Comparison of saphenous vein graft versus right gastroepiploic artery to revascularize the right coronary artery: A prospective randomized clinical, functional, and angiographic midterm evaluation

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Objective: Despite its theoretic advantage over saphenous vein grafts, the right gastroepiploic artery graft has not been accepted as the ideal conduit to revascularize the right coronary artery. We therefore prospectively randomized these 2 grafts types to compare their clinical, functional, and angiographic evolution at 6 months and 3 years.

Methods: From 2003 to 2006, 1397 consecutive patients underwent isolated revascularization at the University of Louvain Medical School. Of this group, 370 patients met the inclusion criteria for randomization and 66% of those were randomized. The right coronary artery was revascularized with saphenous vein grafts in 116 patients and with right gastroepiploic arteries in 122 patients. All patients underwent angiographic control 6 months postoperatively. The end points were major adverse cerebrocardiovascular events and proportion of grafts patent or functional at follow-up angiography.

Results: There were no significant differences between the 2 groups in terms of hospital events. At follow-up there was no significant difference in major adverse cerebrocardiovascular events between the 2 groups. At the 6-month angiographic follow-up, 91% of the anastomoses in the right gastroepiploic artery group and 95% of the anastomoses in the saphenous vein graft group were controlled patent ($P = .92$). In nonoccluded right coronary arteries, the proportion of patent grafts was significantly lower and the proportion of nonfunctioning grafts was significantly higher in the right gastroepiploic artery group than in the saphenous vein graft group.

Conclusion: There were no significant patency or major adverse cerebrocardiovascular events rate differences between the 2 groups; however, the number of functional grafts was significantly higher in the saphenous vein graft group. Careful selection of the coronary target is mandatory to obtain good results in gastroepiploic artery grafting.

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The ideal bypass conduit for the right coronary artery (RCA) remains a subject of intense controversy. A variety of grafts and configurations are used: the right gastroepiploic artery (RGEA),¹ the right internal thoracic artery in situ or in a Y-graft configuration,² the free radial artery implanted into the aorta or the left internal thoracic artery,³ and the saphenous vein graft (SVG).⁴

The influence of the type of graft to the RCA system on clinical results remains poorly documented, and the complementary conduit of choice to this system has yet to be determined. No superior long-term patency rate for any of these grafts to the RCA has been clearly established.⁵ The patency rate of the right internal thoracic artery to the RCA has been reported lower than that obtained when used for the left

Abbreviations and Acronyms

- GEA = gastroepiploic artery
- RCA = right coronary artery
- RGEA = right gastroepiploic artery
- SVG = saphenous vein graft

coronary system.⁶ One evaluation of the SVG to the RCA territory revealed good clinical and angiographic results after long-term follow-up.⁴ The patency rates of radial arteries and RGEAs are highly dependent on the degree of stenosis of the native vessel, and their use remains limited because of their association with a high risk of graft failure owing to competitive flow.⁷

The RGEA was first described 20 years ago by Pym and colleagues.⁸ Since then, its use has not increased as much as that of the internal thoracic artery. Reasons for this less frequent use include concerns about insufficient flow capacity and vasospasm, the need to open the abdomen, a large variation in the artery size, and a patency result at 5 years identical to that of the SVG.⁹

Because of this controversy and our experience with the RGEA (1500 grafts used since 1991), we decided to prospectively randomize 2 grafts (RGEA and SVG) to revascularize the RCA to evaluate their clinical, functional, and angiographic results at 6 months and 3 years. This article reports the midterm evaluation 6 months after randomization.

Materials and Methods

Study Design

All patients referred for isolated surgical coronary revascularization from April of 2003 to November of 2006 were screened according to the inclusion criteria (Table 1). The patients who consented were randomly assigned to undergo surgery according to 2 strategies: RGEA to the posterior descending artery or SVG to the posterior descending artery or posterolateral artery. Randomization was done the day before the operation after inspection of the patients' files without having seen the preoperative angiogram. Complementary grafting to the left coronary system was realized with either bilateral internal thoracic arteries or an SVG depending on the location of the targeted coronary vessel and the surgeon choice. All patients were scheduled for a systematic angiography at 6 and 36 months after surgery. All patients gave written informed consent at the time of bypass surgery and before the angiographic investigation. The study protocol was approved by the ethics committee of the University of Louvain Medical School.

Patients

From 2003 to 2006, 1397 consecutive patients underwent isolated bypass surgery at the University of Louvain Medical School. Of those, 370 patients (26%) met the inclusion criteria for study enrollment, and 244 (66%) of the 370 patients were actually randomized. The remaining patients were not randomized because of 1) refusal of systematic angiographic control (n = 95) and 2) logistic incapacity to randomize patients (n = 31). RGEA grafting was performed in

TABLE 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
<ul style="list-style-type: none">• Angiographic evidence of severe coronary stenosis (>70% by visual estimate)• Elective procedure	<ul style="list-style-type: none">• History of upper abdominal surgery• History of upper gastrointestinal bleeding, active gastric or duodenal ulcer.• Body mass index >35• Reoperation• Cirrhosis• Other configuration than RGEA > PDA SVG > PDA or PLA
<ul style="list-style-type: none">• Isolated CABG• Age <75 y and life expectancy >5 y	

CABG, Coronary artery bypass surgery; RGEA, right gastroepiploic artery; PDA, posterior descending artery; SVG, saphenous vein graft; PLA, posterolateral artery.

122 patients, and SVG grafting was performed in 116 patients. Six patients initially allocated to the SVG group were excluded for protocol violation. In these cases, the surgeon decided to deviate from the assigned revascularization strategy in favor of the RGEA (Figure 1). Patients' basal demographics and clinical characteristics are shown in Table 2. The grafts were harvested and grafted as previously described.^{10,11} The operative characteristics are detailed in Table 3.

Postoperative Management and Follow-up

Patients received prophylactic low-dose fractionated heparin postoperatively and 160 mg of aspirin daily starting on postoperative day 2. Treatment with vasoconstrictor agents was avoided whenever possible. Patients were interviewed by telephone at 3 months, 6 months, and twice yearly thereafter. If the patient had been hospitalized between interviews, inpatient records were obtained. Patients had a systematic stress test on a cycloergometer twice per year performed under the supervision of their referring cardiologist.

Systematic angiographic follow-up was performed 6 months after surgery. Isosorbide dinitrate (2 mg) was injected into each graft before filming to avoid any spasm caused by the catheterization. At least 2 orthogonal views of each internal thoracic artery graft were obtained, with continued exposure as required to visualize the distal runoff and size of the target coronary bed.

Data Analysis

The angiographic end point was the proportion of grafts that were patent or functioning at follow-up angiography. Graft patency was categorized in 3 patency grades: patency grade 0 = not patent (absence of visible opacification by the graft of the target coronary vessel; Thrombolysis In Myocardial Infarction flow grade 0 in the graft); patency grade 1 = balanced or patent but not functioning: when the flow from the native coronary artery is dominant or when flow supply from the native coronary and from the graft is balanced (Thrombolysis In Myocardial Infarction flow grade 1 or 2 in the graft); patency grade 2 = fully patent (complete opacification of the targeted coronary vessel by the graft (Thrombolysis In Myocardial

Figure 1. Consort flow chart of the study. CABG, Coronary artery bypass surgery; RGEA, right gastroepiploic artery; SVG, saphenous vein graft.

Infarction flow grade 3 in the graft). A graft was considered functional when in patency grade 2 and not functional when in patency grade 0 or 1.

All postoperative angiograms were independently reviewed by 2 investigators; discrepancies in patency definition were reviewed by a third investigator and resolved by consensus. Clinical end points were the occurrence of major adverse cerebrocardiovascular events and defined as a combined end point including death from any cause, perioperative myocardial infarction (>30 days), late myocardial infarction (occurring between 31 days and 6 years), additional cardiac surgery, coronary angioplasty, and neurologic events. Myocardial infarction was defined as apparition of a Q wave or an increase of more than 10 ng/mL of troponin I.

Statistical Analysis

We calculated that the enrollment of at least 244 patients would provide the study with 80% power to detect a relative reduction of 10% in the rate of graft occlusion, from an estimated 15% with the SVG grafting to 5% with RGEA, assuming a 20% within-patient correlation for graft occlusion, a 2-tailed test, and an alpha value of 0.05. Data are expressed as mean $\pm$ 1 standard deviation. In bivariate analyses, the association of independent variables with each out-

come variables was tested with the Student *t* test for independent samples (binary variables).

All *P* values are 2-tailed. The Statistical Analysis Software (SAS, 9.1 release, SAS Institute Inc, SAS Campus Drive, Cary, NC) was used in the statistical analysis.

Results

All patients were analyzed on an intention-to-treat basis. The total number of graft anastomoses performed to revascularized the RCA in each patient was similar in both groups (Table 3).

In-hospital Events

Four patients died during hospitalization (4 in the SVG group and none in the RGEA group, ($P = .1$). The first patient underwent reoperation because of ischemia 4 hours after admission to the intensive care unit; all thoracic grafts were doubled with an SVG, and a left ventricular assist device was implanted. This patient died of multiple organ failure on day 8. The second patient underwent reoperation for

TABLE 2. Basal demographic and clinical characteristics

	RGEA n = 122 (%)	SVG n = 116 (%)	P value
Male	106 (87%)	98 (84%)	.73
Mean age (y)	61.8 ± 8.3	63.2 ± 7.7	.2
Hypertension	87 (71%)	93 (80%)	.15
Smokers	60 (49%)	47 (40%)	.22
Diabetic	28 (23%)	24 (21%)	.79
High cholesterol	92 (75%)	83 (72%)	.59
Previous infarction	37 (30%)	42 (36%)	.4
Inferior	25 (20%)	22 (19%)	.89
Obesity (BMI > 30)	52 (43%)	54 (47%)	.63
Peripheral vascular disease	11 (9%)	15 (13%)	.44
Mean euroSCORE (additive)	2.5 (2.5)	2.8 (2.6)	.19
Left ejection fraction <30%	6 (5%)	2 (2%)	.31
No. of 3-vessel disease	100 (82%)	112 (97%)	<.001
RCA stenosis mean % stenosis	90 ± 10	88 ± 11	.11
Location of the stenosis			
RCA	92 (75%)	87 (75%)	.93
PDA	27 (22%)	27 (23%)	.95
PLA	3 (3%)	2 (2%)	.95

BMI, Body mass index; PDA, posterior descending branch; PLA, posterior lateral branch; RCA, right coronary artery.

mediastinitis on day 8 and died of multiple organ failure after multiple abdominal operation for necrotic-hemorrhagic pancreatitis on day 83. The third patient died suddenly on day 5 on the ward, and the fourth patient underwent reoperation for mediastinitis on day 9 and died of cardiogenic shock on day 62 after a massive gastrointestinal hemorrhage. There were no significant differences in the rate of stroke or infarction between the 2 groups (Table 4).

Clinical Follow-up

Clinical follow-up is 100% complete with a mean follow-up of 20.1 ± 11.7 months in the SVG group and 21.8 ± 11.9 months in the RGEA group ($P = .8$). There were no late deaths at follow-up. Three patients in the SVG group and 2 patients in the RGEA group had a recurrence of angina during follow-up ($P = .9$). All of these patients had positive stress test results and underwent a repeated recatheterization. Of these, 1 patient had an occlusion of the graft (RGEA group) and 4 patients had a progression of disease (3 patients in the SVG group and 1 patient in the RGEA group). The progression of the disease appeared on the posterior descending artery in 2 patients (all in the SVG group, 6 and 26 months postoperatively) and on the LAD in 2 patients (1 patient in the SVG group and 1 patient in the RGEA group 20 months postoperatively). They all underwent a percutaneous coronary intervention of the new lesion. One last patient in the RGEA group underwent percutaneous coronary intervention of the RCA after the occlusion of the RGEA (26 months postoperatively).

TABLE 3. Operative characteristics

	RGEA n = 122	SVG n = 116	P value
No. of anastomoses per graft to the RCA			
RGEA			
PDA	122	0	
SVG	12	116	
PLA	12	24	
PDA		105	
Total anastomoses for RCA territory	144/122	140/116	.96
Mean anastomoses for RCA territory per patient	1.2	1.2	
Other operative characteristics			
Off-pump procedure	9	8	.91

PDA, Posterior descending artery; PLA, posterolateral artery; CPB, cardiopulmonary bypass; IABP, intra-aortic balloon pump; RCA, right coronary artery; RGEA, right gastroepiploic artery; SVG, saphenous vein graft.

No patient underwent redo cardiac surgery between hospital discharge and follow-up. Two patients in the RGEA group had a stroke 14 and 31 months postoperatively ($P = .5$).

Functional Follow-up

Functional follow-up is 100% complete with a mean follow-up of 17.8 ± 8.4 months in the SVG group and 18.7 ± 11.2 months in the RGEA group ($P = .8$). Stress test results were positive for ischemia in all 5 symptomatic patients described above (3 patients in the SVG group and 2 patients in the RGEA group; $P = .9$). All other patients had negative stress test results. Mean exercise duration and maximal workloads were similar in the SVG group compared with the RGEA group (125 ± 25 vs 130 ± 30 Watts; $P = .8$).

Angiographic Follow-up

Overall patency. Angiographic follow-up was obtained in 102 patients (88%) in the SVG group and 105 patients (86%) in the RGEA group ($P = .8$) with a mean follow-up of 6.3 ± 0.6 months and 6.1 ± 0.7 months, respectively ($P = .8$). Withdrawal of consent by 37 patients was the main reason for this incomplete 6 months of angiography control.

One asymptomatic patient in the RGEA group had an occlusion of the RGEA grafted onto the dominant right coronary artery at the angiographic follow-up. The RCA was dilated during the systematic control procedure.

In regard to patency grades, 14 grafts were not patent (patency grade 0: 9 in the RGEA group and 5 in the SVG group; $P = .4$), 13 grafts were balanced (patency grade 1: 13 in the RGEA group and 0 in the SVG group; $P = .001$), and 180 grafts were fully patent (patency grade 2: 83 in the RGEA group and 97 in the SVG group; $P = .001$).

TABLE 4. Hospital events

	RGEA n = 122 (%)	SVG n = 116 (%)	P value
Mortality	0	4 (3%)	.11
Reoperation	4 (3%)	6 (5%)	.68
Bleeding	3 (2%)	3 (3%)	
Sternal	1 (1%)	2 (2%)	
Ischemia	0	1 (1%)	
ICU stay (d)	1.7 ± 6.9	2.1 ± 7.8	.11
Morbidity			
Acute myocardial infarction	1 (1%)	0	.98
Pulmonary infection	22 (18%)	16 (14%)	.47
Stroke	1 (1%)	2 (2%)	.96
Arrhythmia	25 (20%)	27 (23%)	.71
Acute renal insufficiency	3 (3%)	5 (4%)	.66
Postoperative hospital stay (d)	9 ± 7	10 ± 9.2	.16

RGEA, Right gastroepiploic artery; SVG, saphenous vein graft; ICU, intensive care unit.

The global patency rate (grades 1 and 2) was 96 (92%) in the RGEA group and 97 (95%) in the SVG group ($P = .4$). The functioning graft rate (grade 2) was 83 (79%) in the RGEA group and 97 (95%) in the SVG group ($P = .001$).

Influence of RCA stenosis on graft patency. a) Occluded RCA: There was no difference between the 2 groups in the proportion of grafts with a patency grade of 0, 1, or 2 (Table 5). b) RCA stenosis between 80% and 99%: There was no difference between the 2 groups in the proportion of grafts with a patency grade of 0 or 2, but the proportion of grafts with a patency grade of 1 was significantly higher in the RGEA group than in the SVG group. c) RCA stenosis less than 80%: The proportions of grafts with a patency grade of 0 or 1 were higher in the RGEA group than in the SVG group; the difference reached significance only for the grafts with a patency grade of 1. Conversely, the proportion of fully patent grafts (patency grade 2) was significantly higher in the SVG group than in the RGEA group.

The proportion of RGEA grafts in grade 1 increased when the stenosis was less critical, but not significantly (15% for stenosis 80%–99% vs 32% for stenosis < 80%; $P = .4$). The proportion of nonfunctioning grafts (patency grade 0 + 1) in the SVG group did not increase with a less stenosed RCA (7% for a stenosis of 100% vs 2% for a stenosis of 80% to 99% vs 10% for a stenosis of <80%; $P = .3$), whereas it increased significantly in the RGEA group (2% for a stenosis of 100% vs 18% for a stenosis of 80%–99% vs 68% for a stenosis of <80%; $P = .001$).

The evolution of left ventricular ejection fractions from the preoperative measurement to the 6-month control was minimal and similar for the 2 groups (61.5% ± 11.5% to 62.7% ± 12% in the RGEA group vs 62.2% ± 10% to 63% ± 11.5% in the SVG group; $P = .8$).

Discussion

In this large prospective, randomized, single-center clinical trial, no significant clinical difference was observed between the 2 types of graft revascularization at midterm follow-up, although angiographic evaluation demonstrated a significantly higher proportion of functional SVGs compared with RGEAs. The percentage of functioning SVGs (95%) as well as the percentage of functioning RGEA (98%) for an occluded RCA compares favorably to previously reported studies.^{1,12} The flow capacity of the RGEA and its sensibility to flow competition¹³ could explain such difference in the number of functional grafts.

The flow capacity of the RGEA and its sensibility to flow competition could explain such a difference in the number of functional grafts. Uchida and Kawaue¹⁴ studied this phenomenon and concluded that flow competition depends on 3 factors: the viability of the revascularized area, the degree of proximal stenosis, and the location of stenosis. In our series no differences could be evidenced between the 2 groups for any of these factors. Another explanation could be the anatomic differences between the gastroepiploic artery (GEA) and the SVG. The aortocoronary SVG is under direct aortic root pressure, whereas the GEA is a branch of the gastroduodenal artery, which in turn diverges from the common hepatic artery and thus is the fourth branch of the abdominal aorta. Because coronary blood supply is determined by a pressure gradient between the aorta and the left ventricle, the driving pressure of the GEA could be lower than that of the SVG.

Shimizu and colleagues¹⁵ compared the RGEA and SVG flow characteristic using a Doppler-tipped guidewire 1.6 years after CABG. They found that when coronary stenosis is moderate, the flow volume of the RGEA was less than that of the SVG. In contrast, the correlation between flow in the SVG and severity of native coronary stenosis was not significant in their series. They explained this difference as the consequence of flow competition between the GEA and the native coronary artery. The results of the present study support these data: The proportion of nonfunctioning grafts in the SVG group did not increase with the decrease of the RCA stenosis, whereas it did in the RGEA group. As it was the case in previous patency studies, our evaluation of reperfusion is mainly based on angiographic flows observed at rest in fasting patients. Previous studies¹⁶ have suggested that eating could modify flow supply in the coeliac circulation up to a point susceptible to influence myocardial reperfusion after RGEA bypass surgery. In addition, physical exercise, by increasing myocardial blood flow demand, could modify flow status through a graft from a balanced status to either predominantly native or graft dependent. Future studies evaluating the influence of changes in splanchnic and myocardial flow conditions as those induced by a fat-rich meal or by physical exercise are under way, which could

TABLE 5. Six months of systematic angiographic control

	RGEA n = 105 (86%)			SVG n = 102 (88%)			P value
	Anastomosis angiographic patency control						
Patency grade	0	1	2	0	1	2	
RGEA							
PDA	9	13	83				
SVG				5	0	97	
Isolated							
PDA				3	0	69	
PLA				0	0	4	
Sequential							
PDA				1	0	22	
PLA				1	0	2	
No. of patent anastomoses/patient	96/105 (91%)			97/102 (95%)			P = .77
Patency grade	0	1	2	0	1	2	
RCA coronary stenosis (visual inspection)							
100%	0	1	55	2	0	27	
80%–99%	0	4	22	1	0	52	
	P = .4			P = .8			
				P = .02			
<80%	9	8	8	2	0	18	
				P = .05			
				P = .02			

RGEA, Right gastroepiploic artery; SVG, saphenous vein graft; PDA, posterior descending artery; PLA, posterolateral artery; RCA, right coronary artery. Patency grades: 0 = not patent; 1 = balanced: patent but not functioning, when the flow from the native coronary artery is dominant or when flow supply from the native coronary and from the graft is balanced; 2 = fully patent.

help to better understand the physiology of these revascularization modalities.

Several technical methods have been proposed to increase RGEA use, such as the skeletonization¹⁷ of the RGEA. Indeed, Gagliardotto and colleagues¹⁷ have found several potential benefits with RGEA skeletonization: The quality evaluation of the graft and the sequential anastomoses can be easier to carry out. Finally, limited periarterial dissection may aid in preserving lymphatic and venous drainage to the stomach and omentum. Another technique is the injection of vasoactive drugs before grafting to increase flow and avoid vasospasm.^{18,19} Ali and colleagues¹⁸ evaluated 3 calcium channel blockers and papaverine in preventing RGEA spasm. They concluded that papaverine, when given externally on the perivascular fat of the RGEA, prevented graft spasm for up to 2 hours, whereas verapamil proved to be the most potent calcium channel blocker vasodilator.

The effect of randomization in this study eradicates the bias of the coronary target selection for the choice of graft, which is found in all of the retrospective studies mentioned. In addition, the systematic angiographic evaluations at 6 months and 3 years are an essential part of a prospective evaluation of graft function as demonstrated by the fact that in asymptomatic patients with negative exercise test results, 12% of the RGEAs were patent but not functioning at control

angiography. An evaluation of graft patency or function based on clinical symptoms or angiographic controls driven by ischemic episodes could only provide a truncated vision of the actual revascularization status of the patients.²⁰

Several observations have demonstrated the capacity of internal thoracic arteries²¹ or RGEAs²² to recover a function at long term after having been found nonfunctional (string sign) at early follow-up. This capacity seems related to endothelial protection mechanisms that are probably absent in SVGs. Because of the natural progression of the disease on native vessels, this property could act in favor of RGEAs in the longer term. The ongoing angiographic reevaluation of the grafts at 3 years postoperatively could thus provide information to clarify the meaning of these early findings, particularly in RGEA grafts with a balanced flow. At this stage of follow-up, we modified our indications for RGEA grafting on the basis of these 6-month angiographic data. We now use only RGEA grafts for RCAs that are suboccluded or occluded in patients aged less than 75 years, and we preferentially use SVGs in older patients and in those with less severely narrowed native coronary arteries.

Conclusions

No significant difference in terms of major adverse cerebrocardiovascular events or patency was found between the 2

groups, but the number of functional graft was significantly higher in the SVG group. Careful selection of the coronary target is mandatory to obtain good results in RGEA grafting. Three years of angiographic control is mandatory to evaluate the long-term outcome of balanced RGEA grafts.

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