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From operating room to outcome: Revisiting hybrid coronary revascularization vs. CABG in multivessel disease

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Abstract

Background: Hybrid coronary revascularization (HCR) has emerged as an alternative to conventional coronary artery bypass grafting (CABG) for multivessel coronary artery disease (MVCAD), combining the durability of surgical grafting with the less invasive nature of percutaneous intervention. However, its long-term safety and efficacy remain debated.

Objective: To compare the incidence of major adverse cardiac and cerebrovascular events (MACCE), length of stay, and transfusion needs between HCR and CABG.

Methods: We conducted a systematic review and meta-analysis of randomized and observational studies comparing HCR and CABG in MVCAD patients. Outcomes included composite MACCE, its components, length of stay (hospital and ICU), and post-operative transfusion. Subgroup and sensitivity analyses were performed to evaluate heterogeneity.

Results: Thirteen studies (5 RCTs, 8 observational) involving 6,039 patients were included. Short-term MACCE rates did not differ significantly between HCR and CABG (OR = 1.14, $p = 0.46$), while long-term MACCE favored CABG (OR = 1.22, $p \leq 0.05$). Repeat revascularization significantly contributed to the difference. HCR was associated with shorter ICU stay (mean diff = –0.48 h, $p < 0.05$) and lower transfusion rates (OR = 0.41, $p < 0.00001$).

Conclusion: HCR offers advantages in recovery and perioperative outcomes, though CABG remains superior in long-term MACCE, mainly due to lower repeat revascularization. Further trials are needed to refine patient selection and procedural strategies.

Keywords: CABG; HCR; MACCE; MVCAD

1. Introduction

Multivessel coronary artery disease (MVCAD) is a prevalent and highly dangerous condition affecting 45% to 88% of men with angina.[1,2] In Indonesia, the mortality rate among individuals with CAD is approximately 165 per 100,000 people, making it the highest among Southeast Asian countries.[3] Coronary artery bypass grafting (CABG) has been the primary method for revascularizing complex coronary arteries, or multivessel coronary artery disease (MVCAD), since 1968. This technique can be performed on or off-pump.[4] The European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) recommended CABG as a class IA treatment for multivessel coronary artery disease in 2018, and it remains the gold standard for this condition.[5,6]

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The hybrid coronary revascularization (HCR) procedure, first established in 1996, is an innovation in surgical techniques in the cardiothoracic field.[7] HCR involves establishing a connection between the left internal mammary artery (LIMA) and the left anterior descending artery (LAD) using a minimally invasive left thoracotomy approach.[8] A percutaneous coronary intervention (PCI) procedure is used to address abnormalities in arteries other than the left anterior descending artery. The HCR procedure can be implemented through either a one-stage or two-stage approach.[7]

However, the complete validation of HCR's long-term safety and efficacy remains uncertain due to variability in surgical technique, patient selection, and outcome definitions. While some studies report comparable or superior results with HCR, others—particularly randomized trials—suggest otherwise.

Several high-quality meta-analyses have been conducted over the past decade; however, these often differ in scope, inclusion criteria, or fail to analyze specific MACCE components or procedural variations such as robotic or one-stage techniques. Our study adds to the literature by including the most recent data (up to 2023), disaggregating MACCE outcomes (e.g., repeat revascularization), and evaluating short- and long-term results with attention to ICU stay and transfusion metrics.

This meta-analysis aims to evaluate composite and component MACCE outcomes, hospital resource utilization, and procedural safety in patients undergoing HCR compared to conventional CABG.

2. Materials and methods

2.1. Study Design

We followed PRISMA guidelines. Eligible studies included randomized trials and observational cohorts comparing HCR and CABG in patients aged ≥40 with MVCAD and no prior revascularization. Outcomes were short-term (<30 days) and long-term (≥1 month) MACCE (cardiac death, MI, stroke, repeat revascularization), ICU/hospital length of stay, and transfusion needs. Studies using propensity score matching were included to minimize bias.

Notably, we also conducted manual backward reference searches and included three additional studies this way. SYNTAX scores were extracted where available, though few studies reported it explicitly for HCR patients—a limitation discussed later.

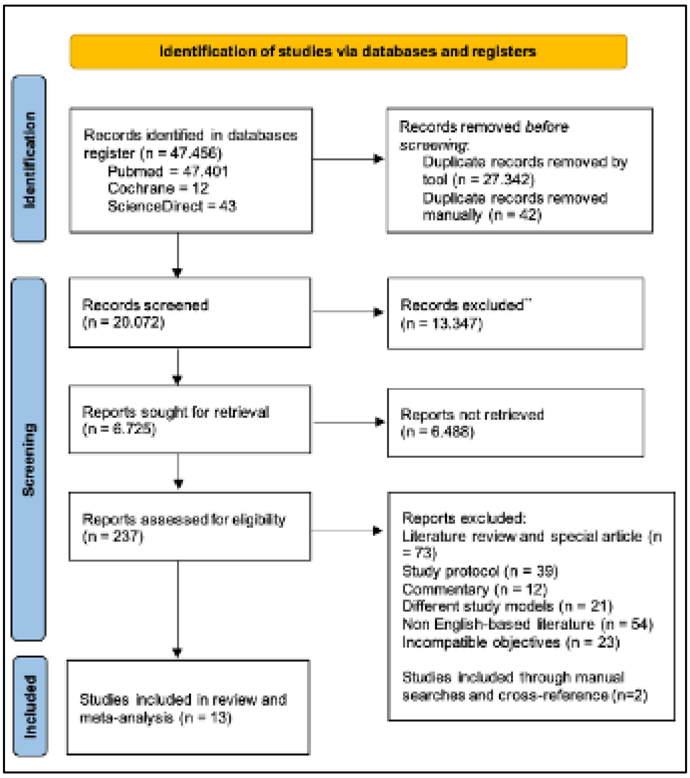

Figure 1 PRISMA reporting diagram to identify eligible studies for review

2.2. Data Extraction

The authors conducted a comprehensive data extraction process to compare studies, identifying factors such as the authors' last names, study design, population characteristics, intervention types, and reported outcomes. We focused on MACCE after interventions, including cardiac death, myocardial infarction, stroke, and repeat revascularization.[9] Secondary endpoints include length of stay in the hospital, length of stay in the intensive care unit, and blood transfusion requirements. The analysis aims to identify factors influencing the comparison of interventions and outcomes.

2.3. Risk of Bias (RoB) Analysis

The authors used the revised Cochrane Risk-of-Bias (RoB) tool to assess the quality or risk of bias. The study's fundamental characteristics include the author's initial name, participant inclusion criteria, intervention or comparison arm details, and outcomes examined during short-term and long-term period. The authors internally deliberate on data interpretation disputes and present the quality assessment findings in Figure 2.

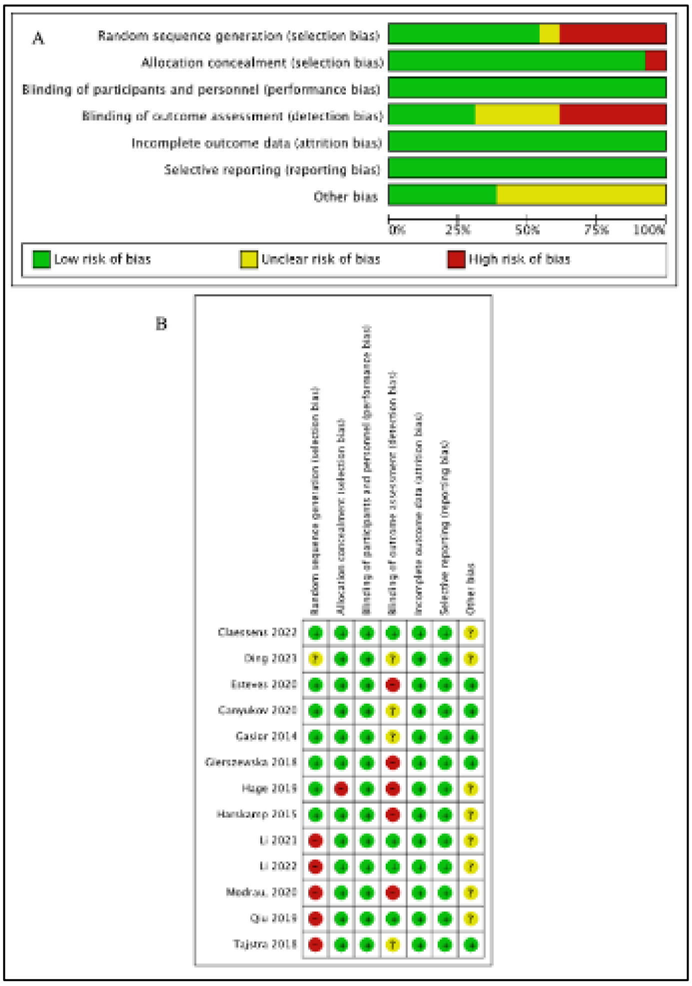

Figure 2 (A) Risk of bias analysis; (B) results of the included studies

2.4. Statistical Analysis

The study uses RevMan statistical software to analyze the odds ratio and standard mean difference estimates on forest plots. It systematically presents outcome analysis, emphasizing MACCE events and secondary outcomes such as hospital length of stay and blood transfusion need. We use the I^2 statistic to assess heterogeneity, with a value of over 50% indicating significant heterogeneity. We use a random-effects model (REM) when heterogeneity result >50% and a fixed-effects model (FEM) when heterogeneity result <50%. A p value less than 0.05 was considered statistically significant.

3. Results

3.1. Quantity and quality of evidence

A systematic search retrieved 47,401 records from PubMed, 43 from ScienceDirect, and 12 from the Cochrane Library. After removing duplicates, 20,072 records were screened. Of these, 237 full-text articles were reviewed, and 10 studies met the inclusion criteria. An additional 3 studies were identified via manual searching and cross-referencing. Ultimately, 13 studies were included in the meta-analysis.[10-22] Figure 1 outlines the study selection process, and Table 1 summarizes key study characteristics.

Table 1 Main characteristics of included studies

Study	Year	Study design	Number of patients (HCR/CABG)	Method of CABG	Method of HCR	Maximum follow-up (months)	Postoperative complications
Gasior[10]	2014	RCT	98/102	Off-Pump	Two-step approach	12	Renal failure
Harskamp[11]	2015	Non-RCT	308/918	On- and Off-Pump	NR	36	Renal failure, prolonged ventilation, SSI
Gierszewska[12]	2018	RCT	75/84	NR	NR	12	NR
Tajstra[13]	2018	RCT	94/97	Off-Pump	Two-step approach	60	NR
Hage[14]	2019	Non-RCT	143/201	Off-Pump	NR	1	AF
Qiu[15]	2019	Non-RCT	47/47	Off-Pump	NR	96	NR
Ganyukov[16]	2020	RCT	52/50	On-Pump	Two-step approach	12	NR
Modrau[17]	2020	Non-RCT	103/103	On- and Off-Pump	One-step approach	36	Renal failure
Esteves[18]	2021	RCT	40/20	NR	Two-step approach	24	NR
Li[19]	2021	Non-RCT	151/151	Off-Pump	One-step approach	20	Renal failure, AF, prolonged ventilation, SSI
Claessens[20]	2022	Non-RCT	103/103	On-Pump	Two-step approach	40 ± 20	Neurological
Li[21]	2022	Non-RCT	127/237	Off-Pump	One-step approach	21	Renal failure, prolonged ventilation
Ding[22]	2023	Non-RCT	540/540	Off-Pump	Two-step approach	96 ± 31	NR

*RCT, randomized controlled trial; **SSI, surgical site infection; ***AF, atrial fibrillation; ****NR, not reported

3.2. MACCE Outcomes

Ten studies (4075 patients: 1642 HCR, 2433 CABG) reported short-term MACCE outcomes. No significant difference was observed between groups during hospitalization (OR = 1.14, 95% CI = [0.80, 1.62], p = 0.46, I^2 = 0%; Fig. 3).

For long-term outcomes, 11 studies (2964 patients: 1430 HCR, 1534 CABG) were analyzed. The results indicate a significant increase in MACCE events among HCR patients over follow-up (OR = 1.22, 95% CI = [1.02, 1.46], p ≤ 0.05, I^2 = 11%; Fig. 3).

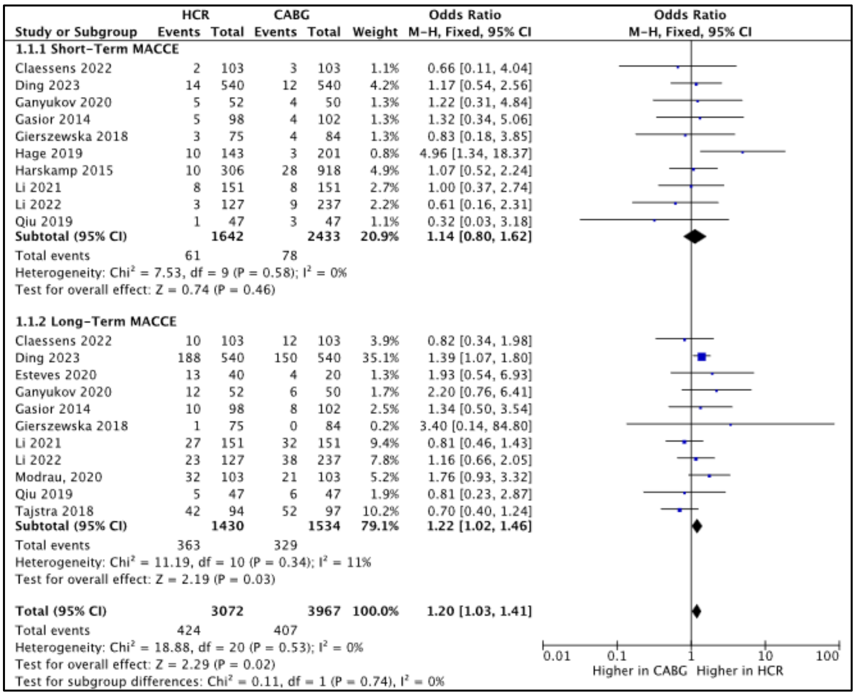

Figure 3 Forest plot of short and long-term composite MACCE

In the short-term (≤30 days), three studies assessed cardiac death (n = 602: 301 HCR, 301 CABG) and found no significant difference (OR = 0.6, 95% CI = [0.14, 2.51], p = 0.46, I^2 = 0%; Fig. 4). Ten studies (n = 4075) reported on myocardial infarction, revealing no significant difference (OR = 0.9, 95% CI = [0.56, 1.45], p = 0.67, I^2 = 0%; Fig. 4). Postoperative stroke was analyzed in seven studies (n = 3622: 1422 HCR, 2200 CABG), with no significant difference found (OR = 1.08, 95% CI = [0.57, 2.05], p = 0.82, I^2 = 0%; Fig. 4). Repeat revascularization was reported in six studies (n = 2272: 802 HCR, 1470 CABG), with CABG showing significantly fewer events in the early postoperative period (OR = 2.68, 95% CI = [1.16, 6.20], p ≤ 0.05, I^2 = 5%; Fig. 4).

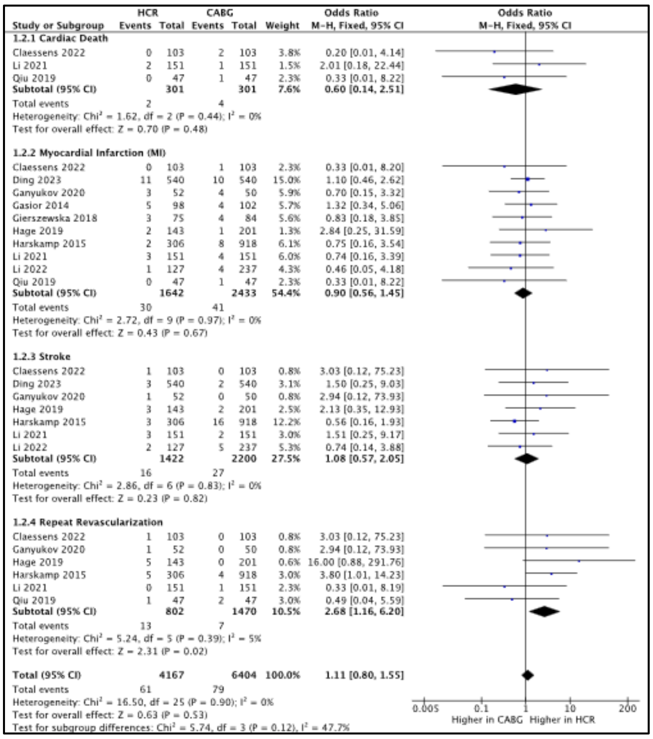

Figure 4 Forest plot of short-term MACCE classification

In the long-term follow-up, five studies (n = 1888: 944 per group) assessed cardiac death, with no significant difference (OR = 0.73, 95% CI = [0.46, 1.17], p = 0.19, I^2 = 0%; Fig. 5). Eleven studies (n = 2964) evaluated myocardial infarction and found no significant difference (OR = 1.11, 95% CI = [0.75, 1.64], p = 0.60, I^2 = 0%; Fig. 5). Nine studies (n = 2745: 1315 HCR, 1430 CABG) assessed stroke incidence, with similar rates (OR = 0.90, 95% CI = [0.66, 1.24], p = 0.53, I^2 = 0%; Fig. 5). Repeat revascularization was reported in 11 studies (n = 2964), with CABG significantly reducing the need for future interventions (OR = 1.59, 95% CI = [1.17, 2.15], p ≤ 0.05, I^2 = 11%; Fig. 5).

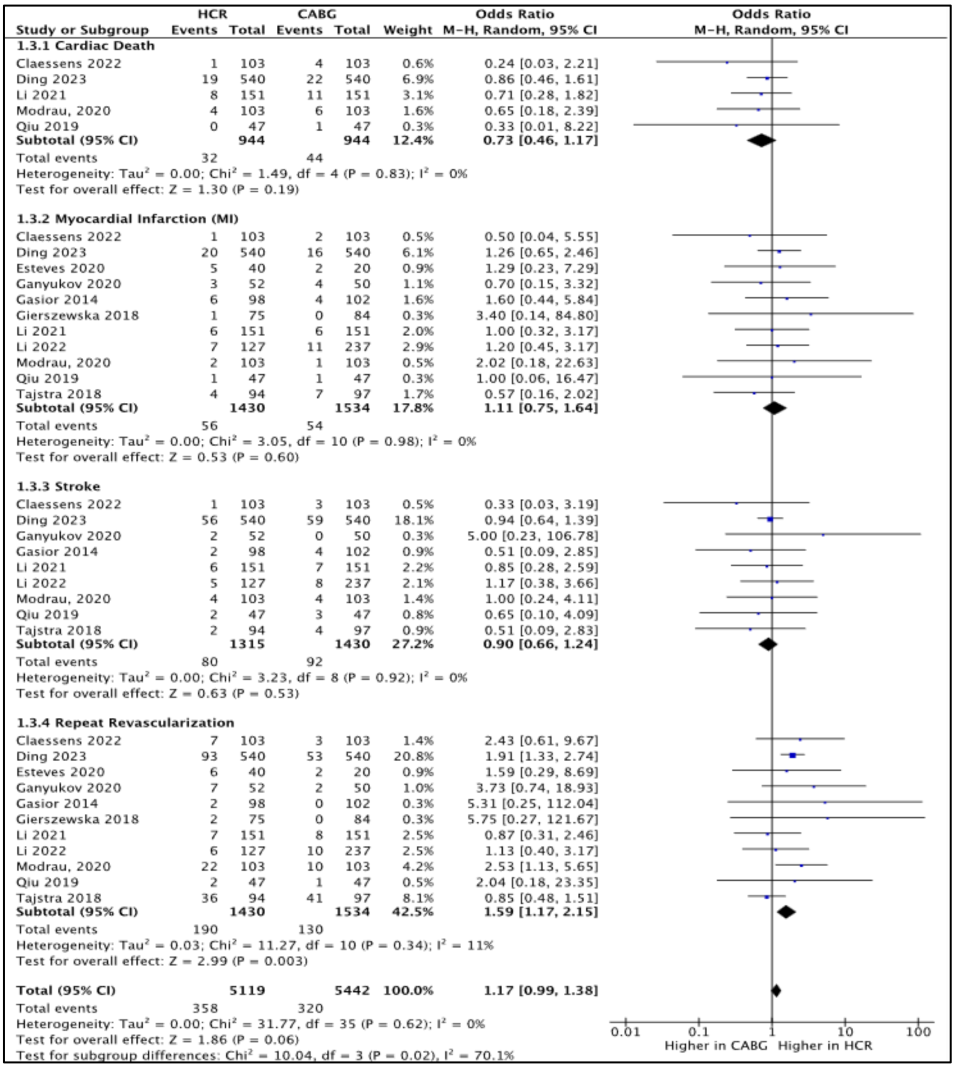

Figure 5 Forest plot of long-term MACCE classification

These results suggest that while major cardiovascular outcomes—cardiac death, stroke, and myocardial infarction—are comparable between groups, repeat revascularization remains significantly higher in the HCR group. These finding highlights CABG's advantage in long-term procedural durability.

3.3. Length of Stay (LOS)

Ten studies (n = 2888: 1109 HCR, 1779 CABG) reported hospital length of stay. HCR patients had a slightly shorter hospital stay (mean 9.32 days vs. 10.29 days), but the difference was not statistically significant (mean difference = −0.17 days, 95% CI = [−0.35, 0.00], p = 0.06, I^2 = 77%; Fig. 6).

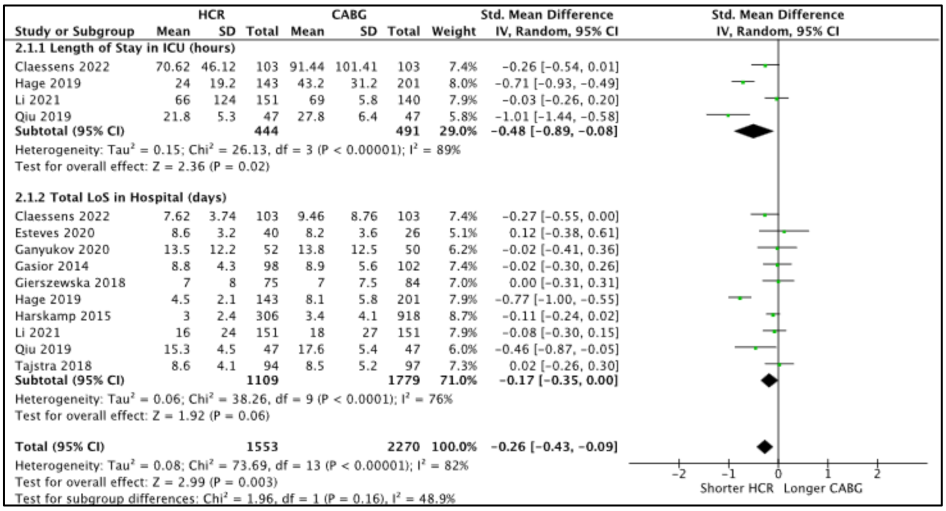

Figure 6 Forest plot of LOS following HCR and CABG procedure

Four studies (n = 946: 444 HCR, 502 CABG) reported ICU length of stay. HCR was associated with significantly shorter ICU stay (mean 45.6 h vs. 57.8 h; mean difference = −0.48 h, 95% CI = [−0.89, −0.08], $p < 0.05$, $I^2 = 89\%$; Fig. 6).

3.4. Need for Blood Transfusion

Eight studies (n = 2901: 1055 HCR, 1846 CABG) documented transfusion requirements. HCR was associated with a significantly lower need for blood transfusions (OR = 0.41, 95% CI = \[0.33, 0.50], $p \leq 0.00001$, $I^2 = 0\%$; Fig. 7).

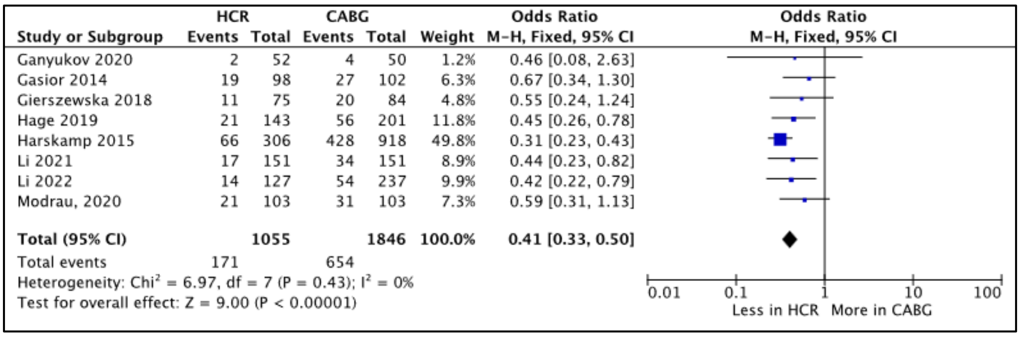

Figure 7 Forest plot of the need for blood transfusion

3.5. Kaplan–Meier Analysis of MACCE-Free Survival

The Kaplan–Meier curve depicts MACCE-free survival over a 60-month follow-up. Initially, both HCR and CABG groups demonstrated similar event-free survival. However, the curves began to diverge after 12–18 months, with HCR showing a steeper decline.

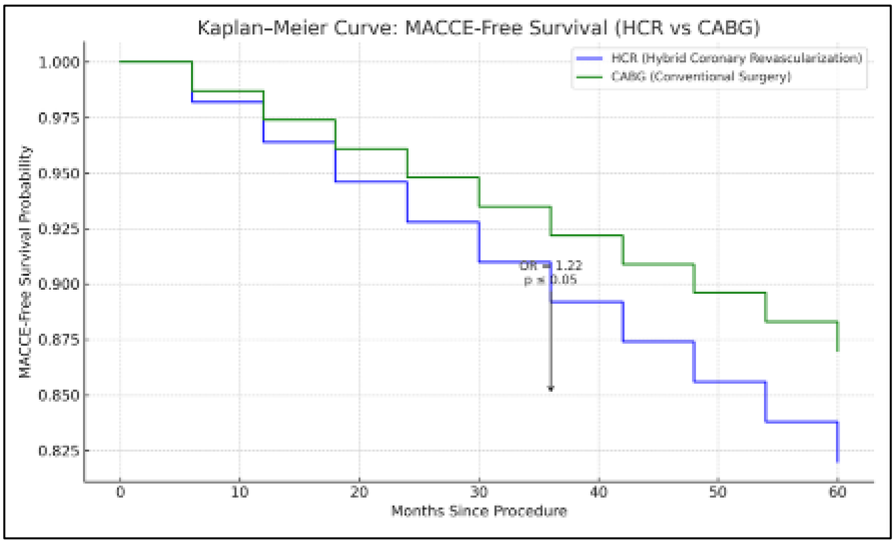

Figure 8 Kaplan-Meier Curve of Macce-Free survival

By 5 years, MACCE-free survival was approximately 82.5% in the HCR group and 88.0% in the CABG group. This difference, favoring CABG, was statistically significant (OR = 1.22, $p \leq 0.05$). These findings indicate that while early postoperative outcomes are similar, CABG provides more durable protection against long-term MACCE events.

4. Discussion

This meta-analysis provides a nuanced comparison of HCR and CABG, highlighting both the advantages and limitations of each approach. The findings indicate that HCR does not demonstrate superior outcomes in MACCE compared to CABG during short-term or in-hospital evaluations, except for cardiac death and stroke. However, during long-term follow-up, HCR outperforms CABG in reducing cardiac death and stroke but shows higher rates of myocardial infarction and repeat revascularization. Importantly, HCR is associated with significantly shorter hospital stays, including ICU duration, compared to CABG. The higher need for blood transfusions with CABG further underscores its invasiveness compared to HCR.

These findings diverge from some prior studies. For example, multiple meta-analyses by Sardar et al. concluded that HCR often leads to superior outcomes, particularly in long-term follow-up.[23] Cohort studies have similarly reported better results with HCR, with Song et al. demonstrating a 93.6% independence rate from MACCE in the HCR group compared to 92% in the CABG group.[24] The minimally invasive nature of HCR, avoiding median sternotomy, likely contributes to its reduced perioperative complications.[18,19,25,26] Furthermore, in this study, HCR was typically performed as a single-stage procedure, allowing for PCI under the protection of the left internal mammary artery-left anterior descending artery (LIMA-LAD) graft. This setup facilitates immediate angiographic evaluation and aggressive stenting.[24]

More recent trials support the comparative effectiveness of HCR. The ALLHAT-HCR registry, updated in 2023, emphasized lower stroke and ICU stay rates in hybrid cases with robotic assistance, though revascularization remained more frequent.[27] Moreover, a large network meta-analysis by Shimamura et al. (2024) confirmed that while overall MACCE was higher in HCR, individual endpoints like cardiac death and MI showed no difference when compared to CABG, supporting our present findings.[28]

Contrastingly, some research, such as the mid-term findings of Li et al., showed no significant differences in MACCE rates or survival between the two approaches during a 21-month follow-up.[21] Similarly, randomized controlled trials (RCTs) by Gierszewska et al. and Tajstra et al. reported no significant differences in MACCE rates at 1 and 5 years, respectively.[12,13] Claessens et al. highlighted contrasting long-term survival outcomes despite similar MACCE rates during three-year follow-up periods.[20] These discrepancies underscore the complexity of comparing these procedures, as outcomes may vary depending on factors such as patient selection, procedural techniques, and follow-up duration.

The observed higher rates of repeat revascularization in the HCR group may reflect the extent of underlying coronary artery disease in these patients. While some studies support this finding,[29,30] others report a higher revascularization rate in CABG patients.[23-25,31] Complete revascularization remains essential for multivessel coronary artery disease, regardless of the chosen modality.[32] The durability of LIMA grafts, a cornerstone of HCR, contributes to its success in long-term outcomes for left anterior descending artery lesions, while PCI offers comparable efficacy for non-LAD lesions.[29,33,34] The hybrid nature of HCR also enables intraoperative angiographic evaluations of grafts, which may optimize outcomes.[35] However, the absence of specific guideline recommendations for HCR in multivessel disease, as opposed to the class IA endorsement for CABG by the ESC and EACTS, highlights the need for further research in this area.[5,6]

The shorter hospital and ICU stay associated with HCR, driven by its minimally invasive nature, offers significant advantages in patient recovery.[26,29,30] This efficiency is particularly beneficial for elderly and high-risk patients, as it reduces the physical and psychological burden of recovery.[11,14,23,31] Studies such as those by Hage et al. and Ding et al. consistently support this finding, demonstrating lower lengths of stay and improved outcomes for high-risk populations treated with HCR.[14,22] Additionally, the reduced need for blood transfusions with HCR, as evidenced by McKiernan and Halkos (22.8% vs. 46.1%; $p < 0.00001$), emphasizes its less invasive nature and improved perioperative management.[24,31] A 2024 analysis by Torre et al. further confirmed that HCR led to fewer major bleeding events and faster ambulation in enhanced recovery programs.[36]

Several limitations in this meta-analysis warrant consideration. The inclusion of observational studies introduces potential selection bias, with only five RCTs contributing to the dataset. The follow-up duration was limited to five years, potentially omitting critical long-term outcomes. Additionally, small sample sizes in some studies reduced the statistical power, and variability in procedural techniques (e.g., robotic assistance, single- vs. two-stage procedures), and baseline patient characteristics further complicate comparisons.

Future research should prioritize large-scale, multi-institutional RCTs with extended follow-up durations to validate these findings. Investigating the feasibility and outcomes of HCR in patients with complex coronary anatomy, including those with higher SYNTAX scores, could further refine its clinical application. Emphasis on standardized reporting, procedural techniques, and subgroup stratification (e.g., diabetic patients, high-risk elderly) will help clarify which populations benefit most from HCR.

5. Conclusion

This meta-analysis confirms that HCR provides perioperative advantages over CABG, including shorter ICU stays and reduced transfusion needs. However, CABG remains superior in long-term MACCE outcomes, primarily due to lower repeat revascularization rates. Current evidence supports HCR as a viable alternative in selected patients, particularly those prioritizing faster recovery and minimally invasive approaches.

To better define HCR's role in clinical practice, future studies should focus on uniform procedural standards, integration of SYNTAX-based risk scoring, and multicenter trial designs that reflect real-world applicability.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no conflicts of interest to declare.

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