Clinical Validation of a Coronary Surgery Technique That Minimizes Aortic Manipulation

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Background. To minimize aortic manipulation and maximize use of arterial conduits are aims of modern coronary surgery.

Methods. From March 2012 to October 2016, 890 consecutive patients with multivessel coronary disease underwent isolated coronary operations using both internal thoracic arteries (ITAs). In 205 (23%; mean age, 67.6 ± 9.2 years), the right ITA was proximally transected and used as a free graft, while its in situ stump was elongated with a saphenous vein graft. The new arteriovenous I conduit was directed to the inferolateral cardiac wall. Operative data and early outcomes of these patients (I group) were compared with the remaining 685 patients (control [C] group). Early and late outcomes were also compared in 184 pairs identified with propensity score matching.

Results. Between the I and C groups there was no significant difference in expected operative risk (European System for Cardiac Operative Risk Evaluation II, $p = 0.28$), although diseased ascending aorta ($p < 0.0001$) and critical preoperative state ($p = 0.027$) were more frequent in the I group. Despite a higher number of coronary anastomoses (mean, 4 ± 0.9 vs 3.7 ± 1, $p < 0.0001$), cardiopulmonary bypass time was shorter in the I group both in overall (86.7 ± 23.7 vs 105.7 ± 34.2 minutes, $p < 0.0001$) and matched series (86.8 ± 24.1 vs 108.8 ± 31.9 minutes, $p < 0.0001$). In-hospital mortality (1% vs 1.9%, $p = 0.54$) and the rates of postoperative complications were similar. During the follow-up period, no intergroup difference was found in matched patients in the nonparametric estimates of freedom from all-cause death ($p = 0.39$) and major adverse cardiac and cerebrovascular events ($p = 0.44$).

Conclusions. Surgery using this arteriovenous I conduit is safe, minimizes aortic manipulation, shortens cardiopulmonary bypass time, and aids complete revascularization.

Throughout the last 20 years, the continuing need of improving the outcome of coronary surgery has generated a great interest in the use of composite arterial grafts against the limited number of usable arterial conduits [1, 2]. Both internal thoracic arteries (ITAs), the radial artery, and, occasionally, the right gastroepiploic artery have been used in many configurations [1–5]. This creative surgery aims to obtain a totally arterial coronary revascularization, often by means of the off-pump technique, and sometimes at the expense of complete revascularization [6]. To minimize or avoid aortic manipulation is another goal of modern coronary surgery. Embolism from an atherosclerotic ascending aorta is the primary cause of neurologic injury in coronary surgery, and the use of in situ or simple or composite arterial conduits has been proven useful to counteract this phenomenon and improve outcomes [7–10].

In the present comparative study, the early and late outcomes of approximately 200 patients who underwent isolated coronary operations using both ITAs and a composite arteriovenous graft were reviewed prospectively. The aim of the study was to perform the first clinical validation of this novel revascularization strategy that minimizes aortic manipulation. The hypothesis that there could be a lower risk of neurologic dysfunctions after the operation attributable to this reduced manipulation was verified as well.

Patients and Methods

Study Patients and Selection Criteria

Between March 2012 and October 2016, 890 patients with multivessel coronary artery disease underwent isolated coronary operations using both ITAs at the Division of Cardiac Surgery of Trieste, Italy. Baseline characteristics of patients, surgical features, operative data, and postoperative complications were prospectively recorded for every patient in a data registry. In 205 of these patients (23%), an arteriovenous I conduit was assembled by anastomosing end-to-end (I anastomosis) the in situ proximal stump of the right ITA with a saphenous vein graft [11, 12]. Operative data and early outcomes of these patients (I group) were compared with those of the remaining 685 patients, who were the control group (C group). Early and late outcomes were also compared in pairs of patients identified with propensity score matching (Supplemental Fig 1). The Trieste University Hospital Ethics Committee approved this study based on retrospective data retrieval. The need for patients to provide individual written consent was waived.

At our institution, the I-graft technique was first used by a senior surgeon (B.B.) for patients with the most severe presentations of atherosclerotic disease of the aorta to avoid aortic clamping and aid more complete coronary revascularization, enhancing potentialities of off-pump surgery. The technique was later extended even to patients without aortic disease at epiaortic ultrasonography scanning who underwent on-pump operations. Within a few weeks, it was used from time to time by the entire surgical team according to the deputed surgeons' preference. (Details on patient selection are reported in the Supplemental Methods.)

Unless otherwise stated, the definitions and cutoff values of the preoperative variables were those used for the European System for Cardiac Operative Risk Evaluation, 2011 revision (EuroSCORE II) [13]. The definitions of postoperative complications were in accordance with the internationally agreed definitions of complications after cardiac operations [14].

Operation and Perioperative Management

The operation was performed through a median sternotomy with cardiopulmonary bypass, with or without cross-clamping the aorta, or with the off-pump technique. When a period of myocardial ischemia was used, myocardial protection was achieved with multidose cold blood cardioplegia delivered in both antegrade and retrograde mode. Off-pump and on-pump beating heart techniques were adopted only in the presence of an atherosclerotic ascending aorta, which was demonstrated by epiaortic ultrasonography scan [15, 16].

Both ITAs were dissected as skeletonized conduits, and the ITA harvesting technique did not change during the study period [15].

In the I group, the right ITA was proximally transected and used as free graft from the in situ left ITA, while its in situ stump (mean length, 3 to 5 cm) was elongated with a saphenous vein graft. The new arteriovenous I conduit
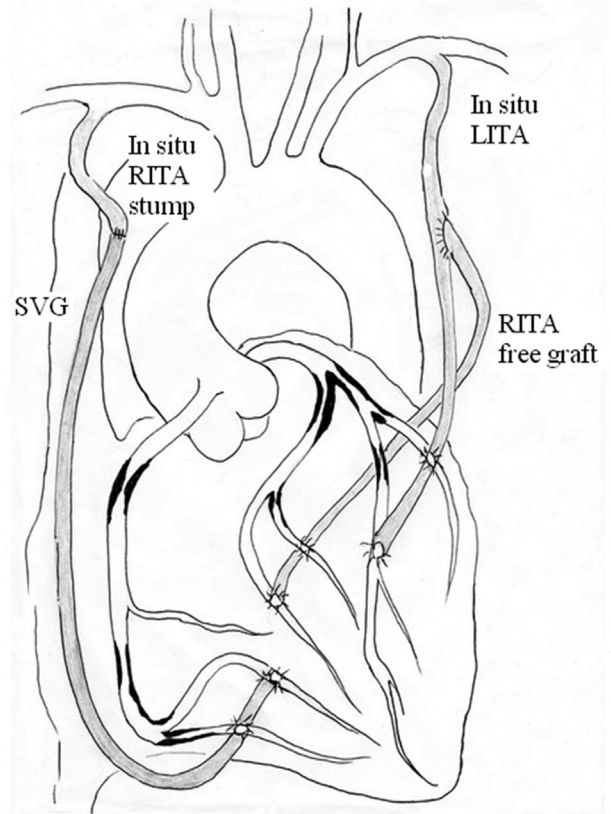

Fig 1. The arteriovenous I conduit, which was obtained anastomosing end-to-end the in situ proximal stump of the right internal thoracic artery (RITA) with a saphenous vein graft (SVG). (LITA = left internal thoracic artery.)

was directed to the inferior or inferolateral cardiac wall (Fig 1; Supplemental Table 1).

In the C group, when both ITAs were used as in situ grafts, the right ITA was directed to the left anterior descending coronary artery and the left ITA to the lateral or posterolateral cardiac wall [11]. Additional coronary bypasses, usually for the right coronary artery, were performed with saphenous vein grafts. The aortic anastomosis of every venous graft was performed during aortic cross-clamping in the on-pump technique and during ultrasonography scan-guided side-clamping in the off-pump and on-pump beating heart techniques (when possible). The right ITA was occasionally used as a free graft from the roof of the proximal (aortic) end of a saphenous vein graft.

In the I and C groups, when the 2 ITAs were used as composite graft, the deriving Y graft was directed to the anterolateral cardiac wall. The composite grafts (I and Y) were assembled after intravenous heparin administration, before aortic cannulation, except for patients with instability of hemodynamics. Transit-time flow measurement has been used since June 2014 for intraoperative functional assessment of every coronary graft [15]. (Further details on the operation and perioperative management are reported in the Supplemental Methods.)

Table 1. Baseline Characteristics of Patients With Arteriovenous I Conduit (I Group) and Control Patients (C Group): Overall and Propensity Score-Matched Series

Variable[a]	Overall Series			Matched Pairs			
	I Group (n = 205)	C Group (n = 685)	p Value	I Group (n = 184)	C Group (n = 184)	St. Diff.	p Value
Age, years	67.6 ± 9.2	66.6 ± 9.7	0.22	67.1 ± 9.3	67.6 ± 8.7		0.63
60–69	69 (33.7)	228 (33.3)		62 (33.7)	67 (36.4)	−0.005	
70–79	80 (39)	240 (35)		71 (38.6)	68 (37)	0.005	
>80	13 (6.3)	57 (8.3)		10 (5.4)	14 (7.6)	−0.023	
Female	25 (12.2)	89 (13)	0.86	23 (12.5)	17 (9.2)	−0.009	0.31
Body mass index, kg/m²	27.8 ± 3.9	27.4 ± 3.9	0.59	27.5 ± 3.8	27.8 ± 4.7		0.55
>35 kg/m²	12 (5.9)	25 (3.6)		10 (5.4)	12 (6.5)	−0.011	
Diabetes	78 (38)	239 (34.9)	0.41	70 (38)	66 (35.9)	0.017	0.66
Diabetes on insulin	12 (5.9)	58 (8.5)	0.22	12 (6.5)	10 (5.4)	0.041	0.66
Poor glycemic control[b]	7 (3.4)	34 (5)	0.35	7 (3.8)	6 (3.3)	−0.02	0.78
Anemia[c]	95 (46.3)	310 (45.3)	0.81	86 (46.7)	84 (45.7)	0.016	0.84
Poor mobility[d]	1 (0.5)	11 (1.6)	0.31	0	0	…	…
Chronic lung disease[d]	13 (6.3)	46 (6.7)	0.84	11 (6)	9 (4.9)	−0.003	0.65
eGFR, mL/min[e]	87.2 ± 29	84.6 ± 30.9	0.29	86.5 ± 28.6	86.7 ± 32.4		0.93
50–85[d]	89 (43.3)	311 (45.4)		80 (43.5)	93 (50.5)	0.002	
<50[d]	14 (6.8)	77 (11.2)		13 (7.1)	13 (7.1)	−0.015	
Chronic dialysis	2 (1)	14 (2)	0.48	0	0	…	…
Extracardiac arteriopathy[d]	60 (29.3)	175 (25.5)	0.29	47 (25.5)	49 (26.6)	0.03	0.81
Diseased ascending aorta[f]	31 (15.1)	26 (3.8)	<0.0001	17 (9.2)	19 (10.3)	−0.013	0.73
NYHA class IV	6 (2.9)	34 (5)	0.22	6 (3.3)	6 (3.3)	−0.004	1
CCS class IV	102 (49.8)	361 (52.7)	0.46	89 (48.4)	98 (53.3)	0.017	0.35
Recent myocardial infarction[d]	36 (17.6)	154 (22.5)	0.13	34 (18.5)	33 (17.9)	−0.077	0.89
Coronary artery disease			<0.0001				0.62
One-vessel[g]	0	4 (0.6)		0	0	…	
Two-vessel	7 (3.4)	154 (22.5)		7 (3.8)	10 (5.4)	−0.035	
Three-vessel	198 (96.6)	527 (76.9)		177 (96.2)	174 (94.6)	−0.003	
Left main coronary artery disease	75 (36.6)	278 (40.6)	0.31	63 (34.2)	71 (38.6)	0.018	0.39
Left ventricular ejection fraction	0.564 ± 0.104	0.558 ± 0.102	0.49	0.563 ± 0.107	0.562 ± 0.102		0.96
0.30–0.50[d]	24 (11.7)	124 (18.1)		29 (15.8)	37 (20.1)	0.001	
0.20–0.30[d]	7 (3.4)	17 (2.5)		7 (3.8)	3 (1.6)	−0.085	
<0.20[d]	1 (0.5)	3 (0.4)		1 (0.5)	2 (1.1)	…	
Critical preoperative state[d]	28 (13.7)	58 (8.5)	0.027	28 (15.2)	23 (12.5)	−0.051	0.45
Use of IABP	22 (10.7)	52 (7.6)	0.15	17 (9.2)	11 (6)	0.013	0.24
Previous coronary operation	0	2 (0.3)	1	0	0	…	…
Surgical priority[d]			0.51				0.97
Elective	50 (24.4)	166 (24.2)		45 (24.5)	43 (23.4)	−0.006	
Urgent	154 (75.1)	506 (73.9)		138 (75)	140 (76.1)	0	
Emergency	1 (0.5)	7 (1)		1 (0.5)	1 (0.5)	…	
Salvage	0	6 (0.9)		0	0	…	
Expected operative risk,[h] %	2.1 (1.2–4.2)	2.3 (1.3–4.8)	0.28	2.1 (1.2–4.1)	2.2 (1.3–4.3)		0.68
>10	13 (6.3)	72 (10.5)		12 (6.5)	15 (8.2)	−0.073	

[a] Unless otherwise stated, the values are the mean ± SD, median (interquartile range), or the number of patients (%). [b] Defined as basal blood glucose level >200 mg/dL at three consecutive measurements before the operation. [c] Defined as hemoglobin <12 g/dL for women and <13 g/dL for men. [d] The definitions and the cutoff values are those used for European System for Cardiac Operative Risk Evaluation 2011 revision [13]. [e] The creatinine clearance rate, calculated according to the Cockcroft-Gault formula, was used for approximating the estimated glomerular filtration rate (eGFR). [f] By intraoperative epiaortic scan [16]. [g] Coronary disease involving the left anterior descending artery and its (big) diagonal branch. [h] By European System for Cardiac Operative Risk Evaluation 2011 revision [13].

CCS = Canadian Cardiovascular Society;   IABP = intraaortic balloon pump;   NYHA = New York Heart Association Functional Classification; St. Diff = standardized difference.

	Overall Series			Matched Pairs		
Variable[a]	I Group (n = 205)	C Group (n = 685)	*p* Value	I Group (n = 184)	C Group (n = 184)	*p* Value
Coronary anastomoses, No.	4 ± 0.9	3.7 ± 1	<0.0001	4 ± 0.9	3.8 ± 1	0.011
Composite arterial Y graft	205	136		184	32	
Bilateral internal thoracic artery in situ	…	538		…	148	
Saphenous vein grafts	205	537	<0.0001	184	157	<0.0001
Saphenous vein-to-coronary artery anastomoses	1.4 ± 0.6	1.1 ± 0.8	<0.0001	1.4 ± 0.6	1.2 ± 0.8	0.037
Surgical technique			<0.0001			1
Off-pump	21 (10.2)	18 (2.6)		13 (7.1)	13 (7.1)	
On-pump beating heart	10 (4.9)	8 (1.2)		4 (2.2)	4 (2.2)	
On-pump	174 (84.9)	659 (96.2)		167 (90.8)	167 (90.8)	
Aortic cross-clamp time, minutes	69.4 ± 20.2	83.7 ± 26	<0.0001	69.1 ± 20.4	87 ± 25	<0.0001
Cardiopulmonary bypass time, minutes	86.7 ± 23.7	105.7 ± 34.2	<0.0001	86.8 ± 24.1	108.8 ± 31.9	<0.0001
Total operating time, minutes	281.7 ± 47.9	282.9 ± 54.8	0.88	283.9 ± 47.1	283 ± 52.7	0.88

[a] The values are the mean ± SD, or the number of patients (%).

Follow-Up

An up-to-date clinical follow-up was obtained by telephone interview with patients or their family. All major adverse cardiac and cerebrovascular events after hospital discharge, defined as sudden death, recurrent angina, myocardial infarction, congestive heart failure, percutaneous coronary intervention, repeat coronary operation, or cerebrovascular accident, were recorded. Patency of the I conduit was checked with electrocardiographic-gated coronary computed tomography angiography or standard coronary angiography in 5 patients with symptoms of heart failure and in the first 55 consecutive, asymptomatic patients who consented to the investigation. Follow-up was closed on February 2, 2018.

Statistical Methods

Continuous variables with normal distribution are expressed as mean ± SD and those without normal distribution as median and the range between the first and the third quartile (interquartile range [IQR]). Discrete variables are expressed as frequencies and percentages. Statistical comparison of baseline characteristics, operative data, and postoperative complications was performed using the χ^2 or the Fisher exact test for categorical variables and the Student *t* test or the Mann-Whitney *U* test for continuous variables. Study patients were divided in two groups according to the use of the new arteriovenous I graft. Because the two groups significantly differed in a few preoperative characteristics, a 1-to-1 propensity score-matched analysis was performed (details on this analysis are reported in the Supplemental Methods).

Nonparametric estimates and curves of freedom from all-cause death, cardiac or cerebrovascular deaths, and major adverse cardiac and cerebrovascular events were generated with the Kaplan-Meier method. Comparisons between survival curves were made by the log-rank test. All tests were two-sided, and a *p* value of less than 0.05 was set for statistical significance. Statistical analysis was performed using SPSS 13.0 software (SPSS Inc, Chicago, IL).

Results

Overall Series

Between the I and C groups there was no significant difference on expected operative risk (EuroSCORE II, $p = 0.28$), although diseased ascending aorta ($p < 0.0001$), 3-vessel coronary artery disease ($p < 0.0001$), and critical preoperative state ($p = 0.027$) were more frequent in the I group. Aortic cross-clamping was avoided in 15.1% of the I-group patients and in 3.8% of C-group patients ($p < 0.0001$). Despite a higher number of coronary anastomoses ($p < 0.0001$), cross-clamp and cardiopulmonary bypass times were shorter in the I group ($p < 0.0001$ for both). The mean flow measured through 106 nonconsecutive I conduits (51.4 ± 28.7 mL/min) was even higher than that measured through 155 nonconsecutive aorto-coronary saphenous vein grafts to the right coronary artery of the C group (43.4 ± 28.1 mL/min, $p = 0.027$). In-hospital mortality (1% vs 1.9%, $p = 0.54$), the rates of postoperative complications, and the hospital lengths of stay were comparable. Prolonged invasive ventilation was more frequent in the C group, but the difference was not quite significant ($p = 0.094$; Tables 1–3).

The follow-up rate was 100% for the 205 I patients. The median follow-up was of 2.8 years (IQR, 1.8 to 3.7 years; Supplemental Fig 2).

In the 2 I patients who died of multiorgan failure in-hospital after the operation, the graft was patent at the autopsy. Repeat coronary revascularization was

Table 3. In-Hospital Death, Postoperative Complications, and Hospital Course of Patients With Arteriovenous I Conduit (I Group) and Control Patients (C Group) for Overall and Propensity Score-Matched Series

Variable[a]	Overall Series			Matched Pairs		
	I Group (n = 205)	C Group (n = 685)	p Value	I Group (n = 184)	C Group (n = 184)	p Value
Death						
In-hospital	2 (1)	13 (1.9)	0.54	2 (1.1)	2 (1.1)	1
≤30 days	2 (1)	9 (1.3)	1	2 (1.1)	2 (1.1)	1
Neurologic dysfunction[b]	5 (2.4)	18 (2.6)	0.89	5 (2.7)	4 (2.2)	1
Permanent	5 (2.4)	10 (1.5)		5 (2.7)	4 (2.2)	
Temporary	0	8 (1.2)		0	0	
Prolonged (>48 hours) invasive ventilation	14 (6.8)	74 (10.8)	0.094	13 (7.1)	18 (9.8)	0.35
Pneumonia	9 (4.4)	33 (4.8)	0.81	8 (4.3)	9 (4.9)	0.81
Diaphragmatic dysfunction[c]	0	6 (0.9)	0.35	0	0	...
Atrial fibrillation, new onset	25 (12.2)	110 (16.1)	0.18	20 (10.9)	28 (15.2)	0.22
Myocardial infarction[b]	1 (0.5)	8 (1.2)	0.48	0	2 (1.1)	0.5
Low cardiac output[b]	13 (6.3)	41 (6)	0.84	12 (6.5)	7 (3.8)	0.24
Use of adrenergic agonists	155 (75.6)	522 (76.2)	0.86	139 (75.5)	138 (75)	0.92
Intra-op or post-op use of IABP	4 (2)	12 (1.8)	1	1 (0.5)	4 (2.2)	0.37
Use of ECMO	0	3 (0.4)	0.59	0	1 (0.5)	1
Acute kidney injury[b]	14 (6.8)	39 (5.7)	0.55	10 (4.9)	6 (3.3)	0.3
Renal replacement therapy	3 (1.5)	12 (1.8)	1	1	0	1
Mesenteric ischemia	0	3 (0.4)	0.59	0	0	...
Multiorgan failure	2 (1)	16 (2.3)	0.27	2 (1.1)	1 (0.5)	1
Sepsis	0	8 (1.2)	0.21	0	1 (0.5)	1
48-hour chest tube output/BSA, mL/m^2	548.3 (337.1−759.1)	516 (328.4−789.3)	0.66	558.2 (348.8−753.5)	474.8 (329.8−749.6)	0.19
Multiple blood transfusions (>2 RBC units)	13 (6.3)	67 (9.8)	0.13	11 (6)	13 (7.1)	0.67
Mediastinal reexploration[d]	11 (5.4)	51 (7.4)	0.31	11 (6)	11 (6)	1
Sternal wound infection[b]	12 (5.9)	34 (5)	0.61	11 (6)	11 (6)	1
Superficial	1 (0.5)	2 (0.3)		1 (0.5)	2 (1.1)	
Deep	11 (5.4)	32 (4.7)		10 (5.3)	9 (4.8)	
Leg wound complication	3/205[e] (1.5)	4/537[e] (0.7)	0.63	2/184[e] (1.1)	1/157[e] (0.6)	1
Any major complication[f]	58 (28.3)	177 (25.8)	0.54	52 (28.3)	47 (25.5)	0.55
Length of stay, days						
Hospital	9 (7–12)	9 (7–12)	0.54	9 (7–12)	8 (7–12)	0.9
Intensive care unit	2 (1–3)	2 (1–3)	0.33	2 (1–3)	2 (1–3)	0.47

[a] The values are the number of patients (%) or the median (interquartile range). [b] Biancari and colleagues [14]. [c] Defined as dysfunction (confirmed by sonography) needing prolonged invasive ventilation. [d] For bleeding or tamponade and through sternotomy or subxyphoid window. [e] The patients who had saphenous vein grafts. [f] Includes stroke, prolonged invasive ventilation, myocardial infarction, low cardiac output, acute kidney injury, mesenteric ischemia, sepsis, multiple blood transfusion, mediastinal reexploration, or deep sternal wound infection.

BSA = body surface area; ECMO = extracorporeal membrane oxygenation; IABP = intraaortic balloon pump; RBCs = red blood cells.

performed in 5 symptomatic (recurrent angina [n = 2], non-ST elevation myocardial infarction [n = 1], congestive heart failure [n = 1], and ventricular fibrillation [n = 1]) and 2 asymptomatic patients. Overall, among the 60 I patients who had been investigated with coronary (computed tomography) angiography at a median time of 4.0 years (IQR, 3.7 to 4.3 years) postoperatively, the patency of the I conduit and of the branches to the anterior and the lateral cardiac wall of Y graft was 88.3%, 100%, and 96.7%, respectively; the I graft was occluded at the I anastomosis in 1 patient, at the coronary anastomosis in another patient, and was nondetectable in 5 patients (Supplemental Table 2).

Matched Series

A propensity score was estimated by logistic regression, and its area under the receiver operating characteristic curve was 0.72 (95% confidence interval, 0.69 to 0.75). Matched analysis resulted in 184 pairs with similar baseline characteristics and operative risk. Even in matched patients, aortic cross-clamp and cardiopulmonary bypass times were shorter in the I group (p < 0.0001 for both),
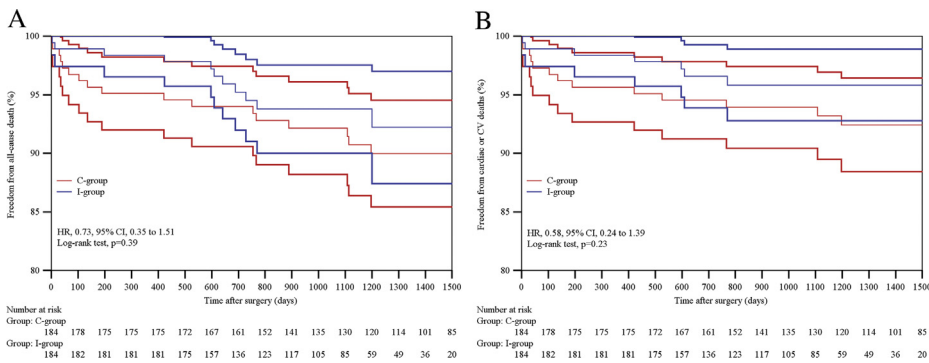
Fig 2. *Patients with arteriovenous I conduit (I group) versus control patients (C group), the matched pairs. Nonparametric curves and estimates of freedom from (A) all-cause death and (B) cardiac or cerebrovascular (CV) deaths. (CI = confidence interval; HR = hazard ratio.)*

despite the higher number of coronary anastomoses (*p* = 0.011). In-hospital mortality, the rates of postoperative complications, and the hospital lengths of stay after the operation were equivalent. Although there was a trend toward increased bleeding in the I group, the difference was not quite significant (*p* = 0.19; Tables 1–3).

During the follow-up period, which was longer for the C group (median, 4.1 [IQR, 2.7 to 5] years vs 3.0 [IQR, 1.9 to 3.7] years; *p* < 0.0001), there were no intergroup differences for the nonparametric estimates of freedom from all-cause death (*p* = 0.39), cardiac or cerebrovascular deaths (*p* = 0.23), and major adverse cardiac and cerebrovascular events (*p* = 0.44; Figs 2, 3; Supplemental Table 2).

Comment

For 205 patients of the present study, an arteriovenous I graft was obtained by means of an end-to-end anastomosis between the proximal stump of the right ITA and a saphenous vein graft and used to bypass the right coronary artery and, occasionally, the posterolateral branch of the circumflex coronary artery. This strategy
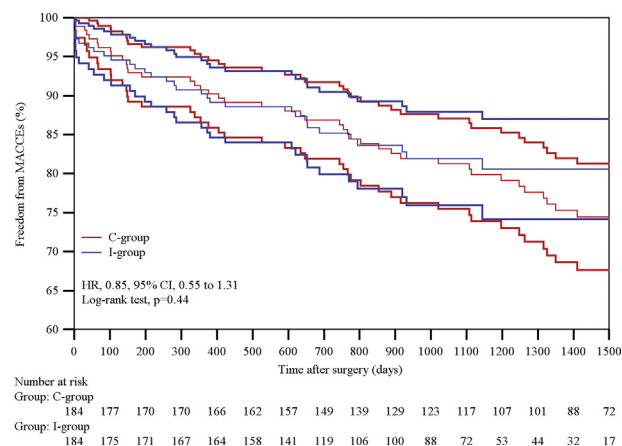
was preferably used in the presence of a diseased ascending aorta to minimize its manipulation and allowed complete coronary revascularization during off-pump operations. This last point has been confirmed by the increased number of coronary anastomoses and the higher rate of off-pump operations (overall series only) of the I group.

The average cross-clamp time was shorter in the I group, both in the overall (14 minutes) and matched series (18 minutes). This was an expected result when proximal inflow was completed during a single cross-clamp time (C group, bilateral in situ ITA patients) or before starting on cardiopulmonary bypass using the right ITA stump and the in situ left ITA (I group). Because up to 10 minutes were needed to make the I or the Y anastomosis, the total time to complete revascularization, which would include the time required to complete the I plus Y anastomosis compared with the time to create proximal aortic anastomoses, was similar between the two groups. The total operating time was also equivalent between the two groups, even though the total time to complete revascularization was a few minutes longer for the Y-graft patients (17.4%) of C group. In this study, a single-clamp technique was used for most cases. The cross-clamp time should be reduced by the interval that would be required to do one proximal anastomosis.

Cardiopulmonary bypass time should have a similar reduction. Yet, after propensity matching, cross-clamp times were meanly and significantly reduced by 19 minutes and cardiopulmonary bypass times by 22 minutes. This difference seems more than would be expected. We have no convincing elements to give reason of this result. There could have been quicker times of weaning from cardiopulmonary bypass using the I-graft technique: allowing blood flow in the coronary grafts before the aortic cross-clamp is removed, the risk of air embolism into the coronary tree would be reduced and the washout of cardioplegia favored. However, because the rate of spontaneous recovery of cardiac rhythm after cross-clamp removal was not analyzed in the study, these arguments remain speculative.

There are two more benefits, one technical and one speculative, that may derive from the use of this arteriovenous I conduit: (1) its flow can be tested before the coronary anastomosis is performed, similarly to every in

Fig 3. *Patients with arteriovenous I conduit (I group) versus control patients (C group), the matched pairs. Nonparametric curves and estimates of freedom from major adverse cardiac and cerebrovascular events (MACCEs). (CI = confidence interval; HR = hazard ratio.)*

situ graft; consequently, the I anastomosis could be safe in learning how to make microvascular anastomoses without the risk of irreparable injuries to the coronary grafts; (2) the long-term patency of this arteriovenous graft could be equivalent to that of totally arterial grafts because of the action onto the intimal layer of its venous component of nitric oxide, which is released from the endothelial cells of the right ITA stump [17].

In this study, the 4-year patency of the I graft to the right coronary artery (88.3%) was lower than that of ITA graft to the left anterior descending (100%) or the circumflex coronary artery (96.7%). However, it is well known that the coronary graft patency also depends on the extension of the revascularized coronary bed and how much poorer could be that of the right coronary artery. On one hand, this arteriovenous graft actually had an improved patency with respect to saphenous vein grafts that arise from the aorta, whose reported patency rates are 78% to 81% at 1 year and 65% to 75% at 5 years postoperatively [18, 19]. On the other hand, although there are conflicting results in the literature about the fate of arteriovenous composite grafts [10, 20, 21], there are no real drawbacks, in our opinion, for the use of this composite graft in coronary operations, except for the need of a good match for size, thickness, and quality of the vessel wall between the proximal right ITA stump and the saphenous vein graft.

Of course, the presence of a significantly stenotic (>50%) or occluded right subclavian artery as well as of a diseased or injured right ITA are contraindications to its use. (None of these events occurred during the present experience.) In fact, in-hospital mortality, the rates of early complications postoperatively, and the post-operative hospital length of stay were equivalent between the I and C groups.

Although on a speculative basis there could be a higher risk of bleeding in the I group because of the use of a nonstandard arteriovenous anastomosis, the difference in bleeding between I and C groups was not quite significant; besides, multiple blood transfusion and mediastinal reexploration did not increase using the I-graft strategy. Kinking and torsion of the I graft and the presence of a competitive flow in the native coronary bed are items of concern and probable cause of the failures observed at coronary computed tomography angiography reconstructions performed at the 1-year follow-up [11, 12].

The lack of randomization of patients to be allocated to one or the other group is the major limitation of this prospective study, where the I-graft strategy was adopted according to the surgeon's preference. Although a propensity-matched analysis was performed, the study results might have been affected by the selection bias of the patients; it is known, indeed, that when a technique is adopted according to a preference, the risk of bias is significant. Titrations of the enzymes of myocardial necrosis and postoperative echocardiographic results were not reported.

Although the major advantage to the I graft would be the ability to minimize manipulation of the ascending aorta, no difference in perioperative morbidity related to aortic manipulation (eg, stroke) was observed. However, because the stroke rate was low, there is the possibility that the I conduit really does reduce stroke rates, but the study did not reach a large enough sample of patients to validate this hypothesis. In addition, only neurologic dysfunctions were considered for analysis, and neither neurocognitive nor psychological changes after the operation were explored. Distinguishing between cardiac and cerebrovascular death during the follow-up period was impossible in some patients, and any late benefits derived from reduced perioperative aortic manipulation in I patients could thus not have been observed.

Because the patients in the C group were operated on at an earlier time (longer follow-up period; Supplemental Table 2) than those in the I group, management techniques could be changed over time, and this might have affected outcomes.

Finally, only midterm outcomes (of matched patients only) could be evaluated; no inference could be obtained on a long-term basis. Consequently, the results reported in this study should not be considered conclusive and should be verified in large patient populations by means of controlled randomized trials that include laboratory, echocardiographic, and angiographic evaluations.

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