Original Article
Yonsei Med J 2023 Aug;64(8):473-480
https://doi.org/10.3349/ymj.2022.0586

Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Bilateral versus Single Internal Thoracic Artery Grafting Strategies Supplemented by Radial Artery Grafting

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Purpose: It is unclear if a second or third arterial graft can improve clinical outcomes in coronary artery bypass graft surgery. We compared the outcomes of bilateral internal thoracic artery (BITA) plus radial artery (RA) grafting versus left internal thoracic artery (LITA) plus RA grafting after off-pump coronary artery bypass grafting.
Materials and Methods: Between January 2009 and December 2020, a total of 3007 patients with three-vessel coronary artery disease who underwent off-pump coronary artery bypass were analyzed. Among them, 971 patients received total arterial grafting using LITA. We divided the patients into two groups [group A, BITA+RA grafting (n=227) and group B, LITA+RA grafting (n=744)], and compared the survival and major adverse cardiac and cerebrovascular event (MACCE) rates between the two groups at 10 years.
Results: After risk adjustment with inverse probability treatment weighting methods, the freedom from all-cause mortality was 93.1% and 88.3% in groups A and B, respectively (p=0.140). The freedom from MACCE rates were 68.3% and 89.0%, respectively (p<0.0001). LITA plus RA grafting [hazard ratio (HR): 1.3, 95% confidence interval (CI): 1.05–2.37, p=0.025] and incomplete revascularization (HR 1.2, 95% CI: 0.70–2.15, p=0.046) were significant risk factors for MACCEs in multivariable Cox regression analysis.
Conclusion: The rates of MACCEs were lower with LITA plus RA grafting than with BITA plus RA grafting in total arterial revascularization. Furthermore, complete revascularization improved long-term outcomes following total arterial grafting.

Key Words: Coronary artery bypass grafting surgery, radial artery, internal mammary-coronary artery anastomosis, myocardial revascularization

INTRODUCTION

Despite increasing interest in additional arterial conduits during coronary artery bypass graft (CABG) surgery, the search for an optimal secondary or tertiary arterial conduit to supplement the left internal thoracic artery (LITA) is ongoing; furthermore, the effects of the use of additional arterial grafts on outcomes remains unclear.[1-3] Many studies have compared the survival benefits between CABG with two arterial grafts [bilateral internal thoracic artery (BITA) or LITA plus radial artery (RA)] and CABG with one arterial graft. A recent meta-analysis of studies using propensity score matching demonstrated better long-term survival when CABG was performed with three rather than two arterial grafts. However, these previous reports were limited as they only compared arterial grafting with saphenous vein (SV) grafting (SVG).

In patients with multi-vessel coronary artery disease (CAD), arterial grafts have the advantage of durability and exert a protective effect by reducing the progression of native CAD in grafted vessels.[4] Therefore, multiple arterial grafting may improve the results in patients receiving total arterial revascular-

Received: January 17, 2023 **Revised:** May 14, 2023
Accepted: June 13. 2023 **Published online:** July 18, 2023
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•The authors have no potential conflicts of interest to disclose.

ization (TAR). However, the optimal combination of arterial grafts remains unclear. Therefore, we sought to investigate the early and late outcomes of BITA plus RA versus LITA plus RA after off-pump coronary artery bypass grafting (OPCAB) in TAR. In addition, we also investigated the effect of RA grafts as a second and third conduit to supplement LITA and BITA grafts, respectively.

MATERIALS AND METHODS

The study was conducted in accordance with the principles of the Declaration of Helsinki, and was approved by the Institutional Review Board of Severance Hospital, Yonsei University College of Medicine [approval number: 4-2019-0216 (2019. 04.25)] which waived the need for informed consent due to the retrospective nature of the study.

Study population

From January 2009 to December 2020, a total of 3344 consecutive patients with triple-vessel CAD who underwent CABG performed by two experienced surgeons were enrolled in this study. Triple-vessel disease was defined as 50% or more stenosis in all three native coronary arteries or in the left main plus right coronary artery. Patients who underwent concomitant procedures, such as valve surgery (n=220), surgical anterior ventricular endocardial restoration (n=30), on-pump bypass surgery (n=6), redo sternotomy (n=53), or emergency/urgent (n=28) surgery, were excluded. From the remaining 3007 patients who underwent primary elective isolated OPCAB, 1697 patients with SVG were excluded. TAR using RA grafting with BITA or LITA grafting was planned for 971 patients. Among these patients, 227 underwent BITA plus RA grafting (group A) and 744 underwent LITA plus RA grafting (group B) (Fig. 1).

Graft harvesting technique and preoperative exclusion criteria for RA harvesting

The internal thoracic arteries were skeletonized and harvested using cautery and clipping, extending from the inferior border of the subclavian vein, distally, to the bifurcation into the superior epigastric and musculophrenic arteries. All RAs were harvested with an open minimal-touch technique using an ultrasonic energy device (HARMONIC). Mild dilatation using heparinized autologous blood was employed to prevent vasospasm.[4,5]

A modified Allen test, using a pulse oximeter placed on the thumb, was used to assess the integrity of the ulnar artery. If the color to the hand and fingers and oxygen saturation returned to normal within 5 seconds, the test was normal. Doppler ultrasonography of the RA allows for not only evaluation of the ulnar collateral circulation to the hand but also preoperative estimation of poor RA quality, such as a small diameter (<2.5 mm), arteriosclerosis (luminal narrowing ≥20%), or calcification.

Graft configurations

The LITA was sutured to the left anterior descending artery (LAD) in most patients (94.3%) in group A and all patients in group B (Fig. 2). The in-situ right internal thoracic artery (RITA) was used when its condition was good, length was suitable, and double inflow was required due to moderate stenosis. A free RITA graft was used in a most cases in group A, and it was proximally anastomosed to LITA for Y composite grafting. One of the simplest methods, our preferred technique, was to attach the RITA graft to the circumflex system targeted on the

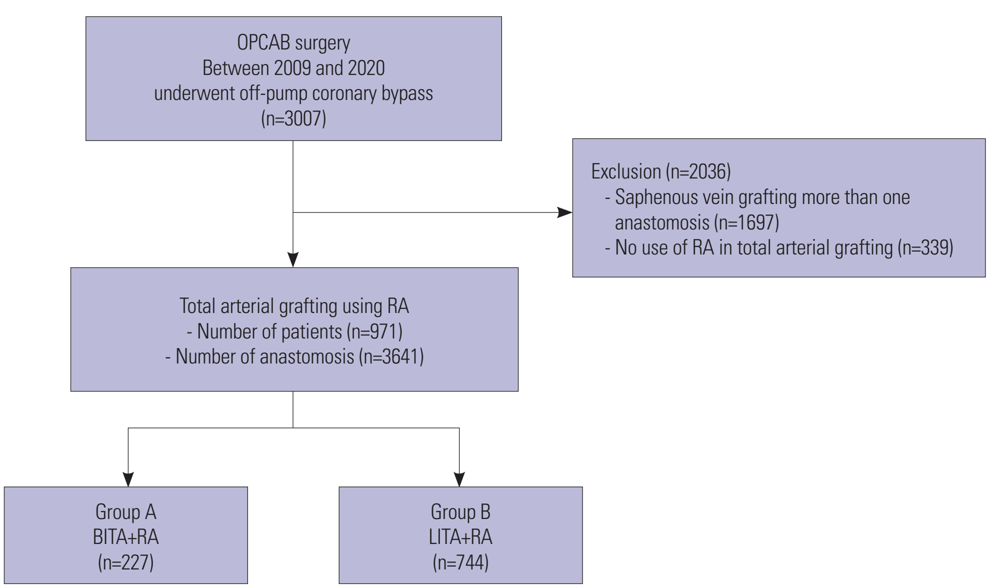

Fig. 1. Flow diagram of the study population. OPCAB, off-pump coronary artery bypass grafting; BITA, bilateral internal thoracic artery; LITA, left internal thoracic artery; RA, radial artery.

https://doi.org/10.3349/ymj.2022.0586

lateral wall of the left ventricle. With this strategy, the RITA conduit reached a circumflex branch or posterior descending artery either singly or sequentially. Arterial revascularization was completed by grafting the RA to a branch of the circumflex or right coronary system to non-LAD territory with moderate target vessel stenosis of 70% or more.[6-8]

The surgical procedure for multiple arterial grafts was performed with careful evaluation and planning by the surgeon. As a second arterial conduit for CABG as an adjust to LITA to LAD anastomosis, the RA and RITA was considered for the anterolateral wall when coronary stenosis was higher than 70%, and the RA was considered for grafting to the distal part of right coronary system when stenosis was sub-occlusive or more than 90%. Furthermore, the BITA conduit has relative contraindications, including obesity, severe airway disease, diabetes mellitus, or radiotherapy. The RA conduit has contraindications, such as: an abnormal ulnar collateral flow as judged by the Allen test, palpable or visible calcifications, trauma following recent cardiac catheterization, or preservation for vascular access to receive dialysis.

In groups A and B, total arterial reconstruction was performed in most patients using LITA to distal LAD grafting, which was supplemented by left RA or RITA grafting to the circumflex and right coronary system.[4] The use of the RA almost entirely involved aortocoronary bypass (Fig. 2). Prior to grafting, the quality of conduits was checked to ensure flushing of blood and sufficient lumen size.

Dual antiplatelet therapy (DAPT) and switching of the medication

Participants in both groups took 100 mg aspirin and 75 mg clopidogrel daily from the first postoperative day. On postoperative days 7 to 9, clopidogrel resistance was evaluated using a point-of-care assay. Among the patients with confirmed clopidogrel resistance, patients assigned to the aspirin plus clopidogrel group were switched to aspirin plus ticagrelor (90 mg twice a day without loading dose). Patients received DAPT for 1 year after OPCAB.[9,10]

Follow-up

Generally, follow-up echocardiographic evaluations were performed at day 7 and 3 months after surgery and annually thereafter in our center. Multidetector computed tomographic (MDCT) angiography was performed at 7 days, 12 months, and yearly thereafter. During follow-up, angiography was conducted in patients with angina or newly developed regional wall motion abnormality. The patency rate was graded according to the FitzGibbon classification, which grades graft patency as A (widely patent), B (flow limited), or O (occluded). For the purposes of our analysis, grades A and B were considered patent and grade O occluded. Postoperative follow-up data were collected from reviewing medical records and conducting telephone interviews. The clinical outcome data was complete in 98.6% of patients. The mean follow-up duration was 7.46±4.10 years (median 6.32 years).

Endpoints

The primary endpoint was all-cause death, and the secondary endpoint was the occurrence of a major adverse cardiovascular event (MACE). MACEs were defined as death from cardiac death, non-fatal myocardial infarction (MI), target vessel revascularization (TVR), or stroke. MI was defined as the appearance of a new regional wall motion abnormality or an elevated creatinine kinase-myocardial band isoenzyme with the appearance of new Q waves or an ST segment change of more than 2 mm on an electrocardiogram. TVR, also called repeat myocardial revascularization, was defined as any surgical or interventional revascularization performed on previously treated vessels. The tertiary endpoint was early outcomes in groups A and B during follow-up.

Statistical analysis

Data are presented as means±standard deviations or median and interquartile ranges. The Wilcoxon rank-sum test was used for continuous variables, while the χ^2 test or Fisher's exact test was used for categorical variables. Stabilized inverse probability treatment weighting (sIPTW) was used to limit confounders and balance results without decreasing the overall sample size

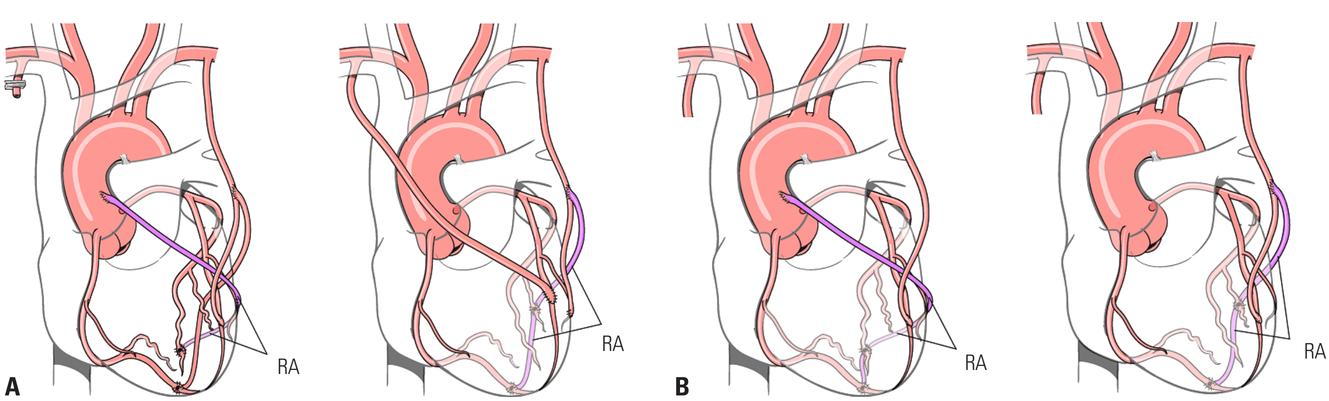

Fig. 2. Graft configuration (A) BITA+RA grafting, (B) LITA+RA grafting. BITA, bilateral internal thoracic artery; LITA, left internal thoracic artery; RA, radial artery.

https://doi.org/10.3349/ymj.2022.0586

in each group. Stabilized weights were calculated by dividing the marginal probability of the observed treatment by the propensity score for the treatment received. Baseline patient variables used in IPTW are listed in Table 1. If the standardized mean difference was less than 10%, we confirmed that the key baseline characteristics were well balanced after sIPTW.

Univariable and multivariable Cox proportional-hazards regression analyses were performed for the analysis of long-term mortality and cardiac events. In order to compare the survival data after the application of sIPTW, weighted Kaplan-Meier and weighted Cox regression analyses were performed for overall mortality and MACEs. The proportional hazard assumption was tested by Schoenfeld residuals in the original cohort. If the assumption was satisfied, the residuals were determined to be independent of time. Data were analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA) and R (version 4.1.1, R Foundation for Statistical Computing).

Table 1. Baseline Characteristics of the Propensity Score-Matched Groups

Variables	Group A BITA+RA (n=227)	Group B LITA+RA (n=744)	*p* value	SMD, %
Age, yr	60.2±8.7	61.0±7.3	0.770	2
Male sex	211 (93.0)	659 (88.6)	0.140	6
BSA, m^2	1.8±0.2	1.8±0.5	0.732	2
Smoking history	104 (45.8)	308 (41.4)	0.240	5
Hypertension	97 (42.7)	361 (48.5)	0.118	6
DM	62 (27.3)	233 (31.3)	0.273	5
CVA	20 (8.8)	74 (9.9)	0.526	4
COPD	7 (3.1)	42 (5.6)	0.064	9
PAOD	13 (5.7)	32 (4.3)	0.816	2
Dyslipidemia	88 (38.8)	305 (41.0)	0.147	6
CKD	29 (12.8)	85 (11.4)	0.443	4
Preoperative Afib	3 (1.3)	22 (3.0)	0.236	5
Prior PCI	13 (5.7)	31 (4.2)	0.264	5
Left main disease	68 (30.0)	245 (32.9)	0.380	5
Prior MI	84 (37.0)	244 (32.8)	0.101	7
LVEF ≤35%	49 (21.6)	149 (20.0)	0.733	2

BITA, bilateral internal thoracic artery; LITA, left internal thoracic artery; RA, radial artery; SMD, standardized mean difference; BSA, body surface area; DM, diabetes mellitus; CVA, cerebrovascular accident; COPD, chronic obstructive pulmonary disease; PAOD, peripheral artery occlusive disease; CKD, chronic kidney disease; Afib, atrial fibrillation; PCI, percutaneous coronary intervention; MI, myocardial infarction; LVEF, left ventricular ejection fraction.
Values are presented as means±standard deviations or n (%).

RESULTS

Clinical characteristics

The preoperative characteristics of unmatched and matched patients are summarized in Supplementary Table 1 (only online). Before intergroup balancing with sIPTW, patients in group B were older and more likely to be female. After propensity score-adjusted analysis, the demographics of both groups were comparable (Table 1). Preoperative patient comorbidities and cardiac characteristics were equally distributed between the two matched groups.

Operative data

Operative data are summarized in Supplementary Table 2 (only online). Most patients (A: 87.2%, B: 97.0%) received RA Y-grafting; sequential grafting was also commonly used (A: 75.8%, B: 81.5%). The mean operation time was longer (p=0.002), and more distal anastomoses (p=0.034) were performed in group A. The aorta no-touch technique was performed for 87.2% of patients in group A and 97.0% of patients in group B, with a significant intergroup difference (p=0.017). In group A, free RITA graft was used for only 4 patients (5.7%); the rest (94.3%) received in situ RITA anastomosis. The target vessel for the LITA was the distal LAD in groups A and B. The target vessel for the RITA was mostly the circumflex branch; in a few cases, it was the right coronary artery (n=14, 20%). Anatomical complete revascularization was achieved in 91.2% and 85.6% patients in groups A and B, respectively (p=0.179).

Early operative results

In-hospital mortality was similar between both groups for the matched populations [n=1 (0.4%) group A vs. n=21 (2.8%) group B; p=0.481]. There was no difference in the risk of bleeding or early stroke (p=0.185 and >0.999, respectively). Mechanical ventilation duration and intensive care unit and hospital stays were similar in both groups (p=0.481, 0.775, and 0.881, respectively). However, BITA grafting was associated with a higher risk of sternal wound infection than LITA grafting (group A: n=10 vs. group B: n=10; p=0.032). Detailed descriptions of the early operative results are summarized in Supplementary Table 3 (only online).

Overall survival

During the follow-up period, 5 (2.2%) and 13 (1.7%) patients died in matched groups A and B, respectively. In the non-matched population, the overall survival rate at 5 years was 94.3% and 93.5% in groups A and B, respectively (p=0.130) (Fig. 3A). After intergroup balancing with sIPTW, this value was not significantly different between the two groups (p=0.140) (Fig. 3B).

Graft patency

The median angiographic follow-up duration was 5.6 years (inter-quartile range: 4.8–6.1 years). The rate of angiographic follow-up (MDCT angiography or coronary angiography) was 94.9% (921 of 971 patients), covering 3131 of 3398 anastomoses (92.1%). In the conduits with complete angiographic follow-up, the rate of graft occlusion was 6.2% vs. 4.1% in group A and B, respectively (p=0.762).

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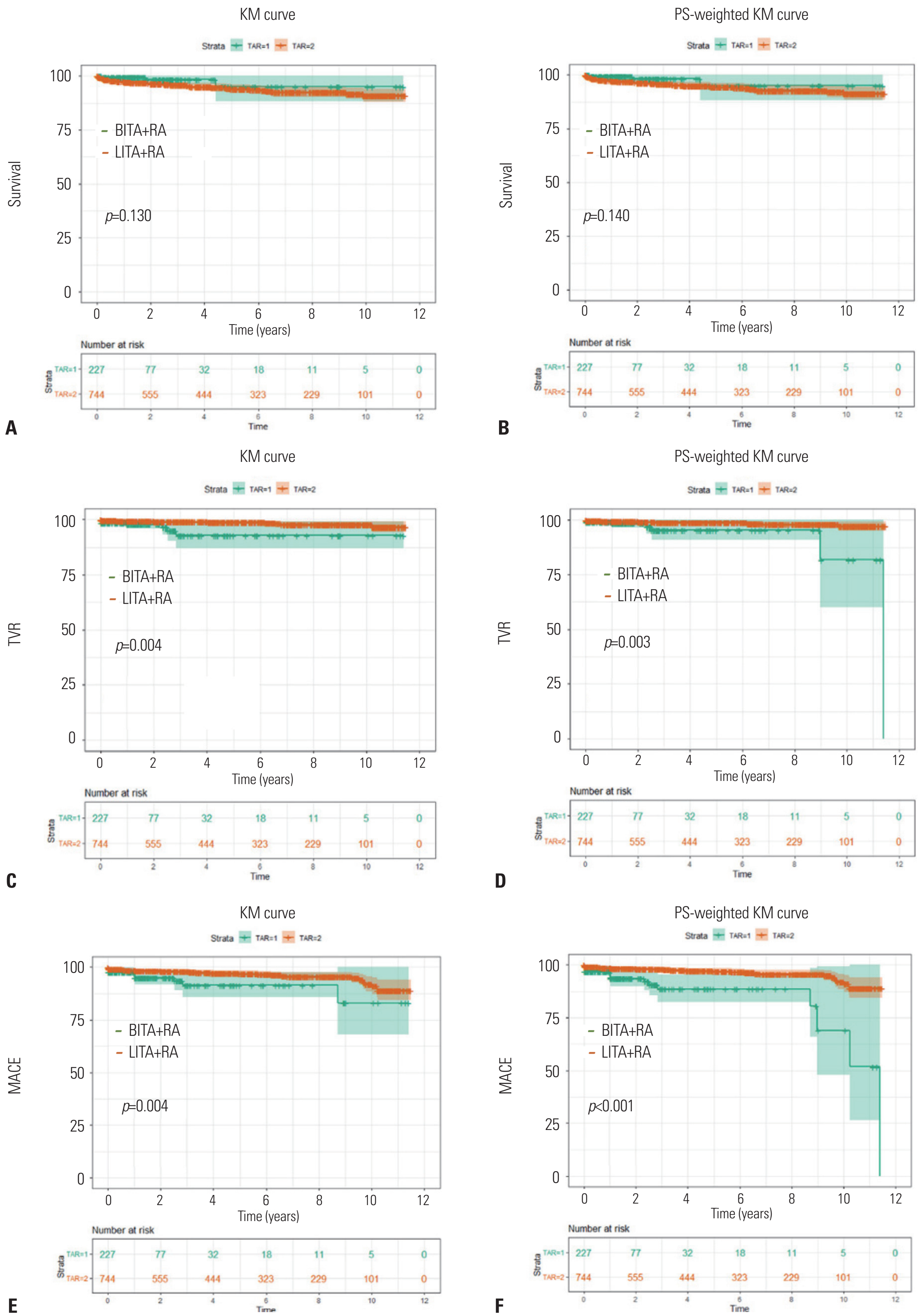

Fig. 3. Freedom from all-cause death in the (A) unmatched and (B) matched patient groups, freedom from TVR in the (C) unmatched and (D) matched patient groups, and freedom from MACEs in the (E) unmatched and (F) matched patient groups. BITA, bilateral internal thoracic artery; LITA, left internal thoracic artery; RA, radial artery; TVR, target vessel revascularization; MACE, major adverse cardiovascular event.

TVR

LITA plus RA grafting was associated with a lower rate of repeat revascularization during follow-up in the unadjusted (Fig. 3C) and adjusted group comparisons (Fig. 3D). The rate of freedom from repeat revascularization at 10 years was 81.2% [95% confidence interval (CI): 61.5–99.0%] for BITA plus RA grafting and 95.3% for LITA plus RA grafting (95% CI: 92.1–99.9%) (*p*=0.003) (Fig. 3D).

MACEs

During the follow-up period, MACEs occurred in 21 patients (8.4%) in group A and 31 (4.2%) patients in group B (*p*=0.032). MI and CABG rates were not significantly different between the two groups (*p*=0.390 and 0.214, respectively). However, percutaneous coronary intervention (PCI) was performed more frequently in group A (n=6, 2.6%) than in group B (n=4, 0.5%, *p*=0.004), and there was a significant difference between both groups in the rate of TVR (*p*=0.008). After weighted matching, the cardiac death rate was significantly higher in group A (*p*=0.015). Thus, the MACE rate was also significantly higher in group A (*p*=0.032) (Table 2).

The rate of freedom from MACEs at 10 years differed between groups A and B (*p*=0.004) (Fig. 3E). With propensity score-adjusted analysis, this rate was 68.5% in group A and 88.0% in group B, with a significant difference between the groups (*p*<0.001) (Fig. 3F).

Factors associated with TVR and MACEs

Cox univariable regression analysis showed that chronic kidney disease (CKD), history of PCI, and BITA plus RA grafting were factors associated with TVR. Multivariable analysis also found CKD [hazard ratio (HR) 1.169, 95% CI 1.002–1.963, *p*=0.034], history of PCI (HR: 1.447, 95% CI: 1.175–2.150, *p*=0.031), and BITA plus RA grafting (HR: 1.127, 94% CI: 1.070–1.990, *p*=0.047) to be significant risk factors for TVR (Table 3).

Table 2. Overall Survival and MACEs

	Group A BITA+RA (n=227)		Group B LITA+RA (n=744)		*p* value
	n (%)	95% CI	n (%)	95% CI	
All-cause death	5 (2.2)	1.9–5.7	13 (1.7)	0.6–2.9	0.033
Cardiac death	4 (1.8)	1.1–2.4	6 (0.8)	0.5–3.6	0.015
Non-cardiac death	1 (0.4)	0.2–1.9	7 (0.9)	0.2–2.7	0.001
Nonfatal myocardial infarction	6 (2.6)	1.4–4.3	6 (0.8)	0.6–3.3	0.394
Target vessel revascularization	7 (3.1)	1.9–5.6	6 (0.8)	0.5–2.6	0.070
Percutaneous coronary intervention	6 (2.6)	1.9–4.5	4 (0.5)	0.2–3.3	0.183
Coronary artery bypass graft	1 (0.4)	0.1–1.4	2 (0.3)	0.1–3.2	0.992
Stroke	4 (1.8)	0.8–3.6	13 (1.7)	1.4–4.9	0.990
Overall MACEs	21 (9.3)	6.7–11.2	31 (4.2)	2.4–6.5	0.032

MACEs, major adverse cardiovascular events; BITA, bilateral internal thoracic artery; LITA, left internal thoracic artery; RA, radial artery.

Cox univariable regression analysis demonstrated that old age (>65 years), BITA plus RA grafting, aortic anastomosis, and incomplete revascularization were independent factors associated with MACEs. BITA plus RA grafting (HR: 1.3, 95% CI: 1.05–2.37, *p*=0.025) and incomplete revascularization (HR: 1.2, 95% CI: 0.70–2.15, *p*=0.046) remained significant risk factors for MACEs in multivariable Cox regression analysis (Table 4). The proportional hazard assumption was not violated for the explored outcomes in any of the comparisons (Supplementary Fig. 1, only online).

DISCUSSION

The most important finding of this study was that OPCAB with three arteries, including the RITA, was not associated with de-

Table 3. Multivariable Cox Proportional Hazards Regression Analysis for TVR

Variables	Univariable	Multivariable		
	p value	HR	95% CI	*p* value
Age >65 years	0.272			
Male sex	0.979			
DM	0.016	1.192	0.728–1.884	0.114
CKD (Grade III–IV)	0.004	1.169	1.002–1.963	0.034
Low LVEF (≤35%)	0.514			
LM disease	0.395			
Previous PCI history	0.028	1.447	1.175–2.150	0.031
Recent myocardial infarction	0.175			
BITA+RA	0.040	1.127	1.070–1.990	0.047
Aorta anastomosis of RA	0.745			
Incomplete revascularization	0.172			

TVR, target vessel revascularization; DM, diabetes mellitus; CKD, chronic kidney disease; LVEF, left ventricular ejection fraction; LM, left main coronary artery; PCI, percutaneous coronary intervention; BITA, bilateral internal thoracic artery; RA, radial artery; HR, hazard ratio; CI, confidence interval.

Table 4. Multivariable Cox Proportional-Hazards Regression Analysis for MACEs

Variables	Univariable	Multivariable		
	p value	HR	95% CI	*p* value
Age >65 years	0.049	1.4	1.11–3.26	0.173
Male sex	0.674			
DM	0.170			
CKD (Grade III–IV)	0.146			
Low LVEF (≤35%)	0.185			
LM disease	0.265			
Previous PCI history	0.978			
BITA+RA used	0.011	1.3	1.05–2.37	0.025
Aorta anastomosis of RA	0.075	1.6	0.10–2.54	0.084
Incomplete revascularization	0.053	1.2	0.70–2.15	0.046

MACEs, major adverse cardiovascular events; DM, diabetes mellitus; CKD, chronic kidney disease; LVEF, left ventricular ejection fraction; LM, left main coronary artery; PCI, percutaneous coronary intervention; BITA, bilateral internal thoracic artery; RA, radial artery; HR, hazard ratio; CI, confidence interval.

https://doi.org/10.3349/ymj.2022.0586

creased TVR or MACE rates. Moreover, compared with conventional LITA plus RA grafting, the use of an additional arterial conduit was associated with a higher risk of MACEs. Therefore, this study presented conflicting reports regarding the association of tertiary arterial grafts with better outcomes than those with two arterial grafts.

BITA plus RA grafting has been shown to provide better patency rates than SVG, particularly for the left coronary artery system. More recently, Rocha, et al.[11] reported that CABG with three arterial grafts, compared to CABG with two arterial grafts, was not associated with fewer major adverse cardiac and cerebrovascular events (MACCEs) or improvements in survival or other clinical outcomes. Our study focused on the use of BITA plus RA versus LITA plus RA in total arterial grafting and showed that LITA plus RA grafting was associated with a lower risk of MACEs. Most importantly, the TVR rate was significantly 1ower in the LITA plus RA group than in the matched BITA plus RA group.

In a previous randomized study comparing RA with free RITA grafting and RA with SVG, the 10-year patency rate for RA was significantly better than that for the free RITA. It suggested that the RITA has a thinner wall than the RA, so it was possibly more fragile and technically more complex to use.[12] Similarly, our results could be attributed to biological differences between grafts.

Taggart, et al.[3] showed that the use of an additional RA graft to supplement both single internal thoracic artery and BITA grafts was associated with a lower risk of MACEs at 5 years. Furthermore, our analysis of early and late outcomes showed that the use of an additional internal thoracic artery was associated with a lower risk of MACCEs during 8 years of follow-up, and this result was seen when the RITA was used to graft both the left (80%) and right (20%) coronary systems.

In the present study, complete revascularization was defined anatomically by the number of the three major vessels (or their branches) that received a bypass graft. An average of 3.5 distal anastomoses were performed in our propensity-score adjusted population. In a previous study, patients with severe angina in whom more complete revascularization was performed showed improved survival (risk ratio 0.87, 95% CI 0.78–0.96, p=0.01).[13] A sub-analysis revealed a significant survival benefit in patients with significant left ventricular dysfunction with multiple vessels bypassed (p=0.04). Our findings are consistent with those of Ong and Serruys[13] who showed that incomplete revascularization was an independent risk factor for MACCEs (HR 1.2, 95% CI 0.70–2.15, p=0.046).

Surprisingly, additional arterial grafting was not associated with a survival benefit. A multiple arterial graft strategy is usually adopted for young patients with low risk and prolonged life expectancy. Our study included patients younger than those seen in the average CABG population in other studies. Furthermore, in the present study, after propensity score-adjusted analysis, the mean age of patients was 60.6 years. Benedetto, et al. showed that the beneficial impact of total arterial grafting on survival may be delayed by as much as 7 to 10 years, although it persists beyond that period.[14-17] However, our follow-up period was less than10 years; therefore, a longer follow-up may be required for future studies.

The effects of using the RA and SV as second or third conduits are unclear with regard to long-term outcomes. Small series have reported on the direct comparison of the RA and SV in addition to BITA, with inferior survival outcomes in the BITA plus RA groups.[18,19] Mohammadi, et al.[20] reported comparable long-term survival in matched pairs of patients undergoing BITA plus RA versus BITA plus SV grafting. Recently, Benedetto, et al.,[21] in a large matched series, reported that the use of the RA as a third arterial conduit, instead of an SV graft plus additional BITA grafting, showed comparable operative outcomes. In our study, all patients that received RA grafting showed non-inferior survival at 5 years compared to other study results. We found that the use of the RA did not increase the operative risk or decrease early and late survival rates; therefore, it fulfilled the current recommendations for the use of the RA.

This study was limited by its retrospective design. Therefore, selection bias or unidentified confounding factors may have influenced the results. However, we attempted to minimize the bias by using multivariable regression analysis with propensity score-adjusted analysis. Furthermore, this study had a relatively small population and short follow-up period; the 7-year mean follow-up period was relatively short. Thus, the influence of BITA grafting on long-term clinical outcomes should be further evaluated. Moreover, the conduit strategy was dependent on the surgeon's personal experience. However, in our institution, two specialized coronary vascular surgeons with more than 10 years of experience as independent operators as well as experience with more than 200 cases per year performed the surgeries; therefore, their surgical skills, including those for OPCAB, did not vary widely. This ruled out operator-related bias. Finally, since different RITA configurations were allowed (in situ, Y composite, or free graft), the type of configuration was a possible bias and hidden confounder between conduits. This may have resulted in limited comparability. However, in the long-term results of the RAPCO trials,[12] only the aortocoronary configuration was used to maximize comparability between conduits, and they also reported that the RA was significantly better than the free RITA; furthermore, the estimated 10-year patency was 89% for the RA versus 80% for free RITA (HR: 0.45, 95% CI: 0.23–0.88).

In conclusion, reasons for the limited use of BITA grafts include longer operating times, technical challenges, and the risk of sternal wound infection. Moreover, BITA plus RA grafting resulted in higher MACE rates compared to LITA plus RA grafting in TAR. Furthermore, complete revascularization improved late outcomes following LITA plus RA grafting, despite less anastomosis. Therefore, the optimization of TAR by considering the benefits of LITA plus RA grafting seems necessary.

ACKNOWLEDGEMENTS

The author would like to thank Dong-su Jang and MFA (medical illustrator) for helping with the illustrations.

AUTHOR CONTRIBUTIONS

Conceptualization: Hyo-Hyun Kim. Data curation: Hyo-Hyun Kim. Formal analysis: Hyo-Hyun Kim. Investigation: Hyo-Hyun Kim. Methodology: Hyo-Hyun Kim. Project administration: Hyo-Hyun Kim and Young-Nam Youn. Resources: Hyo-Hyun Kim. Software: Hyo-Hyun Kim. Supervision: Kyung-Jong Yoo and Young-Nam Youn. Validation: Hyo-Hyun Kim. Visualization: Hyo-Hyun Kim. Writing—original draft: Hyo-Hyun Kim. Writing—review & editing: Hyo-Hyun Kim, Kyung-Jong Yoo, and Young-Nam Youn. Approval of final manuscript: all authors.

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REFERENCES

1. Boylan MJ, Lytle BW, Loop FD, Taylor PC, Borsh JA, Goormastic M, et al. Surgical treatment of isolated left anterior descending coronary stenosis. Comparison of left internal mammary artery and venous autograft at 18 to 20 years of follow-up. J Thorac Cardiovasc Surg 1994;107:657-62.
2. Schmitto JD, Rajab TK, Cohn LH. Prevalence and variability of internal mammary graft use in contemporary multivessel coronary artery bypass graft. Curr Opin Cardiol 2010;25:609-12.
3. Taggart DP, Altman DG, Flather M, Gerry S, Gray A, Lees B, et al. Associations between adding a radial artery graft to single and bilateral internal thoracic artery grafts and outcomes: insights from the arterial revascularization trial. Circulation 2017;136:454-63.
4. Buxton BF, Hayward PA. The art of arterial revascularization-total arterial revascularization in patients with triple vessel coronary artery disease. Ann Cardiothorac Surg 2013;2:543-51.
5. Kim JH, Lee SH, Joo HC, Yoo KJ, Youn YN. Repeated target vessel revascularization after coronary artery bypass for in-stent restenosis. Ann Thorac Surg 2017;104:1332-9.
6. Kim WS, Lee J, Lee YT, Sung K, Yang JH, Jun TG, et al. Total arterial revascularization in triple-vessel disease with off-pump and aortic no-touch technique. Ann Thorac Surg 2008;86:1861-5.
7. Yan TD, Vallely MP. Aortic no-touch off-pump coronary artery bypass grafting: a state-of-the-art surgical technique. Ann Thorac Surg 2010;90:1392-3.
8. Ross DE. Anaortic coronary bypass surgery. Semin Thorac Cardiovasc Surg 2012;24:90-2.
9. Youn YN, Yi G, Lee S, Joo HC, Yoo KJ. Posttreatment platelet reactivity on clopidogrel is associated with the risk of adverse events after off-pump coronary artery bypass. Am Heart J 2014;167:818-25.
10. Brar SS, ten Berg J, Marcucci R, Price MJ, Valgimigli M, Kim HS, et al. Impact of platelet reactivity on clinical outcomes after percutaneous coronary intervention. A collaborative meta-analysis of individual participant data. J Am Coll Cardiol 2011;58:1945-54.
11. Rocha RV, Tam DY, Karkhanis R, Nedadur R, Fang J, Tu JV, et al. Multiple arterial grafting is associated with better outcomes for coronary artery bypass grafting patients. Circulation 2018;138:2081-90.
12. Buxton BF, Hayward PA, Raman J, Moten SC, Rosalion A, Gordon I, et al. Long-term results of the RAPCO trials. Circulation 2020;142:1330-8.
13. Ong AT, Serruys PW. Complete revascularization: coronary artery bypass graft surgery versus percutaneous coronary intervention. Circulation 2006;114:249-55.
14. Benedetto U, Amrani M, Raja SG; Harefield Cardiac Outcomes Research Group. Guidance for the use of bilateral internal thoracic arteries according to survival benefit across age groups. J Thorac Cardiovasc Surg 2014;148:2706-11.
15. Benedetto U, Codispoti M. Age cutoff for the loss of survival benefit from use of radial artery in coronary artery bypass grafting. J Thorac Cardiovasc Surg 2013;146:1078-84.
16. Kieser TM, Lewin AM, Graham MM, Martin BJ, Galbraith PD, Rabi DM, et al. Outcomes associated with bilateral internal thoracic artery grafting: the importance of age. Ann Thorac Surg 2011;92:1269-75.
17. Mohammadi S, Dagenais F, Doyle D, Mathieu P, Baillot R, Charbonneau E, et al. Age cut-off for the loss of benefit from bilateral internal thoracic artery grafting. Eur J Cardiothorac Surg 2008;33:977-82.
18. Di Mauro M, Contini M, Iacò AL, Bivona A, Gagliardi M, Varone E, et al. Bilateral internal thoracic artery on the left side: a propensity score-matched study of impact of the third conduit on the right side. J Thorac Cardiovasc Surg 2009;137:869-74.
19. Grau JB, Kuschner CE, Johnson CK, Ferrari G, Zapolanski A, Brizzio ME, et al. The effects of using a radial artery in patients already receiving bilateral internal mammary arteries during coronary bypass grafting: 30-day outcomes and 14-year survival in a propensity-matched cohort. Eur J Cardiothorac Surg 2016;49:203-10.
20. Mohammadi S, Dagenais F, Voisine P, Dumont E, Charbonneau E, Marzouk M, et al. Impact of the radial artery as an additional arterial conduit during in-situ bilateral internal mammary artery grafting: a propensity score-matched study. Ann Thorac Surg 2016;101:913-8.
21. Benedetto U, Caputo M, Zakkar M, Bryan A, Angelini GD. Are three arteries better than two? Impact of using the radial artery in addition to bilateral internal thoracic artery grafting on long-term survival. J Thorac Cardiovasc Surg 2016;152:862-9.e2.

https://doi.org/10.3349/ymj.2022.0586