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Long-term follow-up of total arterial versus conventional and hybrid myocardial revascularization: A propensity score matched analysis☆

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ABSTRACT

Purpose: To evaluate the impact of the revascularization technique (by means of conventional, total arterial or hybrid myocardial revascularization) in patients with multivessel coronary artery disease.
Methods: A propensity-score analysis of patients undergoing myocardial revascularization from 1998 to 2012 was performed based on the surgical technique utilized, either total arterial (Group1, G1,n° = 89), conventional CABG(LIMA on LAD plus veins, Group2, G2,n° = 89), or hybrid revascularization (LIMA on LAD plus PTCA on non-LAD vessels, Group3, G3, n° = 89). Primary end-points were overall survival and cardiac-related death while secondary composite end-point was survival freedom from major adverse cardiac and cerebrovascular events (MACCEs) defined as myocardial infarction, cardiac death, stroke and repeated target vessel revascularization.
Results: Study population was mostly affected by double-vessels disease (G1 = 2.35 vs G2 = 2.3 vs G3 = 2.4, $p = 0.14$) with a preserved LV function(G1 = 48% vs G2 = 49% vs G3 = 50%, $p = 0.12$). Hospital mortality was 0% in all groups. At a mean follow-up of 6 ± 2 years overall survival was significantly better in patients receiving total arterial myocardial revascularization (G1 = 90.4 ± 3.5% vs G2 = 82.3 ± 4.2% vs G3 = 82.1 ± 5.9%, $p = 0.049$) as well as freedom from MACCEs (G1 = 95.2 ± 2.4% vs G2 = 86.5 ± 4% vs G3 = 68 ± 6.9%, $p = 0.001$) while survival free from cardiac-related death was similar(G1 = 97.7 ± 1.6% vs G2 = 95.1 ± 2.4% vs G3 = 89.5 ± 5.4%, $p = 0.08$). Conversely, at 10 years follow-up only freedom from MACCEs was significantly better in patients of Group 1(G1 = 78.9 ± 8.6% vs G2 = 72.4 ± 5.7% vs G3 = 52 ± 8.7%, $p < 0.001$).
Conclusions: Total arterial revascularization provides improved outcomes at mid and long term follow-up compared with conventional or hybrid revascularization. The latter technique is particularly associated with a significantly higher incidence of late myocardial infarction and repeat revascularization.

1. Introduction

The choice of the optimal graft strategy in multi-vessel myocardial revascularization has still been widely debated. Despite the potential advantages of an extensive use of arterial conduits in addition to the left internal thoracic artery (LITA) to the left anterior descending (LAD) coronary artery [1–3], yet the majority of coronary artery bypass grafting (CABG) procedures worldwide often imply a widespread use (in over 90% of instances) of saphenous vein conduits in non-LAD vessels [4].

Furthermore, there is paucity of data regarding the long-term outcomes either in terms of overall survival and major cardiovascular events when a total arterial grafting strategy was compared with a conventional CABG procedure (with LIMA on LAD and saphenous vein grafts on other target vessels).

Finally, during recent years there has been an increased interest towards a hybrid coronary revascularization strategy which merges a minimally invasive surgical procedure (LITA on the LAD with an off-pump technique) with a transcatheter percutaneous coronary intervention (PCI) on non-LAD target vessels.

We therefore sought to analyze the long-term outcomes of the three different strategies for myocardial revascularization by comparing patients receiving total arterial grafting versus conventional CABG surgery and hybrid revascularization in a propensity-matched analysis.

Abbreviations: CABG, Coronary Artery By-pass Grafting; LAD, left anterior descending; HCR, hybrid coronary revascularization; LITA, Left Internal Thoracic Artery; PTCA, Percutaneous Coronary Intervention; MACCE, Major Adverse Cardiac and Cerebrovascular Events; LV, Left Ventricle; RITA, Right Internal Thoracic Artery; PCI, Percutaneous Coronary Intervention; SVGs, Saphenous Vein Grafts; STEMI, ST Elevation Myocardial Infarction; MIDCAB, Minimally Invasive Direct Coronary Artery By-pass.

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2. Materials and methods

2.1. Study population

Data were retrospectively collected from 593 patients with multivessel coronary disease and scheduled to undergo surgical myocardial revascularization from 2000 to 2015. We perform a propensity score analysis among our groups to obtain homogeneous population to compare different strategies such as total arterial myocardial revascularisation (Group 1, G1), conventional myocardial revascularisation (Group 2, G2; LITA on LAD plus additional SVGs on other target vessels) and hybrid myocardial revascularisation (Group 3, G3, LITA on LAD plus percutaneous revascularisation on other target vessels).

Variables used in the propensity analysis were age, sex, left ventricular ejection fraction, number of diseased vessels, New York Heart Association (NYHA) superior to III class, logistic EuroSCORE, peripheral vascular disease, chronic obstructive pulmonary disease, previous cerebrovascular accidents, chronic renal failure, dyslipidemia, BMI < 30, recent STEMI/nSTEMI.

Exclusion criteria from the study were: redo cases, emergency operations, single-vessel disease, diffuse atherosclerotic disease of the ascending aorta and patients undergoing concomitant procedures in addition to myocardial revascularization.

This study was approved by the Institutional Review Board and no funding or industry support has to be disclosed for the current study. Every patient at time of hospital admission sign an informed consent for anonymous data treatment.

2.2. Operative technique

In the group of patients undergoing total arterial myocardial revascularisation (Group 1) either skeletonised bilateral ITAs were utilised or a pedicled radial artery graft (procured by means of an endoscopic approach) in addition to a single or double ITAs. Composite arterial grafting was performed in the majority of cases. Surgery was performed by means of cardiopulmonary bypass under mild hypothermia and with the use of cold crystalloid cardioplegia for myocardial protection.

In Group 1, RITA was grafted on an obtuse marginal branch in 56, while it was utilised on the right coronary artery and a diagonal branch in 49 and 10 patients respectively; finally the radial artery was anastomosed on an obtuse marginal on 43 patients, on the right coronary artery in 43 cases and on a diagonal branch in 13.

In case of hybrid coronary revascularisation, the strategy adopted was chosen following a multidisciplinary discussion by the Heart Team: a sequential staged strategy was utilised in most instances, with a timeframe of about 3 months between the surgical and transcatheter procedure. Usually, in presence of STEMI/NSTEMI with culprit lesion other than the LAD, PCI was performed first followed by minimally invasive myocardial revascularization (MIDCAB) at least 3–6 months afterwards; conversely, in absence of an acute coronary syndrome, MIDCAB was performed in first instance (with a LIMA on LAD) followed by a PCI on the non-LAD vessels at a timeframe of 1–3 months.

2.3. Follow-up

Follow-up visits were performed at 1, 6 months postoperatively and on a yearly basis thereafter; additional clinical data were collected from referring cardiologists and general practitioners. Primary end-point was overall survival and cardiac-related mortality. Secondary composite endpoint was freedom from major adverse cardiac and cardiovascular events (MACCEs) defined as cardiac mortality, myocardial infarction, stroke and target vessel revascularization.

2.4. Statistical analysis

Continuous variables are expressed as mean and standard deviation; categorical data are summarized by reporting absolute frequency distribution and percentage. Categorical variables were compared using the chi-square test as appropriate. An ANOVA one-way has been performed to compare continuous variables, as appropriate.

Propensity score matching analysis was used to adjust for baseline characteristic differences between the 3 groups (1-to-1 matching based on propensity scores). The propensity score was estimated by a multinomial regression model for each patient choosing as dependent variable the type of treatment. Matching using calipers of width of 0.2 of the standard deviation of the propensity score was performed as previously described [5]. Comparisons between group outcomes were carried out by taking into consideration the matched nature of the propensity score-matched sample. Hosmer-Lemeshow test was performed to assess the goodness-of-fit of propensity-match model ($p = 0.204$).

Survival analysis was performed with Kaplan-Meier curves and population were compared with log-rank test. An univariate and multivariate analysis with Cox Regression was performed on MACCEs, Cox regression analysis was verified by graphical method. Statistical findings were considered significant if the critical level was <5% ($P < 0.05$).

Table 1
Preoperative data of the unmatched populations.

	Total arterial ($n = 319$)	Conventional (145)	HCR (129)	p-Value
	n (%)	n (%)	n (%)	
Age (mean ± SD)	72 ± 11	74 ± 9	64 ± 10	<0.001
EuroSCORE I Log (mean ± SD)	10.3 ± 10.1	11.05 ± 12.4	10.6 ± 13.1	0.82
Ejection fraction (mean ± SD)	48.73 ± 10.9	49.8 ± 9.7	53.5 ± 10.1	<0.001
Number of diseased vessels (mean ± SD)	2.36 ± 0.9	2.3 ± 0.6	2.4 ± 0.5	0.34
Female gender	68 (21.3)	33 (22.8)	21 (16.3)	0.37
Diabetes	98 (30.7)	38 (26.2)	33 (25.6)	0.44
Chronic renal failure	34 (10.7)	17 (11.7)	17 (13.2)	0.74
PAD	59 (18.5)	19 (13.1)	38 (29.5)	0.03
COPD	49 (15.4)	24 (16.6)	30 (23.3)	0.13
Hypertension	229 (71.8)	73 (50.3)	80 (62)	<0.001
Previous CVA	69 (21.6)	33 (22.8)	20 (15.5)	0.4
Dyslipidemia	172 (53.9)	60 (41.4)	74 (57.4)	0.014
Recent myocardial infarction (<90 days)	52 (16.3)	15 (10.3)	49 (38)	<0.001
NYHA class ≥ III	94 (29.5)	20 (13.8)	53 (41)	<0.001
BMI > 30	19 (6)	10 (6.9)	23 (18)	<0.001

COPD = chronic obstructive pulmonary disease; BMI = body mass index; PAD = peripheral artery disease; CVA = cerebrovascular accidents; NYHA = New York Heart Association; EF = ejection fraction.

Table 2
Preoperative characteristics of the three matched groups.

	Total arterial ($n = 89$)	Conventional (89)	HCR (89)	p-Value
	n (%)	n (%)	n (%)	
Age (mean ± SD)	73 ± 10	74 ± 8	72 ± 6	0.45
EuroSCORE I Log (mean ± SD)	9.5 ± 9	10.5 ± 12.4	10.6 ± 12.1	0.13
Ejection fraction (mean ± SD)	48. ± 11	49 ± 9	50 ± 10	0.23
Number of diseased vessels (mean ± SD)	2.35 ± 0.9	2.3 ± 0.6	2.4 ± 0.5	0.34
Female gender	16 (18)	22 (24.7)	14 (15.7)	0.28
Diabetes	25 (28.1)	25 (28.1)	24 (27.0)	0.98
Chronic renal failure	6 (6.7)	8 (9)	10 (11.2)	0.57
PAD	14 (15.7)	12 (13.5)	19 (21.3)	0.35
COPD	10 (11.2)	15 (16.9)	18 (20.2)	0.13
Hypertension	61 (68.5)	50 (56.2)	60 (67.4)	0.08
Previous CVA	34 (38.2)	24 (27.0)	27 (30.3)	0.4
Dyslipidemia	39 (43.8)	38 (42.7)	34 (38.2)	0.72
Recent myocardial infarction (<90 days)	16 (17.9)	12 (13.5)	20 (22.5)	0.29
NYHA class ≥ III	13 (14.6)	12 (13.5)	20 (22.5)	0.14
BMI > 30	5 (5.6)	6 (6.7)	13 (14.6)	0.08

COPD = chronic obstructive pulmonary disease; BMI = body mass index; PAD = peripheral artery disease; CVA = cerebrovascular accidents; NYHA = New York Heart Association; EF = ejection fraction.

Statistical analysis was performed with SPSS software (Version 19, IBM, New York, NY).

3. Results

3.1. Baseline data

Preoperative clinical variables of the study population before matching (Group 1 = 319 patients vs Group 2 = 145 patients vs Group 3 = 129 patients) are listed in Table 1. Of note, in the unmatched cohort patients undergoing total arterial and conventional myocardial revascularization were significantly older and had worse left ventricular ejection fraction. Conversely, patients undergoing hybrid revascularisation were more likely to have peripheral vascular disease, BMI > 30 and recent myocardial infarction (<90 days).

Following propensity analysis and matching, 3 groups of 89 patients each were identified: baseline characteristics of the matched groups are listed in Table 2. In particular, the study population obtained after matching was mainly represented by patients with double-vessels disease (G1: 2.35 ± 0.9; G2: 2.3 ± 0.62 and G3: 2.4 ± 0.5, $p = 0.56$). Among patients undergoing surgical revascularisation cardiopulmonary bypass duration was significantly longer in patients receiving conventional surgery (G1: 47 ± 8 min versus G2: 74 ± 5 min, $p < 0.001$) due to time required to complete proximal anastomoses. Additional intra-operative data were provided in Table 3.

Among patients undergoing hybrid coronary revascularisation, thirty-five (35) underwent PCI in first instance followed by MIDCAB, with 14 undergoing primary PCI on non-LAD culprit lesions due to recent STEMI/NSTEMI. The remaining 54 patients underwent a MIDCAB followed by a staged PCI revascularization; in this group, only 6 cases had a recent myocardial infarction on the LAD and received MIDCAB first.

3.2. Post-operative outcomes

Intra-operative as well as early postoperative variables and results are depicted in Table 4. Of note, postoperative atrial fibrillation onset (G1: 32 pts. [36%]; G2: 35 [39.3%] and G3 12 [12.5%], $p < 0.001$) and incidence of blood transfusion (G1: 39 pts. [43.8%]; G2: 43 [48.3%] and G3 13 [14.6%], $p < 0.001$) was significantly lower in patients undergoing HCR. Mean intensive care unit and mechanical ventilation were similar among the groups of patients.

No hospital mortality was recorded in the current study population.

3.3. Follow-up

Mid and long term follow-up analysis was performed by means of Kaplan-Meier survival for the primary (overall survival, Fig. 1) and secondary end-points (cardiac-related mortality, Fig. 2; MACCEs, Fig. 3) as outlined above in the Methods section. At a mean follow-up of 6 ± 2 years overall survival (G1: 95.2%, CI 91.8–98.6%; G2: 84.9%, CI 81–88.89% and G3: 86.5%, CI 82.1–90.9%, $p = 0.049$) as well as freedom from MACCEs (G1 = 95.2 ± 2.4% vs G2 = 86.5 ± 4% vs G3 = 68 ± 6.9%, $p = 0.001$) was significantly better in patients undergoing total arterial myocardial revascularisation while survival free from cardiac-

Table 3
Intraoperative outcomes.

Variables	Total arterial (n = 89)	Conventional (89)	HCR (89)	p-Value
	n (%)	n (%)	n (%)	
No. Of grafted vessels (mean ± SD)	2.2 ± 0.5	2.1 ± 0.7	2.3 ± 0.7	0.56
CPB time (mean ± SD) (min)	47 ± 8	74 ± 5		<0.001
Crossclamping time (mean ± SD) (min)	36 ± 6	35 ± 6		0.7
Vessel conduits				
LAD-LITA	89	89	89	
Diag:ITAs/RA/SVG/stent	12	7	9	
Cx-RITA/RA/SVG/stent	35	36	40	
RCA-RITA/RA/SVG/stent	60	55	67	
Early operative data				
Ventilation time (mean ± SD) (h)	7 ± 3	5 ± 6	10 ± 4	0.4
ICU stay (mean ± SD) (h)	21 ± 6	19 ± 5	22 ± 4	0.7

CPB = cardio-pulmonary by-pass; LAD = left anterior descending; Cx = circumflex; Diag = diagonal; ICU = intensive care unit.

Table 4
Postoperative outcomes after myocardial revascularization.

	Total arterial ($n = 89$)	Conventional (89)	HCR (89)	p-Value
	n (%)	n (%)	n (%)	
Acute renal failure	7 (7.9%)	9 (10.1)	2 (2.2)	0.01
Prolonged mechanical ventilation (>48 h)	1 (1.1)	1 (1.1)	2 (2.2)	0.7
Atrial fibrillation	32 (36)	35 (39.3)	12 (13.5)	<0.001
Cerebrovascular accidents	0	2 (2.2)	0	0.13
Postoperative MI	1 (1.1)	2 (2.2)	0	0.36
Transfusion	39 (43.8)	43 (48.3)	13 (14.6)	<0.001
Re-operation for bleeding	1 (1.1)	2 (2.2)	1 (1.1)	0.77
Sternal wound complications	2 (2.2)	3 (3.4)	0	0.23
Early mortality (<30 days)	0 (0)	0 (0)	0 (0)	0.77
In-hospital stay	7.4 ± 0.8	7.8 ± 1	5.3 ± 1.2	0.01

MI = myocardial Infarction.

related death was similar among the groups (G1 = 97.7 ± 1.6% vs G2 = 95.1 ± 2.4% vs G3 = 89.5 ± 5.4%, $p = 0.08$).

Conversely, at 10 years follow-up only freedom from MACCEs was significantly better in patients undergoing total arterial grafting (G1 = 78.9 ± 8.6% vs G2 = 72.4 ± 5.7% vs G3 = 52 ± 8.7%, $p < 0.001$) while overall survival (G1: 86.5%, CI 82.1–89.9%; G2: 70.6%, CI 65.5–75.7% and G3: 72.5%, CI 64.2–80.8%, p-value = 0.053) and cardiac related mortality were not (G1: 95.5%, CI 92.8–98.2%; G2: 89.8%, CI 86.2–93.5% and G3: 79.0%, CI 70.5–87.5%, p-value = 0.08).

A univariate and multivariate Cox regression analysis (Table 5) was performed on the incidence of MACCEs and demonstrated that HCR (HR = 5.02, CI 95% = 2.2–11.3; $p < 0.001$) and peripheral artery disease (HR = 2.15, CI 95% = 1.12–4.1; $p = 0.02$) were incremental risk factors for the time-occurrence of major cardiac and cerebrovascular accidents. Moreover, the use of conventional CABG surgery was associated with incremental risk for MACCEs albeit with no statistically significance. (HR = 2.2, CI 95% = 0.97–5.1; $p = 0.059$)

4. Discussion

The use of total arterial myocardial revascularization in multi-vessel coronary artery revascularization still represents a controversial issue, despite several reports demonstrating the mid-term and long-term benefits of an extensive use of arterial conduits compared to the

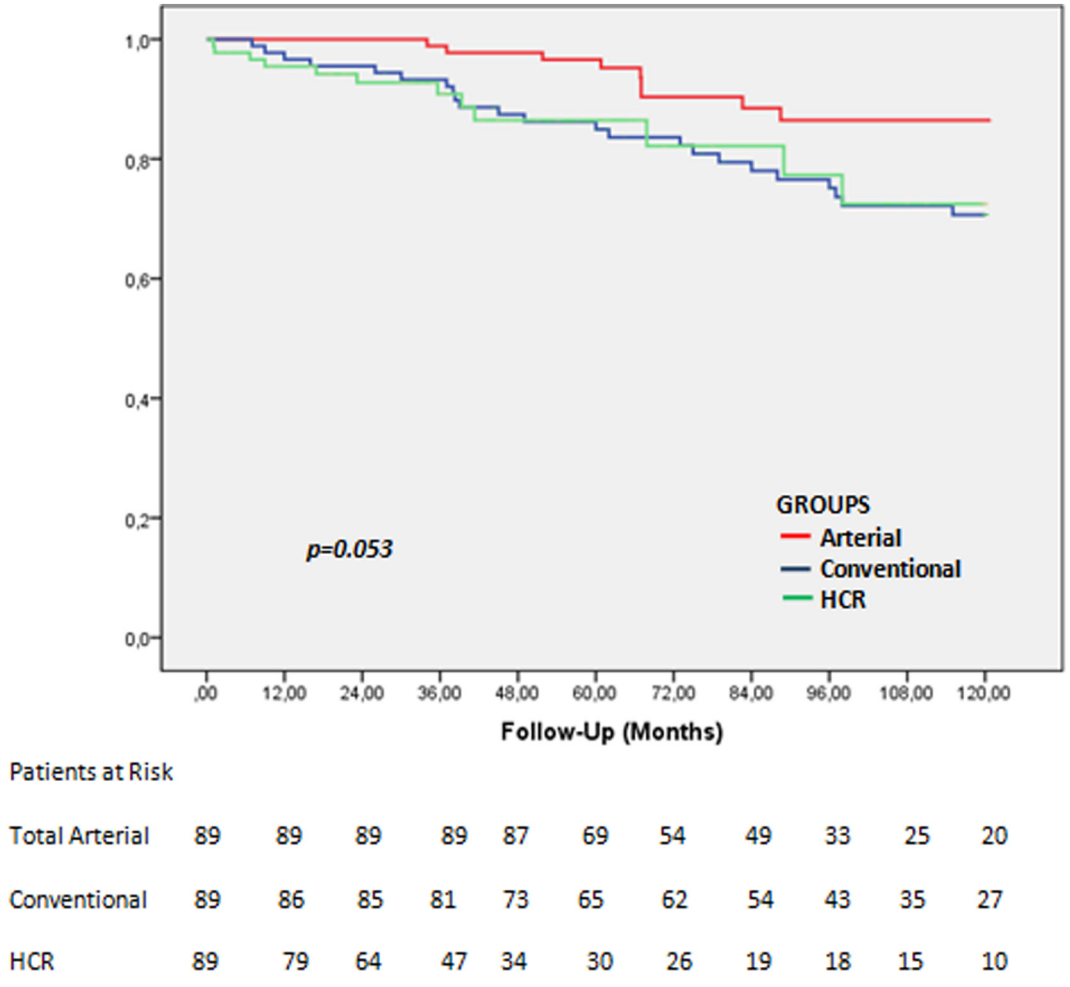

Fig. 1. Kaplan-Meier analysis for over-all survival.

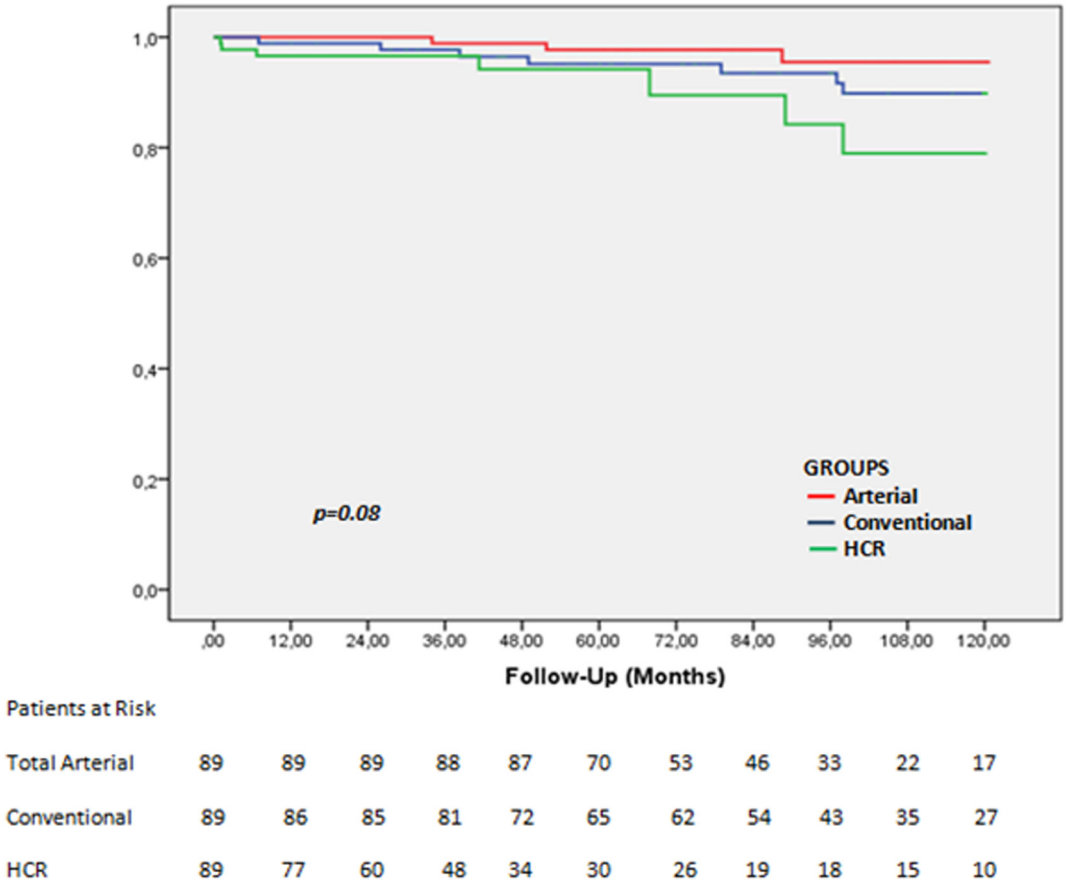

Fig. 2. Kaplan-Meier analysis for cardiac related mortality.

conventional approach. Despite the recent European [6] as well as American [7] guidelines on myocardial revascularization recommended full arterial revascularization to be adopted in well-defined selected cases such patients with good life expectances and younger than 70 years of age, several other reports observed an advantage of total arterial grafting regardless of age [8–10].

A hybrid coronary revascularization strategy (HCR) has emerged over the past decade since it represents an intriguing opportunity in order to reduce the degree of surgical invasiveness. HCR has also been recently introduced into ESC/EACTS guidelines [6] as a potential therapeutical strategy in selected cases and experienced centers; similarly, several studies demonstrated similar short-term [11] and mid-term [12] outcomes of HCR compared with CABG surgery in terms of over-all survival and cardiac related mortality albeit with a higher incidence of MACCEs. Nevertheless, none of these studies specifically analysed the impact of the surgical strategy for myocardial revascularisation (either full arterial or conventional) on late outcomes.

Our study therefore aimed to evaluate perioperative, mid- and long-term outcomes of patients undergoing three different strategies of revascularization: total arterial, conventional and hybrid revascularization.

Perioperative outcomes showed no differences among groups with respect to major post-operative adverse events such as early mortality, early graft failure and post-operative myocardial infarction.

At mean follow-up of 6 ± 2 years we found significantly better overall survival and incidence of MACCEs in the full arterial group, despite clinical outcomes at long term follow-up (10 years) were similar among the groups except for MACCEs. In our series of patients Cox's regression analysis depicts an increased risk of MACCE in hybrid group respect to total arterial revascularization, as well as conventional revascularization, despite this association is only marginally significant in the latter case. The increased incidence for MACCEs is mostly due to the higher need for target lesion revascularization in the HCR group due to percutaneous revascularization failure (in-stent critical restenosis or acute thrombosis) especially in patient with first generation stents and without double antiplatelet therapy after stent deployment. In fact, target vessel revascularization is the Achille's heel of HCR as previously reported by several authors [11,13–15] especially in patients with higher values of SYNTAX score (22–32 and >32). One of the limitations of the current study is the lack of data available in terms of SYNTAX score of the studied population, which could lead to different interpretation of our results.

Therefore, as previously recommended, a careful selection of patients undergoing HCR is advisable [13].

Some evidences have mounted, showing long-term benefits for surgical coronary revascularization with multiple arterial conduits compared with a combination of SIMA and multiple venous grafts [16,17], and also when compared to hybrid coronary revascularization that reflects the same concept of conventional CABG using a single internal mammary artery [18]. In our cohort, all-cause mortality rate was lower in the BIMA group compared with the HCR and SIMA group. According to results obtained in other centres we are convinced that total arterial revascularization can give a real advantage in terms of survival and freedom from MACCE, also in elderly patients [19].

Of note, mean age of the current study population was above 70 years, which may lead to a relative benefit at long term.

Another controversial issue is the use of radial artery as composite Y graft. In our study radial artery was used only in case of severe coronary artery stenosis to avoid competitive flow; we did not use radial artery in case of severe hypertrophy or diffuse calcified coronary disease in order to achieve the best long term patency of this conduit. Literature is not

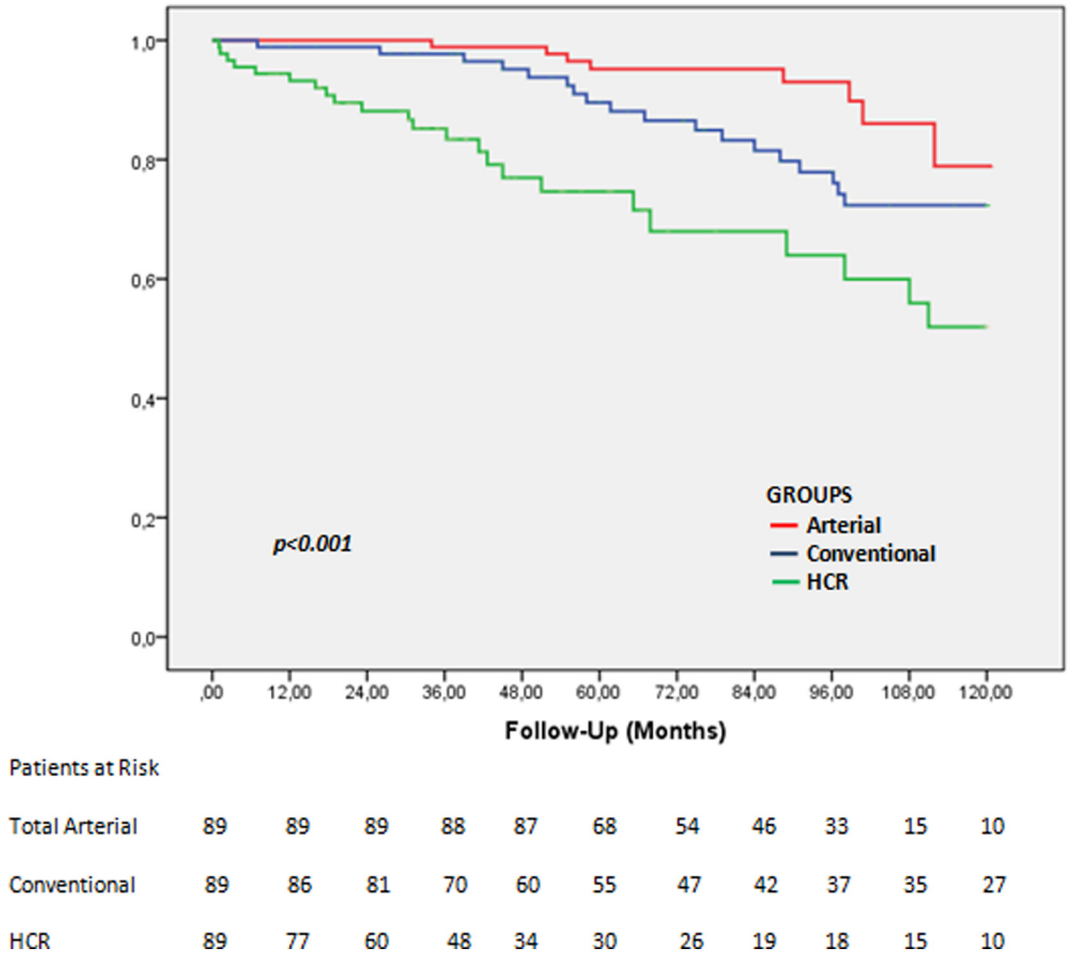

Fig. 3. Kaplan-Meier's survival analysis for MACCEs (Cardiac related mortality mortality, acute myocardial infarction, stroke, Target Vessel Revascularization).

uniform about the use of radial artery: the composite LIMA/RA Y or T grafts have been demonstrated to be able to adapt their diameter to flow demand and to supply sufficient flow to distal branches [20,21]. Evidence supports the use of radial artery as free-graft as second arterial conduit [22], although several studies report excellent results for RA also as Y composite graft meeting adequate flow requirements [20,23,24]. Moreover superiority of right internal thoracic artery compared to radial artery is not proved even as Y graft [25,26].

Finally, given the small sample size especially at 10 years follow-up (with an average number of 20 patients at risk) the results of the current study should be carefully interpreted. Therefore, we believe that further studies on large patients' population and following appropriate patients' stratification (by SYNTAX score) especially at long term are warranted in order to confirm our current findings.

In conclusion, our study showed that total arterial revascularization is associated with incremental benefits both at 5 and 10 years follow-up in terms of overall survival and incidence of major cardiovascular events compared to conventional CABG surgery and hybrid coronary revascularisation.

Table 5
Cox regression analysis for MACCE.

Variables	Univariate			Multivariate		
	HR	95% CI	*p*-Value	HR	95% CI	*p*-Value
Convetional vs total arterial	2.2	0.9–5	0.067	2.2	0.9–5.1	0.059
HCR vs total arterial	5.4	2.4–12.1	<0.001	5.0	2.2–11.3	<0.001
AMI < 90 days	1.2	0.5–2.5	0.58			
Dyslipidemia	0.6	0.3–1.1	0.1			
Diabetes	0.9	0.5–1.8	0.89			
Ejection fraction	0.9	0.8–1.0	0.99			
CRF	1.3	0.5–3.3	0.54			
Female gender	1.1	0.5–2.2	0.65			
EuroSCORE Log	1	0.9–1.2	0.96			
Age	0.9	0.7–1.1	0.7			
BMI > 30	1.1	0.3–3.4	0.9			
COPD	0.6	0.3–1.6	0.36			
PAD	2.5	1.3–4.7	0.005	2.1	1.1–4.1	0.02

Disclosures

Authors have no conflict of Interest to disclose.

References

[1] Lytle BW, Blackstone EH, Loop FD, Houghtaling PL, Arnold JH, Akhrass R, et al. Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 1999; 117:855–72.
[2] Lytle BW, Blackstone EH, Sabik JF, Houghtaling P, Loop FD, Cosgrove DM. The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. Ann Thorac Surg 2004;78:2005–12.
[3] Weiss AJ, Zhao S, Tian DH, Taggart DP, Yan TD. A meta-analysis comparing bilateral internal mammary artery with left internal mammary artery for coronary artery bypass grafting. Ann Cardiothorac Surg 2013;2(4):390–400.
[4] Kon ZN, Brown EN, Tran R, Joshi A, Reicher B, Grant MC, et al. Simultaneous hybrid coronary revascularization reduces postoperative morbidity compared with results from conventional off-pump coronary artery bypass. J Thorac Cardiovasc Surg 2008;135:367–75.
[5] Austin PC. Propensity-score matching in the cardiovascular surgery literature from 2004 to 2006: a systematic review and suggestions for improvement. J Thorac Cardiovasc Surg 2007;134:1128–35.
[6] Coronary Revascularization Writing Group, Patel MR, Dehmer GJ, Hirshfeld JW, Smith PK, Spertus JA, et al. ACCF/SCAI/STS/AATS/AHA/ASNC/HFSA/SCCT 2012 appropriate use criteria for coronary revascularization focused update: a report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force,

Society for Cardiovascular Angiography and Interventions, Society of Thoracic Surgeons, American Association for Thoracic Surgery, American Heart Association, American Society of Nuclear Cardiology, and the Society of Cardiovascular Computed Tomography. J Thorac Cardiovasc Surg 2012;143:780–803.
[7] Kolh P, Windecker S, Alfonso F, Collet JP, Cremer J, Falk V, et al. 2014 ESC/EACTS Guidelines on myocardial revascularization: The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) Developed with the special contribution of the European Association of Percutaneous Cardiovascular Interventions (EAPCI). Eur J Cardiothorac Surg 2014;46:517–92.
[8] Muneretto C, Negri A, Manfredi J, Terrini A, Rodella G, Elqarra S, et al. Safety and usefulness of composite grafts for total arterial myocardial revascularization: a prospective randomized evaluation. J Thorac Cardiovasc Surg 2003;125:826–35.
[9] Matsuura K, Kobayashi J, Tagusari O, Bando K, Niwaya K, Nakajima H, et al. Off-pump coronary artery bypass grafting using only arterial grafts in elderly patients. Ann Thorac Surg 2005;80:144–8.
[10] Muneretto C, Negri A, Bisleri G, Manfredi J, Terrini A, Metra M, et al. Is total arterial myocardial revascularization with composite grafts a safe and useful procedure in the elderly? Eur J Cardiothorac Surg 2003;23:657–64.
[11] Harskamp RE, Bagai A, Halkos ME, Rao SV, Bachinsky WB, Patel MR, et al. Clinical outcomes after hybrid coronary revascularization versus coronary artery bypass surgery: a meta-analysis of 1,190 patients. Am Heart J 2014;167:585–92.
[12] Halkos ME, Rab ST, Vassiliades TA, Morris DC, Douglas JS, Kilgo PD, et al. Hybrid coronary revascularization versus off-pump coronary artery bypass for the treatment of left main coronary stenosis. Ann Thorac Surg 2011;92:2155–60.
[13] Shen L, Hu S, Wang H, Xiong H, Zheng Z, Li L, et al. One-stop hybrid coronary revascularization versus coronary artery bypass grafting and percutaneous coronary intervention for the treatment of multivessel coronary artery disease: 3-year follow-up results from a single institution. J Am Coll Cardiol 2013;61:2525–33.
[14] Repossini A, Tespili M, Saino A, Di Bacco L, Giroletti L, Rosati F, et al. Hybrid coronary revascularization in 100 patients with multivessel coronary disease. Ann Thorac Surg 2014;98:574–80.
[15] Repossini A, Tespili M, Saino A, Kotelnikov I, Moggi A, Di Bacco L, et al. Hybrid revascularization in multivessel coronary artery disease. Eur J Cardiothorac Surg 2013;44:288–93.
[16] Buxton BF, Shi WY, Tatoulis J, Fuller JA, Rosalion A, Hayward PA. Total arterial revascularization with internal thoracic and radial artery grafts in triple-vessel coronary artery disease is associated with improved survival. J Thorac Cardiovasc Surg 2014;148:1238–43.
[17] Johnston DR. Long-term results of multiple arterial bypass conduits. Curr Opin Cardiol 2014;29:542–6.
[18] Rosenblum JM, Harskamp RE, Hoedemaker N, et al. Hybrid coronary revascularization versus coronary artery bypass surgery with bilateral or single internal mammary artery grafts. J Thorac Cardiovasc Surg 2016;151:1081–9.
[19] Bisleri G, Di Bacco L, Turturiello D, Mazzoletti A, Giroletti L, Repossini A, et al. Improved outcomes of total arterial myocardial revascularization in elderly patients at long-term follow-up: a propensity-matched analysis. Ann Thorac Surg 2017;103:517–25.
[20] Affleck DG, Barner HB, Bailey MS, et al. Flow dynamics of the internal thoracic and radial artery T-graft. Ann Thorac Surg 2004;78:1290–4.
[21] Mannacio V, Di Tommaso L, De Amicis V, Musumeci F, Stassano P. Serial evaluation of flow in single or arterial Y-graft to the left coronary artery. Ann Thorac Surg 2011;92:1712–8.
[22] Jung SH, Song H, Choo SJ, Je HG, Chung CH, Kang JW, et al. Comparison of radial artery patency according to proximal anastomosis site: direct aorta to radial artery anastomosis is superior to radial artery composite grafting. J Thorac Cardiovasc Surg 2009;138:76–83.
[23] Mannacio V, De Vita A, Antignano A, Mottola M, Di Tommaso L, Graniero A, et al. Y grafts with the left internal mammary artery and radial artery. Mid-term functional and angiographic results. Cohort study. Int J Surg 2014;12(9):952–7.
[24] Watson RA, Hamza M, Tsakok TM, Tsakok MT. Radial artery for coronary artery bypass grafting: does proximal anastomosis to the aorta or left internal mammary artery achieve better patency? Interact Cardiovasc Thorac Surg 2013;17:1020–4.
[25] Tranbaugh RF, Dimitrova KR, Lucido DJ, Hoffman DM, Dincheva GR, Geller CM, et al. The second best arterial graft: a propensity analysis of the radial artery versus the free right internal thoracic artery to bypass the circumflex coronary artery. J Thorac Cardiovasc Surg 2014;147:133–40.
[26] Ruttmann E, Fischler N, Sakic A, Chevtchik O, Alber H, Schistek R, et al. Second internal thoracic artery versus radial artery in coronary artery bypass grafting: a long-term, propensity score-matched follow-up study. Circulation 2011;124:1321–9.