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Coronary artery bypass grafting versus percutaneous coronary intervention in heart failure with reduced left ventricular ejection fraction

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ABSTRACT

Background: The present study aims to compare the 10-year outcomes of patients with heart failure and left ventricular systolic dysfunction undergoing myocardial revascularization through coronary artery bypass grafting (CABG) or percutaneous coronary intervention (PCI).

Methods: This retrospective, single-center study enrolled 707 patients (pts) treated with CABG (429 pts) or PCI (278 pts) for multivessel coronary artery disease and left ventricular systolic dysfunction (LVEF <50 %). Data were collected between January 2002 and December 2023. Preoperative covariates were adjusted using 1:1 propensity-score matching. The primary endpoints were 30-day and long-term all-cause mortality. Secondary endpoints included the incidence of stroke and repeat target revascularization.

Results: After propensity-score matching, 196 comparable pairs were identified. The 30-day mortality rates were similar between the groups (CABG: 6 pts., 3.1 % vs. PCI: 5 pts., 2.6 %; $p = 0.99$). At the 10-year follow-up, CABG group showed higher overall survival (CABG: 55 % vs. PCI: 37 %, $p < 0.001$), a lower incidence of cardiac death (CABG: 12.3 % vs. PCI: 23.4 %, $p = 0.049$) and repeat target revascularization (CABG: 7.4 % vs. PCI: 23.4 %, $p = 0.003$). The incidence of stroke was comparable between the two groups (CABG: 5.3 % vs. PCI: 10.2 %, $p = 0.440$).

Conclusions: Early outcomes were comparable between PCI and CABG. However, at 10 years, CABG was associated with superior overall survival, lower cardiac death and reduced repeat revascularization rates. Therefore, surgical revascularization should be strongly considered in patients with multivessel coronary artery disease and heart failure with left ventricular systolic dysfunction to achieve long-term survival benefits.

1. Introduction

Ischemic cardiomyopathy and heart failure (HF) remain major global health concerns, with a prevalence of 2.7 per 100,000 in males and 1.9 per 100,000 in females [1]. Management of stable coronary disease in HF patients has advanced, with improved medical therapies and revascularization techniques enhancing symptoms, quality of life, and survival while reducing re-hospitalization.

Although no clear evidence favors interventional strategies over medical therapy [2], population heterogeneity may mask benefits in sicker patients, such as those with reduced ejection fraction (EF) [2–4]. New drug classes like Angiotensin Receptor-Neprilysin Inhibitors (ARNIs) and Sodium-Glucose Co-Transporter 2 (SGLT2) inhibitors improve functional capacity in HF with reduced ejection fraction (HFrEF), though medical therapy alone is less effective in ischemic HFrEF.

Recent data support coronary artery bypass grafting (CABG) as the preferred treatment for ischemic HFrEF, offering better survival, fewer adverse events, and reduced revascularization needs. Some studies suggest similar survival between CABG and percutaneous coronary intervention (PCI) in low EF patients, though PCI has higher rates of postoperative MI and repeat revascularization [5]. The choice between CABG and PCI remains patient-specific, guided by multidisciplinary heart teams and evolving evidence [6,7]. European Society of Cardiology (ESC) guidelines favor CABG for ischemic HFrEF and diabetic patients, with PCI reserved for those at higher surgical risk [8,9]. However, data remain limited and outdated, leaving the optimal strategy uncertain. This study aims to compare short- and

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long-term mortality outcomes between CABG and PCI in reduced EF patients using propensity-matched analysis.

2. Patients and methods

2.1. Ethical statement

The study adhered to the ethical principles outlined in the Declaration of Helsinki. Informed consent to use personal data for scientific research purposes was signed by all patients within the surgical informed consent. Institutional Review Board approval (ID 1812) was granted by the University of Brescia on 15/10/2022.

Between January 2002 and December 2023, consecutive patients from the cardiac surgery department at ASST Spedali Civili Hospital, Brescia, Italy, were enrolled. Inclusion criteria required stable angina and isolated CABG or PCI. Patients had either 3-vessel disease (≥70 % stenosis in all major vessels), 2-vessel disease (≥70 % stenosis, including the proximal left anterior descending artery), or left main stenosis (≥50 %). Exclusion criteria included prior CABG, severe valvular disease, emergent cases (ST-elevated MI), or non-ischemic cardiomyopathy. Revascularization choice was determined by heart-team discussions. This study focused on patients with heart failure and reduced EF (<50 %).

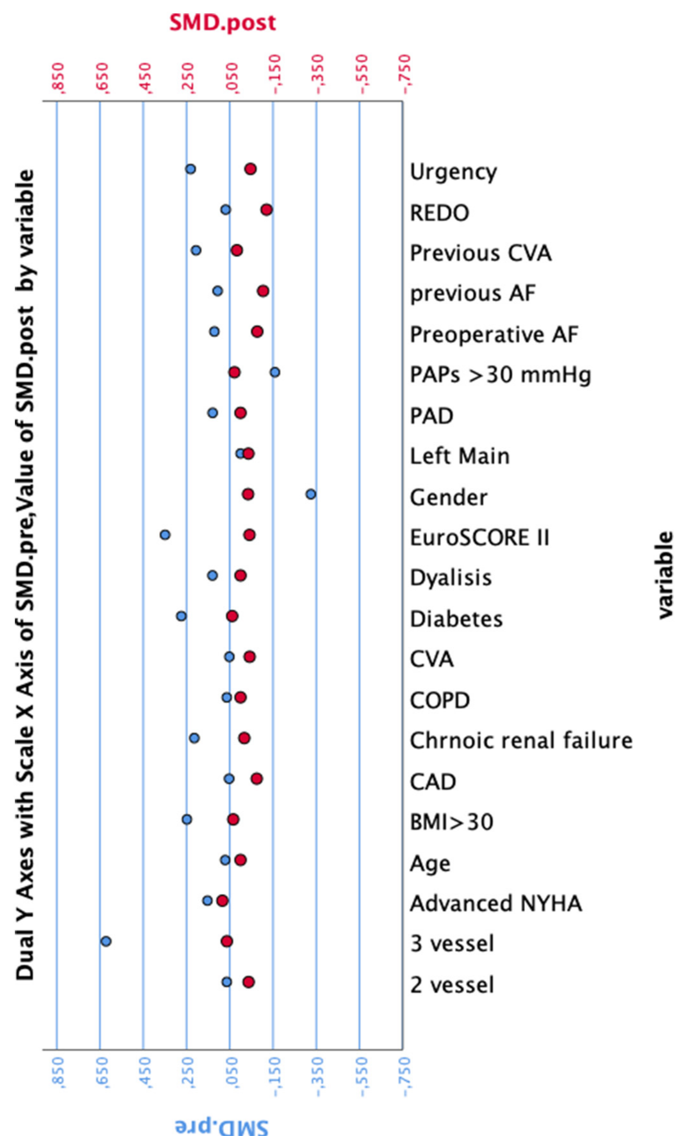

Fig. 1. Love plot of the propensity matched analysis.

Clinical practice for patients undergoing PCI in our center evolved from the use of bare-metal stents and first-generation drug eluting stents (DES; Cypher, Taxus) to second- and third-generation DES (Xience, Resolute Onyx, Orsiro), with thinner struts, more biocompatible polymers, and improved safety. Radial access progressively replaced femoral access, reducing bleeding complications, while physiological assessment and intracoronary imaging (fractional flow reserve, intravascular ultrasound, optical coherence tomography) became integral parts of the procedure. Antiplatelet therapy management also shifted toward shorter and more individualized regimens. In patients with reduced ejection fraction, we pursued complete revascularization whenever feasible. In these higher-risk cases, mechanical circulatory support, most commonly intra-aortic balloon pump (IABP), was adopted to improve procedural safety.

The median number of treated vessels in our study reflected all coronary vessels considered suitable for PCI. Residual untreated vessels were confined to territories without residual viability, characterized by reduced wall thickness and >50 % akinetic segments, or to lesions deemed technically unsuitable for PCI. Thus, the untreated burden did not represent viable myocardium likely to benefit from revascularization.

2.2. Study endpoints

Primary endpoints were 30-day and long-term all-cause mortality. Secondary endpoints included stroke, repeat target revascularization, and MI. Adverse events were analyzed individually to avoid confounding and defined per ARC-2 consensus [10].

2.3. Statistical analysis

Continuous variables were compared using the independent Student's *t*-test if normally distributed or the Mann–Whitney *U* test otherwise.

Table 1
Preoperative characteristics of the matched cohort.

Characteristic	Matched				
	CABG		PCI		*p*-Value
	N = 196	%-IQR	N = 196	%-IQR	
Age	71	63–78	73	61–79	0.26
Female sex	48	24.5	48	24.5	>0.99
BMI	26	23–29	26	21–29	0.32
BMI > 30	38	19.4	45	23	0.46
Preoperative EF	37	30–43	37	30–42	0.70
EuroSCORE II	3	1.2–6			
Dyslipidemia	111	56.6	114	58.2	0.53
COPD (FEV1 > 60)	30	15.3	34	17.3	0.68
Diabetes	87	44.4	95	48.5	0.47
IDDM	26	13.3	30	15.3	0.67
Hypertension	144	73.5	148	75.5	0.73
Previous CVA	17	8.7	18	9.2	>0.99
Previous endocarditis	0	0			
Peripheral artery disease	33	16.8	33	16.8	>0.99
Extracardiac arteriopathy	26	13.3	41	20.9	0.06
Previous PCI	43	21.9	45	23	0.90
Previous AMI	88	44.9	83	42.3	0.65
Previous cardiac surgery	9	4.9	11	5.6	0.82
Previous AF	26	13.3	30	15.3	0.67
NYHA III-IV	59	30.1	55	28.1	0.74
sPAP >30	42	21.4	41	20.9	>0.99
Chronic renal failure	40	20.4	48	24.5	0.40
Dialysis	11	5.6	13	6.6	0.83
Left main	30	15.3	30	15.3	>0.99
Two vessel	128	63.5	135	68.9	0.52
Three vessel	68	34.7	61	31.1	0.52

AF = atrial fibrillation; AMI = acute myocardial infarction; BMI = body mass index; CABG = coronary artery bypass grafting; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; EF = ejection fraction; IDDM = insulin dependent diabetes mellitus; IQR = interquartile range; NYHA = New York Heart Association; sPAP = systolic pulmonary artery pressure; PCI = percutaneous coronary intervention.

Table 2
Perioperative outcomes in the matched population.

Outcome	Matched				
	PCI		CABG		*p*-Value
	N = 196	%-IQR-SD	N = 196	%-IQR-SD	
Cross-clamp	52	20			
CPB	70	26			
Number of grafts/stents	2.3	0.5	2.2	0.6	0.48
Postoperative IABP	13	6.6	11	5.6	0.83
ECMO	2	1.0	0	0.0	0.50
ICU stay (hours)	24	19–48			
Transfusion	51	26.0	20	10.2	<0.001
Procedural bleeding	5	2.6	2	1.0	0.53
Postoperative AF	21	10.7	7	3.6	0.01
CABG/PCI failure	0	0.0	2	1.0	0.50
AMI	2	1.0	3	1.5	>0.99
Sternal complication	3	1.5			
Stroke	2	1.0	2	1.0	>0.99
TIA	1	0.5	1	0.5	>0.99
MAV > 48 h	13	6.6			
AKI with CVVH	11	5.6	7	3.6	0.47
MOF	2	1.0	0	0.0	0.05
In-hospital stay	7	5–8	7	3–14	0.28
30 days mortality	6	3.1	5	2.6	>0.99

AF = atrial fibrillation; AKI = acute kidney injury; AMI = acute myocardial infarction; CABG = coronary artery bypass graft; CPB = cardiopulmonary bypass; CVVH = continuous veno-venous hemofiltration; IABP = intra-aortic balloon pump; ICU = intensive care unit; ECMO = extra corporeal membrane oxygenation; MAV = mechanical assisted ventilation; MOF = multiorgan failure; PCI = percutaneous coronary intervention; TIA = transient ischemic attack.

Categorical variables were analyzed with the chi-squared or Fisher's exact test. To ensure comparability, 1:1 propensity-score matching (PSM) was performed using nearest-neighbor matching without replacement. Balance was assessed by standardized mean difference, with ≤ 0.1 indicating good balance. Matching accounted for key pre- and intraoperative characteristics (Fig. 1).

In matched data, continuous variables were compared using the paired Student's *t*-test if normally distributed or the Wilcoxon signed-rank test otherwise. Survival differences were assessed using Kaplan–Meier curves with log-rank tests. No missing values were present, as all preoperative data were required for matching, and postoperative outcomes were available from patient charts. Cox regression identified independent mortality predictors. A *p*-value ≤ 0.05 was considered significant. Data were extracted using Microsoft Excel, and all analyses were conducted in R (version 4.3.1).

3. Results

3.1. Preoperative characteristics

At baseline patients' population were significantly different for several characteristics, Supplementary Table 1. These differences were balanced after PSM, Table 1, Fig. 1.

3.2. Operative results

In the CABG group after PSM cross-clamp time was 52 min (standard deviation, SD: 20 min) with mean cardiopulmonary bypass time of 70 min (SD: 26 min). No differences were reported in terms of median diseased vessel both in matched and non-matched populations (non-matched: CABG 2.4 SD 0.6 vs PCI 2.2 SD 0.6; $p = 0.827$; matched: CABG 2.3 SD 0.5 vs PCI 2.2 SD 0.6; $p = 0.482$). Thirty-days mortality was similar between group both in matched and non-matched populations (non-matched: CABG 3.3 % vs 1.8 %; $p = 0.341$) (matched: CABG 3.1 % vs PCI 2.6 %; $p = 1.000$). No differences were reported in terms of postprocedural mechanical support with IABP (matched: CABG 6.6 % vs PCI 5.6 %, $p = 0.834$) and ECMO (matched: CABG 1.0 % vs PCI 0.0 %; $p = 0.499$).

In the matched population incidence of postoperative acute myocardial infarction (AMI) and stroke was similar (AMI: CABG 1.0 % vs PCI 1.5 %; $p = 1.000$; Stroke: CABG 1.0 % vs PCI 1.0 %; p = 1.000). In matched population a significantly higher incidence of postoperative atrial fibrillation (AF) and red blood transfusion (RBT) was reported in CABG group (postoperative AF: CABG 10.7 % vs PCI 3.6 %; $p = 0.010$; RBT: CABG 26.0 % vs. PCI 10.2 %; $p < 0.001$). Operative results are listed in Table 2 and Supplementary Table 2.

3.3. Follow-up results

The median follow-up was 60 months (IQR: 23.3–120). At 10 years, overall survival was significantly higher in the matched CABG group than PCI (CABG: 62.5 %, 95%CI: 53.6–71.3 vs PCI: 42.5 %, 95%CI: 33.1–51.9, $p < 0.001$), Fig. 2A. Landmark analysis at 38 months showed similar outcomes ($p = 0.052$), and CABG had a significant survival advantage beyond this point ($p = 0.007$), Fig. 2B.

At 10 years, cardiac death was more frequent in the PCI group (CABG: 14.0 %, 95%CI: 7.4–20.6 vs PCI: 23.0 %, 95%CI: 13.8–32.2, $p = 0.049$), Supplementary Fig. 1. Repeat target revascularization (all with PCI) was also higher in PCI (CABG: 8.2 %, 95%CI: 5.7–10.7 vs PCI: 26.7 %, 95%CI: 22.6–31.8, $p = 0.003$), Fig. 3A. Similarly, cardiac readmissions were

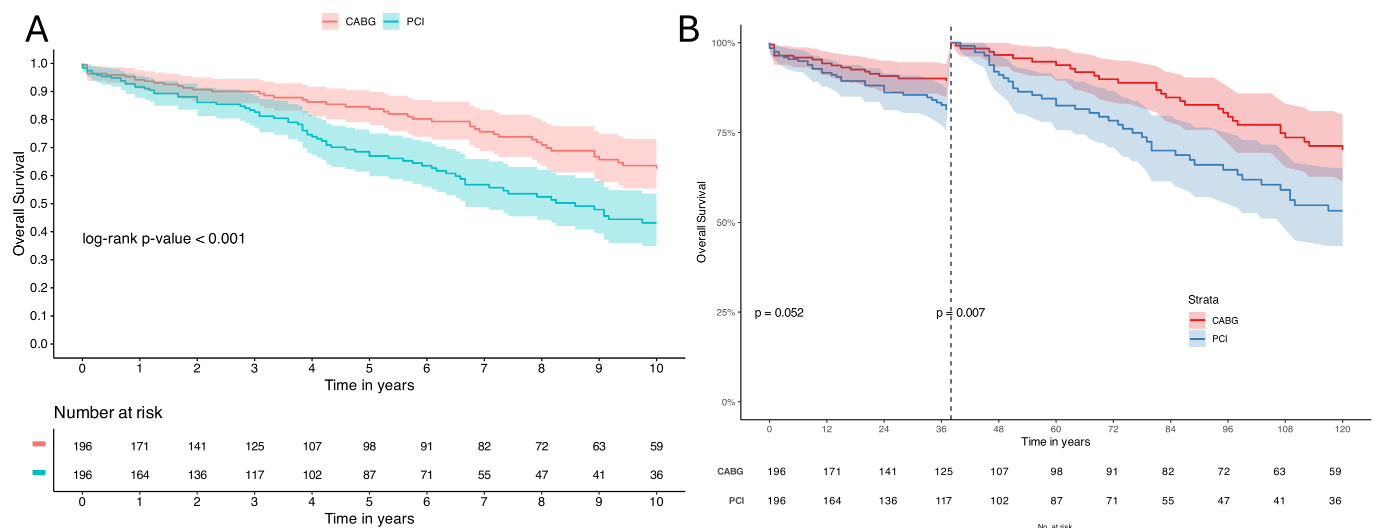

Fig. 2. A. Overall survival in propensity match groups at ten years follow-up CABG versus PCI. B. Overall Survival with landmark analysis at 38 months ($p = 0.052$); Beyond 38 months the difference between CABG and PCI became statistically significant ($p = 0.007$).

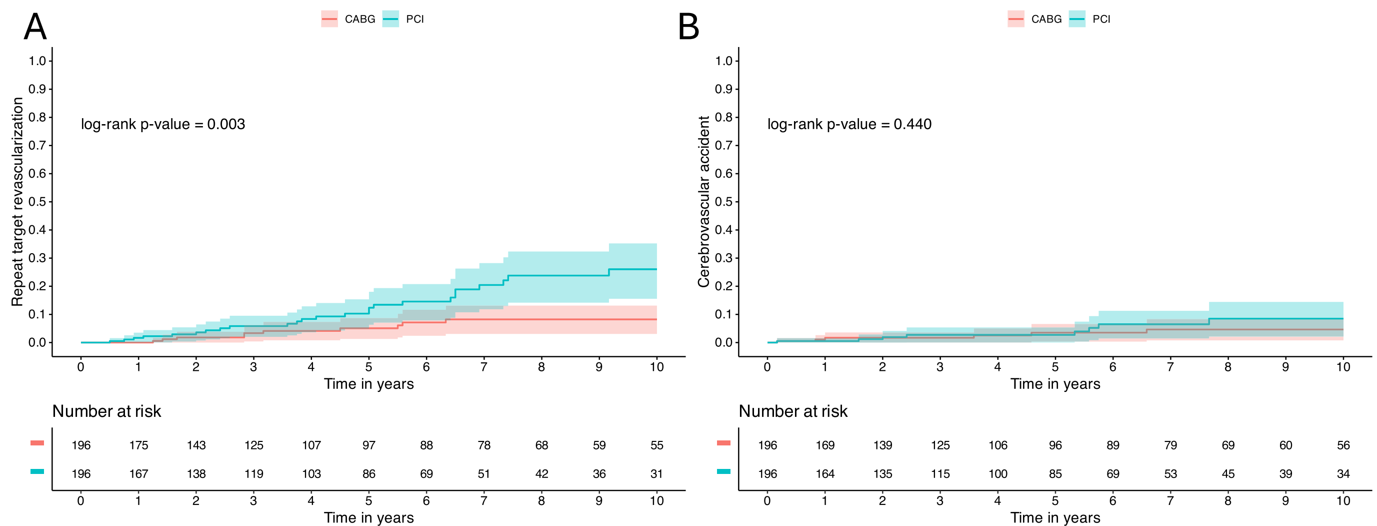

Fig. 3. A. Repeated Target Vessel revascularization at ten years follow-up in propensity match groups; CABG versus PCI ($p = 0.003$). B. Stroke rate at ten years follow-up in propensity match groups, CABG vs PCI ($p = 0.440$).

more frequent in PCI (CABG: 22.7 %, 95%CI: 14.5–30.9 vs PCI: 42.9 %, 95%CI: 33.4–54.3, $p < 0.001$), Supplementary Fig. 2. Stroke and heart failure rates were comparable, Fig. 3B, Supplementary Fig. 3.

Kaplan-Meier curves for myocardial infarction, pacemaker implantation, and hospital readmission are in Supplementary Figs. 4–6, respectively, while unmatched group data are in Supplementary Figs. 7–15. Cox regression identified PCI as an independent mortality predictor (HR 1.974, 95%CI: 1.364–2.856, $p < 0.001$), along with left main disease (HR 1.781, 95%CI: 1.117–2.839, $p = 0.015$) and diabetes (HR 1.913, 95%CI: 1.323–2.765, $p < 0.001$). Follow-up outcomes are summarized in Supplementary Table 3.

4. Discussion

This retrospective propensity-matched study analyzed the outcomes of patients with multivessel coronary disease and reduced LVEF who underwent isolated CABG or PCI. The main findings of this study can be summarized as follows:

I) thirty-day mortality was comparable between CABG and PCI,
II) at 10 years CABG patients had a significantly higher overall survival compared to PCI patients; moreover, PCI was found as an independent predictor for mortality at long term (HR: 1.9; 95 % CI 1.3–2.8, $p < 0.001$),
III) at 10 years, PCI group presented higher rates of target vessel revascularization and readmission for cardiac causes.

The advantages of surgical myocardial revascularization versus PCI in terms of overall survival and incidence of adverse events in patients with multivessel disease are well established, particularly in patients with complex coronary anatomy and diabetes [11,12]. However, evidence in the literature does not clearly support these findings in patients with ischemic cardiomyopathy (ICM) and reduced ejection fraction. To date most of research comparing PCI and CABG in patients with LV dysfunction are provided from observational studies and sub-analysis of trials [13–15]. In addition, CABG surgery in this specific subset of patients has been associated with higher operative risks, worse outcomes and an increased likelihood of postoperative complications and mortality when compared to patients with normal EF [16]. Thus, the treatment of patients with ischemic cardiomyopathy and reduced EF remains a challenge, regardless of the chosen treatment (medical vs PCI vs surgery).

Despite these controversies, current guidelines recommend CABG as the first-line treatment for stable coronary disease in HFrEF due to its potential long-term survival benefits [8,9]. Nevertheless, identifying patients who are most likely to benefit from CABG or PCI remains crucial and evidences supporting PCI and the identification of patients' subset most suited for this approach remain inconclusive [5,17–19].

The present study aimed to shed new light on this topic by comparing outcomes between CABG and PCI in patients with ICM and reduced LVEF. No significant differences were observed in 30-day mortality between CABG (3.1 %) and PCI (2.6 %). Notably, the surgical mortality rate aligned closely with the expected mortality predicted by EuroSCORE II (matched CABG mortality: 3.1 % vs. expected ES II mortality: 3.0 %). These findings are consistent with other studies reporting similar outcomes in the same population [19–21].

Although in the present study early and short-term outcomes (30 days up to 36-months) between CABG and PCI were comparable, the survival advantage for CABG patients was significant after three years (see landmark analysis). These findings are consistent with those of a recent study [20] and metanalyses [21,22] reporting significantly higher overall survival rates in CABG patients compared to PCI.

The observed outcomes may be explained by the underlying mechanism of ischemic myocardial dysfunction, which is characterized by a combination of either fibrotic (irreversible) and hibernating (reversible) myocardium. Revascularization aims to restore hibernating regions' function, enhancing myocardial performance, but its long-term benefits often take months to fully manifest [23,24]. A sub-analysis of patients with heart failure and moderate LV dysfunction from the ISCHEMIA trial demonstrated a survival benefit associated with invasive revascularization strategies [25]. Notably, the degree of functional recovery appears to be more pronounced after CABG, while in the REVIVED-BCIS 2 trial PCI in low EF patients demonstrated a non-significant increase of LVEF, survival, readmission and HF [26].

The improvement in adverse event incidence might not be solely attributable to revascularization itself. Evidence suggests that in patients with low ejection fraction (LVEF <40 %), the burden of ischemia has a direct impact on outcomes. Revascularization yields the greatest benefit in patients with larger ischemic areas (>10 %), as they are more likely to recover significant portions of viable myocardium [27,28]. As a result, CABG might improve outcomes over PCI by revascularizing a larger extent of myocardium, reducing the impact of progressive disease in proximal vessels (surgical collateralization) [29], and utilizing arterial grafts (e.g., internal thoracic arteries), which provide long-term patency via the release of nitric oxide [30,31]. Indeed, is well established that PCI entails higher rate of repeated revascularization associated to multiple ischemic acute/chronic adverse events, which are less well-tolerated in patients with low cardiac reserve. In addition, patients undergoing CABG are more likely to

have a complete revascularization compared to PCI [32,33]. More complete revascularization strategies were associated to reduced rate of repeated revascularization and major cardiac and cerebrovascular events at follow-up [34], while incomplete revascularization was associated to higher rate of morbidity and mortality [13,17,32]. Of note, in the present study we reported a lower rate of repeated revascularization and AMI at follow-up in CABG patients. These findings are confirmed from the results of previous meta-analyses [21,22] and a recent study by Bianco and colleagues [19].

Another key factor in achieving optimal outcomes from revascularization is the left ventricular (LV) capacity to recover its function after treatment. However, even when severe stenoses are successfully treated, patients with larger extent of fibrotic tissue (>10 %) may not respond to revascularization regardless ischemic burden [35]. For this reason, preoperative myocardial viability testing has been proposed as a critical determinant deciding whether to pursue revascularization. This approach aims to assess the LV's potential for functional recovery. However, the evidence supporting the routine use of viability testing in guiding revascularization decisions remains controversial. For instance, a sub-study of the PARR-2 trial suggested that patients with a higher degree of hibernating myocardium experience better outcomes following revascularization [36]. Conversely, other studies [3,4,37,38], found that viability testing does not significantly influence revascularization outcomes.

We believe that an integrated Heart-Team approach is crucial to tailor treatment decisions especially in patients with reduced ejection fraction. The weighing of multiple factors including patient risk profile, LV function, myocardial viability as well as the extension of LV ischemic area, and complexity coronary anatomy is crucial to determine the treatment strategy.

4.1. Limitations

This study has several limitations, mainly due to its retrospective design, which is prone to confounding and selection bias. Data from a single center over a long period may introduce variability in treatment, PCI technology, and pharmacological protocols. Despite propensity matching, baseline differences between the CABG and PCI groups may persist, with the PCI group likely having higher baseline risk. Residual selection bias remains possible. Additionally, the lack of EuroSCORE II mortality risk for the PCI cohort limits comparative risk assessment. EuroSCORE II is not routinely calculated for patients undergoing PCI, as it was specifically developed for surgical risk assessment. Moreover, retrospective calculation of EuroSCORE II in PCI patients is not feasible or reliable. However, the propensity matching already incorporated key clinical and anatomical variables that overlap with EuroSCORE II domains, thus reducing the potential bias associated with this limitation.

5. Conclusion

The findings of this study suggest that in patients with coronary artery disease and reduced EF, CABG offers superior long-term outcomes in terms of overall survival and fewer repeat revascularizations compared to PCI. CABG demonstrates a comparable early and late risk of stroke compared to PCI. However, further RCT are warranted to confirm these results.

CRediT authorship contribution statement

Lorenzo Di Bacco: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Investigation, Conceptualization. **Michele D'Alonzo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Fabrizio Rosati:** Writing – review & editing, Validation, Investigation. **Salvatore Curello:** Writing – review & editing, Validation, Investigation. **Alice Festa:** Writing – review & editing, Visualization, Data curation. **Massimo Baudo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis. **Stefano Benussi:** Writing – review & editing, Resources, Investigation. **Claudio Muneretto:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Investigation, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Claudio Muneretto reports a relationship with Corcym SRL that includes: consulting or advisory. Stefano Benussi reports a relationship with AtriCure Inc. that includes: consulting or advisory. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.carrev.2025.10.002.

Data availability

The data supporting this study's findings are available upon reasonable request from the corresponding author, subject to institutional approval.

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