Journal of the American College of Cardiology
Vol. 51, No. 2, 2008
ISSN 0735-1097/08/$34.00
doi:10.1016/j.jacc.2007.09.030
Published by Elsevier Inc.

Angiographic Predictors of 6-Month Patency of Bypass Grafts Implanted to the Right Coronary Artery

A Prospective Randomized Comparison of Gastroepiploic Artery and Saphenous Vein Grafts

David Glineur, MD, William D'hoore, MD, PhD, Gebrine El Khoury, MD, Sixte Sondji, MD, Gregory Kalscheuer, MD, Jean-Christophe Funken, MD, Jean Rubay, MD, PhD, Alain Poncelet, MD, Parla Astarci, MD, Robert Verhelst, MD, Philippe Noirhomme, MD, Claude Hanet, MD, PhD

Brussels, Belgium

Objectives The purpose of this study was to define the pre-operative angiographic variables that could influence graft patency and flow pattern.

Background Saphenous vein grafts (SVG) and pedicled right gastroepiploic artery (RGEA) grafts are routinely used to revascularize the right coronary artery (RCA). Little is known about the predictive value of objective pre-operative angiographic parameters on the 6-month graft patency and on the interest of these parameters to select the optimal graft material in individual cases.

Methods We prospectively enrolled 172 consecutive patient candidates for coronary revascularization. Revascularization of the RCA was randomly performed with SVG in 82 patients or with the RGEA in 90 patients. Both groups were comparable with respect to all pre-operative continuous and discrete variable and risk factors. All patients underwent a systematic angiographic control 6 months after surgery. Pre-operative angiographic parameters included minimal lumen diameter (MLD), percent stenosis and reference diameter of the RCA measured by quantitative angiography (CAAS II system, Pie Medical, Maastricht, the Netherlands), location of the stenosis, run off of the RCA, and regional wall motion of the revascularized territory.

Results A significant difference in the distribution of flow patterns was observed between SVG and RGEA. In multivariate analysis, graft-dependent flow pattern was significantly associated with both MLD and percent stenosis of the RCA in the RGEA group but with percent stenosis only in the SVG group. In the RGEA group, the proportion of patent grafts was higher when MLD was below a threshold value lying in the third MLD quartile (0.77 to 1.40 mm).

Conclusions Pre-operative angiography predicts graft patency in RGEA, whereas the flow pattern in SVG is significantly less influenced by quantitative angiographic parameters. (J Am Coll Cardiol 2008;51:120–5) © 2008 by the American College of Cardiology Foundation

The choice of the ideal bypass conduit for each diseased coronary vessel remains a subject of intense controversy. For the left coronary system, bilateral internal thoracic arteries have clearly demonstrated their superiority over all other types of grafts (either venous or arterial) in terms of patency, freedom from arteriosclerosis, and survival benefit (1,2). Conduits considered acceptable to revascularize the right coronary artery (RCA) system include the right gastroepiploic artery (RGEA) (3), the right internal thoracic artery (RITA) in situ or used in a Y graft configuration (4), the free radial artery (RA) implanted into the aorta or into the left internal thoracic artery (5), and the saphenous vein graft (SVG) (6).

See page 126

The influence of the type of conduit implanted to the RCA system on clinical results remains unclear, and the complementary conduit of choice for this system has yet to be determined. No superior patency rate for any of these

From the Department of Cardiovascular Medicine and Surgery, University of Louvain Medical School, Brussels, Belgium. This study was supported by grant no. 3.4600.04 from the Fonds de la Recherche Scientifique Médicale, Brussels, Belgium.

Manuscript received February 12, 2007; revised manuscript received September 17, 2007, accepted September 17, 2007.

Table 1 Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Angiographic evidence of severe (>70% by visual estimate) coronary obstruction on the RCA territory	History of upper abdominal surgery
Elective procedure	History of upper gastrointestinal bleeding, active gastric or duodenal ulcus
Isolated CABG	Body mass index >35 kg/m^2
Age <75 yrs and life expectancy >5 yrs	Redo surgery
Pre-operative lumen diameter of the RGEA >1.5 mm	Cirrhosis
	Other configuration than RGEA to PDA or SVG to PDA or PLA

CABG = coronary artery bypass grafting; PDA = posterior descending coronary artery; PLA = posterolateral branch of the right coronary artery; RCA = right coronary artery; RGEA = right gastroepiploic artery; SVG = saphenous vein graft.

grafts to the RCA has been clearly established (7). The patency results of the RITA on the RCA have been reported lower than those obtained when used for the left coronary system (8). One evaluation of the SVG to the RCA territory revealed surprisingly good clinical and angiographic results after long-term follow-up (6). The patency rates of RA and RGEA are highly dependent on the degree of stenosis of the native vessel, and their use remains limited because of its association with a high risk of graft failure, owing to competitive flow (9,10). The flow capacity of the RGEA under maximal stress conditions has also been questioned (11).

Because of these recent studies, debating the potential benefit of an arterial graft to revascularize the RCA, we prospectively randomized 2 types of graft, the RGEA and the SVG, which are routinely used in our department, and analyzed the predictive value of objective pre-operative coronary angiographic parameters on 6-month graft patency.

Methods

Patients. From April 2003 to July 2006, 1,297 consecutive patients underwent isolated bypass surgery in our institution. Of this group, 360 patients met the entrance criteria for randomization (Table 1) and 236 patients were actually randomized. Among those 236 patients, 172 had a pre-operative angiogram suitable for biplane quantitative angiographic analysis and are the subject of the present study. Right coronary artery grafting was performed with an RGEA in 90 patients and with an SVG in 82. Four patients initially allocated to the SVG group were excluded for protocol deviation; in these cases, the surgeon decided to deviate from the assigned revascularization strategy in favor of the RGEA group (Fig. 1). Patients' basal demographic and clinical characteristics are shown in Table 2. The RGEA and the SVG were harvested and grafted as previously described (12,13). The RGEA diameter was measured pre-operatively with a 1.5-mm probe. The RCA was systematically grafted distally to the bifurcation either on the posterior descending artery (PDA) or on the posterolateral branch (PLA) in order to revascularize the RCA distal territory with a single graft. All patients underwent a systematic angiographic control between the 6 to 8 months after coronary artery bypass grafting. The study protocol was approved by the ethics committee of our institution. All patients gave informed consent at the time of bypass surgery and before the angiographic investigations.

Data analysis. Pre-operative angiograms were analyzed with the CAAS II system (Pie Medical, Maastricht, the Netherlands) as previously described (14). The minimal lumen diameter (MLD), percent diameter stenosis (%), and reference diameter of the native RCA were measured in 2 near orthogonal

Abbreviations and Acronyms

MLD = minimum lumen diameter

PDA = posterior descending artery

PLA = posterior lateral artery

RA = radial artery

RCA = right coronary artery

RGEA = right gastroepiploic artery

RITA = right internal thoracic artery

SVG = saphenous vein graft

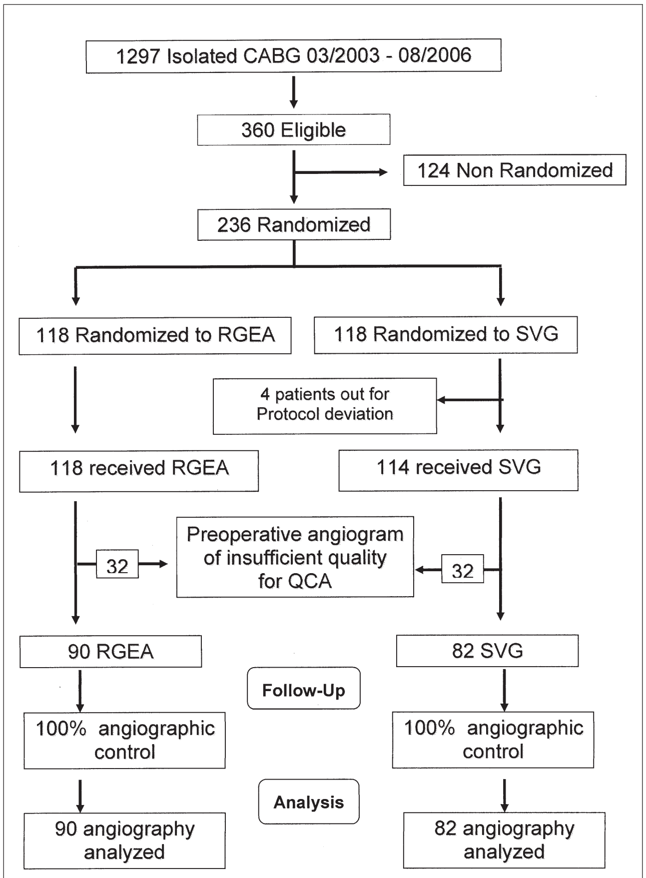

Figure 1 Consort Flow Chart of the Study

CABG = coronary artery bypass grafting; QCA = quantitative coronary angiography; RGEA = right gastroepiploic artery; SVG = saphenous vein graft.

JACC Vol. 51, No. 2, 2008
January 15, 2008:120–5

Table 2 Basal Demographic, Clinical Characteristics, and Pre-operative RCA Stenosis Characteristics

	RGEA (n = 90)	SVG (n = 82)	p Value
Male	80	75	0.75
Mean age (yrs)	61.9 ± 8.3	63.1 ± 7.7	0.55
Hypertension	82	76	0.58
Smokers	61	45	0.11
Diabetic	27	24	0.95
High cholesterol	82	71	0.48
Previous infarction	37	40	0.39
Obesity	52	50	0.78
Peripheral vascular disease	11	15	0.37
Mean Euroscore (additive)	2.5 ± 1.9 (2.1)	2.8 ± 2.0 (2.6)	0.19
Left ejection fraction <30%	5	1	0.25
RCA stenosis			
Mean MLD (mm)	0.81 ± 0.78	0.81 ± 0.85	0.92
Median MLD (mm)	0.80	0.72	0.36
MLD interquartile range	1.32	1.50	
Mean % stenosis	71.3 ± 25.5	71.1 ± 27.2	0.96
Median % stenosis	65.0	67.0	0.71
% stenosis interquartile range	48.0	52.0	

MLD = minimum lumen diameter; other abbreviations as in Table 1.

projections, and the mean value of these measurements was considered for statistical analyses.

All pre- and post-operative angiograms were independently reviewed by 2 investigators and discrepancies in patency scores were reviewed by a third investigator and resolved by consensus. All investigators were blinded to the experimental conditions. Graft patency is scored as 0 for an occluded graft, 1 when the flow from the native coronary artery is dominant, 2 when flow supply from the native coronary and from the graft is balanced, 3 when the native coronary is fully opacified by the graft, and 4 when the native coronary is fully opacified by the graft only (occluded or suboccluded coronary native vessel). A graft was considered "not functional" for patency scores of 0 to 2 and "functional" for patency scores of 3 or 4. The regional wall motion of the inferior wall was defined as normal, hypokinetic, or akinetic on the pre-operative angiogram or echocardiogram. The run off was graded according to the extent of the coronary territory beyond the stenosis on the diagnostic angiogram: incomplete when only 1 branch, either posterior descending or posterolateral and complete when the postero-descending and the posterolateral territory were subject to revascularization.

Statistical analysis. Data are expressed as mean ± 1 standard deviation. To compare the pre-operative characteristics of experimental and control groups, chi-square and *t* tests were used for categorical and continuous variables, respectively (Table 2). To study the relationships between MLD, percent stenosis, and graft function, variables MLD and percent stenosis were transformed into 4° ordinal variables on the basis of the approximate quartiles of their respective distributions. Recoding was justified here by the extreme skewness of data distribution. For MLD, boundaries were 0 mm (first quartile), 0.77 mm (median), and 1.40 mm (third quartile), resulting in a 4° MLD with values 0, 1, 2, and 3 corresponding to 0, 0.01 to 0.76, 0.77 to 1.40, and >1.40 mm, respectively. For percent stenosis, boundaries were 48% (first quartile), 65% (median), and 100% (third quartile), resulting in a 4° percent stenosis with values 0 = 0% to <48%, 1 = 48% to <65%, 2 = 65% to <100%, and 3 = 100%.

Mantel-Haenszel chi-square test was used to test the associations between graft function and type of graft, 4° MLD, and 4° percent stenosis. Multiple logistic regression modeling was then performed to obtain a parsimonious, clinically sound model.

All p values are 2-tailed. A p value <0.05 was considered significant. SAS software (version 9.1, SAS Institute Inc., Cary, North Carolina) was used to perform the statistical analysis.

Results

Pre-operative characteristics of the RCA lesion are shown in Table 2. At the 6-month angiographic follow-up, the difference between the proportions of functional RGEA (62%) and SVG (85%) was statistically significant (odds ratio 3.54; 95% confidence interval 1.68 to 7.47). We hypothesized that the differences were partly explained by the effects of pre-operative RCA characteristics. The proportion of functional RGEA grafts was strongly dependent on the severity of the RCA stenosis (Table 3), only 5% of the RGEA being functional when the MLD of the RCA was in the highest quartile (>1.40 mm). Conversely, only a weak association between MLD or percent stenosis and the function of SVG was observed, indicating the presence of an interaction between either MLD or percent stenosis and the type of graft. Figure 2 displays the interaction between MLD and type of graft.

Table 3 6-Month Graft Function According to Approximate Quartiles of Angiographic Characteristics of the Grafted Coronary Vessel

Grafted RCA	RGEA (90 patients)	SVG (82 Patients)
MLD (mm)	Functional Grafts, n (Percent of MLD Category)	
0	36 (100)	33 (94)
0.01–0.76	7 (88)	7 (78)
0.77–1.40	13 (50)	13 (81)
>1.40	1 (5)	17 (77)
% Stenosis	Functional Grafts, n (Percent of % Stenosis Category)	
100	36 (100)	33 (94)
99–65	11 (92)	7 (88)
64–48	8 (33)	16 (84)
<48	2 (11)	14 (70)

Percent stenosis is a 4-level ordered variable, with 0 = 0% to <48%, 1 = 48% to <65%, 2 = 65% to <100%, and 3 = 100%. The MLD is a 4-level ordered variable, with 0 = 0 mm, 1 = 0.01 to 0.76 mm, 2 = 0.77 to 1.40 mm, 3 = >1.40 mm MLD. RGEA: MLD: Mantel-Haenszel chi-square (1 df) = 52.00, p < .0001. Percent stenosis: Mantel-Haenszel chi-square (1 df) = 52.51, p < 0.0001. SVG: MLD: Mantel-Haenszel chi-square (1 df) = 3.24 p = 0.07. Percent stenosis: Mantel-Haenszel chi-square (1 df) = 5.60, p = 0.018.

Abbreviations as in Tables 1 and 2.

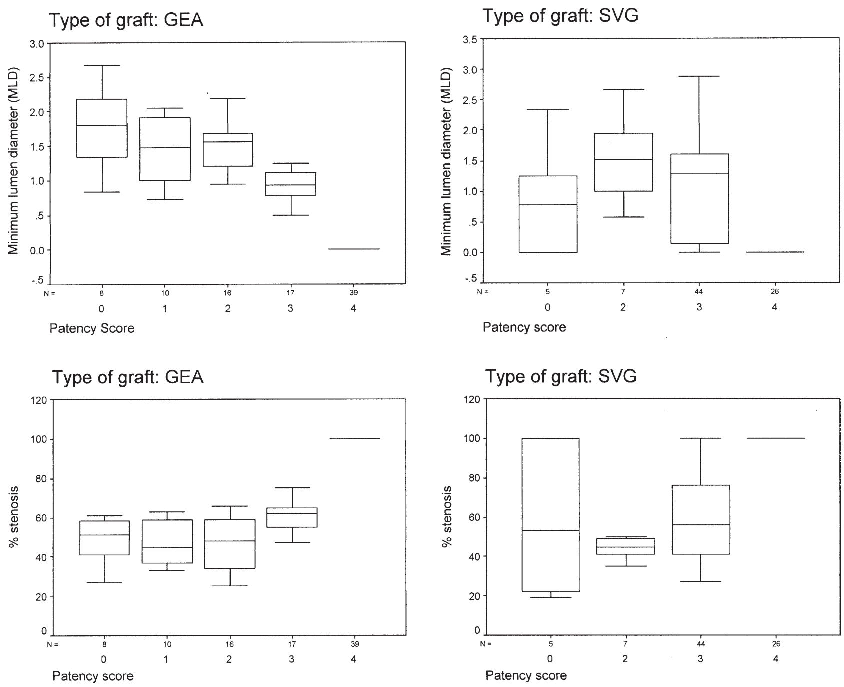

Figure 2 **Relationship Between Patency Score of the Grafts and Right Coronary Lesion Characteristics**

Relationship between patency score of the analyzed grafts (saphenous vein grafts [SVG], right gastroepiploic artery grafts [GEA]) and minimum lumen diameter **(top)** and percent stenosis **(bottom)** of the grafted right coronary artery. The **box ends** are Tukey's hinges; the **whiskers** are at the largest and smallest values that are not outliers or extremes, which are defined as 1.5 and 3.0 interquartile ranges from the hinges.

In the multiple logistic regression modeling strategy, interaction terms were then introduced under the form of cross-products (MLD × type of graft, and percent stenosis × type of graft). The following variables were entered: type of graft (RGEA vs. SVG), MLD, percent stenosis, and the 2 interaction terms. Results are shown in Table 4. The MLD, percent stenosis, and both interaction terms were significantly associated with graft function. No association was observed between graft patency or function and the regional wall motion of the RCA territory or the run off of the RCA graft. The strongest association was observed for the interaction between MLD and type of graft. Separate logistic regression models for SVG and RGEA are presented in Table 5. The MLD and percent stenosis, when tested together in this model, were not significant predictors of graft function for the SVG, whereas for RGEA they were significantly associated with the graft function. When testing the significance of MLD or percent stenosis alone in SVG grafts, only percent stenosis was significant (beta estimate = 0.64, SE = 0.28, p = 0.0250).

Table 4 **Predictors of Graft Function at 6 Months (Multiple Logistic Regression)**

Variables	Beta Estimates	SE	Wald Chi-Square	p Value
SVG	−1.74	2.41	0.52	0.4706
% stenosis	1.57	0.67	5.46	0.0194
SVG × % stenosis	−0.77	0.83	0.85	0.3562
MLD	−1.90	0.78	5.91	0.0150
SVG × MLD	2.11	0.92	5.21	0.0224

Likelihood ratio chi-square = 93.20, 5 df, p < 0.0001. Hosmer-Lemeshow goodness-of-fit test: chi-square = 1.56, 6 df, p = 0.9553. SVG indicates type of graft; SVG = 0 means gastroepiploic artery; SVG = 1 means saphenous vein graft. Percent stenosis is a 4-level ordered variable, with 0 = 100%, 1 = 99% to 65%, 2 = 64% to 48%, 3 = 47% to 0% stenosis. The MLD is a 4-level ordered variable, with 0 = 0 mm, 1 = 0.01 to 0.76 mm, 2 = 0.77 to 1.42 mm, 3 = >1.43 mm MLD. SVG × stenosis and SVG × MLD = interactions of right coronary characteristics with type of graft.

SE = standard error; other abbreviations as in Table 2.

Table 5 **Predictors of Graft Function at 6 Months: Separate Logistic Regression Models for SVG and GEA**

Variables	Beta Estimates	SE	Wald Chi-Square	p Value
SVG*				
% stenosis	0.81	0.49	2.72	0.0989
MLD	0.21	0.49	0.18	0.6756
GEA†				
% stenosis	1.57	0.67	5.47	0.0194
MLD	−1.90	0.78	5.91	0.0150

SVG indicates type of graft; SVG = 0 means gastroepiploic artery; SVG = 1 means saphenous vein graft. Percent stenosis is a 4-level ordered variable, with 0 = 100%, 1 = 99% to 65%, 2 = 64% to 48%, 3 = 47% to 0% stenosis. The MLD is a 4-level ordered variable, with 0 = 0 mm, 1 = 0.01 to 0.76 mm, 2 = 0.77 to 1.42 mm, 3 = >1.43 mm MLD. *Likelihood ratio chi-square = 5.98, 2 df, p = 0.05; Hosmer-Lemeshow goodness-of-fit test: chi-square = 1.78, 4 df, p = 0.776. †Likelihood ratio chi-square = 75.07, 2 df, p < 0.0001; Hosmer-Lemeshow goodness-of-fit test: chi-square = 3.40, 4 df, p = 0.49.

GEA = gastroepiploic artery; other abbreviations as in Tables 2 and 4.

JACC Vol. 51, No. 2, 2008
January 15, 2008:120–5

When the population was divided in 4 equivalent groups on the basis of the severity of the RCA stenosis assessed by MLD and by percent stenosis, the mean patency score of RGEA decreases abruptly in the approximate quartiles corresponding to the less severely obstructive RCA disease. In contrast, the influence of MLD and of percent stenosis of the RCA on the patency score of SVG is significantly less pronounced and completely disappears when MLD is adjusted to percent stenosis. The MLD values approximately 0.77 to 1.4 mm and percent stenosis approximately 48% to 64% seemed to discriminate between functional and nonfunctional RGEA. In contrast, no threshold values could be established for the SVG, the proportion of functional grafts remaining ≥70% in the higher MLD approximate quartiles.

Discussion

This study shows that in patients randomly treated with either an RGEA or an SVG for a stenosis of the RCA, the proportion of grafts found occluded on systematic 6-month angiographic control is low and independent of the type of graft conduit; however, the flow pattern is significantly more affected by the angiographic characteristics of the grafted RCA for RGEA than for SVG. Consequently, most SVG but only a minority of RGEA remained functional when the MLD of the RCA was larger than a threshold value close to 1.0 mm.

Previous angiographic follow-up studies of RGEA have suggested that the graft patency might be affected by the stenosis of the recipient RCA, most likely as a result of competitive flow (3,15,16). The evaluation of stenosis severity was based on visual interpretation of post-operative coronary angiogram at the time of angiographic follow-up. In the present study, the evaluation of RCA stenosis severity was done on pre-operative angiogram to eliminate the possible influence of coronary remodeling secondary to changes in native coronary flow pattern after surgery. In addition, this evaluation was performed with a validated quantitative angiographic analysis system in order to eliminate subjectivity in the assessment of stenosis severity. Although quantitative angiography has been extensively used in interventional cardiology for many years for precise indications and to appreciate the results of percutaneous interventions, little is known about the influence of quantitative angiographic parameters of coronary vessels on the outcome of coronary bypass grafts.

Several factors could contribute to the greater predictive value of RCA stenosis severity on the flow pattern of RGEA. Compared with an SVG, which is directly anastomosed to the ascending aorta and can be considered as a first branch off of the aorta, the pedicled RGEA is the fourth branch originating from a visceral system. This more distal origin from a complex branching arterial system, together with a lumen diameter usually smaller than that of venous grafts, might contribute to a lower flow capacity of RGEA compared with SVG. Intraoperative measurements of pressure waveforms at the tip of RGEA have shown that mean diastolic pressure is significantly lower than that in the ascending aorta or at the tip of a mammary artery graft (17). In addition, the gastroepiploic artery is prone to vasoconstriction and might become more resistive in responses to various pharmacologic and physiologic stimuli (18). In contrast, the range of vasomotor response of SVG is smaller than that of grafted coronary arteries (14). In the presence of an RCA stenosis of moderate severity, the pressure drop across the stenosis might be small, particularly at rest, when myocardial blood flow demand is minimal. We can hypothesize that the perfusion of the distal coronary bed is mainly provided by the less resistive conduit, which explains the superiority of SVG over RGEA in these conditions.

Conclusions

Quantitative angiographic analysis of pre-operative angiograms provides information likely to influence the choice of the most adequate graft conduit in patients who are candidates for coronary bypass grafting of the RCA. In the present study, an MLD above the third quartile (0.77 to 1.4 mm) or a stenosis <55% predicted an unfavorable flow pattern in RGEA but not in SVG at 6-month follow-up. In these stenoses of intermediate severity, the SVG should be preferred to the RGEA.

Reprint requests and correspondence: Dr. David Glineur, Service de Chirurgie Cardiovasculaire et Thoracique, Cliniques Universitaires Saint-Luc–U.C.L.90, Avenue Hippocrate 10/6107, 1200 Brussels, Belgium. E-mail: david.glineur@clin.ucl.ac.be.

REFERENCES

1. Lytle BW, Loop FD. Superiority of bilateral internal thoracic artery grafting: it's been a long time comin'. Circulation 2001;104:2152–4.
2. Buxton BF, Komeda M, Fuller JA, Gordon I. Bilateral internal thoracic grafting may improve outcome of coronary artery surgery. Risk-adjusted survival. Circulation 1998;98 Suppl:II1–6.
3. Suma H, Isomura T, Horii T, Sato T. Late angiographic result of using the right gastroepiploic artery as a graft. J Thorac Cardiovasc Surg 2000;120:496–8.
4. Tector AJ, Schmahl TM. Techniques for multiple internal mammary artery bypass grafts. Ann Thorac Surg 1984;38:281–6.
5. Buxton BF, Raman JS, Ruengsakulrach P, et al. Radial artery patency and clinical outcomes: five-year interim results of a randomized trial. J Thorac Cardiovasc Surg 2003;125:1363–71.
6. Dion R, Glineur D, Derouck D, et al. Complementary saphenous grafting: long-term follow-up. J Thorac Cardiovasc Surg 2001;122:296–304.
7. Pevni D, Uretzky G, Yosef P, et al. Revascularization of the right coronary artery in bilateral internal thoracic artery grafting. Ann Thorac Surg 2005;79:564–9.
8. Dion R, Etienne PY, Verhelst R, et al. Bilateral mammary grafting. Eur J Cardiothorac Surg 1993;7:287–94.
9. Maniar HS, Sundt TM, Barner HB, et al. Effect of target stenosis and location on radial artery graft patency. J Thorac Cardiovasc Surg 2002;123:45–52.
10. Voutilainen S, Verkkala K, Jarvinen A, Keto P. Angiographic 5-year follow-up study of right gastroepiploic artery grafts. Ann Thorac Surg 1996;62:501–5.
11. Ochi M, Hatori N, Fujii M, Saji Y, Tanaka S, Honma H. Limited flow capacity of the right gastroepiploic artery graft: postoperative

echocardiographic and angiographic evaluation. Ann Thorac Surg 2001;71:1210–4.
12. Albertini A, Lochegnies G, El Khoury R, et al. Use of the right gastroepiploic artery as a coronary artery bypass graft in 307 patients. Cardiovasc Surg 1998;6:419–23.
13. Dion R, Lavenne-Pardonge E, Scheiff JM, Verhelst R, Baele P, Moriau M. A novel preservation medium protecting prostacyclin production and endothelial integrity of the human saphenous vein graft. Thromb Res Suppl 1990;12:81–6.
14. Hanet C, Robert A, Wyns W. Vasomotor response to ergometrine and nitrates of saphenous vein grafts, internal mammary artery grafts and grafted coronary arteries late after bypass surgery. Circulation 1992;86:II210–6.
15. Hashimoto H, Isshiki T, Ikari Y, et al. Effects of competitive blood flow on arterial graft patency and diameter. Medium-term postoperative follow-up. J Thorac Cardiovasc Surg 1996;111:399–407.
16. Uchida N, Kawaue Y. Flow competition of the right gastroepiploic artery graft in coronary revascularization. Ann Thorac Surg 1996; 62:1342–6.
17. Tedoriya T, Kawasuji M, Sakakibara N, Ueyama K, Watanabe Y. Pressure characteristics in arterial grafts for coronary bypass surgery. Cardiovasc Surg 1995;3:381–5.
18. Hanet C, Seeman C, El Khoury G, Dion R, Robert A. Differences in vasoreactivity between gastroepiploic artery grafts late after bypass surgery and grafted coronary arteries. Circulation 1994;90: II155–9.