Heart Vessels (2008) 23:316–324
DOI 10.1007/s00380-008-1055-8

ORIGINAL ARTICLE

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Intraoperative behavior of arterial grafts in the elderly and the young: a flowmetric systematic analysis

Received: September 25, 2007 / Accepted: March 7, 2008

Abstract Extensive arterial grafting (Art-CABG) in the elderly is still questioned due to the reduced life expectancy and the supposed higher periprocedural risk. Reports further demonstrated accelerated atherosclerosis of arterial grafts in the elderly, with hampered short-term and long-term results. We reviewed our experience of patients undergoing Art-CABG between January 2003 and January 2007, divided into two groups: the elderly (238 patients ≥70 years; Group A) and the young (195 patients ≤60 years; Group B). Transit time flowmetric (TTF) maximum and mean flow, pulsatility index (PI), and graft flow reserve (GFR) were compared. Hospital outcome was analyzed. Hospital mortality, need for intra-aortic balloon pump, troponin I, and echocardiographic segmental kinetics were comparable between the two groups (P = not significant [NS]). Stratifying patients for target vessels and type of arterial CABG, no differences in TTF results were recorded between the two groups either on-pump (P = NS) and off-pump (P = NS), both for the two internal mammary arteries (P = NS irrespective of the target vessel) and the radial artery conduits (P = NS irrespective of the target vessel). Although graft flow reserve was significantly recruited in all patients ($P < 0.05$ in young and elderly, either on-pump and off-pump, irrespective of the arterial conduit and the grafted vessel), GFR of all arterial grafts was comparable between elderly and young patients, either on-pump (P = NS) or off-pump (P = NS). Art-CABG showed similar TTF results in elderly and young patients, regardless of the arterial conduit, target vessel, or surgical technique employed. These functional results supported the reported survival benefit of arterial revascularization in the elderly.

Key words Coronary artery bypass grafting · Arterial grafting · Radial artery · Transit-time flowmetry · Elderly

Introduction

Despite the worldwide demonstration of the long-term patency of the internal thoracic arteries (ITAs) together with a clear demonstration of their benefits in terms of survival and freedom from cardiovascular events,[1,2] saphenous vein grafts (SVG) continue to be extensively used and are still considered the conduit of first choice.[3,4] Moreover, with the exponential growth of the geriatric population, it is not surprising that SVG continue to be the backbone of daily coronary revascularization (CABG), being the second conduit employed in both STS National and EuroSCORE Databases.[3,4] Furthermore, reluctance to use arterial grafts in the elderly is based on concerns about long-term survival, and on the concept that extensive arterial grafting may carry the risk for an increased morbidity and mortality related to the higher invasiveness and the prolonged operative time.[5,6] Moreover, it has been recently demonstrated that the prevalence of pre-existing atherosclerotic lesions and calcifications among the arterial conduits (primarily the radial artery) may hamper their functional short-term and long-term results, furthermore suggesting the avoidance of extensive arterial grafting in some high-risk categories, such as the elderly, diabetics, and hypertensive patients.[7] Therefore, the acceptance of extensive arterial revascularization in the elderly is still questioned, and studies focusing on this topic are still scarce. Moreover, surgeons have recently acquired the possibility for an intraoperative functional assessment of the quality of their CABGs, with the aid of the transit-time flow technology (TTF), whose intraoperative results predict graft patency at angiographic follow-up.[8] Literature lacks studies comparing intraoperative TTF findings of arterial grafts in the elderly. Therefore, it was the aim of the present study to systematically review our experience on the TTF method in the elderly (>70 years) and the young (<60 years) undergoing myocardial revascularization

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with at least one arterial graft during the last 4 years at a single academic institution.

Materials and methods

The present study evaluates clinical and flowmetric results of a prospective series of elderly patients (>70 years; Group A) undergoing at least one arterial CABG during isolated myocardial revascularization, performed either off-pump (OPCABG) or on-pump, during the last 4 years at a single academic institution: the elderly were compared with a cohort of young patients (<60 years; Group B) undergoing arterial CABG during the same time period. Patients aged 60–70 years were excluded from the study to better differentiate the elderly from the young.

The study protocol was approved by institution's Ethical Committee/Institutional Review Board, and informed consent was obtained from each patient. Two hundred and thirty-eight consecutive elderly patients and 195 consecutive young patients, admitted between January 2003 and January 2007 for first-time elective CABG, were enrolled in the study.

Additional cardiac or vascular surgical procedures and severe systemic comorbidities (dialysis, hepatic failure, cancer, autoimmune disease) were the exclusion criteria. Analysis of TTF results of "Y-" and "T-" grafts was excluded in order to avoid the bias of suboptimal TTF data in a branch because of "steal" phenomena or "preferential" flows in the other branch.

Angiography

Preoperative coronary angiography of each patient was reviewed by two cardiologists, blinded with regard to the study, and Thrombosis in Myocardial Infarction (TIMI) scores were calculated for each vessel.

Surgery

Anesthesia consisted of intravenous propofol infusion at 3 mg/kg per hour combined with fentanyl administration at 0.10 mg each 20 min, and 4 mg/h pancuronium bromide. The lungs were ventilated to normocapnia with air and oxygen (45%–50%). All surgical procedures were performed by three senior surgeons. In all patients CABG was performed through a median sternotomy and the left anterior descending artery always grafted using pedicled left internal mammary artery (LIMA). Right internal mammary artery was always harvested in a pedicled fashion, and never used as a free graft. Proximal obtuse marginal branches (OM) or right coronary artery (Rx) were the preferred targets of right internal mammary artery (RIMA) conduits. The radial artery (RA) was always used as a pedicled free-graft. Following a negative Allen test, RA was harvested with a harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA), using the variable mode at moderate intensity. Major collateral branches were controlled with small clips. All the RA harvested were employed as conduits. Arterial graft pedicles were always secured with two epicardial stitches using 6-0 polypropylene on both sides after completion of distal anastomoses. OM, Rx, or diagonals (DIAG) were the targets of RA grafts.

A standard cardiopulmonary bypass circuit was used: a Dideco (Mirandola, Modena, Italy) tubing set, which included a 40-μm filter, a Stockert roller pump (Stockert Instrumente, Munich, Germany) and a hollow fiber membrane oxygenator (Dideco D903 Avant). Systemic temperature was kept between 32° and 34°C. Myocardial protection was achieved by using intermittent warm antegrade and retrograde blood cardioplegia as previously reported.[9] On completion of all distal anastomoses, the aortic cross-clamp was removed and proximal anastomoses performed with partial clamping. When OPCABG was accomplished, exposure and stabilization was achieved with the Octopus-IV±Starfish-II tissue stabilizer (Medtronic, Minneapolis, MN, USA). Intracoronary shunts were used routinely, with a success rate approximating 100%. The first grafted vessel was always the left anterior descending artery, followed by proximal anastomoses with saphenous vein or radial artery, and finally, distal anastomoses.

Anticoagulation protocol

A heparinization protocol of 300 IU/kg was used in patients undergoing cardiopulmonary bypass (CPB) in order to maintain an activated clotting time of 480 s. Heparinization protocol of 150 U/kg was used in OPCABG to obtain an activated clotting time greater than 300 s. Protamine was always used when hemodynamic stability was achieved at a dose of 1 mg of protamine for each 100 IU of heparin, in order to achieve complete heparin neutralization, confirmed by an activated clotting time below 120 s. In both groups 4000 IU nadroparin/die was started 8 h following surgery and maintained until the 4th postoperative day. Oral antiplatelet therapy (150 mg/day of salicylic acid) was started following chest drain removal, or at least 48 h following surgery.

Flowmetric analysis

Assessment of each graft was performed under stable hemodynamic conditions in both groups, generally 30 min after protamine administration. Flowmetry of the grafts was performed with a transit-time flowmeter (HT313, Transonic, Transonic Systems, Ithaca, NY, USA). Different probe sizes (2, 2.5, or 3 mm) were available to avoid distortion or compression to the graft. Skeletonization of a small segment of the RA, LIMA, and RIMA was necessary to reduce the quantity of tissue interposed between the vessel and the probe. Maximum, mean, and minimum flows, flow curve, and pulsatility index (PI) were obtained directly from the flowmeter. The curves were always coupled with the EKG tracing, to correctly differentiate the systolic from the diastolic flow. Transit-time flowmetry measurements were interpreted as previously suggested by D'Ancona et al.[10] The maximum, minimum, and mean flow were reported as ml/min, and PI as an absolute number.[10] Data from arterial conduits were recorded and compared between the two groups.

Graft flow reserve (GFR)

It is institutional policy to insert an intra-aortic balloon pump (IABP) preoperatively—before anesthetic induction—in patients with unstable angina despite maximal i.v. nitrates, in order to improve myocardial protection before the completion of myocardial revascularization. According to the previous demonstration that IABP recruits graft flow reserve during assistance,[11] mean flow and PI were recorded in all patients undergoing preoperative intra-aortic balloon pumping, either during IABP support and during temporary IABP cessation, so as to evaluate GFR. Graft flow reserve was calculated from the mean flow assessed during 1:1 IABP support divided by the mean flow at baseline (IABP off).[12]

Postoperative care

According to an institutional policy, inotropes were started immediately after aortic cross-clamp removal with enoximone at a dosage of 5 µg/kg per minute.[13] The need for a further increase in inotropes was recorded. Inotropic support was defined as low dose when enoximone was administered at a dosage lower than or equal to 5 µg/kg/min, medium dose when enoximone was employed at a dosage between 6 and 10 µg/kg/min, or dobutamine was added at a dosage between 5 and 10 µg/kg/min, and high dose when enoximone or dobutamine infusion was >10 µg/kg/min or epinephrine at any dose was added.

Biochemical analysis

Determinations of blood concentration of cardiac troponin I (TnI) were conducted preoperatively before anesthetic induction, and postoperatively at 12, 24, 48, and 72 h. The assays were carried out using diagnostic kits provided by Beckman Coulter for TnI (Access Immunoassay System; AccuTnI). Diagnostic criteria for perioperative myocardial infarction were peak TnI greater than 3.7 µg/l and a TnI concentration greater than 3.1 µg/l at 12 h or greater than 2.5 µg/l at 24 h.[9,12,13]

Echocardiography

All studies were performed using a transthoracic Acuson Sequoia C256 echocardiography system (Acuson, Mountain View, CA, USA) with probe 3V2C and always by the same two physicians in a blinded manner, at the time of hospital admission and before discharge. Left ventricular ejection fraction (EF) and wall motion score index (WMSI) were recorded.

Statistical analysis

Statistical analysis was performed by the SPSS program for Windows, version 10.1 (SPSS, Chicago, IL, USA). Continuous variables are presented as mean±standard deviation (SD) and categorical variables presented as either absolute numbers and percentages. Data were checked for normality before statistical analysis. Normally distributed continuous variables were compared using the unpaired *t*-test, whereas the Mann–Whitney *U*-test was used for those variables that were not normally distributed. Categorical variables were analyzed using either the chi-square test or Fisher's exact test. Comparisons were considered significant if $P < 0.05$.

Results

The two groups demonstrated comparable demographic data, except for age, prevalence of diabetes, and EUROScore (Table 1). One hundred and one patients belonging to Group A (42.4%) were diabetics, 94 suffered for hypertension (39.5%); when the young were considered, there were 58 (29.7%) diabetics and 86 (44.1%) hypertensive patients. Intraoperative data are shown in Table 2. Of 238 elderly patients enrolled, 79 (33.2%) underwent OPCABG, as well as 62 of 195 young patients (31.8%).

Hospital mortality was comparable between the two groups: 5 patients belonging to Group A (2.5%) and 1 to Group B (0.5%) died during hospitalization; of these, 1 patient in Group A and the patient of Group B developed low output state following perioperative myocardial infarction; another 2 patients of Group A developed multiorgan failure following pneumonia, and finally 1 patient died following stroke. No differences were recorded between the two groups either in terms of postoperative acute myocardial infarction (Group A: 4/238, 1.7% vs Group B: 2/195, 1.0%; $P = 0.440$) or need for postoperative IABP (Group A: 3/238, 1.3% vs Group B: 4/195, 2.1%; $P = 0.393$). However, no IABP-related complications were registered during the period of assistance. Similar proportions of patients in the two groups required medium doses of inotropes (Group A: 51/238, 21.4% vs Group B: 37/195, 19.0%; $P = 0.305$), as well as high doses (Group A: 5/238, 2.1% vs Group B: 3/195, 1.5%; $P = 0.476$).

No differences were recorded between the two groups in postoperative TnI (preoperative: Group A: 0.02 ± 0.03 µg/l vs Group B: 0.02 ± 0.02; $P = 0.457$; 12 h: Group A: 0.59 ± 0.29 vs Group B: 0.45 ± 0.24; $P = 0.269$; 24 h: Group A: 1.09 ± 0.55 vs Group B: 1.06 ± 0.76; $P = 0.286$; 48 h: Group A: 1.07 ± 0.43 vs Group B: 1.02 ± 0.46; $P = 0.916$; 72 h: Group A: 0.79 ± 1.21 vs Group B: 0.89 ± 1.41; $P = 0.758$). Intensive care unit stay (Group A: 2.1 ± 1.7 days vs Group B: 1.9 ± 1.5; $P = 0.640$) and hospital stay (Group A: 7.5 ± 2.3 vs Group B: 6.2 ± 2.8; $P = 0.08$) proved to be similar.

Table 1. Demographic data

	Group A (Elderly) 238 patients	Group B (Young) 195 patients	*P*
Age (years)	76.7 ± 3.76	51.1 ± 8.42	0.0001
Male sex	218 (91.6%)	169 (86.7%)	0.067
EuroSCORE (mean ± SD)	4.74 ± 2.87	2.49 ± 1.31	0.0001
Diabetes	101 (42.4%)	58 (29.7%)	0.004
Hypertension	94 (39.5%)	86 (44.1%)	0.192
Smoke	67 (28.2%)	53 (27.2%)	0.454
Dyslipidemia	93 (39.1)	74 (37.9%)	0.444
COPD	48 (20.2%)	51 (26.1%)	0.063
Acute coronary syndrome	88 (37.0%)	78 (40.0%)	0.293
AMI ≤4 weeks	39 (16.4%)	39 (20.0%)	0.198
Left main stem disease	49 (20.6%)	43 (22.1%)	0.400
Preoperative IABP	93 (39.1%)	67 (34.3%)	0.181
Preoperative EF <30%	15 (6.3%)	14 (7.2%)	0.431
Preoperative EF 31%–49%	167 (70.2%)	140 (71.8%)	0.396
Preoperative EF >50%	56 (23.5%)	41 (21.0%)	0.307
LAD TIMI score	0.71 ± 0.66	0.75 ± 0.72	0.408
Cx TIMI score	1.01 ± 0.77	0.94 ± 0.89	0.642
DIAG TIMI score	1.07 ± 0.58	1.13 ± 0.63	0.395
Rx TIMI score	0.82 ± 0.42	0.77 ± 0.65	0.573

AMI, acute myocardial infarction; IABP, intra-aortic balloon pump; COPD, chronic obstructive pulmonary disease; EF, left ventricular ejection fraction; LAD, left anterior descending artery; DIAG, diagonals; OM, obtuse marginal branches; PD, posterior descending artery; PL, postero-lateral branches; TIMI, Thrombosis in Myocardial Infarction; Cx, circumflex artery; Rx, right coronary artery

Table 2. Intraoperative data

	Group A (Elderly) 238 patients	Group B (Young) 195 patients	*P*
ACC time (min)	40.4 ± 16.5	40.6 ± 14.1	0.905
CPB time (min)	75.4 ± 29.2	73.2 ± 25.3	0.457
No. of anastomoses/patient	3.30 ± 0.96	3.21 ± 0.90	0.287
LIMA	236 (99.1%)	195 (100%)	0.302
RA	75 (31.5%)	57 (29.2%)	0.259
RIMA	15 (6.3%)	12 (6.2%)	0.556
Total arterial grafting	52 (21.8%)	50 (25.6)	0.208

ACC, aortic cross-clamp; CPB, cardiopulmonary bypass; LIMA, left internal mammary artery; RA, radial artery

According to graft flowmetry, 4 LIMA-to-LAD anastomoses demonstrated unsatisfactory results: 1 patient belonging to Group B demonstrated a diastolic pattern but low maximum (13 ml/min) and mean flow (6 ml/min), with a sufficient PI (4.2), compatible with the poor runoff of a severely diseased LAD: the anastomosis was left as-is, but the patient developed perioperative acute myocardial infarction (AMI), requiring IABP assistance. The perioperative course was then uneventful and the patient was discharged home in healthy condition on postoperative day 13; another patient belonging to Group B undergoing off-pump double CABG demonstrated low maximum (9 ml/min) and mean flow (3 ml/min), and high PI (5) of the LIMA-to-LAD anastomosis. The anastomosis was redone with the aid of an intravascular shunt, and TTF results completely recovered (maximum flow: 48 ml/min, mean: 38 ml/min, PI 2.0, diastolic pattern of the curve). Another two patients of Group A showed high PI, low flow, and systolic patterns of LIMA-to-LAD anastomoses: in one case, this was due to a torsion of the anastomosis secondary to its fixation to the epicardial fat, and TTF results completely recovered by simply relieving the fixation stitch; in the other patient, graft revision demonstrated an early thrombosis of the heel, and TTF results completely recovered following revision. All these last three patients undergoing graft revision because of unacceptable TTF results demonstrated an uncomplicated postoperative course with optimal postoperative ECG-graphic, echocardiographic and biochemical (TnI) results.

When TTF values—stratified by the type of graft and the type of target vessel—were considered, elderly patients undergoing arterial revascularization demonstrated comparable results with those of the young, either on-pump (Table 3) or off-pump (Table 4) CABG. One hundred and sixty patients underwent preoperative IABP. In particular, 93 were elderly (39.1% of Group A) and 67 (34.3%) young patients. To rule out differences in GFR between the elderly and the young, these patients underwent intraoperative TTF analysis with either 1:1 IABP and temporary cessation. 1:1 IABP support recruited graft flow reserve in all, and no differences were detectable in graft mean flow and PI between the two groups, either on-pump (Table 5) or off-pump (Table 6): similar graft flow reserve was also detected both in off-pump and on-pump CABG (Fig. 1).

Table 3. TTF results of on-pump CABG stratified by grafts and target vessels

	Group A (Elderly) 159 patients	Group B (Young) 133 patients	*P*
LIMA-to-LAD			
Maximum flow	54.7 ± 29.4	66.6 ± 46.5	0.429
Mean flow	27.5 ± 15.7	33.7 ± 23.2	0.427
PI	1.61 ± 0.80	1.39 ± 0.82	0.610
RIMA-to-OM			
Maximum flow	55.1 ± 18.5	76.2 ± 60.6	0.245
Mean flow	31.4 ± 18.6	35.7 ± 26.9	0.705
PI	1.37 ± 0.69	1.40 ± 0.77	0.520
RIMA-to-Rx			
Maximum flow	52.3 ± 27.4	58.6 ± 33.9	0.399
Mean flow	29.7 ± 17.1	28.9 ± 15.0	0.844
PI	1.51 ± 0.69	1.78 ± 0.83	0.151
RA-to-OM			
Maximum flow	77.9 ± 52.2	70.1 ± 34.3	0.656
Mean flow	41.9 ± 25.7	36.3 ± 18.2	0.505
PI	1.35 ± 0.94	1.21 ± 0.50	0.152
RA-to-Rx			
Maximum flow	64.7 ± 41.8	64.1 ± 27.6	0.968
Mean flow	31.3 ± 20.8	26.2 ± 14.7	0.507
PI	1.97 ± 0.94	2.98 ± 2.22	0.183
RA-to-DIAG			
Maximum flow	51.3 ± 35.8	40.8 ± 13.2	0.601
Mean flow	28.1 ± 20.6	29.9 ± 16.1	0.476
PI	1.55 ± 1.02	1.28 ± 0.48	0.652

TTF, transit time flowmetry; CABG, coronary artery bypass grafting; PI, pulsatility index; LIMA, left internal mammary artery; RIMA, right internal mammary artery

When echocardiography is considered, the two groups demonstrated a comparable recovery of either left ventricular ejection fraction (Group A: preoperative EF: 42.4% ± 8.6% vs postoperative EF: 49.8% ± 7.8%, statistical probability within group: $P < 0.01$; Group B: preoperative EF: 41.4% ± 9.1% vs postoperative EF: 50.6% ± 7.3%, statistical probability within group: $P < 0.01$; statistical probability between groups $P = 0.250$) and wall motion score index (Group A: preoperative WMSI: 1.48 ± 0.32 vs postoperative WMSI: 1.26 ± 1.09, statistical probability within group:

Table 4. TTF results of off-pump CABG stratified by grafts and target vessels

	Group A (Elderly) 79 patients	Group B (Young) 62 patients	*P*
LIMA-to-LAD			
Maximum flow	44.1 ± 17.3	50.1 ± 28.7	0.756
Mean flow	20.7 ± 17.3	23.3 ± 16.1	0.810
PI	1.59 ± 0.47	1.80 ± 0.80	0.701
RIMA-to-Rx			
Maximum flow	33.2 ± 10.9	45.9 ± 12.9	0.132
Mean flow	16.7 ± 7.8	20.8 ± 4.6	0.416
PI	1.54 ± 0.31	2.03 ± 0.25	0.082
RA-to-OM			
Maximum flow	73.1 ± 53.8	55.4 ± 28.7	0.391
Mean flow	36.3 ± 26.5	28.3 ± 13.9	0.431
PI	1.49 ± 0.62	1.41 ± 0.38	0.725
RA-to-Rx			
Maximum flow	63.9 ± 31.8	59.0 ± 24.7	0.833
Mean flow	38.9 ± 23.1	33.4 ± 10.5	0.659
PI	2.46 ± 2.20	1.20 ± 0.32	0.273
RA-to-DIAG			
Maximum flow	44.1 ± 17.3	50.1 ± 28.7	0.756
Mean flow	20.7 ± 7.3	23.3 ± 16.1	0.810
PI	1.59 ± 0.47	1.80 ± 0.80	0.701

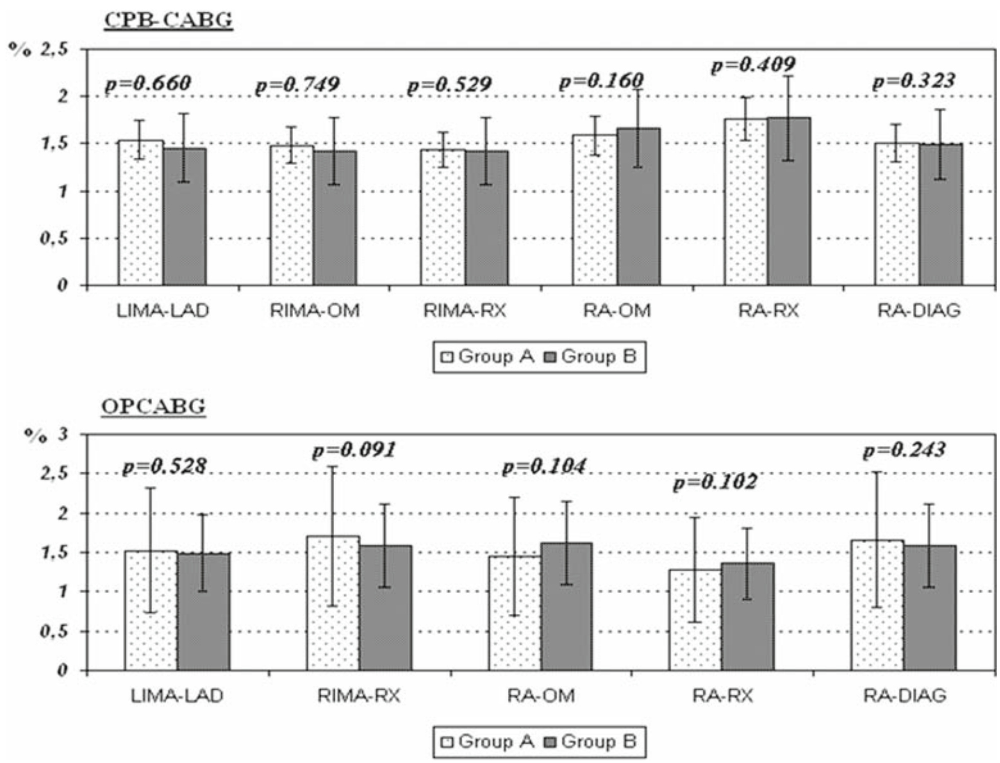

Fig. 1. Graft flow reserve comparison between the elderly (Group A) and the young (Group B), stratified by surgical technique (cardiopulmonary bypass, off-pump), graft type, and grafted vessel. *CPB-CABG*, cardiopulmonary bypass—coronary artery bypass graft; *OPCABG*, off-pump CABG; *LIMA*, left internal mammary artery; *RIMA*, right internal mammary artery; *RA*, radial artery; *LAD*, left anterior descending artery; *OM*, obtuse marginal branches; *RX*, right coronary artery; *DIAG*, diagonals

Table 5. TTF mean flow and PI during 1:1 IABP and IABP-off according to graft type in CABG on cardiopulmonary bypass

	Group A IABP 1:1	Group A IABP off	Group B IABP 1:1	Group B IABP off	P^1*	P^2*
LIMA-LAD Mean flow	42.5 ± 24.6	28.6 ± 17.4	48.9 ± 41.2	31.5 ± 14.9	Group A 0.001 Group B 0.001	0.467
PI	2.91 ± 1.30	1.51 ± 1.03	2.56 ± 1.24	1.40 ± 0.97	Group A 0.01 Group B 0.01	0.688
RIMA-OM						
Mean flow	46.6 ± 24.8	29.2 ± 13.3	47.1 ± 33.3	32.6 ± 17.5	Group A 0.003 Group B 0.003	0.560
PI	2.02 ± 1.05	1.34 ± 0.78	2.21 ± 1.34	1.58 ± 0.69	Group A 0.02 Group B 0.03	0.283
RIMA-Rx						
Mean flow	42.6 ± 12.5	28.5 ± 15.8	41.1 ± 19.9	28.7 ± 16.2	Group A 0.005 Group B 0.006	0.103
PI	2.67 ± 0.88	1.55 ± 0.92	2.94 ± 1.11	1.67 ± 0.77	Group A 0.02 Group B 0.01	0.385
RA-OM						
Mean flow	66.8 ± 23.4	40.2 ± 16.9	60.6 ± 18.3	38.8 ± 12.9	Group A 0.001 Group B 0.001	0.446
PI	2.08 ± 1.33	1.35 ± 1.01	2.20 ± 1.08	1.30 ± 0.62	Group A 0.04 Group B 0.03	0.359
RA-Rx						
Mean flow	55.2 ± 21.6	33.2 ± 16.2	46.3 ± 16.1	29.9 ± 14.5	Group A 0.001 Group B 0.001	0.417
PI	2.87 ± 1.38	1.98 ± 0.97	3.35 ± 1.55	2.68 ± 1.03	Group A 0.005 Group B 0.009	0.773
RA-DIAG						
Mean flow	42.6 ± 15.9	27.2 ± 18.1	44.7 ± 10.5	29.5 ± 14.8	Group A 0.002 Group B 0.003	0.598
PI	2.87 ± 1.88	1.50 ± 0.84	1.75 ± 0.99	1.33 ± 0.71	Group A 0.001 Group B 0.003	0.206

* P^1 = 1:1 IABP vs baseline (IABP off); P^2 = Elderly vs Young patients

Table 6. TTF mean flow and PI during 1:1 IABP and IABP-off according to graft type in off-pump CABG

	Group A IABP 1:1	Group A IABP off	Group B IABP 1:1	Group B IABP off	P^1*	P^2*
LIMA-LAD						
Mean flow	31.6 ± 14.2	22.6 ± 11.1	34.8 ± 12.5	25.1 ± 9.6	Group A 0.005 Group B 0.005	0.587
PI	2.67 ± 0.98	1.50 ± 0.73	2.74 ± 1.23	1.8 ± 0.92	Group A 0.01 Group B 0.03	0.389
RIMA-Rx						
Mean flow	28.7 ± 10.7	18.8 ± 10.2	31.0 ± 6.5	20.4 ± 8.3	Group A 0.006 Group B 0.004	0.462
PI	2.26 ± 1.03	1.72 ± 0.80	2.68 ± 0.57	1.91 ± 0.85	Group A 0.04 Group B 0.03	0.487
RA-OM						
Mean flow	52.5 ± 28.4	38.3 ± 20.2	46.1 ± 15.0	30.2 ± 18.4	Group A 0.008 Group B 0.007	0.542
PI	2.69 ± 1.13	1.61 ± 1.01	2.60 ± 1.28	1.56 ± 0.94	Group A 0.02 Group B 0.02	0.577
RA-Rx						
Mean flow	49.2 ± 23.8	39.2 ± 16.9	45.5 ± 12.7	34.1 ± 9.9	Group A 0.010 Group B 0.009	0.187
PI	2.58 ± 1.63	2.02 ± 0.88	2.54 ± 1.56	1.78 ± 0.68	Group A 0.05 Group B 0.02	0.078
RA-DIAG						
Mean flow	34.5 ± 7.1	22.7 ± 13.9	37.2 ± 10.5	26.1 ± 14.0	Group A 0.03 Group B 0.04	0.293
PI	2.60 ± 0.78	1.63 ± 0.52	2.83 ± 1.18	1.78 ± 0.67	Group A 0.05 Group B 0.05	0.597

* P^1 = 1:1 IABP vs baseline (IABP off); P^2 = Elderly vs Young patients

$P < 0.01$; Group B: preoperative WMSI: 1.51 ± 0.34 vs postoperative WMSI: 1.24 ± 1.06, statistical probability within group: $P < 0.01$; statistical probability between groups $P = 0.213$).

Discussion

Numerous advances in operative techniques and perioperative care have resulted in an increasing number of patients in the 7th or 8th decade of life being referred for CABG.[14] It therefore becomes increasingly important to determine which operative techniques enhance perioperative and long-term survival and quality of life. Moreover, despite higher perioperative risk in the elderly, different studies have demonstrated a survival advantage for the surgical therapy in the short-term and the long-term follow-up.[2,6,15,16]

It is well known that LIMA is the conduit of choice for CABG in all the published series of the literature, because of its superior patency rate. However, despite an initial enthusiasm for the use of this conduit, based on the demonstrated improvement in the long-term survival,[17] and recent reports showing that IMA grafting is associated with decreased operative mortality,[18,19] Ferguson et al. in an analysis of 99 942 patients 75 years of age and older have recently shown a declining survival benefit of LIMA grafting with age.[20] Furthermore, despite the fact that Lytle et al. showed improved long-term benefits with double internal mammary artery grafting in patients undergoing CABG,[1] concerns regarding increased operative and pump times, sternal fragility, adequacy of graft flow in acutely ischemic patients, and limited benefits in patients with a shortened life expectancy have generally discouraged the use of arterial grafting in the last decades of life. Accordingly, saphenous vein grafts continue to be considered as the first or at least the second conduit of choice in the elderly.[3,4]

When arterial grafts different from LIMA are considered, the demonstrated advantages on short-term and long-term prognosis in the young are furthermore questioned in the elderly. Some authors[7,21,22] have demonstrated that RA can be affected by atherosclerotic lesions, thus suggesting its careful use as a conduit for CABG;[7] other authors have excluded age per se as a contraindication,[21] claiming that atherosclerotic lesions do not have the potential to affect graft patency and endothelial function.[22] Moreover, it has to be considered that all these studies focused on histopathology and morphometry of the arterial conduits, rather than their in vivo (i.e., following completion of CABG) functional behavior.

The recent introduction in the routine surgical practice of TTF has given the ability to analyze intraoperatively the results of the surgical practice, and to detect early graft failure or malfunction.[10] Our experience demonstrated four early graft failures, one of which was misdiagnosed by the surgeons, leading to a perioperative AMI. However, all the remaining three graft malfunctions were correctly diagnosed, ruling out three different causes of graft failure (i.e., torsion of the pedicle, early thrombosis, and restrictive anastomosis). Therefore, agreeing with the study of D'Ancona et al., we take down and do over the anastomoses in which systolic spiky pattern of the curves and very low flow values and high PIs are reported; on the other hand, low flow and normal PI, preserved diastolic pattern without major ECG changes, associated with intraoperative findings of small and severely diseased vessels, do not indicate graft revision. Moreover, good TTF results can be helpful in the decision-making process whenever complications, such as minor ECG changes, hypotension, or arrhythmias occur during the sternal wiring, and TTF confirms unchanged findings.[12]

Recent studies have demonstrated that arterial revascularization improves the outcome of patients undergoing CABG, regardless of the type of arterial conduit.[1,23,24] Although concerns on this strategy in the elderly population still exist, a number of authors have reported satisfactory results with arterial grafts also in this category of patients: Muneretto et al. demonstrated that the use of full arterial revascularization in the elderly did not increase postoperative complications, exhibiting a better clinical outcome in a mid-term follow-up in terms of freedom from angina and AMI;[24] Kurlansky et al. showed that arterial grafting conferred an operative survival benefit and an enhanced long-term quality of life in elderly patients, pointing out the relevance of early graft failure—significantly reduced in arterial conduits—in determining such results.[25] Again, these studies focused on mid-term and long-term results of arterial CABG in elderly patients, but did not report the intraoperative functional results of arterial CABG. In particular, the literature lacks studies reporting TTF results of arterial conduits in the elderly: we reported here not only the maximum and mean flows of these arterial conduits, but also pulsatility index—the best indicator of intraoperative graft function[10]—and, most importantly, the graft flow reserve, demonstrating comparable results in the young and the elderly, regardless of the type of arterial conduit and the type of target vessel. In fact, it has been demonstrated that IABP recruits GFR during assistance.[11] Again, our subset of patients undergoing GFR analysis demonstrated a significant improvement of graft flows and PI of both elderly and young patients, without differences on comparing the two groups. Therefore the comparable GFR further confirm that arterial grafts in the elderly act just as in the young. The potential for the evaluation of GFR is another tool to be kept in mind for patients undergoing IABP assistance, because it can further explore the accuracy of the anastomosis and the quality of the graft: we now routinely assess flowmetric values during IABP assistance, and compare them to those values obtained during temporary IABP cessation, whenever issues on the quality of the surgery are argued.

On the other hand, the use of RA has been questioned in subgroups of patients undergoing CABG with risk-factors for an accelerated atherosclerosis, such as diabetes and hypertension. Again, our TTF results demonstrated that the in vivo functional properties of these grafts are comparable to those of young patients with the same risk factors.

Finally, some concerns have been raised on graft quality and technical accuracy of off-pump surgery.[26] Our data, as already reported,[12] seem to exclude such findings, further demonstrating that arterial conduits in the elderly behave as those of the young, regardless of the surgical technique employed.

Therefore, our data show that arterial grafts in the last decades have demonstrated the same in vivo functional results of the younger decades, together with a comparable recruitable GFR, regardless of the type of the arterial conduit, the type of the target vessel, or the type of the surgical technique employed. All these data may explain the reported survival benefit of arterial revascularization in elderly patients of previous published series.

Limitations of the study

The main limitation of the study is the absence of a systematic angiographic control in the two groups: certainly, when graft function is considered, angiography is still the gold standard method to detect patency; however, it was the aim of the study to detect the "acute" behavior of arterial grafts in the elderly, compared to the young, furthermore according to the recent demonstration of a good correlation between TTF results and angiographic patency rate. However, the absence of angiographic control implies that nothing can be said about the real evolution of these grafts at follow-up and their clinical evolution. So the actual long-term benefit of complete arterial grafting cannot be measured at least in this group of elderly patients. On the other hand, it can be hypothesized that a perfectly patent arterial graft may outlive an elderly candidate. However, a systematic angiographic control, in the absence of angina, raises ethical issues in performing repeat contrast medium injection in the elderly, according to their physiologically reduced glomerular filtration rate.

Finally, we did not report a flowmetric comparison between saphenous veins and arterial grafts in elderly patients. However, it was the aim of the study to compare functional in vivo behavior of arterial grafts between the elderly and the young.

References

1. Lytle BW, Blackstone EH, Loop FD, Houghtaling PL, Arnold JH, Akhrass R, McCarthy PM, Cosgrove DM (1999) Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 117:855–872
2. Bonacchi M, Prifti E, Maiani M, Frati G, Giunti G, Di Eusanio M, Di Eusanio G, Leacche M (2006) Perioperative and clinical-angiographic late outcome of total arterial myocardial revascularization according to different composite original graft techniques. Heart Vessels 21:69–77
3. Ferguson TB, Dziuban SW, Edwards FH, Eiken MC, Shroyer AL, Pairolero PC, Aderson RP, Grover FL (2000) The STS National Database: current changes and challenges for the new millennium. Ann Thorac Surg 69:680–691
4. Nashef SAM, Roques F, Michel P, Cortina J, Faichney A, Gams E, Harjula A, Jones MT (2000) Coronary surgery in Europe: comparison of the national subsets of the European System for Cardiac Operative Risk Evaluation database. Eur J Cardiothorac Surg 17:396–399
5. Morris RJ, Strong MD, Grunewald KE, Kuretu MLR, Samuels LE, Kresh JY, Brockman SK (1996) Internal thoracic artery for coronary artery grafting in octogenarians. Ann Thorac Surg 62:16–22
6. Simek M, Nemec P (2007) Postoperative and mid-term wound disturbance outcomes of minimally invasive saphenous vein harvest using the VEGA system. Heart Vessels 22:94–98
7. Chowdhury UK, Airan B, Mishra PK, Kothari SS, Subramaniam GK, Ray R, Singh R, Venugopal P (2004) Histopathology and morphometry of radial artery conduits: basic study and clinical application. Ann Thorac Surg 78:1614–1621
8. Takami Y, Ina H (2001) Relation of intraoperative flow measurement with postoperative quantitative angiographic assessment of coronary artery bypass grafting; Ann Thorac Surg 72:1270–1274
9. Onorati F, Renzulli A, De Feo M, Santarpino G, Gregorio R, Biondi A, Cerasuolo F, Cotrufo M (2003) Does antegrade blood cardioplegia alone provide adequate myocardial protection in patients with left main stem disease? J Thorac Cardiovasc Surg 126:1345–1351
10. D'Ancona G, Karamanoukian HL, Ricci M, Schmid S, Bergsland J, Salerno TA (2000) Graft revision after transit time flow measurement in off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 17:287–293
11. Tedoriya T, Kawasuji M, Sakakibara N, Takemura H, Watanabe Y, Hetzer R (1998) Coronary bypass flow during use of intraaortic balloon pumping and left ventricular assist device. Ann Thorac Surg 66:477–481
12. Onorati F, Olivito S, Mastroroberto P, di Virgilio A, Esposito A, Perrotti A, Renzulli A (2005) Perioperative patency of coronary artery bypass grafting is not influenced by off-pump technique. Ann Thorac Surg 80:2132–2140
13. Onorati F, Renzulli A, De Feo M, Galdieri N, Santè P, Mastroroberto P, Bilotta M, Cotrufo M (2004) Perioperative enoximone infusion improves cardiac release after CABG. J Cardiothorac Vasc Anesth 18:409–414
14. Peterson ED, Jollis JG, Bebchuk JD, DeLong ER, Muhlbaier LH, Mark DB, Pryor DB (1994) Changing mortality following myocardial revascularization in the elderly: the National Medicare Experience. Ann Intern Med 121:919–927
15. The TIME Investigators (2001) Trial of invasive versus medical therapy in elderly patients with chronic symptomatic coronary-artery disease (TIME): a randomised trial. Lancet 358:951–957
16. Graham MM, Ghali WA, Faris LP, Galbraith PD, Norris CM, Knudtson ML (2002) APPROACH Investigators. Survival after coronary revascularization in the elderly. Circulation 105:2378–2384
17. Loop FD, Lytle BD, Cosgrove DM, Stewart RW, Goormastic M, Williams GW, Golding LA, Gill CC, Taylor PC, Sheldon WC (1986) Influence of the internal mammary artery graft on 10-year survival and other cardiac events. N Engl J Med 314:1–6
18. Edwards FH, Clark RE, Schwarz M (1994) Impact of internal mammary artery conduits on operative mortality in coronary revascularization. Ann Thorac Surg 57:27–32
19. Leavitt BJ, O'Connor GT, Olmstead EM, Morton JR, Maloney CT, Dacey LJ, Hernandez F, Lahey SJ (2001) Use of the internal mammary artery graft and in-hospital mortality and other adverse outcomes associated with coronary artery bypass surgery. Circulation 103:507–512
20. Ferguson TB Jr, Coombs LP, Peterson ED (2002) Internal thoracic artery grafting in the elderly patient undergoing coronary artery bypass grafting: room for process improvement? J Thorac Cardiovasc Surg 123:869–880
21. Wildhirt SM, Voss B, von Canal F, Benz M, Grammer JB, Bauernschmitt R, Tassani P, Lange R (2006) Graft function, histopathology and morphometry of radial arteries used as conduits for myocardial revascularization in patients beyond age 70. Eur J Cardiothorac Surg 30:333–340
22. Gaudino M, Tondi P, Serricchio M, Spatuzza P, Santoliquido A, Flora R, Girala F, Nasso G, Pola P, Possati G (2003) Atherosclerotic involvement of the radial artery in patients with coronary artery disease and its relation with midterm radial artery graft patency and endothelial function. J Thorac Cardiovasc Surg 126:1968–1971

23. Calafiore AM, Contini M, Vitella G, Di Mauro M, Mazzei V, Teodori G, Di Giammarco G (2000) Bilateral internal thoracic artery grafting: long term clinical and angiographic results of in situ versus Y grafts. J Thorac Cardiovasc Surg 120:990–998
24. Muneretto C, Negri A, Bisleri G, Manfredi J, Terrini A, Metra M, Nodari S, Dei Cas L (2003) Is total arterial myocardial revascularization with composite grafts a safe and useful procedure in the elderly? Eur J Cardiothorac Surg 23:657–664
25. Kurlansky PA, Williams DB, Traad EA, Carrillo RG, Schor JS, Zucker M, Singer S, Ebra G (2003) Arterial grafting results in reduced operative mortality and enhanced long-term quality of life in octogenarians. Ann Thorac Surg 76:418–427
26. Khan NE, De Souza A, Mister R, Flather M, Clague J, Davies S, Collins P, Wang D, Sigwart U, Pepper J (2004) A randomized comparison of off-pump and on-pump multivessel coronary artery bypass surgery. N Engl J Med 350:21–28