Original article

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Hybrid coronary revascularization versus percutaneous strategies in left main stenosis: a propensity match study

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Aims **Hybrid revascularization (HCR) has been recently proposed as an alternative strategy in multivessel coronary disease, particularly in patients with high SYNTAX scores and risk scores. The objective of this study is to evaluate the outcomes of HCR versus percutaneous coronary intervention (PCI) drug-eluting stenting in left main treatment.**

Methods **A series of 198 consecutive patients with left main stenosis have been treated. HCR, was performed in 77 patients (G1) whereas 121 patients (G2) received PCI on left main. An adjusted analysis using inverse probability weighting (IPW) was performed. Primary outcomes include: 30-day mortality, postoperative acute myocardial infarction, 18 months' MACCEs: cardiac death, stroke, acute myocardial infarction (AMI), repeated target vessel revascularization (TVR).**

Results **SYNTAX score was 29.5 ± 6.9 in G1 and 29.1 ± 6.5 in G2 ($P = 0.529$). In G2, three patients (2.7%) died because of cardiogenic shock; no deaths occurred in G1 ($P = 0.603$). No major complications were reported in G1 and there was no mortality at 18 months' follow-up in both groups. Survival freedom from MACCEs at 18 months' follow-up was significantly higher in G1 (G1: 93.3 ± 4.6% versus G2: 72.3 ± 6.3; $P = 0.001$) mostly because of the higher freedom from TVR (G1: 93.3 ± 4.6% versus G2: 75.5 ± 5.6; $P = 0.002$). At Cox regression analysis, PCI was an independent predictor of MACCEs and TVR (hazard ratio 3.9, CI 1.36–9.6; $P = 0.027$).**

Conclusion **PCI in patients with left main and multivessel disease is a viable strategy, with a good outcome. HCR, demonstrated a lower incidence of cardiac adverse events such as AMI and TVR. Future comparative studies will be helpful to identify the optimal patient population for HCR.**

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Keywords: hybrid coronary revascularization, percutaneous coronary intervention, unprotected left main stenosis

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Introduction

Percutaneous coronary intervention (PCI), thanks to the improvement in results of the new generation of drug-eluting stents (DES), is gaining more popularity in the treatment of left main coronary lesions.[1] Within the SYNTAX trial, in the cohort of patients with left main disease, similar results for the composite outcome were reported for either patients undergoing coronary artery bypass grafting (CABG) or percutaneous intervention.[2]

As left main lesions still represent a technical challenge for PCI stenting, in particular, for complex or distal lesions, US and European guidelines report that CABG is still the gold standard therapy[3,4] and that results after PCI treatment are acceptable only for ostial/midshaft left main or simple noncalcified lesions.[5,6]

Despite superiority of CABG on PCI for left main treatment has been proven by several studies and randomized trials[7,8] in terms of reduced cardiac death, myocardial infarction and particularly long-term freedom from repeated coronary revascularization, in 'real-world' clinical practice, the optimal strategy for coronary artery revascularization is still controversial, and PCI is largely diffused for unprotected left main (ULM) treatment.

Nowadays hybrid coronary revascularization (HCR) strategy is gaining new popularity in addition to CABG and PCI for ULM treatment, combining the most proven efficacious therapeutic proposals of cardiac surgery and interventional cardiology, meaning minimally invasive direct coronary artery bypass (MIDCAB) and PCI-stenting for non-LAD lesions to perform a functionally complete revascularization.

The current strategy offers to patients a solution integrating all the advantages of both techniques, by avoiding major surgical traumas, such as complete median sternotomy, aortic manipulation, use of cardiopulmonary bypass and cardioplegia and by reducing the rate of postoperative complications of conventional CABG, such as atrial fibrillation, bleeding, transfusions and lung infections.[9] On the other side, the combined technique allows the rate of repeated TVR to be reduced, mainly because of low-patency rate of complex left main stent procedures.

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Many comparative studies and trials on CABG versus PCI outcomes in left main treatment have been published[1,10–13] whereas HCR versus CABG[14] or OPCAB[9,15–17] experience in MVD patients is limited and over a 10-year period cumulates approximately 500 patients from a number of small, single-center series.[18–21]

The only randomized trial to date is the Polish experience comparing hybrid approach to CABG/OPCAB showing feasibility and safety of the hybrid approach and reporting no differences in terms of graft patency and stent restenosis at 12 months' follow-up.[22]

HCR versus PCI studies demonstrated that the complexity of the coronary lesion directly affects the outcomes of PCI, especially the TVR, which is mainly concentrated in the LAD, whereas PCI with DES for non-LAD offered low and similar TVR rates in both HCR and PCI groups.[23]

The only recently published multicenter observational US study exploring outcomes of patients undergoing HCR and multivessel PCI[24] suggested that there is no significant difference in MACCE rates.

We sought to investigate midterm outcomes in two cohorts of patients with left main disease, treated by HCR and multiple PCI.

Patients and methods

Study population

From January 2013 to June 2016, data were retrospectively collected from 198 consecutive patients with left main coronary disease treated, after heart team evaluation, by HCR or multivessel PCI with either DES or bare metal stents (BMS). After multidisciplinary assessment based on preoperative risk (Logistic EuroSCORE I) and on coronary lesions complexity (SYNTAX score), 77 patients underwent HCR and 121 underwent multiple PCI. The two groups were:

- HCR (LITA- LAD and PCI on other target vessels: Group 1, G1)
- PCI (Group 2, G2).

Patients considered eligible to be scheduled in the study were patients with critical left main stenosis or equivalent left main lesion, with or without multivessel coronary lesions.

Patients that underwent primary/rescue PCI for acute coronary syndrome on non-LAD lesions with residual lesions on left main were also considered in the study.

In particular, only patients with a coronary anatomy suitable either for HCR and PCI were included in the study: patients with distal heavy calcified lesions and isolated ostial or proximal-mid-body left main disease have been excluded from the study.

Other exclusion criteria were patients undergoing concomitant surgical procedures in addition to myocardial revascularization.

Primary endpoints include: 30-day mortality, postoperative acute myocardial infarction (AMI) and survival freedom from MACCEs at 18 months: cardiac death, stroke, AMI, repeated target vessel revascularization (TVR).

Secondary endpoints were survival freedom from TVR at 18 months' follow-up and Cox regression analysis of independent predictor factors for MACCE and TVR.

This study was approved by the Institutional Review Board and no funding or industry support has to be disclosed. All patients provided informed consent to be enrolled in our institutional registry for patients with coronary disease.

Statistical analysis

Continuous variables were reported as mean ± SD; means were compared using Student's *t*-test for independent samples. Categorical variables were expressed as number of observations and percentage and they were compared with Fisher's exact test.

Inverse probability treatment weighting (IPTW) based on propensity score evaluation was used in order to obtain two balanced populations, reducing selection biases in the two groups.

The propensity score was calculated for every patient using a binary logistic regression, and 10 patients from G1 and 13 patients from G2 were discarded because they were outside the common support area after full-match analysis. Variables used in the propensity analysis are included in the analysis if P value was less than 0.10. Then each patient was weighted by the inverse probability of receiving the treatment that they actually received; the weight was calculated on the basis of propensity score match value as following $G1 = (1/\text{propensity score})$ and $G2 = [1/(1 - \text{propensity score})]$. Standardized difference in the weighted population for covariates in the analysis was less than 10%.

Survival analysis was performed with weighted Kaplan–Meier curves and population were compared by log-rank test. A weighted Cox regression analysis was used to verify if there were independent predictors for the hard end points. It was verified by graphical method. Statistical findings were considered significant if the critical level was less than 5% ($P < 0.05$). Statistical analysis was performed with SPSS software (Version 23, IBM, New York, New York, USA).

Treatment strategy

HCR strategy and timing were chosen following a multidisciplinary discussion by the heart team: culprit lesion was treated first and a sequential staged strategy was utilized, with a timeframe of about 1–4 weeks between

the surgical and transcatheter procedure. For unprotected left main coronary disease, a surgical revascularization via MIDCAB was performed as the first step of the hybrid revascularization strategy, followed by PCI stenting of circumflex artery and non-LAD lesions. No patient in G1 had a simultaneous surgical and percutaneous revascularization.

Surgical technique

In G1 patients, a standard MIDCAB was performed as described elsewhere.[25] A single lumen tube ventilation was used in every case, the chest was opened through an anterior left minithoracotomy in the fourth intercostal space and LIMA was harvested as a skeletonized vessel from the fourth to the first intercostal space with the Thoralift retractor (US Surgical Corporation, Norwalk, Connecticut, USA). Pericardium was incised horizontally (parallel to the intercostal space) and LAD was explored. If LAD was too lateral or the left lung was particularly bulky, LIMA was harvested to the fifth intercostal space, disarticulating the cartilage of the fifth rib, or to the sixth rib by a fifth intercostal space approach. After systemic heparinization (100 IU/kg) LIMA was interrupted distally and LAD was then occluded proximally using a silicone vessel loop to avoid any direct compression on the coronary wall. Distal occlusion was seldom necessary and intracoronary shunts were never used. An 8-min preconditioning was performed, without any hemodynamic instability, major arrhythmias or significant ST-T changes; LAD was incised after 1-min reperfusion. The anastomosis was then performed with a single 8-0 or 7-0 polypropylene running suture. Local immobilization of the myocardial surface was achieved using a pressure stabilizer. At the end, the effect of heparin was reversed with half dose of protamine.

Percutaneous coronary intervention

Coronary angiography was routinely performed via radial artery. In 17 cases in HCR group and 14 cases in PCI group, angiography was performed via femoral artery because of severe atherosclerosis of radial and brachial artery. Decision about PCI staging and stent selection were left to the discretion of single operators: DES (Cypher sirolimus, Cordis Johnson & Johnson, Warren, New Jersey, USA; Taxus paclitaxel, Boston Scientific, Natick, Massachusetts, USA and Xience everolimus, Abbot Vascular, Santa Clara, California, USA) and BMS were both used.

Antithrombotic therapy

In patients who underwent PCI before MIDCAB or those who underwent MIDCAB before PCI but had a recent acute coronary syndrome, and therefore were on double antiplatelet therapy (Clopidogrel 75 mg/day and Aspirin 100 mg/day), only Clopidogrel was interrupted 3 days before intervention. An early administration of Aspirin was performed on the first postoperative day in addition to antithrombotic dose of low molecular weight heparin (LMWH). Clopidogrel was administered on the second postoperative day.

Follow-up

Follow-up visits were performed at 1 and 6 months postoperatively and on a yearly basis thereafter; additional clinical data were collected from referring cardiologists and general practitioners. Follow-up is 95.5% complete (nine patients were lost at follow-up).

Results

Patient characteristics before matching

Before matching, 77 patients were in HCR group (G1) and 121 patients in PCI group (G2). SYNTAX score was 29.3 ± 7 in G1 and 27 ± 6 in G2 ($P = 0.151$).

The mean age was significantly lower in G1 (66 ± 10 in G1 versus 70 ± 9 years in G2; $P = 0.019$). EuroSCORE I was 10.4 ± 7.8 and 10.8 ± 8.4 in G1 and G2, respectively, $P = 0.045$. Patients in G1 had better mean left ventricular ejection fraction (52 ± 8 versus 49.5 ± 7.1; $P = 0.041$) with fewer women than in G2 (13 versus 30.6%; $P = 0.006$). Dyslipidemia incidence was greater in G1 than in G2 (64.9 versus 57%, respectively; $P = 0.049$) whereas there was only one REDO case in G1 (reintervention after valvular cardiac surgery) versus 13 cases in G2 (1.3 versus 10.7%, respectively, $P = 0.010$). The number of patients with CCS class greater than III was higher in G2 (26 versus 42.9%; $P = 0.020$). All the other preoperative variables were not statistically different in the two groups (Table 1).

Patients characteristics after matching

After matching, there were 67 and 108 patients, respectively, in G1 and G2 and no variables differed between the two matched groups (Table 2). Preoperative characteristics were balanced with the IPTW method derived from the propensity score and after matching all standardized differences were less than 10% among variables. SYNTAX score was 29.5 ± 6.9 in G1 and 29.1 ± 6.5 in G2 ($P = 0.529$) and EuroSCORE I Log was 12.9 ± 14.6 versus 11.6 ± 14.7, respectively, $P = 0.329$.

Intraoperative and early postoperative results

There were three emergency/urgency procedures in G1 and 23 in G2 (4.4 versus 21.3% respectively; $P < 0.001$). Mean ICU stay for HCR patients was 17 ± 4.5 h and mean mechanical assisted ventilation (MAV) was 7 ± 2.1 h; in only one case, MAV was longer than 24 h (1.4%).

In seven patients in G2 (6.4%), left main dissection during the procedure occurred: two had fatal AMI and cardiac arrest whereas five had an uneventful course.

One patient in G1 needed a reintervention for bleeding, performed through the same left minithoracotomy (1.4%), whereas in one case, postoperative bleeding

Table 1 Preoperative unmatched variables

	Hybrid coronary revascularization (HCR), *n*, 77 (%)	Percutaneous coronary intervention (PCI) *n*, 121 (%)	*P* value	SD
Age (years)	66 ± 10	70 ± 9	0.019	0.783
EuroSCORE I Log (mean ± SD)	10.4 ± 7.8	10.8 ± 8.4	0.045	−0.031
Euro SCORE II (mean ± SD)	3.9 ± 3.1	3.3 ± 2.9	0.031	0.128
SYNTAX score	29.3 ± 7.0	27 ± 6	0.151	−0.012
Ejection fraction (mean ± SD)	52 ± 8.0	49.5 ± 7.1	0.041	−0.285
Female sex	10 (13)	37 (30.6)	0.006	0.380
Hypertension	56 (72.7)	73 (62.3)	0.092	0.252
Diabetes	20 (26)	41 (33.9)	0.271	0.166
CRF (GFR <30 ml/kg/min)	10 (13)	24 (19.8)	0.249	0.171
COPD	16 (20.8)	21 (17.4)	0.589	−0.090
PAD	17 (22.1)	28 (23.1)	1.000	0.025
Previous CVA	14 (18.2)	14 (11.6)	0.214	−0.206
Atrial fibrillation	4 (5.2)	16 (13.2)	0.090	0.236
Obesity (BMI >30)	16 (20.8)	19 (15.7)	0.445	−0.139
Dyslipidemia	50 (64.9)	69 (57)	0.049	−0.258
REDO	1 (1.3)	13 (10.7)	0.010	0.304
STEMI/nSTEMI less than 90 days	21 (27.3)	39 (32.2)	0.059	0.342
CCS class greater than III	20 (26.0)	52 (42.9)	0.020	0.252

CCS, Canadian Cardiovascular Society; COPD, chronic obstructive pulmonary disease; CRF, chronic renal failure; CVA, cerebrovascular accidents; NYHA, New York Heart Association; PAD, peripheral artery disease; REDO, reoperation; SD, standardized differences; STEMI, ST elevation myocardial infarction.

exceeded 1000 ml anyhow not requiring surgical revision (1.4%). One patient required conversion to sternotomy and CPB because of intramural course of LAD (1.4%). In five cases of HCR, all with left main equivalent lesions with ostial stenosis of both LAD and circumflex artery (Cx), PCI stenting from Cx to left main was performed before MIDCAB. All the other patients in HCR group received MIDCAB before PCI.

The mean number of diseased treated vessel was higher in G2 (2.3 ± 0.8 in G1 versus 2.7 ± 0.7 in G2, $P = 0.074$).

There was no in-hospital mortality in G1 whereas three patients died because of cardiogenic shock after PCI in G2 (G1: 0% versus G2: 2.7%; $P = 0.603$). No major postoperative complications were reported in G1, whereas one postoperative stroke and one myocardial infarction occurred in G2. Eleven patients in G1 required more than two transfusions with packed red blood cells versus four patients in G2 (16.2 versus 3.7%, respectively; $P = 0.027$). One patient of each group required prolonged catecholamines support (1.4% in G1 and 0.9% in G2, $P = 0.919$) and only one patient in PCI group needed IABP positioning (0% in G1 versus 1.4% in G2; $P = 0.839$). Postoperative atrial fibrillation incidence was significantly higher in G1 than in G2 (11.9 versus 0.9%, respectively; $P = 0.008$) whereas acute renal failure incidence was significantly higher in G2 (0 versus 9.2%, respectively; $P = 0.003$). Three cases of pneumothorax (4.4%) and six cases of pleural effusion (8.9%) were reported in G1. Pericardial effusion incidence was similar between the two groups (4.4% in G1 versus 4.6 in G2; $P = 0.984$) never requiring a revision. Results are reported in Table 3.

Table 2 Preoperative matched variables

	Hybrid coronary revascularization (HCR), *n*, 67 (%)	Percutaneous coronary intervention (PCI), *n*, 108 (%)	*P* value	SD
Age (years)	68 ± 9	69 ± 11	0.278	0.112
EuroSCORE I Log (mean ± SD)	12.9 ± 14.6	11.6 ± 14.7	0.329	0.105
Euro SCORE II (mean ± SD)	3.4 ± 2.9	3.4 ± 3.2	0.087	0.014
SYNTAX score	29.5 ± 6.9	29.1 ± 6.5	0.529	0.065
Ejection fraction (mean ± SD)	51.8 ± 10.2	50.7 ± 10.7	0.309	0.105
Female sex	22.7	24.8	0.717	−0.061
Hypertension	66.4	64.7	0.745	0.044
Diabetes	26.8	30.8	0.426	−0.111
CRF (GFR<30 ml/kg/min)	16.5	17.9	0.785	−0.055
COPD	19.3	19.9	0.897	0.020
PAD	19.9	23.4	0.454	−0.133
CVA	15.3	12.9	0.555	0.105
Atrial fibrillation	6.8	10.0	0.355	−0.227
Obesity (BMI >30)	15.3	16.4	0.888	−0.045
Dyslipidemia	48.9	47.8	0.837	0.085
REDO	4.5	5.7	0.846	0.020
STEMI/nSTEMI less than 90 days	28.2	29.5	0.472	0.091
CCS class greater than III	35.8	38.9	0.625	0.050

CCS, Canadian Cardiovascular Society; COPD, chronic obstructive pulmonary disease; CRF, chronic renal failure; CVA, cerebrovascular accidents; NYHA, New York Heart Association; PAD, peripheral artery disease; REDO, reoperation; SD, standardized differences; STEMI, ST elevation myocardial infarction.

Table 3 In-hospital and 30-day outcomes

	Hybrid coronary revascularization (HCR) *n*, 67 (%)	Percutaneous coronary intervention (PCI), *n* , 108 (%)	*P* value
Emergency	3 (4.4)	23 (21.3)	<0.001
ICU stay (mean ± SD; h)	17 ± 4.5		
MAV (mean ± SD; h)	7 ± 2.1		
PCI then MIDCAB	18		
MAV greater than 24 h	1 (1.4)		
In-hospital mortality	0	3 (2.7)	0.603
Stroke	0	1 (0.9)	0.839
Rethoracotomy for bleeding			
Sternotomy	0		
Lateral minithoracotomy	1 (1.4)		
Bleeding greater than 1000 ml without reoperation	1 (1.4)		
Transfusions greater than two PBRC	11 (16.2)	4 (3.7)	0.027
Low-cardiac output			
Prolonged catecholamines	1 (1.4)	1 (0.9)	0.919
IABP necessary	0	1 (0.9)	0.839
Myocardial infarction	0	1 (0.9)	0.839
Reoperation for pericardial effusion	0		
Postoperative atrial fibrillation	8 (11.9)	1 (0.9)	0.008
Pneumothorax	3 (4.4)		
Pleural effusion	6 (8.9)		
Pericardial effusion	3 (4.4)	5 (4.6)	0.984
Revision for pericardial effusion	0	0	1
Acute renal failure	0	10 (9.2)	0.003
Conversion to sternotomy	1 (1.4)		

IABP, intra-aortic balloon pump; MAV, mechanical assisted ventilation; MIDCAB, minimally invasive direct coronary artery bypass; PBRC, packed red blood cells; PCI, percutaneous coronary intervention.

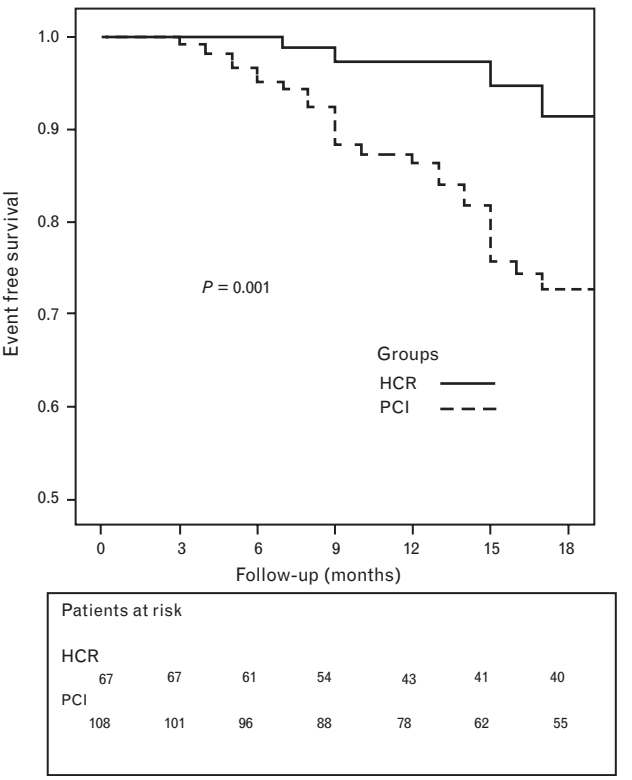
Results at follow-up

Mean follow-up was G1: 15.4 ± 2.6 months versus G2 15.2 ± 2.8 months; G1 1190 years/patients versus G2 1850 patient/years. No mortality at 18 months' follow-up was reported in both groups. Two major cerebral adverse events and seven AMIs (in six cases receiving TVR) were reported in G2 whereas neither strokes nor myocardial infarction were registered in G1 at follow-up. At 100% complete angiographic follow-up at 12 months, four cases of TVR were reported in G1: two in-stent restenosis of left main-Cx stent, one case of poststent stenosis and one in-stent restenosis on a right coronary artery (RCA) lesion; no procedures on LAD for LIMA-LAD graft failure or stenotic anastomosis were reported. In G2, seven patients received plain old balloon angioplasty (POBA; kissing balloon) on left main for bifurcation initial restenosis; moreover, there were three in-stent restenoses treated by new PCI, four cases of poststent stenosis, two cases of incomplete distal stent expansion and eight cases of in-stent restenosis on a RCA lesion.

Survival freedom from MACCEs at 12 and 18 months' follow-up (Fig. 1) was significantly higher in G1 (12 months, G1: 97.2 ± 2.5% versus G2: 86.3 ± 3.2; 18 months, G1: 93.3 ± 4.6% versus G2: 72.3 ± 6.3; $P = 0.001$) mostly because of the higher survival freedom from TVR (Fig. 2; G1: 93.3 ± 4.6% versus G2: 75.5 ± 5.6; $P = 0.002$).

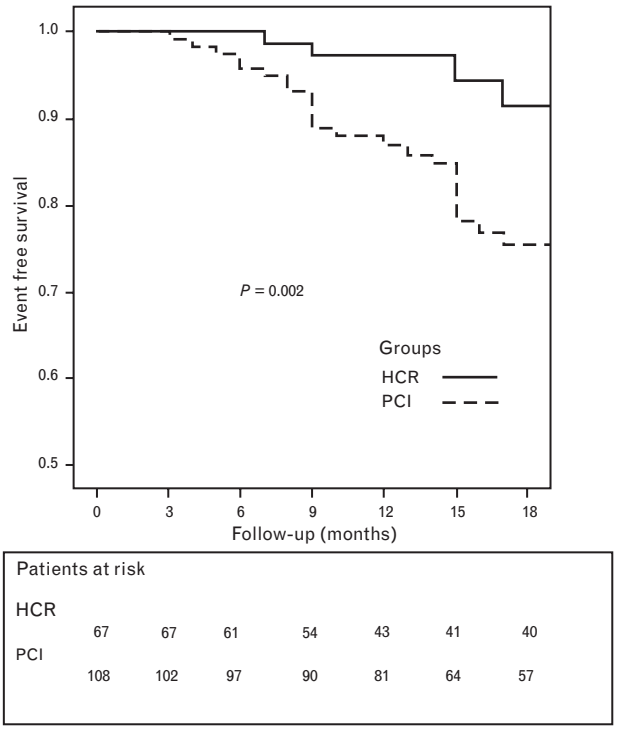
At Cox regression analysis, PCI stenting on left main was an independent predictor of MACCEs (hazard ratio 4.1, CI 2.4–11.3; $P = 0.001$) and TVR (hazard ratio 3.9, CI 1.36–9.64; $P = 0.002$). Female sex was an independent predictor of TVR (hazard ratio 2.1, CI 1.12–4.65; $P = 0.049$).

Fig. 1



Survival freedom from major adverse cardiac and cerebrovascular events at follow-up.

Fig. 2



Survival freedom from target vessel revascularization. TVR, target vessel revascularization.

Discussion

CABG still remains the gold standard for the treatment of significant left main stenosis. Nevertheless, PCI has emerged as an alternative therapy for selected patients with left main disease and in latest guidelines; it has recently been upgraded to Class I for SYNTAX score 22 or less and to Class IIa for SYNTAX score between 23 and 32. Surgery is still mandatory whenever SYNTAX score is at least 32.[26]

Although HCR has been considered in the past only suitable for high-risk patients, it has recently gained a new interest[27,28] and nowadays HCR is considered as a valid alternative to traditional surgical and interventional strategies, mostly because of the proven long-term duration of left internal mammary artery (LIMA-LAD) graft[29] and to the improvement of DES results.[1,5]

Several observational analyses have demonstrated that HCR is a well tolerated, feasible and minimally invasive alternative to on–off pump CABG for treatment of left main[9,16,30] with comparable in-hospital and midterm results. With an effective revascularization of LAD, left main-PCI is a much simpler and safer procedure than unprotected left main stenting (ULMS). Placement of a single left main DES into the circumflex, as frequently occurs, has no consequences and would be expected to result in lower restenosis and TVR rates compared with more complex stent procedures.[31]

In this study, the largest on this topic, we investigated the midterm outcomes of HCR strategy for left main disease, compared with multiple DES PCI. Because of lack of data on HCR in left main patients, we compared our clinical outcomes with the main studies on HCR in MVD patients[23,24] and with CABG, as standard surgical approach.[11]

Patients with isolated ostial or proximal-mid-body left main disease, who would currently be considered a low-risk score and in whom PCI with stenting effectively provides complete revascularization, have been excluded from our series, our main concern being the competitive flow to the LIMA-LAD system. Proximal LAD stenosis must be always present in our ideal hybrid left main patient.

In our clinically driven series, incidence of urgent procedures has been significantly higher in PCI group, being responsible for a certain bias and limitation. Nevertheless, in-hospital mortality, AMI and periprocedural complications were very low and similar in the two groups, although slightly, but not significantly superior in the PCI group. In particular, we experienced no deaths in G1 and three cardiac deaths in G2 (2.7%), which is similar to recent data of Delta Registry and other papers on left main PCI[32,33] with 2.3% cardiac death incidence in PCI group and 1.1% in CABG group.

MI incidence was absent in G1 and 0.9% in G2, significantly inferior to the reported 3.7% of PCI group and particularly to 22.5% of the CABG group.[11]

Stroke incidence was similar in G1 and G2 (0 and 0.9%, respectively) in line with the literature and inferior to reported data for CABG.[11] In our experience, G1 had a significantly higher incidence of blood transfusions (16.4 versus 3.7%, $P = 0.027$) and postoperative atrial fibrillation (11.9 versus 0.9%, $P = 0.008$) compared with G2, whereas acute renal failure was significantly higher in G2 (9.2 versus 0%, $P = 0.003$).

Results of the hybrid strategy are particularly encouraging if we consider that our mean EuroSCORE in the HCR group (G1: $12.9 \pm 14.6\%$) is much higher than in Delta Registry for CABG (5.2 ± 2.6)[11] and in the main HCR studies (3.1 ± 2.3).[23]

Moreover, our cohort, identified by EuroSCORE greater than 5 and SYNTAX score less than 32 reflects the ideal HCR population, characterized by superior 30-day composite cardiac and cerebrovascular outcomes in respect of CABG.[34]

Survival freedom from MACCEs at 18 months' follow-up, differently from results of Puskas *et al.*[24] that report

similar incidence of MACCEs in the two groups, was significantly higher in G1 ($93.3 \pm 4.6\%$) versus G2 ($72.3 \pm 6.3\%$, $P = 0.001$) mostly because of the higher freedom from TVR. In particular, they reported a superior stroke incidence in the HCR group, which was absent in our series and five cases of PCI to the LAD or LIMA-LAD anastomosis, maybe because of robotic LIMA harvest (54%), totally endoscopic coronary artery bypass (21%) and cardiopulmonary bypass (8%) responsible for worse results than standard MIDCAB.[35] In our series, (100% complete angiographic follow-up at 12 months) no procedures on LAD for LIMA-LAD graft failure have been performed, suggesting that the benefits of LIMA-LAD over PCI in terms of patency rates or disease progression seems to be crucial and explains the better freedom from MACCEs outcomes.

No simultaneous surgical and PCI procedures have been performed in G1, whereas 85% of G2 patients underwent revascularization in a single-staged procedure. Aware of other positive series[15,23] and obvious advantages as immediate angiography of LIMA-LAD and PCI of high-risk lesions with documented patent LIMA-LAD, we believe that single-step revascularization possibly enhances bleeding and thrombotic risks, and no patients in our HCR series underwent this strategy. A sequential staged strategy was utilized, with a timeframe of about 1–4 weeks between the surgical and transcatheter procedure, and even in case of very critical high-risk left main stenosis, no patient had MI or ischemic complications in the postoperative and pre-PCI period.

Study limitations

This is an observational retrospective and a propensity-score adjustment and matching was performed to reduce the imbalance between the two groups, and biases in the study. The study was clinically and anatomically driven after heart team discussion. The majority of DES used in this study were first generation DES, and thus our results may not reflect outcomes for left main-PCI with the currently used newer DES, even if this does not affect comparative results between the two groups.

Most emergent/urgent and unstable cases have been included in G2 for ethical and clinical reasons, thus creating a potential bias on early outcomes, which did not affect results. As we do not have complete data regarding the reasons for repeat revascularization (clinical versus angiographic driven), we cannot exclude an excessive unnecessary prudential repeat revascularization rate in case of initial restenosis. Longer follow-up would help allow a better understanding of the relative benefits of HCR, especially in regard to multiarterial surgical revascularization.

Conclusion

In this large series of HCR and multivessel PCI for patients with left main stenosis, we demonstrated favourable outcomes. For patients with a medium–high EuroSCORE and SYNTAX score less than 32, HCR may provide a promising alternative to conventional CABG and multiple PCI with similar postoperative results. Risk-adjusted MACCEs rates at 18 months' follow-up were significantly increased in the PCI group mostly because of the higher freedom from TVR and the proven long-term duration of left internal mammary artery (LIMA-LAD) graft in the HCR group. This favourable observational study, all limitations considered, provides evidence to support further investigation in HCR and the need for future comparative trials with PCI, not only in multivessel, but even in left main stenosis disease.

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Conflicts of interest

There are no conflicts of interest.

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