Revascularization of multiple bypassable extended right coronary arteries

Mehmet Raşit Güney, MD
Ergin Eren, MD

Background: Extended right coronary arteries are not uncommon in coronary surgery. They can be revascularized optionally either by conventional single or complete multiple bypassing. However, there are still no objective data showing the superiority or appropriateness of one of these methods over the other.

Methods: Extended right coronary arteries were identified by preoperative angiographic scoring and randomized to multiple-bypassing (group A; $n = 32$) or single-bypassing (group B; $n = 32$) groups. Four parameters that show the completeness of right coronary territory revascularization were evaluated and compared between the 2 groups.

Results: Although overall perioperative ischemic events seemed to increase in the single-bypass group ($P = .0059$), half of them were reversible, and there were no statistical differences between the definitive perioperative ischemic event rates, namely, infarction rates, and the remaining 3 parameters of the groups. Logistic regression analysis showed that preoperative left ventricular dysfunction (ejection fraction $<50\%$) was the most significant predictor of these perioperative ischemic events. Hence, the subgroups of patients with left ventricular dysfunction were also evaluated (subgroup A, $n = 13$; subgroup B, $n = 12$). Overall perioperative ischemic event ($P = .001$), definitive perioperative ischemic event (infarction; $P = .0324$), and consequent right ventricular dysfunction ($P = .0324$) rates were significantly higher in the single-bypass subgroup. Postoperative reperfusion status and graft patency rates of the right coronary territory did not change with the different revascularization methods.

Conclusions: Complete revascularization of extended right coronary arteries did not seem advantageous over its conventional operation in patients with normal ventricular function; however, in patients with poor ventricular function (ejection fraction $<50\%$), it prevented perioperative ischemic events in the right coronary territory and the consequent functional impairment that appeared with conventional operation.

The ultimate goal of coronary artery bypass grafting (CABG) is to prolong the patient's life to match the actuarial survival curve of the healthy population. The prerequisite of this goal is complete revascularization, which is proven to decrease postoperative events (infarction, recurrent angina, and reintervention) and provide better long-term survival.¹⁻³ Although complete revascularization is described as the bypassing of 3 major coronary arteries with critical stenosis,³ in practice, the number of bypasses used in many large series exceeds 3 per patient because large branches are also bypassed.^{1,3}

From the Siyami Ersek Chest and Cardiovascular Surgery Center, Istanbul, Turkey.

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Requests for reprints: Mehmet Raşit Güney, Derya sok, Beta-2 site E-blok No. 2/53 Sahrayı Cedid, 81060, Istanbul, Turkey (E-mail: mrguney@e-kolay.net).

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An extended right coronary artery (RCA) with multiple bypassable branches is not uncommon in CABG. Whether complete revascularization of this group of RCAs accrues additional benefit for the patients compared with conventional single bypassing is still an open question. There are still no objective data showing the superiority or appropriateness of one of the methods over the other. Therefore, individual surgeons are inclined to prefer one method of revascularization or the other according to their personal preferences. This prospective study was designed to evaluate and discover the most appropriate method of extended RCA revascularization.

Patients and Methods

Definitions

For the purposes of this study, dominant RCAs, which have wider supplying areas (including a posterior left ventricle [LV]), larger size, and multiple longer and bypassable branches in addition to the posterior descending (PD) branch, were defined as extended RCAs.⁴ Complete revascularization was described as the bypassing of all vessels that had sufficient length, size >1.5 mm, and diameter loss $>70\%$. This approach assumes that multiple-branch bypassing of RCAs provides complete revascularization of RCA territory and that conventional bypassing of such multiple bypassable RCAs is incomplete.

To detect extended RCAs, preoperative angiographic scoring was used. A branch was scored 1 if it had $>80\%$ of the PD length in multiple projections. If the branch had 50% to 80% of the PD length, it was strictly required to have a >1.5 -mm diameter to be scored 1. Remaining branches were scored 0. A cumulative score of any RCA ≥ 2 was accepted as multiple bypassable. This type of angiographic scoring of RCA has been shown to have complete correlation with thallium perfusion scoring for the same branches.⁵ The completeness percentage of RCA bypassing for any given group (or patient) was obtained from the ratio of bypassed vessel number to bypassable vessel number (angiographic score) of RCA territory.

Patients

Between June 2000 and June 2001, 64 patients with an RCA angiographic score ≥ 2 and with severe ($>70\%$) and generalized atherosclerotic narrowing in the RCA were randomized for the study. This study was initiated with the approval of the institutional review board, and patients gave informed consent. Patients were excluded if there was sizable nonviable myocardium in the RCA territory that caused a right ventricular (RV) contraction defect more significant than hypokinesia. Therefore, patients' RV regional wall motions were examined before the operation by 2-dimensional echocardiography (Sonos 1500; Hewlett-Packard, Andover, Mass) and assessed visually as normal, hypokinetic, akinetic, or dyskinetic.⁶ Hypokinesia, which could be due to small infarction or severe ischemia, was assumed to be highly viable and did not cause patient exclusion.

Study

Thirty-two of the patients (group A: 31 men and 1 woman; mean age, 62 ± 7 years) were randomized to complete (multiple-branch)

RCA revascularization, and another 32 patients (group B: 30 men and 2 women; mean age, 64 ± 8 years) were randomized to conventional (single main) RCA revascularization. Four reperfusion parameters that show the completeness of RCA territory revascularization were evaluated and compared between the 2 groups.

1. Perioperative ischemic event rate: during the perioperative period (including day 0), overall ischemic events (reversible and infarctions) of the RCA territory were observed. For reversible events, ST elevations (>1 mm) in the inferior (DII, III, or aVF) or inferoposterior (DII, III, aVF, V_1 , or V_2) derivations of electrocardiography (ECG) were considered. For myocardial infarctions, typical Pardee wave, new pathologic Q wave (>0.04 seconds) in the same derivations of ECG, high R wave in V_1 and V_2 , and enzyme signals while left derivations were normal (troponin T >12 $\mu\text{g/L}$ and creatine kinase-myocardial band >50 U/L) were considered indicative. Moreover, RV infarctions were confirmed by ST elevation in the right precordial ECG derivation $V_4\text{R}$, which is the most sensitive and specific finding.⁷
2. RV function: during the early postoperative period (within 72 hours) after cardiopulmonary bypass (CPB), severe RV dysfunction causing hemodynamic compromise was observed. For this purpose, clinical findings of acute RV failure—such as Kussmaul sign, elevated neck veins (jugular venous pressure >10 mm Hg), hypotension (systolic blood pressure <90 mm Hg), increased RV end-diastolic or right atrial pressure (>15 mm Hg), and echocardiographic findings (new or advanced RV contractility defect or RV dilatation)—were considered.
3. Reperfusion: all patients were subjected to stress thallium 201 single photon emission computed tomography (APEX SPX Cardinal System; Elscint, Ma'alot, Israel) analysis at 3 months after surgery (mean procedure time: group A, 97.9 ± 6.8 days; group B, 95 ± 5 days; *P* value is not smaller than .05—insignificant), to document the RCA territory reperfusion status. A treadmill exercise with the Naughton and Hader⁸ protocol or intravenous dipyridamole (0.142 mg/kg) was used to create cardiac stress. Visual readings and quantitative data of RCA territory based on the Cedars-Sinai assessment (0, normal; 1, equivocal; 2, moderate; 3, severe defects) were recorded prospectively for each patient.⁹ Patients were considered to have perfusion defects if their perfusion scores were ≥ 2 on the scintigraphic images. The completeness percentage of RCA territory reperfusion of the groups was obtained from the ratio of patients without perfusion defects to the entire group.
4. Graft patency: patients were subjected to conventional angiography (Integris H 3000 model; Philips, Best, The Netherlands) at 1 year after surgery (mean time: group A, 12.7 ± 0.80 months; group B, 13.02 ± 0.78 months; *P* = not significant) to compare the patency rates of RCA grafts. Two patients in group A and 4 patients in group B were lost to follow-up (procedure completeness was 93.75% and 87.5%, respectively). The graft patency rate of the groups was expressed as the percentage of the patients with patent grafts in the group.

Operative Technique

The same surgical team performed all operations by using the standard techniques. CPB, moderate hypothermia (28°C), intermittent cold crystalloid cardioplegia via antegrade-retrograde routes and grafts, and topical cooling were used in all patients. A Swan-Ganz thermodilution catheter (American Edwards Laboratories, Santa Ana, Calif) was introduced into all patients to evaluate RV function and hemodynamics. In most patients (87.5%), complete RCA revascularization was performed by sequential grafting, in which anastomoses were arranged in the same “single snake” saphenous vein graft. However, RCAs in 4 (12.5%) patients were unsuitable for a sequential approach because of technical reasons (very close branches, too-long single snake graft, and so on) and received bypasses with individual saphenous grafts.

Statistics

Patients' baseline information was registered prospectively on our hospital charts and also entered into the computerized database of the SPSS (version 9.0; SPSS Inc, Chicago, Ill) program. Patient variables were expressed as mean $\pm$ SD or as proportions. Comparative analyses were performed by using Fischer exact and unpaired Student *t* tests. Risk factors for perioperative ischemic events were depicted in the relative risk table and evaluated for predictors by univariate and multivariate analyses.

Results

Patients who formed the complete (group A) and conventional (group B) RCA revascularization groups had no significant differences with respect to their preoperative demographic, comorbidity, clinical, or angiographic data, except for smoking, which was significantly higher ($P = .0211$) in group A (Table 1). In groups A and B, preoperative cardiac dysfunction (41% and 37.5%, respectively) and severe ischemia (50% and 62%, respectively) rates were high but comparable. There were hypokinetic areas (22% vs 37.5% in group B) in mostly viable RCA territories, which implied their hibernating status.¹⁰

All RCAs had similar anatomical structure (or branching) and complex lesions in both groups. In total, 32 PD (or main RCA) branches, 19 acute margin (AM) branches, 16 anterior ventricular branches (AVB₁), 3 AVB₂, 11 posterolateral branches, and 3 variant branches (separate-originated giant conus and early PD anomalies suitable for multiple bypassing¹¹) were revascularized with different combinations in the complete revascularization group, whereas only main-course RCAs (main RCA, 53%; PD, 47%) were revascularized by single bypasses in the conventional revascularization group. Combinations included a maximum of 3 bypasses (in 16% of the patients). The most frequent combination was PD plus AM (37.5%). The endarterectomy rate was high (7 vs 1; $P = .0534$) in the conventional operation group because of bypassing on extensively diseased main courses instead of bypassing on open branches, as in the complete operation group.

TABLE 1. Preoperative demographic, clinical, and angiographic data of the patients

Variable	Group A (n = 32)	Group B (n = 32)
Age (y)	62 $\pm$ 7	64 $\pm$ 8
Male/female	31/1	30/2
Hypertension	8 (25%)	11 (34%)
Smoking*	18 (56%)	8 (25%)
Hyperlipidemia	7 (22%)	14 (44%)
Type 2 diabetes mellitus	0 (0%)	2 (6%)
Prior myocardial infarction		
Inferior-inferoposterior	5 (16%)	4 (13%)
Anterior	17 (53%)	15 (47%)
Total	22 (69%)	19 (59%)
LV dysfunction (EF <50%)	13 (41%)	12 (38%)
CCS class 3 or 4	16 (50%)	20 (62%)
RV hypokinesia	7 (22%)	12 (38%)
No. of diseased vessels		
2	13 (41%)	8 (25%)
3	19 (59%)	24 (75%)
Bypassable RCA branches		
AM branch	19 (59%)	21 (66%)
AVB	19 (59%)	15 (47%)
PL	11 (34%)	8 (25%)
Variant vessels	3 (9%)	1 (3%)
Pattern of RCA stenosis		
Solitary	2 (6%)	4 (12%)
Multiple sequential	25 (79%)	24 (75%)
Diffuse	5 (15%)	4 (13%)
% Stenosis of RCA		
Total	2 (6%)	1 (3%)
90–99	16 (50%)	19 (59%)
70–89	14 (44%)	12 (38%)

AM, Acute margin; AVB, anterior ventricular branch; CCS, Canadian Cardiovascular Society; EF, ejection fraction; LV, left ventricle; PL, posterolateral; RCA, right coronary artery; RV, right ventricle.

* $P < .005$.

Early postoperative (including the first month) mortality was nil in both groups. Although both groups had similar preoperative angiographic scores, the mean RCA distal bypass number was higher in the complete operation group, as expected (2.125 ± 0.42 vs 1 ± 0 ; Table 2). However, the revascularization completeness ratio was not 100% (81%) for the complete operation group because some of the branches that required bypass were not bypassed because of technical reasons (close course, small size [<1 mm] of branches, or distal extension of the disease). This ratio was 43% for the conventional single-bypass group.

The overall perioperative ischemic event rate was significantly higher in the conventional operation group (1/32 [3%] vs 10/32 [31%]; $P = .0059$). However, half of these overall events were reversible, and the definitive perioperative ischemic event rates, namely, perioperative infarction rates, did not differ between the groups (0/32 vs 5/32; $P = .053$). Consequent RV failure occurred in 4 patients (12.5%) in the conventional operation group, whereas none occurred

TABLE 2. Results of RCA territory revascularization

Results	Group A (n = 32)	Group B (n = 32)	P values
Total RCA distal bypass number* (mean)	68 (2.12 ± 0.42)	32 (1 ± 0)	
Total RCA angiographic score (mean)	84 (2.65 ± 0.86)	77 (2.40 ± 0.66)	.1999
RCA revascularization completeness*	81%	42.6%	<.0001
Perioperative ischemic events*	1 (3%)	10 (31%)	.0059
Perioperative MI	0 (0%)	5 (15.5%)	.0528
Hemodynamic derangement (RVF)	0 (0%)	4 (12.5%)	.1132
Reperfusion completeness	93.75%	90.6%	1.0000
RCA graft patency	30 (86.7%)	28 (85.7%)	1.0000

MI, Myocardial infarction; RCA, right coronary artery; RVF, right ventricular failure.

*P value < .05.

in the complete operation group (P = not significant). Two patients of the complete operation group and 3 patients of the conventional operation group had RCA territory perfusion defects in their scintigraphic examinations 3 months after surgery. Reperfusion completeness ratios of the complete and conventional operation groups were 94% and 90.5%, respectively (P = not significant). Similarly, 4 patients of the complete operation group and 4 patients of the conventional operation group had RCA graft occlusions in their angiographic examinations 1 year after surgery. Graft patency rates of the complete and conventional operation groups were 86.5% and 85.7%, respectively (P = not significant).

RCA territory perioperative ischemic event rates were unusually high in this study, probably because all patients had extended RCAs with complex lesions, severely ischemic but viable extended RCA territories, and high RCA endarterectomy rates. These ischemic events were examined for their predictors. Many risk factors were evaluated by univariate analysis, and important ones are depicted in the relative risks table in Figure 1. Predictors of perioperative ischemia, given as odds ratios with 95% confidence intervals (OR [95% CI]), were hypertension (6.0 [1.5-23.9]; P = .01), hyperlipidemia (8.2 [1.9-35.6]; P = .004), LV dysfunction (ejection fraction <50%; 25.3 [3.0-215.6]; P = .0002), class 3 or 4 angina pectoris (0.2 [0.05-0.96]; P =

Univariate predictors of periop ischemic events (odds ratio & 95% CI)

Figure 1. Relative risks (x axis) ± 95% confidence intervals (CI; y axis) for RCA territory perioperative ischemic events in complete versus conventional right coronary revascularization. Values >1 (reference line) imply increased risk. Note that the x axis is logarithmic. *Collateralization of RCA territory was graded by traditional assessment.¹² Periop, Perioperative; isch., ischemia; collateral, collateralization; ACC, aortic crossclamp; EF, ejection fraction; LAD, left anterior descending; NYHA, New York Heart Association; RCA, right coronary artery; RV, right ventricle.

.046), total left anterior descending artery occlusion (9.8 [2.3-41.5]; P = .002), RCA endarterectomy (7.0 [1.4-34.6]; P = .02), and single RCA grafting (32.2 [1.8-575.5]; P = .0004).

In the following step, logistic regression analysis gave significant results for only 2 of these predictors. According to this, LV dysfunction was the most significant predictor [P = .0242; B = 3.214; SE = 1.426; $Wald$ = 5.080; df = 1; R = 0.229; $\exp(B)$ = 24.877] of perioperative ischemic events, followed by single RCA grafting [P = .0449; B = 2.795; SE = 1.393; $Wald$ = 4.024; df = 1; R = 0.186; $\exp(B)$ = 16.265]. This result led us to evaluate the subgroups of patients with LV dysfunction within each group for their RCA territory revascularization status. These subgroups (group A, n = 13; group B, n = 12) had similar preoperative data (Table 3). However, the perioperative ischemic event rates (both overall and definitive) (P = .001) and consequent RV failure rate (P = .0391) were found significantly higher in patients who had an ejection fraction less than 50% (poor ventricular function) of the conventional RCA revascularization group. Two patients of the group A subgroup and 3 patients of the group B subgroup had perfusion defects in their RCA territories 3 months after surgery. Three patients of the group A subgroup and 3

patients of the group B subgroup had RCA graft occlusions at 1 year after surgery. RCA territory reperfusion completeness ratios (84.5% vs 75%) and graft patency rates (75% vs 70%) did not differ statistically for the patients of groups A and B who had an ejection fraction less than 50%.

Discussion

According to our data, complete RCA revascularization conferred benefits against RCA territory perioperative ischemic events and RV failure in the early postoperative period. However, these benefits were restricted to the subgroup of patients with LV dysfunction and did not extend to parameters observed during late follow-up, namely, RCA territory reperfusion status at 3 months and RCA graft patency at 1 year. For the general population, which mostly comprises patients with normal ventricular function, complete or conventional RCA revascularization had no different effect on these early and late parameters of RCA territory. Although overall perioperative ischemic events seemed to increase in the conventional group, this parameter also comprised the reversible events, which have no effect on the consequence of RCA territory. Therefore, only definitive perioperative ischemic events (infarctions) were considered and compared between the groups, as usual, and presented no difference.

Today, patients still experience severe RV failures after CPB, despite a usual RCA operation and excellent myocardial preservation. Although RCA territory ischemic insult can be tolerated uneventfully by some patients, the same degree of ischemic insult may cause intractable (sometimes fatal) RV failure in others.¹³ Recoverability of the RV can be explained by its small muscular mass, mild workload, and high collateralization capacity.¹⁴ However, catastrophic consequences point out incomplete revascularization of the RCA territory. The rationale for the necessity of complete RCA revascularization comes from a few directions. The first line of evidence comes from the conclusions of CABG series with complete RCA revascularization. Akins and Carroll¹⁵ observed no demonstrable RV failure in their CABG series by sequentially bypassing all obstructed PD, posterolateral, and AM branches of RCAs for 5 years (30% of their patients required multiple RCA bypasses). Consequently, they concluded that incomplete RCA revascularization was the most important determinant of RV failure after CPB.¹⁶ Farrar and associates¹⁷ also emphasized the ischemic nature of fatal RV failures after CPB. The second line of evidence comes from the observations of RV failure caused by a lack of branch perfusion or inadvertent RCA branch occlusions. A hemodynamic study in fatal RV failure indicated that loss of right atrial transport function due to loss of atrial contraction or atrioventricular dyssynchrony (due to loss of RCA branch perfusion to the right atrium and atrioventricular node) contributed to the severity of RV

TABLE 3. Preoperative data and operative results of the poor ventricular patients (EF <50%)

Variable	Group sub A (n = 13)	Group sub B (n = 12)	P value
Preoperative			
Age (y)	64 ± 6.9	66 ± 8.3	
Smoking	9 (69.2%)	4 (33.3%)	
Hypertension	5 (38.5%)	7 (58.3%)	
Hyperlipidemia	5 (38.5%)	9 (75%)	
Prior MI	13 (100%)	10 (83.3%)	
Class 3 or 4 angina	3 (23%)	3 (25%)	
RV hypokinesia	3 (23%)	5 (41.6%)	
RCA multiple	12 (92.3%)	9 (75%)	
sequential disease			
RCA stenosis >90%	7 (53.8%)	11 (91.6%)	
Operative			
Total RCA distal bypass number (mean)	27 (2.07 ± 0.27)	12 (1 ± 0)	
Total RCA angiographic score (mean)	31 (2.38 ± 0.65)	27 (2.25 ± 0.62)	
RCA revascularization completeness	88.5%	43.75%	<.0001
Perioperative ischemic events	1 (7.7%)	9 (75%)	.0010
Perioperative MI	—	4 (33.3%)	.0391
Consequent RVF	—	4 (33.3%)	.0391
Reperfusion completeness	84.6%	75%	
RCA graft patency	12 (75%)	10 (70%)	

MI, Myocardial infarction; RCA, right coronary artery; RV, right ventricle; RVF, right ventricular failure; EF, ejection fraction.

failure.¹⁸ In another study, spasm of a large AVB caused severe RV free wall akinesia.¹⁹ In many percutaneous transluminal coronary angioplasty series, accidental occlusion of a large side branch during dilation of the main RCA lesions caused serious RV failure.^{20,21} The third line of evidence comes from observations of the role of patent RCA branches in ischemic processes. In a case of anterior myocardial infarction, the large patent RCA conal branch limited the ischemic insult by saving the right paraseptal part of the ventricle.²² Our data extended these findings and brought some questions together, which have been discussed in the following paragraphs.

The first question that arose from our series was why patients with LV dysfunction were vulnerable to RCA territory ischemic insult and how complete RCA revascularization helped. It may be because transseptal compression of a dilated LV (increased intraventricular pressure) reduced subendocardial perfusion of the RCA territory, because a low ejection fraction reduced the perfusion pressure and the

antegrade flow of RCA territory after CPB, because increased LV end-diastolic pressure increased RV afterload, because severe disease of the left coronary artery reduced preoperative collateral support to the RV, or for a combination of these reasons. These impaired LV-related factors must have augmented the likelihood of RV ischemia and failure. Complete RCA revascularization probably increased the RCA territory flow and prevented ischemia, hence RV failure.

The second question that arose was why the benefits of complete RCA revascularization did not extend to the late parameters, namely, reperfusion status or graft patency of RCA territory. We believe that complete RCA revascularization actually played its essential role in the most vulnerable recovery period after CPB and improved the supply/demand ratio of the RCA territory by increasing its flow. Similarly, the third question was why patients with LV dysfunction had similar late parameters in both groups when there were more perioperative ischemic events and there was more RV failure in the conventional group. This may be explained by the well-known characteristic of RV: high collateralization and regeneration capability.^{14,23} We believe that the high recuperative power of the RV may have compensated for the early events of the RCA territory in the conventional group. Also, increasing flow runoff in RCA grafts because of fast and effective collateralization of underperfused RCA areas in the conventional group may have prevented the new graft occlusions and, hence, perfusion defects in the RCA territory.

In conclusion, complete revascularization of the extended right coronary did not seem to be advantageous over its conventional operation in patients with normal ventricular function; however, in patients with LV dysfunction, it prevented the RCA territory perioperative ischemic events and consequent functional impairment that appeared with conventional operation. Patients with LV dysfunction are already open to postoperative hemodynamic compromise because of impaired LV function. It is not difficult to estimate what will happen with the addition of RV ischemic insult. However, there is only extended absolute ischemic time for mostly 1 and sometimes 2 bypasses on the risk side of the risk/benefit balance of the operation. Consequently, we suggest that if an extended RCA with a complex lesion and viable RCA territory exist in patients with preoperative LV dysfunction (ejection fraction <50%), complete RCA revascularization should be considered for better outcomes (improved risk/benefit ratio).

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