 3 = poor.

Statistical Analysis

Multiple imputation (m = 3) was used to address missing data. Rubin's method was used to combine results from each of the imputed data sets (Amelia package for the R software program [R Foundation for Statistical Computing, Vienna, Austria]).[10] Because of the lack of randomization with regard to receiving off-pump, a propensity score was generated for each patient from a multivariable logistic regression model based on pretreatment covariates listed in Table 1. Pairs of patients were derived using greedy 1:1 matching with a caliper of width of 0.005 (nonrandom R package). Because the sample size of the 2 groups was comparable as well as the prevalence of most prematching features, we used a more restrictive value than the 0.2 standard deviation of the logit of propensity score to obtain comparable pairs. The quality of the match was assessed by comparing selected pretreatment variables in propensity score–matched patients using the standardized mean difference, with an absolute standardized mean difference >0.10 taken to represent meaningful covariate imbalance.[11] McNemar test and paired *t* test were used to assess the statistical significance of the risk difference for hospital outcomes. In absence of competing events, the 1 minus Kaplan-Meier estimator was used to calculate cumulative incidence function with its relative 95% standard error while the Fine and Gray approach was used to account for presence of competing risk on a subdistribution hazard function.

Event rates for 10-year outcomes were calculated according to Kaplan-Meier estimates and were compared using a stratified log-rank test. The treatment effect on the 10-year outcomes was investigated by means of mixed effect Cox regression models stratified by matched pairs (coxme R package). This approach accounts for the within-pair homogeneity by allowing the baseline hazard function to vary across matched sets.[11] Individual surgeon identifier was used as a random effect to account for any clustering effect due to different individual surgeons. Risk competing framework was used to estimate the treatment effect on nonfatal events and cardiovascular death. The Schoenfeld residuals test was used to test the independence between residuals and time, and thus to test the proportional hazards assumption in Cox models. Treatment effect was reported as hazard ratio (HR) and 95% confidence interval (95% CI).

As sensitivity analysis, the treatment effect was re-estimated by further adjustment for medications at discharge. Subgroup and interaction term analyses were performed to investigate whether BITA versus SITA grafting was a potential effect modifier in the comparison between off-pump versus on-pump surgery. We also investigate the interaction between off-pump versus on-pump surgery and the use of the radial artery and the use of multiple arterial grafting defined as the use of 2 or more arterial grafts.

To account for the potential influence of individual surgeons' off-pump experience, we compared off-pump versus on-pump surgery stratified by surgeon expertise in off-pump surgery. The number of off-pump procedures within the trial was used as proxy for individual surgeon expertise in off-pump surgery. The cutoff to define high off-pump volume surgeons corresponded to the 75th percentiles of total number of off-pump cases performed by each off-pump surgeon (10 off-pump surgeries). Five groups were compared: off-pump surgery performed by high off-pump volume surgeon, off-pump surgery performed by low off-pump volume surgeon, on-pump surgery performed by high off-pump volume surgeon, on-pump surgery performed by low off-pump volume surgeon, and on-pump surgery performed by on-pump only surgeon. The treatment effect on outcomes of interest was investigated using mixed Cox models using individual surgeon as random effect (random intercept) and all baseline characteristics as fixed effect. On-pump surgery performed by on-pump only surgeons was considered as reference group. To investigate the effect of surgeon off-pump volume, the original sample was used. All statistical analysis was performed using R Statistical Software version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The unmatched sample consisted of 1699 and 1252 patients undergoing off-pump or on-pump surgery, respectively (Tables E1 and E2). Overall, the off-pump group presented a trend toward a higher risk profile including increased creatinine level and higher prevalence of unstable angina. The prevalence of 3-vessel disease was also higher among off-pump patients and the quality of native vessels tended to be worse. BITA grafts were more likely to be used in the off-pump group, whereas a radial artery was more likely to be used in the on-pump group. Propensity score matching identified 1078 pairs (total matched sample = 2156) for final comparison, balanced for all baseline characteristics (standardized mean difference, <0.10) (Table 1) and propensity score distribution was comparable between the 2 matched groups (Figure 1).

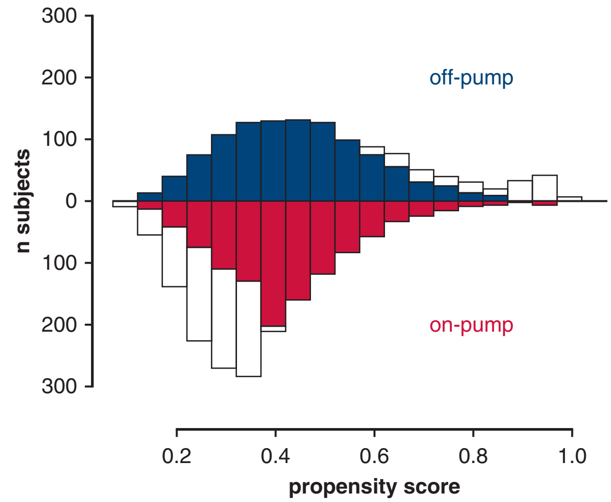

FIGURE 1. Mirrored histogram showing propensity score distribution in the off-pump versus on-pump groups before (*white*) and after (*blue* and *red*, respectively) matching.

Hospital Outcomes

In-hospital outcomes in the matched sample are reported in Table 2. A total of 27 patients (2.5%) in the off-pump group required conversion to on-pump surgery. The off-pump and on-pump group received a comparable number of total grafts (3.2 ± 0.89 vs 3.1 ± 0.8; $P = .88$). Off-pump surgery resulted in a lower rate of transfusion and a lower incidence of postoperative atrial fibrillation and perioperative MI with a marginally nonsignificant reduction of creatine kinase-MB release postoperatively. In-hospital mortality, stroke, and repeat revascularization was comparable between the groups. Patients undergoing off-pump surgery were more likely to be discharged on dual antiplatelet therapy, but they were less likely to receive statins (Table E3).

Ten-year Outcomes

Ten-year outcomes and treatment effect are summarized in Table 3. The incidence of all-cause mortality and the composite of death, MI, stroke, and revascularization was 232 (21.5%) versus 215 (19.9%) and 355 (32.7%) versus 356 (33.0%) in the off-pump and on-pump group respectively (Figure 2). When compared with on pump, off-pump surgery was not associated with increased risk of all-cause death (HR, 1.1; 95% CI, 0.84-1.4; $P = .47$)

TABLE 2. Hospital outcomes in the off-pump and on-pump group (matched sample)

Outcome	Off-pump surgery (n = 1078)	On-pump surgery (n = 1078)	P value
No. grafts	3.21 ± 0.89	3.10 ± 0.79	.88
Conversion	27 ± 2.5		
Red blood cell transfusion	107 (10.1)	138 (13.2)	**.04**
Re-exploration	32 (3.0)	41 (3.8)	.34
Need for IABP	50 (4.6)	42 (3.9)	.45
Renal replacement therapy	61 (5.7)	58 (5.4)	.85
Acute kidney injury	179 (17.4)	174 (17.1)	.90
Creatinine peak at 48 h (mmol/L)	111 ± 44	107 ± 61	.18
CK-MB at 24 h (U/L)	36 ± 194	78 ± 122	.06
Troponin at 24 h (U/L)	6.5 ± 24	7.5 ± 61	.85
Sternal wound complication	30 (2.8)	45 (4.2)	.10
Death	9 (0.8)	12 (1.1)	.66
Myocardial infarction	10 (0.9)	28 (2.6)	**.01**
Stroke	14 (1.3)	15 (1.4)	1
Repeat revascularization	7 (0.6)	6 (0.6)	1
Postoperative atrial fibrillation	247 (22.9)	295 (27.4)	**.02**

Values are presented as mean ± standard deviation or n (%). Statistically significant *P* values are in bold. *IABP*, Intra-aortic balloon pump; *CK-MB*, creatine kinase-MB.

nor the composite of death, MI, stroke, and revascularization (HR, 0.92; 95% CI, 0.72-1.2; $P = .47$). No significant differences were recorded for composite outcome individual components (Figure 3). The equipoise between the 2 groups persisted after adjusting for medications at discharge.

When the analysis was stratified by BITA versus SITA grafting, the presence of BITA versus SITA grafting did not significantly influence the comparison between off-pump and on-surgery for all outcomes of interest (Table 4 and Figure 4). However, when compared with on-pump, off-pump surgery was associated with a non-significant excess of cardiovascular deaths when SITA (off-pump vs on-pump HR, 2.0174; 95% CI, 1.1-3.7) but not BITA grafts (off-pump vs on-pump HR, 1.0; 95% CI, 0.45-2.3) were used (interaction $P = .21$). Off-pump and on-pump surgery were comparable in terms of 10-year mortality and incidence of major adverse cardiac and cerebrovascular outcomes regardless the use of the RA (Figure E2) or any multiple arterial grafting configuration (Figure E3).

A total of 159 participating surgeons were involved (Figure E4). Ninety-eight surgeons performed on-pump only, whereas off-pump was performed by 61 surgeons, including 21 surgeons who performed off-pump only. For 133 patients (59 off-pump and 74 on-pump), no information on participating surgeon was available and these were not included in this analysis. High off-pump volume surgeons were defined those performing over the 75th percentile. Based on the identified cutoff of least 10 off-pump procedures, 21 surgeons were classified as high volume off-pump performing 1075 procedures and the remaining 40 surgeons were classified as low-volume off-pump performing a total of 118 off-pump procedures. A total of 98 surgeons performed on-pump only. Patient characteristics, hospital outcomes stratified for off-pump versus on-pump surgery, and surgeon off-pump volume are summarized in Tables E4 and E5. The use of BITA vs SITA graft (as treated) according to off-pump surgeon volume is summarized in Table E6. High volume off-pump surgeons were more likely to perform BITA grafting. For low-volume off-pump surgeons, the use of off-pump technique did not influence the use of BITA or SITA grafting. Surgeons only performing on-pump surgery had the lowest rate of BITA graft use.

Ten-year outcomes and adjusted treatment effect estimation on these outcomes stratified by surgeon off-pump volume are presented in Tables E7 and E8. When performed by low-volume off-pump surgeons, off-pump surgery resulted in a significantly lower number of grafts and higher conversion rates, whereas this trend was not observed when off-pump was performed by high-volume off-pump surgeons. When compared with on-pump surgery performed by on-pump only surgeons, off-pump surgery performed by low-volume off-pump surgeons was associated with a significantly increased risk-adjusted incidence of cardiovascular death (HR, 2.39; 95% CI, 1.28-4.47; $P = .006$) and increased risk of late

TABLE 3. Ten-year outcomes in the off-pump and on-pump group (matched sample)

Outcome	Off-pump surgery (n = 1078)	On-pump surgery (n = 1078)	PSM model only: HR (95% CI)	PSM model only: P value	PSM-model + medication at discharge: HR (95% CI)	PSM-model + medication at discharge: P value
All-cause death	232 (21.5)	215 (19.9)	1.1 (0.84-1.4)	.54	1.25 (0.98.1.6)	.07
Cardiovascular death	90 (8.3)	70 (6.5)	0.97 (0.57-1.6)	.91	1.07 (0.61-1.8)	.82
MI	49 (4.5)	64 (5.9)	0.78 (0.53-1.2)	.21	0.79 (0.51-1.2)	.28
Stroke	50 (4.6)	47 (4.4)	1.2 (0.45-1.5)	.52	0.95 (0.47-1.9)	.88
Revascularization	114 (10.6)	111 (10.3)	0.75 (0.47-1.2)	.21	0.70 (0.44-1.1)	.10
Death/MI/stroke/revascularization	353 (32.7)	356 (33.0)	0.92 (0.72-1.2)	.47	0.95 (0.75-1.2)	.66

Values are presented as n (%). *PSM*, Propensity score matching; *HR*, Hazard ratio; *CI*, confidence interval; *MI*, myocardial infarction.

ADULT

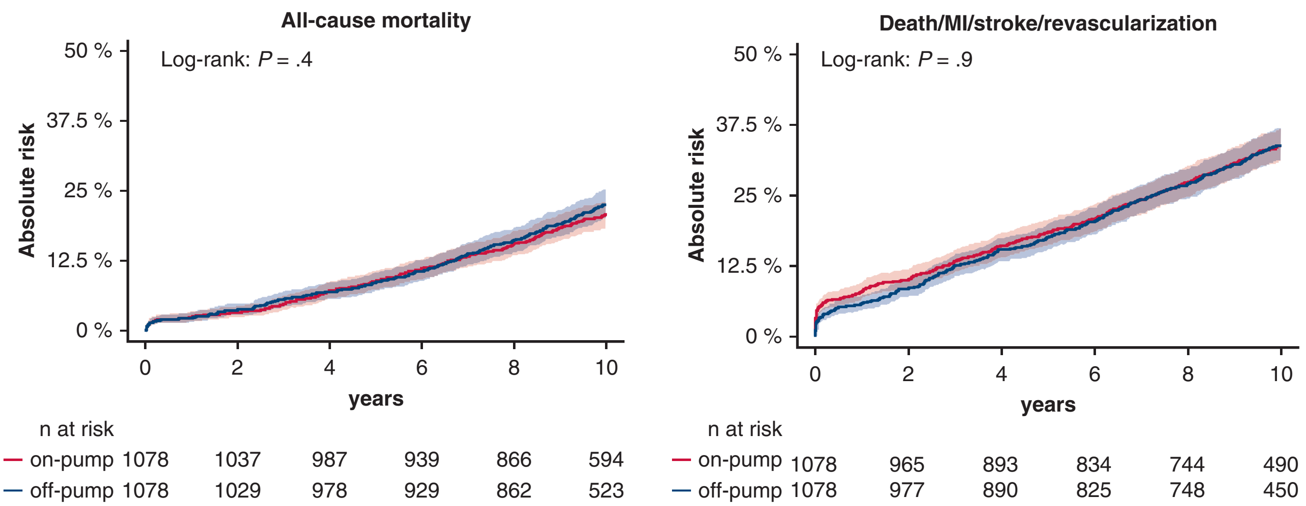

FIGURE 2. Cumulative incidence of all-cause death (*left*) and the composite of all-cause death, myocardial infarction (*MI*), stroke, and revascularization (*right*) in the matched sample in the off-pump versus on-pump groups.

stroke (HR, 3.97; 95% CI, 1.81-7.95; $P < .001$) at 10 years. No difference in long-term outcomes was demonstrated for off-pump surgery performed by high volume off-pump surgeons and for on-pump surgery performed by high and low volume off-pump surgeons. BITA vs SITA grafting was not an effect modifier in the comparison between off-pump and on-pump surgery.

DISCUSSION

The main finding of the present post-hoc analysis of the ART was that at 10 years, off-pump and on-pump surgery were associated with comparable outcomes, including all-cause mortality and the composite of death, MI, stroke, and repeat revascularization. When compared with on-pump, off-pump surgery was associated some advantage

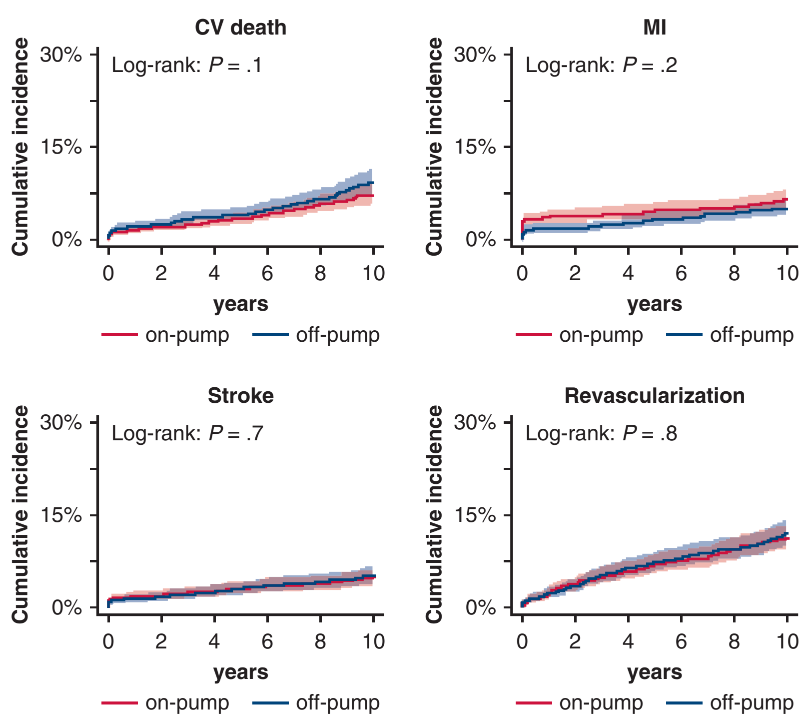

FIGURE 3. Cumulative incidence of cardiovascular (*CV*) death, myocardial infarction (*MI*), stroke, and revascularization in the matched sample in the off-pump versus on-pump groups.

TABLE 4. Ten-year outcomes in the off-pump and on-pump group in the matched sample stratified for single internal thoracic artery (SITA) versus bilateral internal thoracic artery (BITA)

	SITA grafting			BITA grafting			
Outcome	Off-pump surgery (n = 581)	On-pump surgery (n = 581)	HR (95% CI)	Off-pump surgery (n = 497)	On-pump surgery (n = 483)	HR (95% CI)	Interaction *P*
All-cause death	136 (23.4)	125 (21.0)	1.2 (0.84-1.8)	96 (19.3)	90 (18.6)	1.1 (0.74-1.7)	.68
Cardiovascular death	54 (9.3)	39 (6.6)	2 (1.1-3.7)	36 (7.2)	31 (6.4)	1 (0.45-2.3)	.21
MI	28 (4.8)	32 (5.4)	0.89 (0.34-2.4)	21 (4.2)	32 (6.6)	0.77 (0.34-1.8)	.82
Stroke	34 (5.9)	29 (4.9)	1.1 (0.46-2.4)	16 (3.2)	18 (3.7)	0.78 (0.29-2.1)	.68
Revascularization	66 (11.4)	54 (9.1)	1.1 (0.68-1.9)	48 (9.7)	57 (11.8)	0.75 (0.41-1.4)	.27
Death/MI/stroke/revascularization	204 (35.1)	199 (33.4)	1 (0.72-1.5)	149 (30.0)	157 (32.5)	0.9 (0.63-1.3)	.41

Values are presented as n (%). *HR*, Hazard ratio; *CI*, confidence interval; *MI*, myocardial infarction.

in terms of hospital outcomes, including a lower rate of transfusion and postoperative atrial fibrillation.

The use of SITA or BITA grafts was not found to be a significant effect modifier in the comparison between off-pump and on-pump surgery. It has been suggested that off-pump surgery may increase the risk of saphenous vein graft failure[6] without affecting graft patency of arterial conduits, including BITA grafts. However, other reports have shown that both arterial and vein grafts durability is not reduced when off-pump surgery is performed by experienced surgeons.[12] Available randomized comparative studies on long-term survival after off-pump versus on-pump surgery included mainly procedures with SITA grafting.[2-4] Observational studies have suggested that off-pump surgery with multiple arterial grafts but not vein grafts provides long-term outcomes comparable with those observed on-pump surgery with multiple arterial grafts.[7]

Our findings suggest that off-pump surgery can safely performed regardless the use of BITA or SITA grafts. Because the choice to perform on-pump or off-pump was based on individual surgeon preference, the overall experience in off-pump surgery in the ART was likely to be adequate and this can explain the equipoise between the 2 techniques regardless the graft selection adopted.[12] However, it must be noticed that although not statistically significant, off-pump surgery was associated with a nonsignificant excess of cardiovascular deaths in patients who received SITA graft but not in those with BITA grafts and this observation requires further investigation.

We further analyzed the effect of off-pump surgery according to individual surgeon off-pump volume. When compared with on-pump performed by on-pump–only surgeons, off-pump surgery performed by low-volume off-pump surgeons was associated with a significantly lower number of grafts and significantly increased risk of

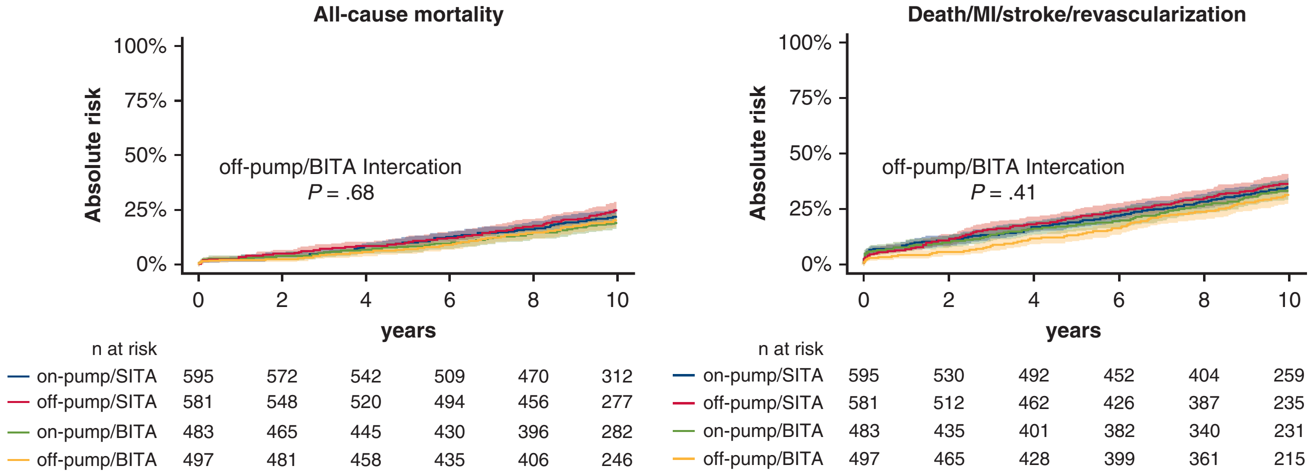

FIGURE 4. Cumulative incidence of all-cause death (*left*) and the composite of all-cause death, myocardial infarction (*MI*), stroke, and revascularization (*right*) in the matched sample in the off-pump versus on-pump groups stratified for the use of single internal thoracic artery (*SITA*) versus bilateral internal thoracic artery (*BITA*) grafts.

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on-pump conversion, cardiovascular death, and late stroke at 10 years. On the contrary, off-pump surgery performed by high off-pump volume surgeon was associated with comparable number of grafts and 10-year outcomes.

Off-pump volume at individual surgeon or hospital level are intuitive measures of expertise and a proxy of enhanced safety and quality[5] and studies suggesting an increased risk of late mortality after off-pump surgery have been criticized by those who believe that surgeon experience plays a major role in determining outcomes. In the Randomized On/Off Bypass trial,[2] 53 participating surgeons enrolled an average of only 8 patients per year during the study period and had unacceptably high conversion rates to on-pump surgery (12%) and incomplete revascularization (18%). Moreover, in 60% of cases, a resident physician was the primary surgeon. These aspects might have contributed to the higher mortality observed in the off-pump group.

In the CABG Off or On Pump Revascularization Study,[3] where each procedure was performed by a surgeon who had expertise in the specific type of surgery (completion of >100 cases of the specific technique; ie, off-pump or on-pump), the difference in terms of number of grafts (3.0 vs 3.2) and incidence of incomplete revascularization (11.8% vs 10.0%) were only marginal and off-pump and on-pump surgery showed similar 5-year outcomes, including mortality with both techniques. Similar results were observed in the German off-pump CABG trial in elderly patients study,[4] where surgeons were established experts with an average of 514 off-pump CABG procedures (median, 322 procedures) performed, and where no significant differences between off-pump and on-pump outcomes were found.

A potential limitation of studies supporting the equipoise between the techniques is the limited follow-up duration of 5 years and the ART, with 10-year follow-up, can provide further insights into the long-term comparison between off-pump and on-pump surgery. Off-pump surgery was performed at the individual surgeon's discretion. Furthermore, it is likely that the overall off-pump experience in the ART was adequate—a similar number of grafts were used in the off-pump and on-pump groups, the very low off-pump to on-pump conversion rates, and the equipoise between the groups at 10 years. This hypothesis is supported by other reports from high off-pump volume centers.[13]

The number of grafts performed with off-pump surgery and the incidence of conversion from off-pump to on-pump surgery in the ART was lower than those reported in other series.[2] Finally, we also found that off-pump surgery was also associated with a nonsignificant reduction of myocardial enzymes and a lower rate of perioperative MI as defined by the study protocol. It is well recognized that off-pump surgery is associated with a lower release of myocardial enzymes,[14] but the clinical relevance of this observation remains unclear (Table E8) also in view of comparable long-term outcomes between the techniques. Moreover, the definition of perioperative MI after myocardial revascularization remains controversial.[15]

Limitations

The main limitation of the present study is its observational nature. The propensity technique can adjust only for measurable and included variables, and we cannot exclude a selection bias based on a nonmeasurable eye-balling, including the quality of the targets. We had no information on specific surgeon off-pump expertise and we used the total number of off-pump procedures performed in the ART as a surrogate of off-pump expertise. We had no information on reasons for preferring off-pump over on-pump and vice versa across surgeon subgroups. The number of off-pump surgeries performed by low off-pump volume surgeons was relatively small thus increasing the risk of type I error. Therefore, subgroup analysis based on surgeon off-pump volume should be considered only as descriptive and hypothesis generating.

It should also be noted that, by today's standards, the ART population might be considered a relatively low-risk subset of CABG patients (although the only formal exclusion criteria were evolving MI, redo surgery, or the need for a single graft). It is possible that a difference between the techniques could exist in patients at higher surgical risk.

CONCLUSIONS

We found that when performed by experienced surgeons, off-pump surgery was as safe and effective as on-pump surgery at long-term follow-up regardless the use of BITA versus SITA grafts. In the current era, an increasing number of patients with a high-risk profile are being referred for surgical revascularization, and off-pump surgery represents an attractive strategy to potentially reduce operative morbidity. However, the unique technical challenges of off-pump surgery may lead to poorer outcomes during each surgeon's learning curve and this further emphasizes the need for recognition of off-pump surgery as a subspecialty with a formally structured training program.[16]

Conflict of Interest Statement

Dr Taggart is a consultant/advisor for Medtronic. All other authors have nothing to disclose with regard to commercial support.

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Key Words: off-pump, on-pump, CABG, arterial revascularization

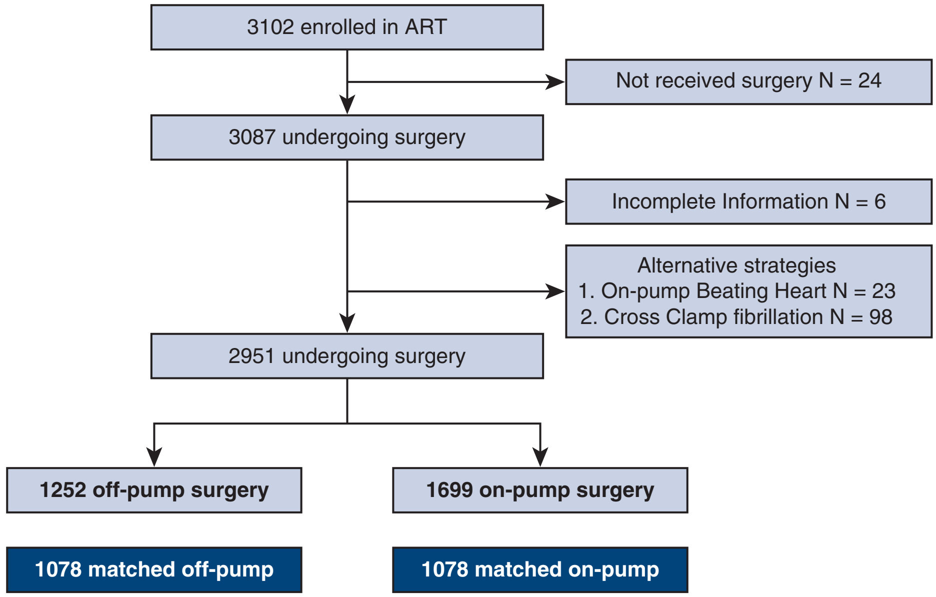

FIGURE E1. Flow chart of patients enrolled in the Arterial Revascularization Trial (*ART*) who are included in the present post-hoc analysis.

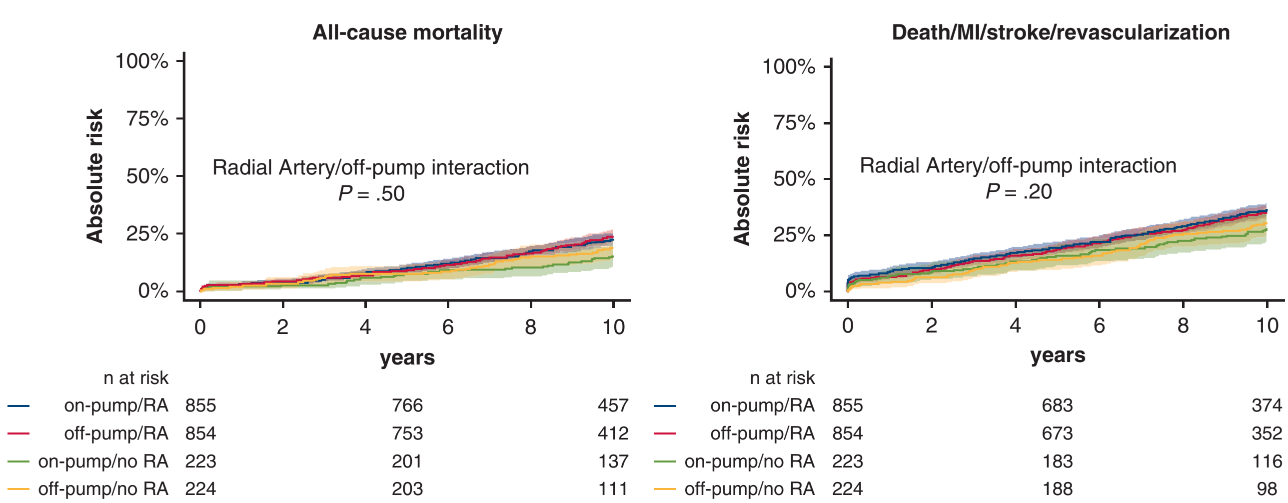

FIGURE E2. Cumulative incidence of 10-year all-cause mortality and major adverse cardiac and cerebrovascular event according to off-pump versus on-pump surgery and the use of the radial artery (*RA*) with relative interaction term *P*.

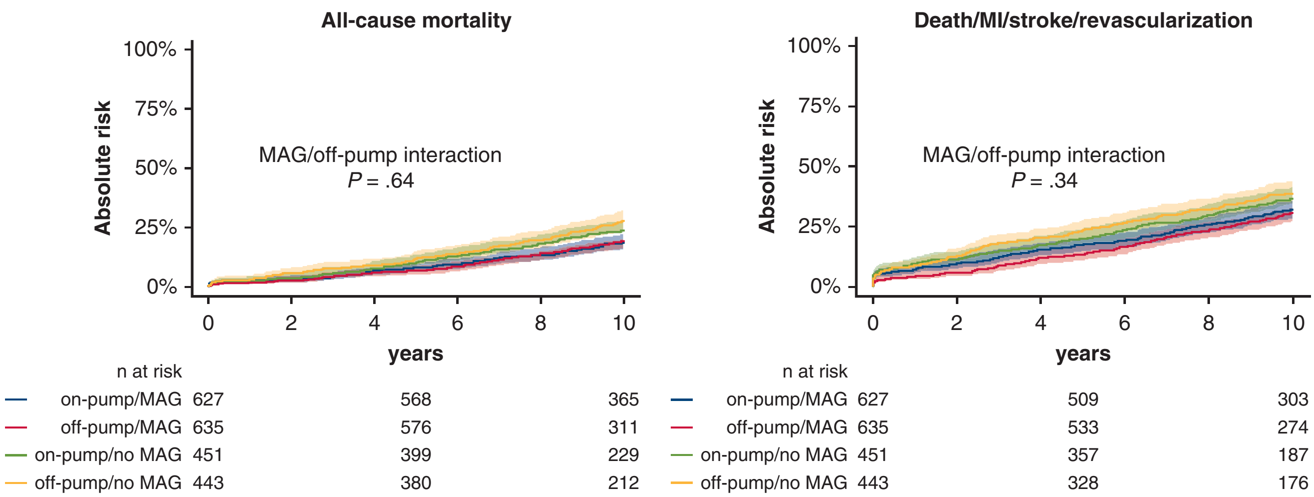

FIGURE E3. Cumulative incidence of 10-year all-cause mortality and major adverse cardiac and cerebrovascular event according to off-pump versus on-pump surgery and the use of multiple arterial grafting (*MAG*) (defined as the use of 2 or more arterial grafts) with relative interaction term *P*.

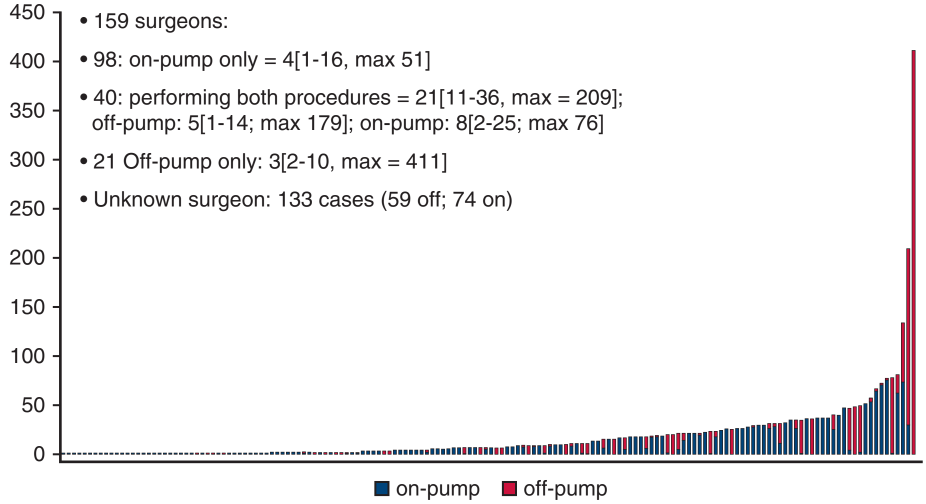

FIGURE E4. Distribution of off-pump and on-pump surgeries according to the participating surgeons.

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TABLE E1. Baseline characteristics in the off-pump and on-pump group (original sample)

Characteristic	Off-pump surgery (n = 1252)	On-pump surgery (n = 1699)	*P* value	SMD
Age (y)	63.60 ± 9.07	63.50 ± 8.80	.75	0.01
Female	180 (14.4)	240 (14.1)	.89	0.007
Ethnicity			< .001	0.46
White	1064 (85.0)	1644 (96.8)		
East Asian	1 (0.1)	4 (0.2)		
South Asian	104 (8.3)	41 (2.4)		
Afro-Carribean	0 (0.0)	2 (0.1)		
African	0 (0.0)	4 (0.2)		
Other	83 (6.6)	4 (0.2)		
Body mass index	28.11 ± 4.10	28.28 ± 3.88	.25	0.04
Serum creatinine (mmol/L)	99.98 ± 22.54	94.27 ± 20.33	< .001	0.26
Unstable angina	133 (10.6)	79 (4.6)	< .001	0.22
Treated hypertension	939 (75.0)	1359 (80.0)	.001	0.12
Treated hyperlipidemia	1169 (93.4)	1600 (94.2)	.41	0.03
Diabetes			.25	0.06
No	976 (78.0)	1285 (75.6)		
Insulin dependent	69 (5.5)	93 (5.5)		
Noninsulin dependent	207 (16.5)	321 (18.9)		
Smoking			.001	0.13
Current smoker	180 (14.4)	242 (14.2)		
Ex-smoker	660 (52.7)	998 (58.7)		
Never	412 (32.9)	459 (27.0)		
COPD	29 (2.3)	43 (2.5)	.80	0.01
Asthma	62 (5.0)	65 (3.8)	.16	0.05
Extracardiac arteriopathy	88 (7.0)	119 (7.0)	1	0.001
Stroke	40 (3.2)	46 (2.7)	.50	0.03
Myocardial infarction	506 (40.4)	726 (42.7)	.22	0.04
PCI	205 (16.4)	270 (15.9)	.76	0.01
History of AF	18 (1.4)	24 (1.4)	1	0.002
LVEF*			.2	0.04
≥50%	978 (78.1)	1290 (75.9)		
31%-49%	239 (19.1)	388 (22.8)		
≤30%	35 (2.8)	21 (1.2)		
APLT within 3 d	181 (14.5)	315 (18.5)	.004	0.11
RCA disease	779 (62.2)	1246 (73.3)	< .001	0.24
Mean vessel quality†	1.73 ± 0.60	1.60 ± 0.52	< .001	0.21
Endarterectomy	15 (1.2)	33 (1.9)	.15	0.06
BITA	594 (47.4)	691 (40.7)	< .001	0.13
Radial artery	238 (19.0)	381 (22.4)	.03	0.08
Saphenous vein graft	931 (74.4)	1343 (79.0)	.003	0.11

Values are presented as mean ± standard deviation or n (%). *SMD*, Standardized mean difference; *COPD*, chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention; *AF*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; *APLT*, antiplatelet therapy; *RCA*, right coronary artery; *BITA*, bilateral internal thoracic arterial. *LVEF was categorized as good (≥50%), moderate (31%-49%), or poor (≤30%). †Quality was categorized as 1 = good, 2 = moderate, or 3 = poor.

TABLE E2. Hospital outcomes in the off-pump and on-pump group (original sample)

Outcome	Off-pump (n = 1252)	On-pump (n = 1699)	*P* value
No. grafts	3.20 ± 0.87	3.19 ± 0.76	.70
Conversion	29 (2.3)		
Red blood cell transfusion	130 (10.6)	221 (13.4)	.02
Re-exploration	36 (2.9)	58 (3.4)	.47
Need for IABP	58 (4.6)	59 (3.5)	.13
Renal replacement therapy	72 (5.8)	79 (4.6)	.20
Acute kidney injury	211 (17.7)	265 (16.4)	.40
Creatinine peak at 48 h (μmol/L)	112.08 ± 52.17	102.80 ± 52.22	< .001
CK-MB at 24 h (U/L)	816.55 ± 1140.14	790.42 ± 909.59	.76
Troponin at 24 h (U/L)	33.54 ± 178.53	80.46 ± 124.93	.007
Sternal wound complication	5.26 (21.20)	5.88 (47.31)	.87
Death	34 (2.7)	66 (3.9)	.10
Myocardial infarction	12 (1.0)	18 (1.1)	.93
Stroke	10 (0.8)	40 (2.4)	.002
Repeat revascularization	20 (1.6)	19 (1.1)	.33
Postoperative atrial fibrillation	8 (0.6)	7 (0.4)	.55
No. grafts	276 (22.0)	449 (26.4)	.007

Values are presented as mean ± standard deviation or n (%). *IABP*, Intra-aortic balloon pump; *CK-MB*, creatine kinase-MB.

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TABLE E3. Medication at discharge in the matched off-pump and on-pump groups

Medication	Off-pump surgery (n = 1069)	On-pump surgery (n = 1066)	*P* value
Antiplatelet therapy			< .001
Aspirin	640 (59.9)	903 (84.7)	
Clopidogrel	41 (3.8)	30 (2.8)	
Dual antiplatelet therapy	377 (35.3)	114 (10.7)	
None	11 (1.0)	19 (1.8)	
Beta blocker	892 (83.4)	890 (83.5)	1
Statin	963 (90.1)	1002 (94.0)	.001
ACEI/ARB	531 (49.7)	552 (51.8)	.35
Calcium channel blocker	157 (14.7)	125 (11.7)	.05

Values are presented as n (%). *ACEI/ARB*, Angiotensin converting enzyme inhibitor/angiotensin receptor blocker.

TABLE E4. Baseline characteristics in the off-pump and on-pump group (original sample) stratified for individual surgeon off-pump volume

Characteristic	Off-pump by high off-pump volume surgeon (n = 1134)	Off-pump by low off-pump volume surgeon (n = 118)	On-pump by high off-pump volume surgeon (n = 232)	On-pump by low off-pump volume surgeon (n = 513)	On-pump by on-pump only surgeon (n = 954)	*P* value
Age (y)	63.78 ± 9.09	61.91 ± 8.72	64.45 ± 8.89	62.42 ± 8.62	63.85 ± 8.83	.002
Female	167 (14.7)	13 (11.0)	29 (12.5)	90 (17.5)	121 (12.7)	.08
Ethnicity						< .001
White	951 (83.9)	113 (95.8)	212 (91.4)	504 (98.2)	928 (97.3)	
East Asian	1 (0.1)	0 (0.0)	1 (0.4)	1 (0.2)	2 (0.2)	
South Asian	99 (8.7)	5 (4.2)	18 (7.8)	6 (1.2)	17 (1.8)	
Afro-Carribean	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	1 (0.1)	
African	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (0.4)	
Other	83 (7.3)	0 (0.0)	1 (0.4)	1 (0.2)	2 (0.2)	
Body mass index	28.18 ± 4.14	27.45 ± 3.70	28.51 ± 4.32	28.25 ± 3.95	28.24 ± 3.72	.21
Serum creatinine (mmol/L)	100.50 ± 22.05	94.95 ± 26.38	100.41 ± 17.27	92.10 ± 18.71	93.95 ± 21.55	< .001
Unstable angina	129 (11.4)	4 (3.4)	18 (7.8)	20 (3.9)	41 (4.3)	< .001
Treated hypertension	841 (74.2)	98 (83.1)	179 (77.2)	427 (83.2)	753 (78.9)	< .001
Treated hyperlipidemia	1054 (92.9)	115 (97.5)	226 (97.4)	493 (96.1)	881 (92.3)	.002
Diabetes						.31
No	878 (77.4)	98 (83.1)	180 (77.6)	380 (74.1)	725 (76.0)	
Insulin dependent	63 (5.6)	6 (5.1)	15 (6.5)	34 (6.6)	44 (4.6)	
Noninsulin dependent	193 (17.0)	14 (11.9)	37 (15.9)	99 (19.3)	185 (19.4)	
Smoking						.002
Current smoker	156 (13.8)	24 (20.3)	27 (11.6)	85 (16.6)	130 (13.6)	
Ex-smoker	596 (52.6)	64 (54.2)	141 (60.8)	305 (59.5)	552 (57.9)	
Never	382 (33.7)	30 (25.4)	64 (27.6)	123 (24.0)	272 (28.5)	
COPD	27 (2.4)	2 (1.7)	10 (4.3)	12 (2.3)	21 (2.2)	.41
Asthma	60 (5.3)	2 (1.7)	12 (5.2)	13 (2.5)	40 (4.2)	.06
Extracardiac arteriopathy	83 (7.3)	5 (4.2)	19 (8.2)	29 (5.7)	71 (7.4)	.43
Stroke	39 (3.4)	1 (0.8)	3 (1.3)	9 (1.8)	34 (3.6)	.06
Myocardial infarction	450 (39.7)	56 (47.5)	97 (41.8)	236 (46.0)	393 (41.2)	.11
PCI	173 (15.3)	32 (27.1)	51 (22.0)	88 (17.2)	131 (13.7)	< .001
History of AF	18 (1.6)	0 (0.0)	6 (2.6)	6 (1.2)	12 (1.3)	.33
LVEF*						.008
≥50%	883 (77.9)	95 (80.5)	168 (72.4)	385 (75.0)	737 (77.3)	
31%-49%	218 (19.2)	21 (17.8)	58 (25.0)	124 (24.2)	206 (21.6)	
≤30%	33 (2.9)	2 (1.7)	6 (2.6)	4 (0.8)	11 (1.2)	
APLT within 3 d	150 (13.2)	31 (26.3)	35 (15.1)	96 (18.7)	184 (19.3)	< .001
RCA disease	724 (63.8)	55 (46.6)	182 (78.4)	380 (74.1)	684 (71.7)	< .001
Mean vessel quality†	1.74 ± 0.60	1.58 ± 0.55	1.55 ± 0.56	1.61 ± 0.49	1.61 ± 0.5	< .001
Endarterectomy	14 (1.2)	1 (0.8)	6 (2.6)	7 (1.4)	20 (2.1)	.35
BITA	544 (48.0)	50 (42.4)	84 (36.2)	227 (44.2)	380 (39.8)	.001
Radial artery	218 (19.2)	20 (16.9)	29 (12.5)	132 (25.7)	220 (23.1)	< .001
Saphenous vein graft	856 (75.5)	75 (63.6)	206 (88.8)	377 (73.5)	760 (79.7)	< .001

Values are presented as mean ± standard deviation or n (%). *SMD*, Standardized mean difference; *COPD*, chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention; *AF*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; *APLT*, antiplatelet therapy; *RCA*, right coronary artery; *BITA*, bilateral internal thoracic arterial. *LVEF was categorized as good (≥50%), moderate (31%-49%), or poor (≤30%). †Quality was categorized as 1 = good, 2 = moderate, or 3 = poor.

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TABLE E5. Hospital outcomes in the off-pump and on-pump group (original sample) stratified for individual surgeon off-pump volume

Outcome	Off-pump by high off-pump volume surgeon (n = 1134)	Off-pump by low off-pump volume surgeon (n = 118)	On-pump by high off-pump volume surgeon (n = 232)	On-pump by low off-pump volume surgeon (n = 513)	On-pump by on-pump only surgeon (n = 954)	*P* value
No. grafts	3.25 ± 0.86	2.74 ± 0.84	3.30 ± 0.72	3.19 ± 0.75	3.16 ± 0.77	< .001
Conversion	19 (1.7)	10 (8.5)	–	–	–	< .001
Red blood cell transfusion	108 (9.7)	22 (18.8)	41 (21.2)	69 (13.6)	111 (11.7)	< .001
Re-exploration	27 (2.4)	9 (7.6)	10 (4.3)	16 (3.1)	32 (3.4)	.03
Need for IABP	51 (4.5)	7 (5.9)	7 (3.0)	22 (4.3)	30 (3.1)	.352
Renal replacement therapy	68 (6.0)	4 (3.4)	8 (3.4)	45 (8.8)	26 (2.7)	< .001
Acute kidney injury	196 (17.9)	15 (15.2)	33 (15.9)	77 (16.1)	155 (16.8)	.83
Creatinine peak at 48 h (μmol/L)	112.38 ± 51.87	108.87 ± 55.51	109.75 ± 37.82	97.96 ± 35.47	103.69 ± 61.59	< .001
CK-MB at 24 h (U/L)	18.03 ± 25.22	111.59 ± 431.74	25.03 ± 23.83	70.67 ± 118.79	101.01 ± 138.48	< .001
Troponin at 24 h (U/L)	4.43 ± 20.78	8.22 ± 22.72	3.38 ± 3.27	7.22 ± 62.78	4.29 ± 9.30	.93
Sternal wound complication	33 (2.9)	1 (0.8)	14 (6.0)	19 (3.7)	33 (3.5)	.083
Death	9 (0.8)	3 (2.5)	3 (1.3)	5 (1.0)	10 (1.0)	.48
Myocardial infarction	7 (0.6)	3 (2.5)	2 (0.9)	23 (4.5)	15 (1.6)	< .001
Stroke	20 (1.8)	0 (0.0)	3 (1.3)	5 (1.0)	11 (1.2)	.41
Repeat revascularization	7 (0.6)	1 (0.8)	1 (0.4)	1 (0.2)	5 (0.5)	.81
Postoperative atrial fibrillation	253 (22.3)	23 (19.5)	46 (19.8)	130 (25.3)	273 (28.6)	.003

Values are presented as mean ± standard deviation or n (%). *IABP*, Intra-aortic balloon pump; *CK-MB*, creatine kinase-MB.

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TABLE E6. Use of single internal thoracic artery (SITA) versus bilateral internal thoracic artery grafts (BITA) stratified for off-pump surgeon volume

Group	SITA	BITA	BITA:SITA
Off-pump by high off-pump volume surgeons	590	544	0.92
On-pump by high off-pump volume surgeons	148	84	0.57
Off-pump by low off-pump volume surgeons	68	50	0.74
On-pump by low off-pump volume surgeons	286	227	0.79
On-pump by on-pump only surgeons	574	380	0.66

TABLE E7. Ten-year outcomes (cumulative incidence) in the off-pump and on-pump group (original sample) stratified for individual surgeon off-pump volume

Outcome	Off-pump by high off-pump volume surgeon (n = 1134)	Off-pump by low off-pump volume surgeon (n = 118)	On-pump by high off-pump volume surgeon (n = 232)	On-pump by low off-pump volume surgeon (n = 513)	On-pump by on-pump only surgeon (n = 954)
All-cause death	240 (21.2)	27 (22.9)	57 (24.6)	84 (16.4)	191 (20.0)
Cardiovascular death	97 (8.6)	13 (11.0)	24 (10.3)	22 (4.3)	56 (5.9)
MI	50 (4.4)	6 (5.1)	9 (3.9)	31 (6.0)	43 (4.5)
Stroke	51 (4.5)	10 (8.5)	15 (6.5)	20 (3.9)	31 (3.2)
Revascularization	127 (11.2)	8 (6.8)	28 (12.1)	33 (6.4)	110 (11.5)
Death/MI/stroke/revascularization	372 (32.8)	40 (33.9)	89 (38.4)	145 (28.3)	306 (32.1)

Values are presented as n (%). *MI*, Myocardial infarction.

TABLE E8. Treatment effect (off-pump vs on-pump surgery) on 10-year outcomes stratified for individual surgeon off-pump volume (original sample)

Variable	Adjusted hazard ratio	95% confidence interval	*P* value
10-y all-cause mortality			
Off-pump performed by high off-pump volume surgeon	0.92	0.75-1.13	.44
Off-pump performed by low off-volume volume surgeon	1.37	0.90-2.07	.13
On-pump performed by high off-pump volume surgeon	0.95	0.70-1.30	.76
On-pump performed by low off-pump volume surgeon	0.82	0.63-1.06	.13
10-y cardiovascular death			
Off-pump performed by high off-pump volume surgeon	1.12	0.79-1.61	.52
Off-pump performed by low off-volume volume surgeon	**2.39**	**1.28-4.47**	**.006**
On-pump performed by high off-pump volume surgeon	1.31	0.79-2.16	.29
On-pump performed by low off-pump volume surgeon	0.67	0.41-1.11	.12
10-y MI			
Off-pump performed by high off-pump volume surgeon	0.77	0.50-1.19	.24
Off-pump performed by low off-volume volume surgeon	1.15	0.48-2.75	.75
On-pump performed by high off-pump volume surgeon	0.72	0.35-1.49	.37
On-pump performed by low off-pump volume surgeon	1.33	0.83-2.14	.22
10-y stroke			
Off-pump performed by high off-pump volume surgeon	1.22	0.75-1.98	.42
Off-pump performed by low off-volume volume surgeon	3.79	1.81-7.95	< **.001**
On-pump performed by high off-pump volume surgeon	1.85	0.97-3.51	.08
On-pump performed by low off-pump volume surgeon	1.32	0.74-2.34	.35
10-y repeat revascularization			
Off-pump performed by high off-pump volume surgeon	0.91	0.69-1.20	.49
Off-pump performed by low off-volume volume surgeon	0.55	0.27-1.14	.11
On-pump performed by high off-pump volume surgeon	1.05	0.69-1.61	.82
On-pump performed by low off-pump volume surgeon	0.71	0.34-1.75	.09
Death/MI/stroke/revascularization			
Off-pump performed by high off-pump volume surgeon	0.90	0.77-1.06	.22
Off-pump performed by low off-volume volume surgeon	1.19	0.85-1.66	.31
On-pump performed by high off-pump volume surgeon	1.05	0.82-1.34	.70
On-pump performed by low off-pump volume surgeon	0.88	0.72-1.08	.23

On-pump surgery performed by ''on-pump only'' surgeons is used as reference group in all comparisons. Adjusted for: age, female, ethnicity, body mass index, creatinine level, unstable angina, treated hypertension, treated hyperlipidemia, diabetes, smoking, chronic obstructive pulmonary disease, asthma, extracardiac arteriopathy, stroke, myocardial infarction, percutaneous coronary intervention, history of atrial fibrillation, left ventricular ejection fraction, antiplatelet within 3 days, right coronary artery disease, mean vessel quality, endarterectomy, single and bilateral internal thoracic artery grafts, radial artery, saphenous vein grafts. Statistically significant *P* values are in bold. *MI*, Myocardial infarction.

ADULT

000 **Ten-year outcomes after off-pump versus on-pump coronary artery bypass grafting: Insights from the Arterial Revascularization Trial**

David P. Taggart, PhD, Mario F. Gaudino, MD, Stephen Gerry, MSc, Alastair Gray, PhD, Belinda Lees, PhD, BSc, Lokeswara R. Sajja, MD, Vipin Zamvar, MD, Marcus Flather, MD, and Umberto Benedetto, MD, PhD, on behalf of the Arterial Revascularization Trial Investigators, Oxford, Edinburgh, Norwich and Bristol, United Kingdom; New York, NY; and Hyderabad, India

In experienced hands, off-pump surgery can achieve long-term outcomes comparable to those observed after on-pump surgery and can therefore be considered a valid alternative to on-pump surgery to reduce morbidity. The choice of bilateral versus single internal thoracic artery grafts should not influence the decision to adopt the off-pump technique.