Radial-artery vs saphenous-vein grafts for sequential coronary bypass grafting as a second conduit for the left coronary territory

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Abstract

Objective

Although the radial artery graft has an adaptive property to flow demand, its flow characteristics in aorto-coronary sequential bypass grafting are not well elucidated. We evaluated the differences between the vein and radial artery grafts in the patency and the transit time flow meter-derived parameters (flow and pulsatile index), according to the stenosis rate of terminal target vessels and the number of anastomoses, in sequential bypass grafting to the left coronary territories as a second conduit.

Methods

We analyzed 222 patients who underwent isolated on pump beating coronary artery bypass grafting with an aorto-coronary bypass to the left coronary territory. The patients were divided into radial artery group (n=154) and vein graft group (n=68). Sequential bypass was performed 1n 171 patients (127 radial arteries, 44 veins).

Results

Flow of the radial artery grafts was lower than that of the vein grafts (40.9 ± 22.3 vs 47.5 ± 23.8 mL/min, p=0.044), while it became higher as the number of anastomoses per graft increased (1: 28.9 ± 16.3 vs 2: 40.9 ± 19.9 vs 3: 55.8 ± 27.5, p<0.001). The patency of radial artery grafts was better than that of vein grafts (98.0% vs 92.6%, p=0.010; p<0.001 after propensity score weighting).

Conclusions

Although intraoperative flow rate of the radial artery graft is lower, it has sufficient flow reserve for sequential bypass grafting, and its early patency is high enough. Radial artery is suitable for sequential bypass grafting to the left coronary territories as a second arterial conduit.

Introduction

In multivessel coronary artery disease, controversy still exists about the optimal graft as a second conduit to achieve complete myocardial revascularization. Despite the recommendation for its use [1, 2], bilateral internal thoracic arteries grafting is underutilized because it may not be suitable for the patients with diabetes and is accompanied by technical complexity [3, 4].

The radial artery (RA), with its suitable length and diameter, can be used as a free graft and reported to be an appropriate conduit for sequential bypass to maximize arterial grafting [5, 6]. The use of RA compared with the saphenous vein graft (SVG) was associated with similar ease of handling, lower rate of adverse cardiac events and a higher rate of patency [7, 8, 9]. The evidence level is high because several meta-analyses of the randomized control trials showed its superiority [7, 8, 9]. Preserved flow-mediated vascular reactivity of the RA grafts, a feature not found in SVGs, may partly explain the more favorable patency of RA grafts over SVGs [10]. On the other hand, RA grafts have a concern that the patency rate is significantly influenced by the stenosis rate of the native coronary arteries [11].

Sequential bypass grafting is known to improve patency due to the increased distal run-off [12]. With SVG, sequential bypass grafts have been reported to be associated with higher mean flow assessed by the intraoperative transit time flow meter (TTFM) and superior mid-term patency compared with the individual grafts [13]. In performing sequential bypass grafting, the target vessel stenosis and graft arrangement are crucial factors influencing the graft patency [5]. Several reports

have shown that sequential RA grafts were associated with better mid-term and long-term patency compared with the individual RA grafts [5, 14]. However, information regarding the intraoperative flow and early graft patency are scarce, although the flow-mediated reactivity is considerably different between RA grafts and SVGs.

The objective of this study is to elucidate the differences between RA grafts and SVGs in the postoperative early patency rate, intraoperative mean graft flow rate (Qm), and pulsatile index (PI), examined by the TTFM, according to the stenosis rate of the terminal target vessels and the number of anastomoses, in the setting of sequential bypass grafting to the left coronary territories other than left anterior descending artery (LAD).

Subjects

From the day TTFM was introduced into our hospital (July 2011) to August 2017, a total of 242 patients underwent isolated on pump beating coronary artery bypass grafting (CABG) with an aorto-coronary bypass graft to the left coronary territory in addition to the left internal thoracic artery (LITA) to LAD. After excluding 7 patients who did not undergo postoperative coronary evaluation, 12 patients who underwent sequential bypass grafting covering both the left and right coronary territories, and 1 patient who underwent T-composite bypass grafting, 222 patients were retrospectively analyzed. The reason for no postoperative coronary evaluation in the 7 patients was

renal dysfunction in all patients. CABG was performed by four surgeons. Preoperative coronary angiography was performed in all patients and the stenosis rate of the vessels was assessed by experienced interventional cardiologists who performed angiography. Stenosis rate of the terminal target for sequential bypass grafting was obtained. All patients underwent echocardiography preoperatively and no patient had additional significant valvular pathology. Clinical information was obtained from the patient charts. This study was approved by the institutional review board (21-294), and waiver of informed consent was granted as this study was a retrospective analysis of collected data for routine care.

Methods

Surgical technique

On pump beating CABG was performed through a full median sternotomy under general anesthesia in all cases. All arterial grafts were harvested in a skeletonized fashion with an ultrasonic scalpel (Harmonic Scalpel; Ethicon Endo-Surgery, Inc, Blue Ash, Ohio). Milrinone solution (50 mg/L) was injected into the RA grafts and preserved in a heparinized normal saline solution. SVGs were harvested in the conventional open technique and were stored in a normal saline solution. The LITA was always anastomosed first to LAD in an end-to-side fashion with 8-0 polypropylene suture. In sequential bypass grafting, terminal side-to-end anastomosis was performed with 7.5-0

polypropylene running suture, followed by side-to-side anastomoses toward the proximal portion of the graft. Side-to-side anastomoses were constructed in the diamond-shape with a 7.5-0 polypropylene suture in most cases. The proximal anastomosis was constructed on to the ascending aorta with a continuous 6-0 polypropylene suture using the Enclose II device (Péters Surgical, Bobigny, France). After the completion of all anastomoses and the cardiopulmonary bypass discontinuation, we routinely assessed Qm (mL/min) and PI between the aorta and the first side-to-side anastomosis using a TTFM equipment (HT-353, Nihon Kohden, Tokyo, Japan). PI was automatically calculated by the flowmeter according to the following formula: (maximum flow - minimum flow) / mean flow.

Postoperative management and follow-up

All patients were postoperatively treated with oral aspirin, nicorandil, beta-blockers, and statins unless contraindicated. Patients who received the RA graft were routinely given intravenous diltiazem perioperatively, followed by oral administration, to prevent spasm. Postoperative graft patency was evaluated before discharge by electrocardiogram-gated multi-slice computed tomography or coronary angiography. Graft failure was defined as non-visualization or poor stringy visibility of the graft. In the sequential grafts, each anastomotic segment was regarded as a separate bypass graft. If a single distal segment of a sequential graft showed non-visualization, only the anastomosis represented by that segment was regarded as being occluded, and other visualized

segments were considered as being patent. Patency rate (%) was defined as 100 x (total number of anastomotic sites - total number of anastomotic sites with stenosis or occlusion) / total number of anastomotic sites. Complete revascularization was defined as the treatment of any lesion with more than 50% stenosis in vessels ≥1.5 mm as estimated on the diagnostic coronary angiogram during the local heart team conference [2].

Statistical analyses

All statistical analyses were performed with the SPSS software version19.0 (IBM, Armonk, NY, USA). Comparisons between the two groups were made using the Chi-square or Fisher's exact test for categorical variables. The Student's t-test was used for continuous variables that followed a normal distribution, and the Mann-Whitney test for those not following a normal distribution. To compare the mean values of three or more groups, the one-way analysis of variance test was used for the data following a normal distribution, and the Kruskal-Wallis test for the data not following a normal distribution. Dunn's nonparametric comparison was used as a multiple comparison test. A p-value less than 0.05 was considered statistically significant. Continuous variables were expressed in means ± standard deviations. Categorical variables were reported as frequencies and percentages.

To reduce the impact of graft selection bias and potential confounders in the comparison of patency between the RA grafts and SVGs, inverse probability of treatment weighting (IPTW) using propensity score (PS) was employed. PS was calculated using the logistic regression model that

incorporated all the baseline variables listed in Table 1. Since no RA grafts were used for patients on hemodialysis, these patients were excluded from the IPTW analysis. The Hosmer–Lemeshow test was used to assess the goodness of fit for the logistic regression model. Balance between the groups after weighting was assessed using standardized mean differences (SMDs). An absolute standardized difference of ≤ 0.1 was considered to indicate ideal balance and that of ≤ 0.2 was considered to indicate acceptable balance [15].

Results

The age of patients was 68.5 ± 9.5 years and 174 (78.4%) were men. The patients were divided into the RA group (n=154) and the SVG group (n=68). The SVG group was significantly older with emergent operation and renal dysfunction more prevalent than the RA group (Table 1). Operative data were described in Table 2. The number of coronary anastomoses per patient was 3.9 ± 1.1. Complete revascularization was achieved in 220 patients (99.1%). Sequential bypass grafting was performed in 171 (77.0%) cases. Patients in the RA group were more likely to receive sequential bypass grafting with multiple anastomoses.

The p-value of Hosmer-Lemeshow goodness-of-fit test for the propensity score model was 0.623, indicating no evidence of poor fit. After IPTW, the balances between the 2 groups were acceptable, except for those in hypertension, diabetes mellitus, renal dysfunction, and the history of

percutaneous coronary intervention (PCI) (Table 1). Of note, 3 of the 4 unmatched factors were well balanced in the original cohort.

RA grafts vs SVGs

RA grafts showed significantly lower Qm than the SVGs (40.9 ± 22.3 vs 47.5 ± 23.8 mL/min, p=0.044), while PI was comparable (1.8 ± 0.7 vs 1.9 ± 0.7, p=0.533). The patency rate was significantly higher in the RA grafts than in SVGs (295/301, 98.0% vs 112/121, 92.6%, p=0.010). The stenosis rate of terminal target vessels was comparable (89.3 ± 8.7 vs 87.1 ± 11.9, p=0.215). After IPTW, the difference in patency remained highly significant; RA grafts 97.9% vs SVGs 83.4% (p<0.001, odds ratio=9.445, 95% confidence interval 4.459-20.008).

Effects of sequential bypass grafting

Sequential grafts showed a significantly higher Qm and lower PI than the individual grafts (Qm: 47.5 ± 23.5 vs 32.0 ± 17.4, p < 0.001, PI: 1.7 ± 0.5 vs 2.1 ± 0.9, p = 0.001). There were no significant differences in the early graft patency rate (343/355, 96.6% vs 64/67, 95.5%, p=0.435) and the stenosis rate of terminal target vessels (89.5 ± 7.8% vs 86.4 ± 13.6%, p=0.334) between the two groups.

When the sequential grafts were divided into those with 3 coronary anastomoses (n=33) and those with 2 (n=128), Qm of the grafts with 3 anastomoses was significantly higher than that of the grafts with 2 anastomoses (57.2 ± 26.3 vs 45.0 ± 22.1 mL/min, p =0.034), while PI was comparable (1.7 ±

0.5 vs 1.7 ± 0.5, p=1.000). There were no significant differences in the early graft patency rate (97/99, 98.0% vs 246/256, 96.1%, p=0.303). The stenosis rate of terminal target vessels was 92.2 ± 6.2% for those with 3 coronary anastomoses and 88.8 ± 8.0% for those with 2 (p=0.086).

Influence of grafted territories

Target vessels for the RA grafts and SVGs were described in Table 3. Covered territories were similar between the RA group and SVG group for individual bypass and sequential bypass with 2 coronary anastomoses, while sequential bypass with 3 coronary anastomoses was predominantly used in the RA group.

The design of sequential bypass grafting with 2 coronary anastomoses was classified into 3; that covering the obtuse marginal and postero-lateral branches (C-C design; n=45), that covering the diagonal and obtuse marginal / postero-lateral branches (D-C design; n=77), and that covering the diagonal branches (D-D design; n=6). There were no significant differences in the early graft patency, Qm, and PI among the 3 groups (Figure 1). The stenosis rate of terminal target vessels was also comparable (C-C: 88.8± 7.6%; D-C: 88.9 ± 8.5%; D-D: 88.3 ± 4.1%, p=0.894).

Differences in the effects of sequential bypass grafting between RA grafts and SVGs

Early graft patency, Qm, and PI of the RA grafts and SVGs according to the number of coronary anastomoses per graft were shown in Figure 2. There was a significant difference in the early graft patency of the sequential grafts with 2 coronary anastomoses between the RA grafts and SVGs,

differences in Qm between the individual RA and double RA, individual RA and triple RA, individual SVG and double SVG, and double RA and double SVG. There were no significant differences in the PI. Stenosis rate of the terminal target vessels were comparable (RA grafts: 87.6 ± 11.2% for the individual grafts, 88.8 ± 8.1% for the sequential grafts with 2 coronary anastomosis, and 93.1 ± 5.8% for the sequential grafts with 3 coronary anastomoses; SVGs: 85.1 ± 15.9% for the individual grafts, 88.7 ± 7.9% for the sequential grafts with 2 coronary anastomosis, and 87.0 ± 6.7% for the sequential grafts with 3 coronary anastomosis). After IPTW, the difference between the RA grafts and SVGs in the patency of the sequential grafts with 2 coronary anastomoses remained highly significant (RA grafts 98.2% vs SVGs 76.4%, $p<0.001$, odds ratio 16.734, 95% confidence interval 5.979-46.832.

Discussion

The hemodynamics of the sequential vein grafts have been reported to be superior to the individual vein grafts [12, 13]. Previous studies have investigated the intraoperative flow characteristics of sequential SVGs by TTFM and reported their effects on graft patency [13, 16]. Kim et al. [13] reported that the sequential SVGs compared with the individual SVGs showed a higher mean flow with a superior mid-term patency. They also reported that as the number of anastomoses per graft increased, the mean flow increased linearly, while the PI decreased in a commensurate manner. In

the present study, the sequential grafts showed significantly greater mean flow and lower PI than the individual grafts, and the mean flow of RA grafts increased proportionately to the number of anastomoses. These results were consistent with the previous studies on SVGs and showed that the hemodynamic superiority of sequential bypass is also true for the RA grafts. Interestingly, this hemodynamic superiority of the sequential grafts was not associated with better early patency in the present study. This may be explained by the fact that 8/12 of the occluded anastomoses on the sequential grafts were found on the terminal end-to-end anastomosis, and only two side-to-side anastomoses were occluded without concomitant occlusion of terminal anastomosis (data not shown). Since graft flow immediately before the terminal anastomosis is not increased by sequential bypass grafting, its patency seems to have depended on the quality of anastomosis and run off of the final target vessel.

Although the flow-mediated vascular reactivity measured in the long-term has been reported to be preserved in the RA grafts but not in SVGs [10], no study evaluated the difference in intraoperative flow characteristics between the two grafts in aorto-coronary sequential bypass grafting. Intraoperative flow reserve depends on several factors including the flow-mediated vasodilation (endothelium-dependent) and the drugs directly acting on the vascular smooth muscles. The endothelial function may also be temporarily affected by operative maneuvers during harvesting, preservation, and anastomosis. Therefore, flow reserve of the RA grafts during surgery may be

considerably different from those measured in the long-term. Concerning the early graft patency and the sufficiency of perioperative myocardial blood supply, it is important to know the graft flow reserve per se, as a net effect of several contributing factors including the flow-mediated vasodilation. The majority of previous studies have focused on the flow reserve of the composite LITA-RA graft design [17, 18], which primarily depends upon the flow capacity of LITA. By evaluating the influence of the number of anastomoses per graft on the flow of aorto-coronary sequential grafts, we were able to evaluate it independently from the capacity of inflow artery. We showed that flow through the RA grafts increased proportionately to the number of anastomoses, although flow itself was lower than that of SVGs. This means that RA grafts had a flow reserve that was sufficient to fulfill the need of sequential bypass grafting, and the low flow rate did not result from a limited flow capacity but reflected the low flow demand; a finding consistent with the preserved vascular reactivity of the RA grafts.

Concerning the aorto-coronary individual grafts, intraoperative flow of the RA grafts has generally been shown to be lower than that of SVGs [19, 20]. Our results were consistent with these reports. However, some authors reported controversial results [21, 22], which may partly be explained by the difference in the technique of graft harvesting, graft preparation, and CABG. Santarpino et al. reported that RA grafts showed higher Qm and lower PI than SVGs in the circumflex territory [22]. They used pedicled RA grafts but did not show the detail of graft preparation, such as the use of

high-pressure distention, to reverse the spasm that was anticipated in the pedicled technique [23]. Ennker et al. reported that Qm and PI after conventional CABG were not different between the two grafts [21]. Coronary flow demand after conventional CABG with cardiac arrest should be increased as a consequence of global myocardial ischemia, which may have resulted in vasodilation of RAs to meet the increased demand. In our study, CABG was performed on the empty beating heart with the use of intraluminal shunts, so that energy debt during revascularization should have been minimum. As a result, coronary flow demand was not as high as that in the Ennker' study.

Several authors have shown that sequential RA grafts are associated with better mid-term and long-term patency [5, 6, 14, 24]. Adaptive property of RA grafts to maintain flow velocity seems to play a role in this regard because high blood flow velocity and increased wall shear stress have been reported to have a positive influence in preventing the development of intimal hyperplasia and subsequent arteriosclerosis of the graft, which are responsible for late graft failure [13, 15, 25]. The result of the present study that RA grafts had higher patency despite the lower flow rate than the SVGs suggests that adaptive property of RA grafts may also be beneficial to early graft patency by maintaining flow velocity when the target vessels have low flow demand.

Competitive flow has been recognized as one of the main causes of graft failure, especially for the RA grafts that has the adaptability to flow demand [26]. The degree of stenosis in the native coronary artery significantly influences the patency rate [11, 27, 28] and grafting to a coronary artery

with a low-grade stenosis increases the risk of competitive flow [11]. Because the severity of native artery stenosis may be variable among the target vessels of a sequential graft, one may anticipate that the patency rate drops as the number of anastomoses per graft increases. In the present study, the patency rate of sequential grafting was not affected by the number of anastomoses per graft. This may be because we selected a coronary artery with a high-grade stenosis as the final target vessel. Nakajima et al. [27] reported that in the sequential RA grafts, severity of stenosis in the most distal target has a significant impact on the competitive flow and long-term patency in all targets. Their results support our speculation.

In the SVGs, on the other hand, the effect of competitive flow has been reported to be less significant and the patency of the SVGs has been suspected to be poorly associated with the native coronary stenosis [25]. In the present study, the stenosis rate of the terminal target vessels was high enough and comparable between the RA grafts and SVGs, and between the individual grafts and sequential grafts. Therefore, target vessel stenosis does not seem to have influenced the observed differences in the patency rate.

The run-off of the target coronary artery is another powerful determinant of the graft patency [26]. Several investigators have reported that, with the most distal target of a sequential graft having the greatest flow reserve and a good run-off, the proximal segment would benefit from the increased blood flow rate throughout the entire conduit resulting in superior graft patency [12, 13, 16, 29]. The

distal run-off is the cumulative blood flow in the post-stenotic region of target vessels [16]. LAD have the largest run-off followed by the diagonal and the obtuse marginal branches of the left coronary artery [26]. The right coronary artery (RCA) has the lowest run-off limited by the thin right ventricular myocardium [26]. Achouh et al. [14] reported that RA graft patency was higher for the diagonal branches compared to the circumflex branches and RCA. In the present study, only the grafts to the left coronary territories were evaluated and no differences in Qm and patency were observed among the three graft designs (C-C, D-C, and D-D). Therefore, it is also unlikely that the observed differences in Qm and patency rate were affected by the grafted territories.

Study limitations

This study was limited by the inherent disadvantages of the retrospective single-center design. The results may be highly susceptible to the technique of graft harvesting and preparation, such as the no-touch technique for SVGs and the use of different instruments for skeltonization of the RAs. Qm may also be considerably different among the patients undergoing off pump CABG, conventional CABG on the arrested heart [19], and on pump beating CABG. Therefore, the results may not be applicable when a different operation technique is employed, as stated in the discussion section. The patient's background was considerably different between the RA and SVG group, reflecting our graft selection policy of using RA grafts for younger patients and avoiding its use in patients with end-stage renal disease or in emergency settings. Although IPTW was employed to reduce the graft

selection bias, the 2 groups were not well balanced in several aspects. These factors, together with other potential confounding factors that were not evaluated, may have contributed to the observed difference in the patency rate. Finally, since long-term outcomes were not investigated, whether the present results could be reflected in the long-term benefits remains to be determined. However, the finding that RA graft flow increased proportionately to the number of coronary anastomoses does not seem influenced by such limitations, suggesting the sufficient flow reserve for sequential bypass and preserved vascular reactivity of the RA grafts. Together with its sufficiently high early patency rate, preserved reactivity to flow demand may have a positive impact on the long-term patency of RA grafts.

Conclusions

RA grafts have sufficient flow reserve for sequential bypass grafting. Early patency rate of the sequential RA grafts is high enough, although intraoperative flow rate is lower than the sequential SVGs, presumably because of its adaptive properties to the flow demand. RA is suitable as a conduit for sequential bypass grafting to the left coronary territories as a second arterial conduit.

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2 Compliance with ethical standards

3 Conflict of interest: All authors have no conflicts of interest to report.

4 Ethical approval: The study was approved by the institutional review board of Hamamatsu

5 University School of Medicine (21-294).

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Figure legends

Figure 1. Early graft patency rate (a), mean bypass graft flow (b), and pulsatile index (c) of the sequential bypass graft with 2 coronary anastomoses according to the grafted territories.

Data are shown in mean ± standard deviation.

Qm: mean bypass flow, PI: pulsatile index, CC: sequential bypass grafting to 2 branches of the circumflex coronary artery, DC: sequential bypass grafting to a diagonal branch and a branch of the circumflex coronary artery, DD: sequential bypass grafting to 2 diagonal branches

Figure 2. Early graft patency rate (a), mean bypass graft flow (b), and pulsatile index (c) of the radial artery grafts and saphenous vein grafts according to the number of coronary anastomosis per graft.

Data are shown in mean ± standard deviation.

RA: radial artery, SVG: saphenous vein graft, Qm: mean bypass flow, PI: pulsatile index

*1: p=0.007, *2: p=0.048, *3: p<0.001, *4: p=0.009, *5: p=0.044

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1 Table 1. Patient's characteristics

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	Original				After IPTW		
	RA (n=154)	SVG (n=68)	P-value	SMD	RA (n=195)	SVG (n=213)	SMD
Age (years)	66.6 ± 9.6	72.7 ± 7.8	<0.001	0.645	68.1 ± 9.4	69.6 ± 7.3	0.184
Male gender	122 (79.2)	52 (76.5)	0.646	0.067	153 (78.5)	183 (85.9)	0.197
Body surface area (m^2)	1.8 ± 0.4	1.7 ± 0.5	0.003	0.440	1.8 ± 0.4	1.8 ± 0.4	0.004
Hypertension	123 (79.9)	53 (77.9)	0.744	0.047	157 (80.5)	190 (89.6)	0.253
Hyperlipidemia	125 (81.2)	42 (61.8)	0.002	0.448	157 (80.1)	180 (84.5)	0.114
Diabetes mellitus	95 (62.1)	36 (52.9)	0.201	0.186	120 (61.5)	160 (75.5)	0.299
Smoking history	82 (53.2)	37(54.4)	0.873	0.023	105 (53.8)	108 (50.7)	0.064
Cerebrovascular accident	9 (5.8)	4 (5.9)	0.604	0.002	12 (6.2)	6 (2.8)	0.164
Peripheral vascular disease	9 (5.8)	9 (13.2)	0.063	0.270	17 (8.7)	13 (6.1)	0.105
Renal dysfunction (Scr>1.3mg/dL)	14 (9.1)	22 (32.4)	<0.001	0.630	17 (8.7)	42 (19.8)	0.320
Hemodialysis	0 (0)	18 (26.5)	<0.001	0.968	-	-	-
Atrial fibrillation	31 (20.1)	10 (14.7)	0.337	0.139	37(19.0)	42 (19.7)	0.022
Carotid artery stenosis	11 (7.1)	10 (14.7)	0.076	0.258	22 (11.3)	20 (9.4)	0.054
PCI history	41 (26.6)	16 (23.5)	0.627	0.071	47 (24.1)	80 (37.6)	0.288
Ejection fraction (%)	60.6 ± 14.3	59.7 ± 16.4	0.900	0.060	61.1 ± 14.2	62.4 ± 16.2	0.082
Emergency operation	20 (13.0)	29 (42.6)	<0.001	0.714	34 (17.4)	40 (18.9)	0.034
Intra-aortic balloon pumping	8 (5.2)	11 (16.2)	0.007	0.392	12 (6.1)	12 (5.7)	0.007
Number of disease vessels	2.8 ± 0.5	2.7 ± 0.5	0.129	0.176	2.7 ± 0.5	2.8 ± 0.4	0.065

Single-vessel disease	3 (1.9)	0 (0)	0.332	0.168	4 (2.1)	0 (0)	0.202
Double-vessel disease	31 (20.1)	22 (32.4)	0.049	0.286	43 (22.1)	49 (23.0)	0.023
Triple-vessel disease	120 (77.9)	46 (67.6)	0.104	0.236	148 (75.9)	164 (77.0)	0.023
Left main disease	57 (37.0)	29 (42.6)	0.427	0.115	78 (40.0)	88 (41.3)	0.028

1 Values are n (%) or mean ± standard deviation.

2 IPTW: inverse probability of treatment weighting, RA: radial artery, SVG: saphenous vein graft, SMD: standardized mean difference,

3 Scr: serum creatinine, HD: hemodialysis, PCI: percutaneous coronary intervention

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Table 2. Operative data

	RA (n=154)	SVG (n=68)	P value
Coronary anastomosis per patient	4.0 ± 1.0	3.5 ± 1.0	0.002
Coronary anastomosis per graft (sequential bypass)	2.2 ± 0.4	2.1 ± 0.3	0.110
Sequential bypass	127 (82.5)	44 (64.7)	0.004
Complete revascularization	154 (100)	66 (97.1)	0.093
Operation time (min)	456.3 ± 86.6	465.6 ± 97.2	0.545
Cardiopulmonary bypass time (min)	211.3 ± 55.6	206.8 ± 60.0	0.556

Values are expressed as n (%) or mean ± standard deviation

RA: radial artery, SVG: saphenous vein graft

Table 3. Target vessels

Graft	Target vessel	RA		SVG	
		Number of grafts	Number of anastomosis	Number of grafts	Number of anastomosis
Individual	D	9	9	9	9
	C	26	26	23	23
Sequential with 2 coronary anastomoses	D-D	4	8	2	4
	D-C	55	110	22	44
	C-C	32	64	13	26
Sequential with 3 coronary anastomoses	D-D-C	3	9	0	0
	D-C-C	24	72	5	15
	C-C-C	1	3	0	0

RA: radial artery, SVG: saphenous vein graft, C: left circumflex artery, D: Diagonal branch

Fig 1a

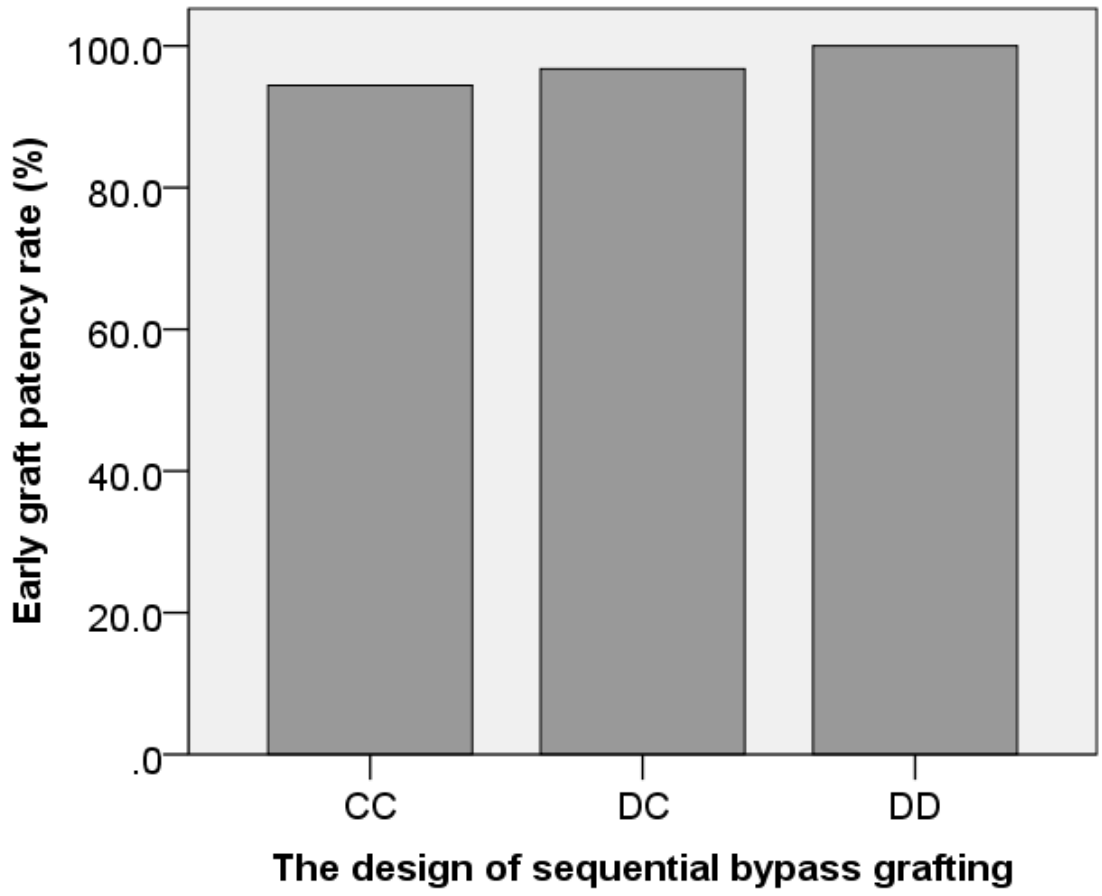
Early graft patency rate (%)
100.0
80.0
60.0
40.0
20.0
.0
CC
DC
DD
The design of sequential bypass grafting

Fig 1b

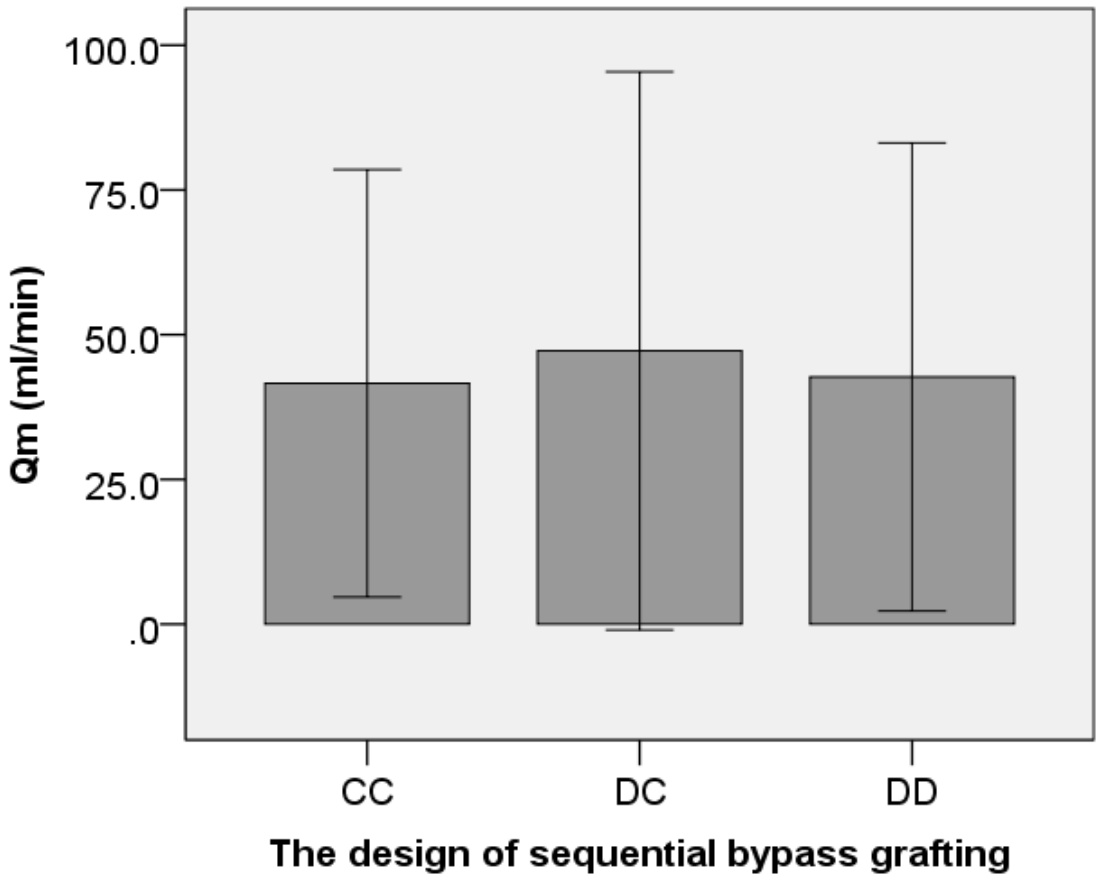
100.0
75.0
50.0
25.0
.0
Qm (ml/min)
CC
DC
DD
The design of sequential bypass grafting

Fig 1c

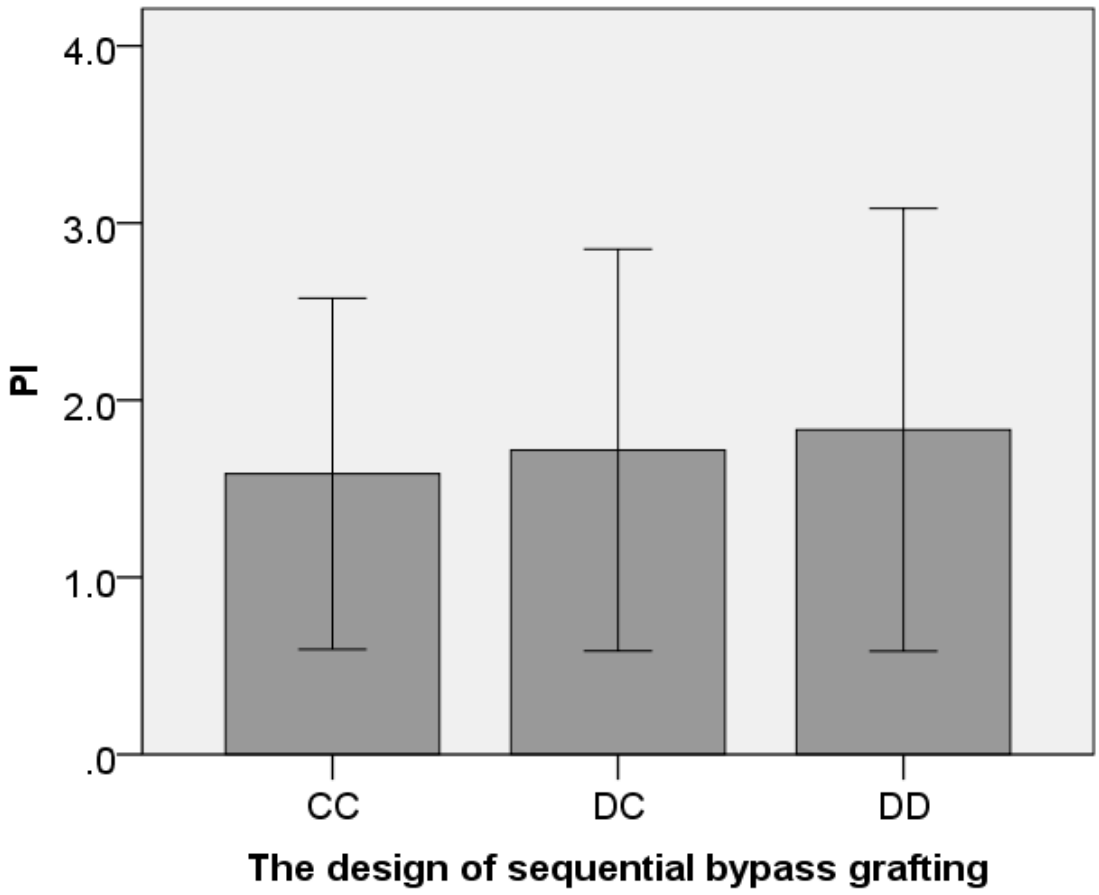
4.0
3.0
2.0
1.0
.0
PI
CC
DC
DD
The design of sequential bypass grafting

Fig 2a

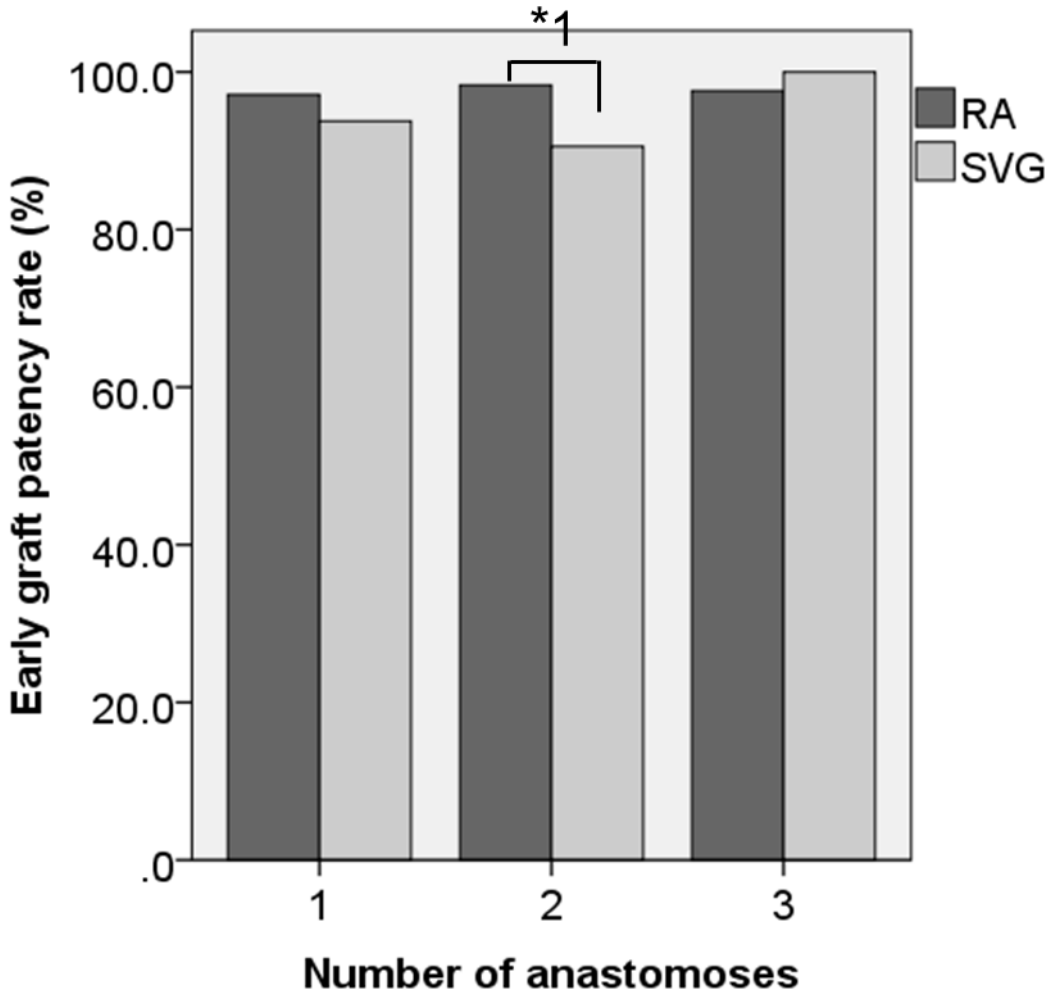
*1
100.0
80.0
60.0
40.0
20.0
.0
Early graft patency rate (%)
1
2
3
Number of anastomoses
RA
SVG

Fig 2b

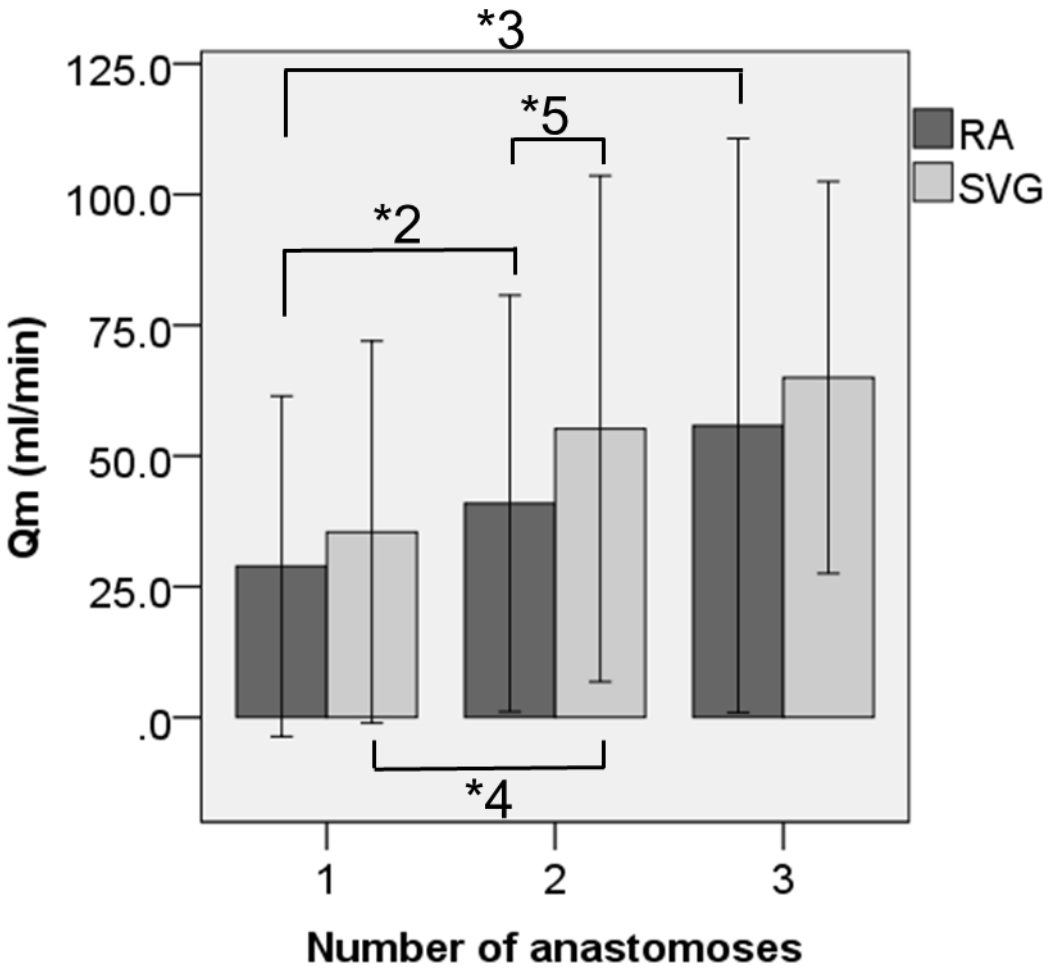
*3
*5
*2
*4
125.0
100.0
75.0
50.0
25.0
.0
Qm (ml/min)
RA
SVG
1
2
3
Number of anastomoses

Fig 2c