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Complete versus culprit-only revascularization in microaxial flow pump-supported acute myocardial infarction complicated by cardiogenic shock: a systematic review and meta-analysis

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Abstract

Background

The optimal revascularization strategy in patients with acute myocardial infarction complicated by cardiogenic shock (AMI-CS) receiving support by a microaxial flow pump (Impella) support remains uncertain. While culprit-only percutaneous coronary intervention (PCI) is generally recommended in unselected AMI-CS populations, the applicability of this strategy to mechanically supported patients is unclear.

Methods

We conducted a systematic review and meta-analysis of studies comparing complete or multivessel revascularization with culprit-only or incomplete revascularization in adults with Impella-supported AMI-CS. PubMed, Scopus, Web of Science, Embase, and CENTRAL were searched from inception through May 2026. The primary outcome was short-term all-cause mortality. Secondary outcomes included acute kidney injury, renal replacement therapy, bleeding, stroke, and vascular complications. Random-effects meta-analyses were performed to calculate pooled odds ratios (ORs) with 95% confidence intervals (CIs).

Results

Three observational studies, including 11,835 patients, were included. Four short-term mortality effect estimates were available because one study contributed more than one follow-up time point. There was no statistically significant difference in mortality between culprit-only/incomplete and multivessel/complete revascularization strategie. No significant difference in all-cause mortality was observed between culprit-only/incomplete and multivessel/complete revascularization strategies (OR 1.06, 95% CI 1.00–1.12; p = 0.055; I^2=48.8%). Subgroup analyses according to follow-up duration demonstrated no significant differences for either in-hospital or 30-day mortality. Similarly, no significant differences were observed for acute kidney injury (OR 1.07, 95% CI 0.94–1.23), blood transfusion (OR 0.92, 95% CI 0.83–1.03), ischemic stroke (OR 1.10, 95% CI 0.70–1.74), hemorrhagic stroke (OR 0.88, 95% CI 0.73–1.06), or vascular complications (OR 1.28, 95% CI 0.83–1.99). Access-site hematoma was less frequent in the culprit-only/incomplete revascularization group (OR 0.54, 95% CI 0.37–0.77).

Conclusions

Among patients with Impella/pLVAD-supported AMI-CS, current observational evidence does not demonstrate a significant difference in mortality between culprit-only/incomplete and multivessel/complete revascularization strategies. Given the limited number of available studies and the very low certainty of evidence, adequately powered prospective studies are needed to determine the optimal revascularization strategy in this high-risk population.

1. Introduction

Acute myocardial infarction complicated by cardiogenic shock (AMI-CS) occurs in 5–10% of ST elevation myocardial infarctions (STEMI) and remains associated with a high mortality rate depending on the severity of shock, historically with an average 40%-50% mortality despite advances in revascularization and critical care management (1). Early coronary revascularization is the cornerstone of treatment and has been shown to improve survival in patients with AMI-CS. However, approximately 50%–80% of patients with AMI-CS present with multivessel coronary artery disease, making the optimal revascularization strategy an area of ongoing debate (2, 3).

The CULPRIT-SHOCK trial demonstrated that culprit-lesion-only percutaneous coronary intervention (PCI) was associated with a lower risk of death or severe renal failure at 30 days compared with immediate multivessel PCI in patients with AMI-CS and multivessel coronary artery disease (4). Consequently, current guidelines recommend culprit-only PCI during the index procedure in this population. Nevertheless, microaxial flow pump devices were used in only a minority of patients enrolled in CULPRIT-SHOCK, limiting the applicability of these findings to contemporary shock populations receiving advanced hemodynamic support (4).

The increasing use of microaxial flow pumps such as the Impella device has transformed the management of cardiogenic shock by providing ventricular unloading and hemodynamic stabilization during high-risk PCI (5). Thus may facilitate more complete revascularization. Therefore, outcomes associated with multivessel PCI in mechanically supported patients may differ from those observed in historical studies conducted before the widespread adoption of contemporary MCS strategies.

Several recent observational studies have specifically evaluated revascularization strategies in Impella-supported AMI-CS populations. Lemor et al. reported comparable survival and acute kidney injury rates between multivessel PCI and culprit-vessel PCI among patients treated within the National Cardiogenic Shock Initiative protocol (6). In contrast, Schäfer et al. demonstrated that more complete revascularization, defined by a

residual SYNTAX score ≤ 8, was associated with lower 30-day mortality in Impella-supported AMI-CS patients (7). More recently, Patel et al. analyzed a large national cohort of percutaneous left ventricular assist devices (pLVAD)-supported AMI-CS patients and found no significant differences in mortality or dialysis-requiring acute kidney injury between culprit-vessel PCI and multivessel PCI strategies (8).

Given these findings that seems to either favor complete revascularization or find it non-inferior, but lack of randomized evidence supporting this and current guidelines not supporting the former approach, we focused specifically on Impella supported AMI-CS patients, with a dedicated systematic review and meta-analysis is warranted. Therefore, the present study aims to compare complete or multivessel revascularization versus culprit-only PCI in adults with AMI-CS receiving Impella or pLVAD support, with particular emphasis on short-term mortality and major clinical outcomes.

2. Methods

This study was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (9). The results were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (10). Additionally, this study has been registered with PROSPERO under the identification number (CRD420261442220).

2.1. Information Sources and Search Strategy

A comprehensive literature search was conducted using five electronic databases: PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Central Register of Controlled Trials (CENTRAL). The databases were searched from their respective dates of inception to 30 May 2026. The search strategy was developed by the review team and was not formally peer-reviewed by a medical librarian. No language or publication-date restrictions were applied. The search strategy combined controlled vocabulary terms, including MeSH and Emtree terms where applicable, with free-text keywords related to acute myocardial infarction, cardiogenic shock, mechanical circulatory support, Impella or percutaneous left ventricular assist devices, and revascularization strategy. Key search terms included “myocardial infarction,” “acute myocardial infarction,” “STEMI,” “NSTEMI,” “acute coronary syndrome,” “cardiogenic shock,” “AMI-CS,” “Impella,” “microaxial flow pump,” “percutaneous left ventricular assist device,” “pLVAD,” “mechanical circulatory support,” “multivessel PCI,” “complete revascularization,” “culprit-only PCI,” “culprit-vessel PCI,” “non-culprit PCI,” “residual SYNTAX score,” and “percutaneous coronary intervention,” along with relevant synonyms and spelling variations.

The search terms were organized into three main concept blocks: acute myocardial infarction and cardiogenic shock; mechanical circulatory support; and revascularization strategy. These blocks were combined using the Boolean operator AND. No study-design filters were applied in order to maximize sensitivity and capture both randomized and observational studies. The complete search strategy for each database is provided in the Supplementary Appendix Table A1. Two reviewers independently performed the database searches. The reference lists of included studies and relevant review articles were also screened manually to identify additional eligible studies not retrieved through the electronic database search.

2.2. Eligibility criteria

Studies were selected according to predefined eligibility criteria based on the Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) framework.

Inclusion Criteria

Population

Eligible studies included adults aged 18 years or older with acute myocardial infarction complicated by cardiogenic shock (AMI-CS) and multivessel coronary artery disease or residual non-culprit coronary disease who received Impella support or another percutaneous left ventricular assist device (pLVAD).

Intervention

The intervention of interest was complete or multivessel revascularization. This included multivessel percutaneous coronary intervention (PCI), non-culprit lesion PCI, or complete/near-complete revascularization as defined by the original study, including definitions based on residual SYNTAX score, such as residual SYNTAX score ≤ 8.

Comparator

Eligible comparators included culprit-only PCI, culprit-vessel PCI, culprit-lesion-only PCI, or incomplete revascularization. For the purpose of this review, the culprit-only group referred to patients in whom PCI was limited to the infarct-related or culprit vessel despite the presence of

multivessel coronary artery disease or residual non-culprit disease. Therefore, this group should not be interpreted as patients with isolated single-vessel coronary disease.

Outcomes

The primary outcome of interest was short-term all-cause mortality, preferentially reported as in-hospital or 30-day mortality. Secondary outcomes included long-term mortality, acute kidney injury (AKI), renal replacement therapy, major bleeding, stroke, vascular or access-site complications, limb ischemia, reinfarction, stent thrombosis, repeat revascularization, intensive care unit (ICU) length of stay, and hospital length of stay. Stent thrombosis was extracted according to the timing definitions reported in the original studies, including acute, subacute, late, or overall stent thrombosis when available. Stent thrombosis was planned as a secondary outcome and was extracted according to the timing definitions reported in the original studies. When available, events were categorized as acute, subacute, late, or overall stent thrombosis. If timing was not reported, the outcome was recorded as overall stent thrombosis.

Study types

Randomized controlled trials, post hoc analyses of randomized trials, prospective cohort studies, retrospective cohort studies, registry-based studies, propensity-matched studies, and conference abstracts with sufficient extractable data were eligible for inclusion.

Exclusion Criteria

Studies were excluded if they met any of the following criteria: studies not including patients with AMI-related cardiogenic shock; studies not including an Impella- or pLVAD-supported population; studies evaluating intra-aortic balloon pump (IABP)-only populations; studies including exclusively venoarterial extracorporeal membrane oxygenation (VA-ECMO) patients without a separately extractable Impella/pLVAD subgroup; studies involving elective high-risk PCI without AMI-related cardiogenic shock; studies comparing Impella versus IABP, VA-ECMO, or medical therapy without assessment of revascularization strategy; studies without a comparison between complete/multivessel and culprit-only/incomplete revascularization; studies without extractable clinical outcomes according to revascularization strategy; case reports; small case series with fewer than 10 patients; editorials; letters; narrative reviews; systematic reviews; meta-analyses; animal studies; and duplicate or overlapping populations unless additional non-duplicative outcome data were available.

2.3. Screening and Data Management

The screening process was carried out in two distinct phases. In the first phase, two reviewers independently screened titles and abstracts of all retrieved records using Rayyan software (11). Potentially relevant articles were forwarded to the second phase, in which the full texts were reviewed against the eligibility criteria. Any disagreement between the two reviewers was resolved by discussion or by consulting a third reviewer. Duplicate publications and overlapping populations were identified and excluded, retaining only the most comprehensive report (11).

2.4. Data Extraction

Data extraction was performed independently by two reviewers using a standardized and pilot-tested Microsoft Excel data collection form. For each eligible study, information regarding study characteristics was extracted, including first author, year of publication, country of origin, study design, data source or registry, study period, sample size, definition of revascularization strategy, type of mechanical circulatory support device, and duration of follow-up.

Baseline patient characteristics were also collected whenever available, including age, sex, clinical presentation as ST-segment elevation myocardial infarction (STEMI) or non-ST-segment elevation myocardial infarction (NSTEMI), diabetes mellitus, hypertension, chronic kidney disease, prior myocardial infarction, previous PCI, prior coronary artery bypass grafting, cardiac arrest, left ventricular ejection fraction, lactate concentration, and baseline and residual SYNTAX scores.

For outcome assessment, the number of events and total participants in each treatment group were extracted for dichotomous endpoints whenever available. Adjusted and unadjusted effect estimates, including odds ratios (ORs), risk ratios (RRs), hazard ratios (HRs), and their corresponding 95% confidence intervals (CIs), were recorded when reported by the original studies. For continuous outcomes, means and standard deviations were extracted preferentially; when unavailable, medians and interquartile ranges were collected and converted using established statistical methods when appropriate. Any discrepancies in data extraction were resolved through discussion and consensus between the reviewers.

2.5. Risk of Bias Assessment

Non-randomized studies were assessed using the Risk Of Bias In Non-randomized Studies of Interventions tool (ROBINS-I). The assessed domains included bias due to confounding, bias in the selection of participants, bias in the classification of interventions, bias due to deviations from intended interventions, bias due to missing data, bias in the measurement of outcomes, and bias in the selection of the reported result. Overall judgments were categorized as low, moderate, serious, critical risk of bias, or no information (12).

Disagreements between reviewers were resolved by discussion or by consultation with a third reviewer. Risk-of-bias figures were generated using the robvis visualization tool (13).

2.6. Publication Bias

As indicated by Egger et al., the assessment of potential publication bias within this review utilizing Egger's test for funnel plot asymmetry is not feasible when the number of included studies is fewer than ten (14).

2.7. Calculation of missing data

When outcome data were reported as percentages rather than absolute event counts, the number of events was calculated using the reported percentages and the total sample size of the corresponding treatment group. When multiple follow-up time points were reported, data were extracted separately for each predefined follow-up interval. For studies reporting adjusted effect estimates without sufficient raw event data, the reported estimates were recorded for qualitative interpretation but were not combined quantitatively unless compatible summary statistics were available.

For studies in which outcome definitions varied slightly across reports, clinically comparable endpoints were harmonized according to the predefined outcome categories. Complete revascularization, defined by residual SYNTAX score and multivessel PCI, was considered an equivalent intervention strategy for the purpose of quantitative synthesis. In contrast, culprit-only PCI and incomplete revascularization were grouped as comparator strategies (15–17) (18).

2.8. Data Synthesis, Statistical Analysis & Assessment of Heterogeneity

Meta-analyses were performed using R software (version 4.4.1) with the meta and metafor packages. For dichotomous outcomes, pooled odds ratios (ORs) with corresponding 95% confidence intervals (CIs) were calculated. The Mantel–Haenszel method was used for common-effect analyses. In contrast, random-effects analyses were performed using the inverse-variance method with restricted maximum likelihood (REML) estimation of between-study variance (τ^2).

Given the anticipated clinical and methodological heterogeneity among studies, including differences in study design, definitions of complete revascularization, patient characteristics, and follow-up duration, random-effects models were considered the primary analytical approach. Common-effect estimates were additionally reported for completeness.

Statistical heterogeneity was assessed using Cochran's Q test and the I^2 statistic. I^2 values of 25%, 50%, and 75% were considered indicative of low, moderate, and high heterogeneity, respectively. A p-value < 0.10 for Cochran's Q test was considered statistically significant heterogeneity.

Predefined subgroup analyses were conducted according to follow-up duration for mortality outcomes (in-hospital versus 30-day mortality) and according to outcome category for safety analyses. Differences between subgroups were evaluated using χ^2 tests for subgroup interaction.

Because of the limited number of included studies, meta-regression and formal assessment of publication bias were not performed. Statistical significance was defined as a two-sided p-value < 0.05 for all analyses (19–21).

3. Results

3.1. Search and Screening

The literature search was last updated on 30 May 2026. A total of 2,081 records were identified across five electronic databases: PubMed/MEDLINE (n = 640), Scopus (n = 739), Web of Science (n = 290), Cochrane CENTRAL (n = 67), and Embase (n = 345). After removing 992 duplicate records, 1,089 unique records remained for title and abstract screening. Of these, 1,041 records were excluded, and 48 reports were sought for full-text retrieval. Thirty-five reports could not be retrieved, leaving 13 full-text reports for eligibility assessment. Ten reports were excluded because they did not meet the predefined eligibility criteria, primarily because they lacked an Impella- or pLVAD-supported population, did not compare culprit-only/incomplete with multivessel/complete revascularization, used alternative mechanical circulatory support devices without separately extractable Impella/pLVAD data, or did not provide extractable outcome data according to revascularization strategy. Ultimately, three studies (6–8) met the eligibility criteria and were included in the systematic review and quantitative synthesis. **(**Fig. 1**)**

3.2. Study characteristics

The three included studies comprised observational evidence evaluating revascularization strategy in patients with acute myocardial infarction complicated by cardiogenic shock who received Impella or pLVAD support. The included studies were published between 2020 and 2025 and included a total of 11,835 patients.

Lemor et al. analyzed 198 patients with AMI-CS and multivessel coronary artery disease enrolled in the National Cardiogenic Shock Initiative. All patients were treated according to an early mechanical circulatory support protocol using Impella, and outcomes were compared between multivessel PCI and culprit-vessel PCI.

Schäfer et al. conducted a multicenter retrospective cohort study including 202 Impella-supported AMI-CS patients from four European shock centers in Germany and Italy. Revascularization was classified according to completeness using residual SYNTAX score, with complete revascularization defined as a residual SYNTAX score ≤ 8 and incomplete revascularization defined as a residual SYNTAX score > 8.

Patel et al. performed a large retrospective administrative database study using the Nationwide Readmission Database from 2016 to 2021. The study included 11,435 AMI-CS patients undergoing PCI with day-0 pLVAD/Impella support and compared culprit-vessel PCI with multivessel PCI. Across studies, the primary outcomes were short-term mortality outcomes, including in-hospital mortality or 30-day mortality. Secondary outcomes included acute kidney injury, renal replacement therapy, stroke, bleeding, vascular complications, access-site hematoma, readmission, and longer-term mortality when available.

Importantly, the included comparisons were intended to evaluate different revascularization strategies among patients with multivessel coronary disease or residual coronary disease. Thus, the culprit-only arms should not be interpreted as single-vessel CAD populations; rather, they represent patients with multivessel disease in whom operators elected to treat only the culprit vessel during the index procedure. (Table 1,2)

Table 1
Study Characteristics and Design

Study	Country / data source	Design	Study period	Population	Device	Treatment arms	N	Primary outcome	Follow-up
Lemor 2020	USA; NCSI	Retrospective analysis of multicenter NCSI registry/protocol data	Jul 2016–Dec 2019	AMI-CS + multivessel CAD	Impella, mainly CP	MV-PCI vs CV-PCI	198	Hospital survival	In-hospital
Schäfer 2021	Germany/Italy; 4 shock centers	Retrospective multicenter cohort	2012–2018	Impella-supported AMI-CS	Impella CP	rSS ≤ 8 vs rSS > 8	202	30-day mortality	30 days
Patel 2025	USA; NRD	Retrospective administrative database study	2016–2021	AMI-CS + PCI + day-0 pLVAD/Impella	pLVAD/Impella	CV-PCI vs MV-PCI	11,435	In-hospital mortality	In-hospital, 30 days, 6 months, 12 months

Table 2
Baseline Demographics and Risk Scores by Treatment Arm

Variable	Lemor 2020		Schäfer 2021		Patel 2025	
	CV-PCI n = 72	MV-PCI n = 126	Incomplete n = 72	Complete n = 130	CV-PCI n = 7860	MV-PCI n = 3575
Age, years	63.3 ± 11.6	64.8 ± 11.8	67 ± 11	65 ± 12	65 ± 12.2	67 ± 11.9
Male sex	55 (76.4%)	103 (81.8%)	57 (79%)	111 (85%)	5708 (72.6%)	2606 (72.9%)
STEMI	52 (72.2%)	97 (76.8%)	36 (50%)	85 (65%)	6644 (84.5%)	2709 (75.8%)
NSTEMI	20 (27.8%)	29 (23.2%)	36 (50%)	45 (35%)	1216 (15.5%)	866 (24.2%)
Diabetes mellitus	40 (55.1%)	70 (55.4%)	28 (39%)	36 (28%)	2685 (34.2%)	1439 (40.3%)
Hypertension	NR	NR	47 (65%)	86 (66%)	5176 (65.9%)	2562 (71.7%)
CKD, any stage	12 (17.2%)	10 (8.3%)	20 (28%)	23 (18%)	658 (8.4%)	317 (8.9%)
Prior MI	15 (21.1%)	23 (18.6%)	NR	NR	877 (11.2%)	440 (12.3%)
Prior PCI	20 (28.2%)	30 (23.7%)	NR	NR	1009 (12.8%)	463 (12.9%)
Prior CABG	6 (8.5%)	5 (4.1%)	NR	NR	283 (3.6%)	135 (3.8%)
Cardiac arrest	32 (44.8%) OHCA	56 (44.4%) OHCA	27 (38%)	67 (52%)	1669 (21.2%)	603 (16.9%)
VT/VF	NR	NR	NR	NR	4188 (53.3%)	1652 (46.2%)
LVEF, %	NR	NR	27 ± 11	26 ± 11	NR	NR
Admission lactate, mmol/L	NR	NR	5.3 ± 4.3	6.0 ± 4.6	NR	NR
3-vessel CAD	37 (50.7%)	62 (49.2%)	58 (80%)	71 (55%)	NR	NR
Impella pre-PCI	51 (70.4%)	91 (72.0%)	36 (50%)	60 (46%)	Day-0 pLVAD	Day-0 pLVAD

3.3. Risk of Bias Assessment

Risk of bias was assessed using ROBINS-I because all included studies were observational. No randomized trial directly addressing the review question in an Impella/pLVAD-supported population was included; therefore, RoB 2 assessment was not applicable.

Overall, one study was judged to have a moderate risk of bias, and two studies were judged to have a serious risk of bias. Lemor et al. were rated as having a moderate risk of bias, mainly because the choice of multivessel versus culprit-vessel PCI was not randomized and may have been influenced by patient anatomy, hemodynamic status, and operator discretion. However, the study used a standardized shock protocol and reported objective clinical outcomes.

Schäfer et al. were rated as having a serious risk of bias because treatment groups were defined according to the achieved completeness of revascularization using the residual SYNTAX score. This introduces important potential for confounding by coronary anatomy, baseline disease complexity, shock duration, and procedural feasibility. Although adjusted and propensity analyses were performed, residual confounding remains likely.

Patel et al. were also rated as having a serious risk of bias due to the use of administrative claims data, which may introduce coding misclassification and lack granular clinical information such as coronary anatomy, shock severity, hemodynamic parameters, timing and duration of Impella support, residual disease burden, and staged revascularization. Despite these limitations, mortality and major in-hospital outcomes were objectively defined and available in a large national cohort. (Fig. 2)

3.4. Outcomes

3.4.1. All-cause mortality

Four mortality comparisons were included, comprising 22,714 patients and 10,301 mortality events. Overall, there was no statistically significant difference in all-cause mortality between culprit-only or incomplete revascularization and multivessel or complete revascularization. The pooled odds ratio was 1.06 using both the common-effect model (OR 1.06, 95% CI 1.00–1.12; p = 0.055) and the random-effects model (OR 1.06, 95% CI 1.00–1.12; p = 0.055). Heterogeneity was moderate but not statistically significant (I^2=48.8%; Q = 5.86, p = 0.119).

In subgroup analysis by follow-up duration, no significant difference was observed for in-hospital mortality (OR 1.05, 95% CI 0.97–1.13; I^2=0%) or 30-day mortality using the common-effect model (OR 1.07, 95% CI 0.98–1.16). However, the 30-day subgroup demonstrated substantial heterogeneity (I^2=81.9%), largely reflecting the divergent estimate from Schäfer et al., in which complete revascularization was associated with lower 30-day mortality. Using the random-effects model, the pooled 30-day mortality estimate remained statistically non-significant (OR 1.41, 95% CI 0.71–2.79). There was no significant difference between follow-up subgroups for either the common-effect model (p = 0.784) or random-effects model (p = 0.402). **(**Fig. 3**)**

3.4.2. Renal and safety outcomes

Eight safety outcome comparisons were included, comprising 80,243 observations and 3,654 events. Overall, there was no statistically significant difference between revascularization strategies for the composite set of renal and safety outcomes. The pooled OR was 0.95 using the common-effect model (95% CI 0.88–1.02; p = 0.139) and 0.91 using the random-effects model (95% CI 0.76–1.10; p = 0.326). However, heterogeneity was substantial and statistically significant (I^2=63.5%; Q = 19.20, p = 0.0076), indicating that these outcomes should be interpreted individually rather than as a single pooled safety endpoint.

For renal outcomes, the subgroup including acute kidney injury and AKI requiring dialysis showed no significant difference between treatment strategies (OR 1.07, 95% CI 0.94–1.23; I^2=0%). Blood transfusion was also not significantly different between groups (OR 0.92, 95% CI 0.83–1.03). Similarly, no statistically significant differences were observed for ischemic stroke (OR 1.10, 95% CI 0.70–1.74), hemorrhagic stroke (OR 0.88, 95% CI 0.73–1.06), or vascular complications (OR 1.28, 95% CI 0.83–1.99).

Access-site hematoma was significantly more frequent in the multivessel PCI group, corresponding to a lower odds of this event in the culprit-only group (OR 0.54, 95% CI 0.37–0.77). Pericardiocentesis also showed a borderline lower odds in the culprit-only group (OR 0.59, 95% CI 0.34–1.00). Tests for subgroup differences were statistically significant for safety outcomes (p = 0.0042), suggesting that the effect of revascularization strategy varied across different safety endpoints. **(**Fig. 4**)**

3.5. GRADE Assessment

The certainty of evidence was assessed according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. Because all studies included in the quantitative synthesis were observational, the certainty of evidence initially started at low certainty. The certainty was subsequently downgraded according to predefined GRADE domains, including risk of bias, inconsistency, indirectness, imprecision, and publication bias.

For the primary outcome of all-cause mortality, the certainty of evidence was judged to be very low. This rating was driven by serious risk of bias arising from the observational design of the included studies, important clinical heterogeneity related to differing definitions of complete revascularization and follow-up durations, and imprecision resulting from the limited number of studies and wide confidence intervals.

Similarly, the certainty of evidence for renal and safety outcomes was considered very low. Although statistical heterogeneity was low for acute kidney injury, most secondary outcomes were derived from a single study, limiting confidence in the pooled estimates and increasing susceptibility to imprecision and reporting bias.

Overall, the available evidence suggests no clear mortality or safety advantage of either culprit-only or multivessel/complete revascularization in Impella-supported AMI-CS patients; however, confidence in these estimates remains limited because of the observational nature of the evidence base and the small number of available studies. **(**Table 3**)**

Table 3
GRADE Assessment of Evidence Certainty

Outcome	No. studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty
All-cause mortality	3	Observational	Serious	Serious	Not serious	Serious	Undetected	⨁●●● Very low
Acute kidney injury	2	Observational	Serious	Not serious	Not serious	Serious	Undetected	⨁●●● Very low
Blood transfusion	1	Observational	Serious	Not assessable	Not serious	Serious	Undetected	⨁●●● Very low
Stroke	1	Observational	Serious	Not assessable	Not serious	Serious	Undetected	⨁●●● Very low
Vascular complications	1	Observational	Serious	Not assessable	Not serious	Serious	Undetected	⨁●●● Very low

4. Discussion

Principal Findings

This systematic review and meta-analysis evaluated the impact of complete or multivessel revascularization compared with culprit-only or incomplete revascularization in patients with acute myocardial infarction complicated by cardiogenic shock (AMI-CS) receiving Impella or pLVAD support. Across the available evidence, we found no statistically significant difference in short-term mortality between revascularization strategies. Similarly, no significant differences were observed for acute kidney injury, stroke, blood transfusion, or major vascular complications. However, culprit-only/incomplete revascularization was associated with a lower incidence of access-site hematoma.

These findings suggest that the survival advantage of culprit-only PCI established in the general AMI-CS population may not be directly applicable to patients supported with contemporary mechanical circulatory support (MCS). While current guidelines largely rely on evidence from the CULPRIT-SHOCK trial, the growing use of Impella devices may fundamentally alter the balance between procedural risk and the potential benefits of more complete revascularization (22, 23).

Comparison With Previous Randomized and Observational Evidence

The cornerstone evidence supporting culprit-only PCI in cardiogenic shock comes from the CULPRIT-SHOCK trial. In this landmark randomized study, culprit-only PCI reduced the composite endpoint of death or severe renal failure requiring renal replacement therapy at 30 days compared with immediate multivessel PCI (3). At one year, mortality remained numerically lower with culprit-only PCI, although the difference was no longer statistically significant. Importantly, repeat revascularization and heart failure rehospitalization occurred more frequently in the culprit-only arm (4).

However, only a minority of patients in CULPRIT-SHOCK received advanced mechanical circulatory support, limiting extrapolation to contemporary Impella-supported populations (3, 4). Subsequent real-world investigations have produced conflicting results. The Polish PL-ACS registry confirmed the short-term benefit of culprit-only PCI, demonstrating lower 30-day mortality compared with multivessel PCI and supporting current guideline recommendations (24).

In contrast, studies focusing on patients receiving advanced mechanical support have suggested that more complete revascularization may be beneficial. Choi et al. evaluated patients with refractory cardiogenic shock requiring VA-ECMO and found that immediate multivessel PCI was associated with lower rates of 30-day mortality or renal replacement therapy and lower 12-month mortality compared with culprit-only PCI (25). Similarly, the recent DanGer Shock substudy demonstrated a significant reduction in mortality among patients undergoing immediate multivessel PCI compared with culprit-only PCI (26).

Our pooled results differ from these individual reports because they aggregate heterogeneous Impella-supported cohorts and suggest that any mortality advantage of complete revascularization remains uncertain. The absence of a significant mortality difference likely reflects substantial variability in patient selection, shock severity, timing of Impella implantation, and definitions of complete revascularization across studies.

Potential Mechanistic Explanations

The rationale for complete revascularization in AMI-CS is biologically plausible. Patients with multivessel coronary artery disease frequently have large ischemic territories beyond the culprit lesion. Persistent ischemia in non-culprit territories may impair recovery of stunned myocardium, perpetuate low cardiac output, and contribute to progressive multiorgan dysfunction.

Impella support may modify this equation. By unloading the left ventricle, reducing myocardial oxygen consumption, and improving systemic perfusion, Impella devices can provide hemodynamic stability during prolonged and complex PCI procedures (6, 7). This stabilization could theoretically permit safer multivessel intervention than was possible in historical studies.

The concept is supported by the analysis from Schäfer et al., in which complete revascularization defined by a residual SYNTAX score ≤ 8 was associated with substantially lower 30-day mortality compared with incomplete revascularization (7). Mortality was particularly low when Impella implantation occurred before PCI and complete revascularization was achieved (7).

Conversely, multivessel PCI inevitably increases procedural complexity, fluoroscopy time, contrast exposure, and vascular manipulation. These factors may offset any ischemic benefit, particularly in unstable patients with severe shock and multiorgan dysfunction. The neutral findings of our meta-analysis may therefore reflect a balance between these competing mechanisms.

Influence of Mechanical Circulatory Support

A notable aspect of the included studies is the consistent use of Impella or pLVAD support. Earlier analyses of Impella in AMI-CS demonstrated improved hemodynamic parameters but inconsistent effects on survival. The matched-pair analysis comparing Impella-treated patients with

controls from the IABP-SHOCK II trial found no reduction in 30-day mortality and reported higher rates of bleeding and vascular complications (27).

Nevertheless, contemporary shock protocols emphasize earlier device implantation and structured hemodynamic management. The National Cardiogenic Shock Initiative reported similar survival and acute kidney injury rates between multivessel PCI and culprit-only PCI among Impella-supported patients, suggesting that non-culprit intervention can be performed safely in selected patients (6).

Likewise, Patel et al. analyzed a large national cohort of Impella-supported AMI-CS patients and found no significant differences in in-hospital mortality, 30-day mortality, one-year mortality, or dialysis-requiring acute kidney injury between culprit-only and multivessel PCI strategies (8).

These findings align closely with the results of the present meta-analysis and suggest that in the setting of mechanical support, multivessel PCI may be neither clearly beneficial nor clearly harmful.

Safety Outcomes

One of the major concerns regarding multivessel PCI in cardiogenic shock is the potential increase in renal injury and bleeding complications. In the original CULPRIT-SHOCK trial, concern regarding contrast-induced nephropathy contributed to the preference for culprit-only PCI (3).

In our analysis, however, acute kidney injury rates were similar between treatment strategies. This observation is consistent with findings from both the National Cardiogenic Shock Initiative and the recent Patel study (6, 8).

Similarly, no significant differences were identified in stroke, transfusion requirements, or major vascular complications. The only safety signal observed was a lower incidence of access-site hematoma among patients undergoing culprit-only or incomplete revascularization. This finding likely reflects shorter procedures and reduced vascular manipulation rather than a direct effect of the revascularization strategy itself.

Clinical Implications

Current ESC and ACC/AHA guidelines recommend culprit-only PCI as the preferred initial strategy in AMI-CS with multivessel disease, largely based on the CULPRIT-SHOCK trial (22, 23). Our findings do not provide sufficient evidence to challenge these recommendations. However, they suggest that the risks associated with multivessel PCI may be attenuated when contemporary Impella support is used.

Therefore, the revascularization strategy should likely be individualized rather than universally dictated by historical trial data. Patients with large residual ischemic burden, low residual SYNTAX score achievable after intervention, persistent shock despite culprit PCI, or Impella support established before PCI may represent populations most likely to benefit from a more complete revascularization strategy. Conversely, patients with extensive comorbidity, severe renal dysfunction, prolonged shock duration, or complex chronic total occlusions may still be better served by an initial culprit-only approach.

Strengths and Limitations

The present study represents the first meta-analysis specifically focused on Impella/pLVAD-supported AMI-CS populations. By restricting inclusion to mechanically supported patients, it addresses an important gap left by previous guideline-defining trials.

Several limitations should be acknowledged. First, all included studies were observational, introducing the possibility of residual confounding and selection bias. Second, definitions of complete revascularization varied substantially across studies, ranging from angiographic multivessel PCI to residual SYNTAX score–based definitions. Third, the timing of Impella implantation differed considerably and may be an important treatment effect modifier. Fourth, only a limited number of studies and outcomes were available, reducing statistical power. Finally, patient-level data were unavailable, precluding adjustment for important clinical variables such as shock severity, lactate concentration, and cardiac arrest status.

5. Conclusion

Among patients with AMI complicated by cardiogenic shock receiving Impella or pLVAD support, current evidence does not demonstrate a significant difference in mortality between complete/multivessel and culprit-only/incomplete revascularization strategies. Although observational studies suggest that complete revascularization may improve outcomes in selected mechanically supported patients, these benefits were not confirmed in pooled analyses. Future adequately powered randomized trials specifically enrolling Impella-supported AMI-CS patients are required to determine the optimal revascularization strategy in this increasingly important high-risk population.

Abbreviations

ACS: Acute coronary syndrome
AKI: Acute kidney injury
AMI: Acute myocardial infarction
AMI-CS: Acute myocardial infarction complicated by cardiogenic shock
CABG: Coronary artery bypass grafting
CAD: Coronary artery disease
CENTRAL: Cochrane Central Register of Controlled Trials
CI: Confidence interval
CPR: Cardiopulmonary resuscitation
CV-PCI: Culprit-vessel percutaneous coronary intervention
ECMO: Extracorporeal membrane oxygenation
GRADE: Grading of Recommendations Assessment, Development and Evaluation
HR: Hazard ratio
IABP: Intra-aortic balloon pump
ICU: Intensive care unit
LVEF: Left ventricular ejection fraction
MCS: Mechanical circulatory support
MH: Mantel–Haenszel
MI: Myocardial infarction
MV-PCI: Multivessel percutaneous coronary intervention
NRD: Nationwide Readmission Database
NSTEMI: Non-ST-segment elevation myocardial infarction
OHCA: Out-of-hospital cardiac arrest
OR: Odds ratio
PCI: Percutaneous coronary intervention
pLVAD: Percutaneous left ventricular assist device
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO: International Prospective Register of Systematic Reviews
RCT: Randomized controlled trial
REML: Restricted maximum likelihood
ROBINS-I: Risk Of Bias In Non-randomized Studies of Interventions
RoB 2: Risk of Bias 2 tool
RR: Risk ratio
rSS: Residual SYNTAX score
SCAI: Society for Cardiovascular Angiography and Interventions
SD: Standard deviation
STEMI: ST-segment elevation myocardial infarction
SYNTAX: Synergy Between Percutaneous Coronary Intervention With Taxus and Cardiac Surgery
VA-ECMO: Venoarterial extracorporeal membrane oxygenation
VF: Ventricular fibrillation
VT: Ventricular tachycardia

Declarations

Ethics approval and consent to participate

Not applicable. This study was a systematic review and meta-analysis of previously published data and did not involve the recruitment of human participants or the collection of identifiable patient information.

6.3 Consent for publication

Not applicable.

6.4 Availability of data and materials

All data generated or analyzed during this study are included in this article and its supplementary information files.

6.5 Competing interests

The authors declare that they have no competing interests.

6.6 Funding

No funding was received for this study.

6.7 Authors' contributions

Mohammad Ghannam, Mustafa Abomohsen, and Khaled Moghib contributed to the study conception and design. Mohammad Ghannam, Mustafa Abomohsen, Iyad Y. Idries, Khaled Moghib, and Ayman Elsheikh developed the methodology and performed the literature search, study screening, data extraction, and evidence synthesis. Khaled Moghib and Mohammad Ghannam conducted the statistical analysis and prepared the tables and figures. Iyad Y. Idries, Abdullah Ahmad, and Bader Abu Ghalyoun contributed to data verification and risk-of-bias assessment. Mohammad Ghannam, Mustafa Abomohsen, and Khaled Moghib drafted the original manuscript. Fayez Shamoon, Ahmed Amro, Habib A. Habib, and Abdul Moiz Hafiz provided clinical interpretation, critical intellectual revision, and supervision. All authors reviewed and edited the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

6.8 Acknowledgements

Not applicable.

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Figures

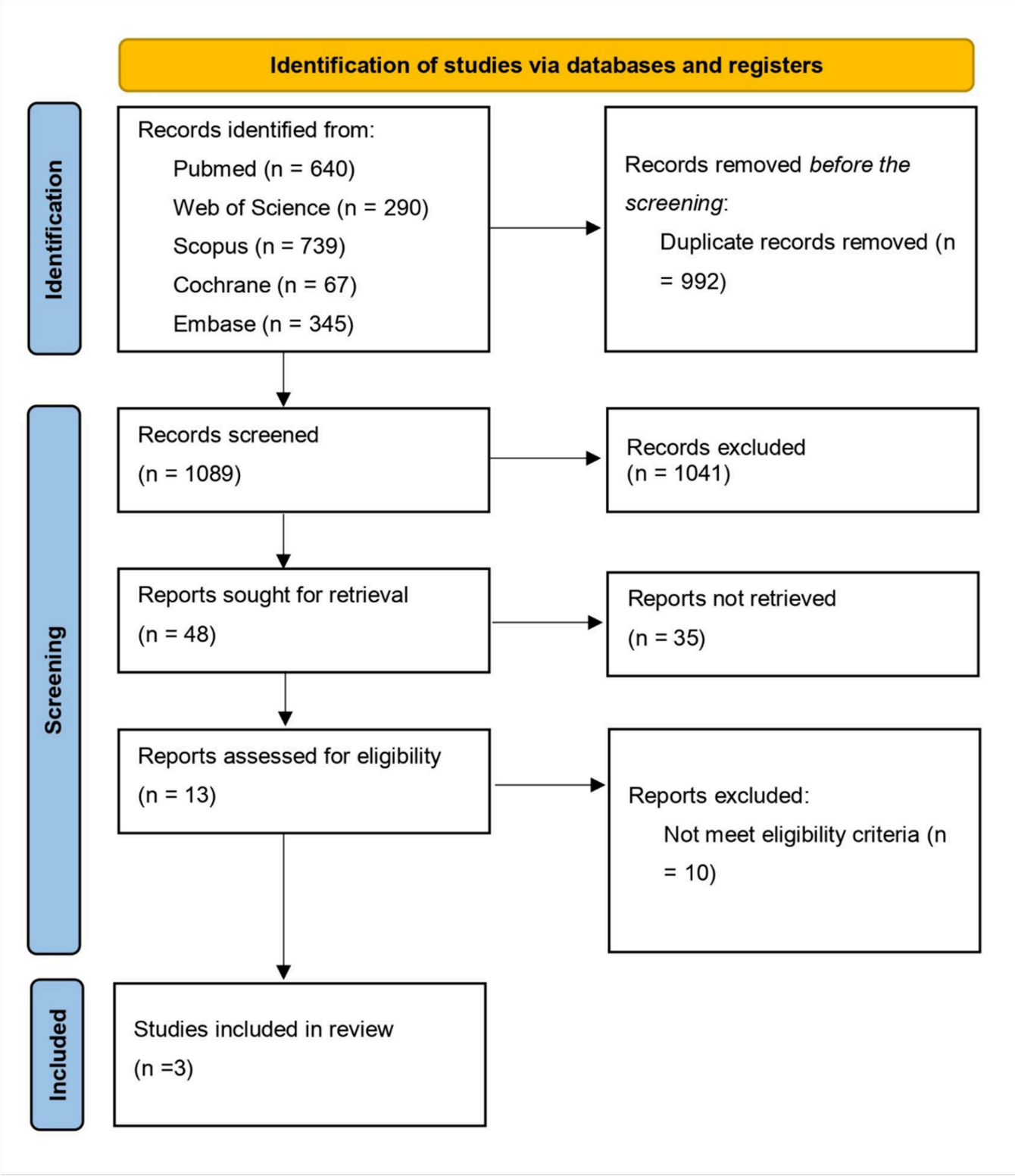


Figure 1

PRISMA flow chart for study screening and inclusion.

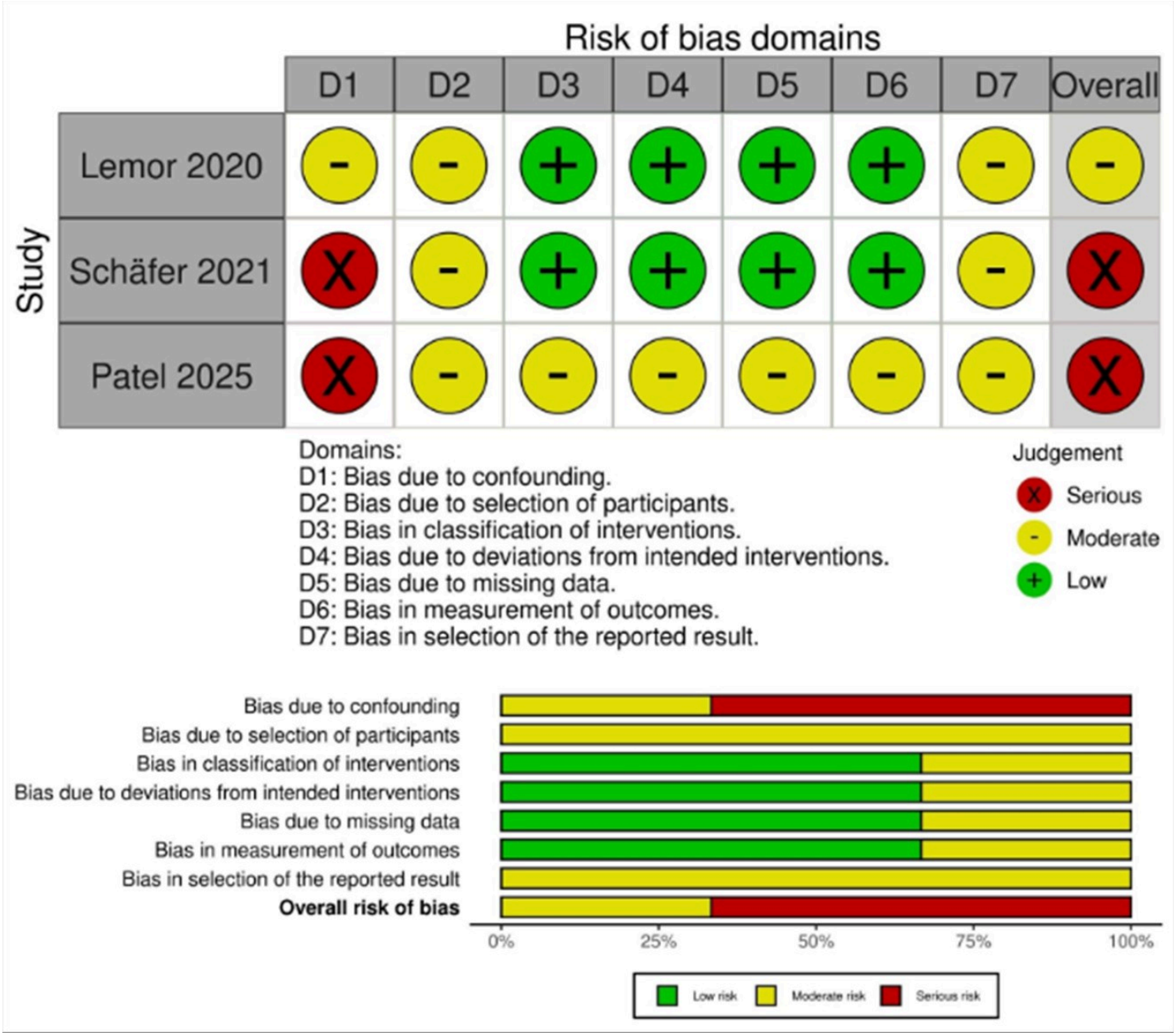


Figure 2

'Risk of bias graph': review authors' judgments about each risk of bias item presented as percentages across all included studies, and 'Risk of bias summary': review authors' judgments about each risk of bias item for each included study.

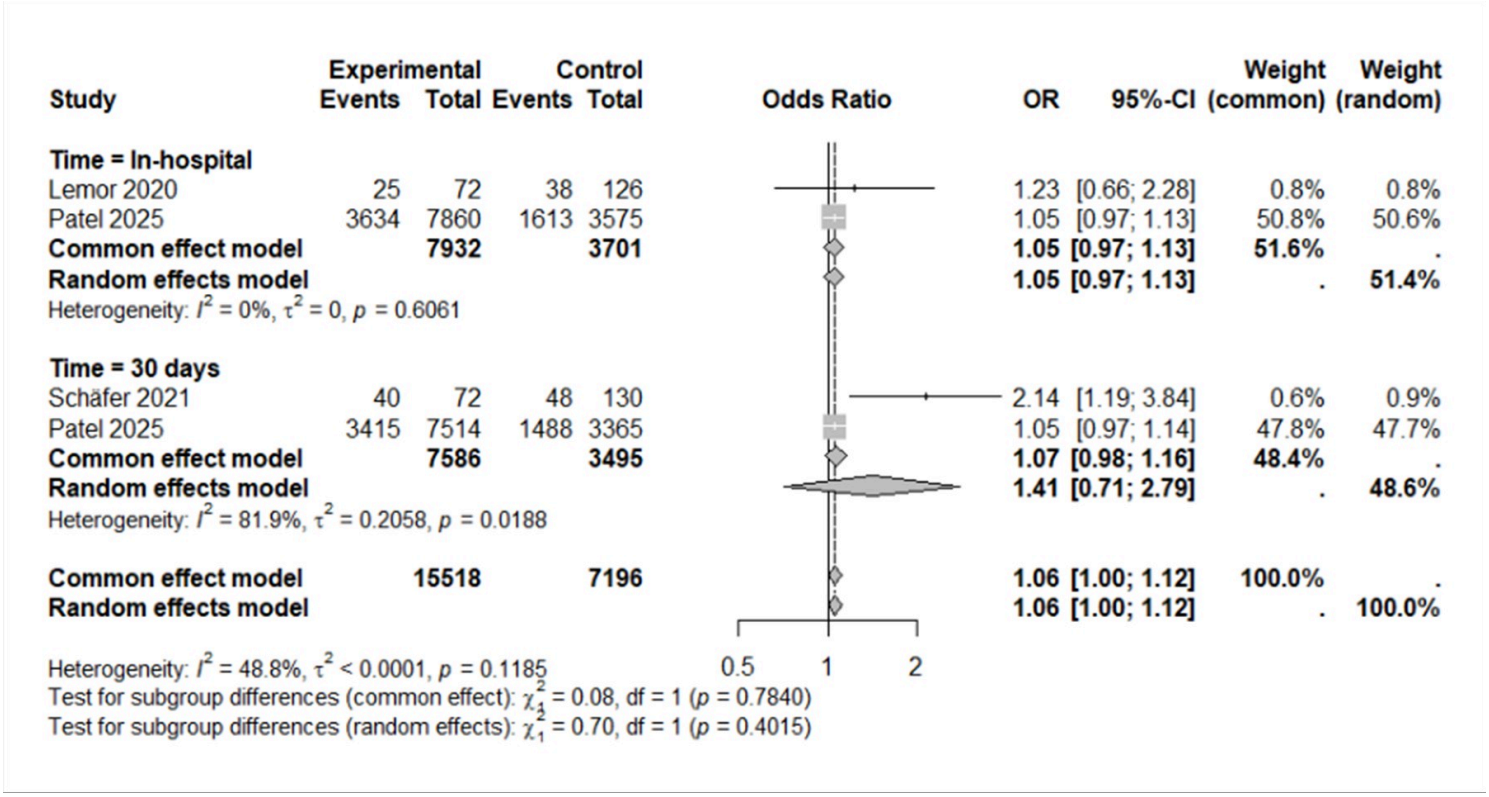


Figure 3

Forest plot of all-cause mortality; Forest plot comparing all-cause mortality between culprit-only/incomplete revascularization and multivessel/complete revascularization in patients with acute myocardial infarction complicated by cardiogenic shock receiving Impella or pLVAD support. Subgroup analyses were performed according to follow-up duration (in-hospital and 30-day mortality). Odds ratios (ORs) were pooled using the Mantel–Haenszel method. Squares represent study-specific effect estimates, with square size proportional to study weight; horizontal lines indicate 95% confidence intervals (CIs); diamonds represent pooled estimates.

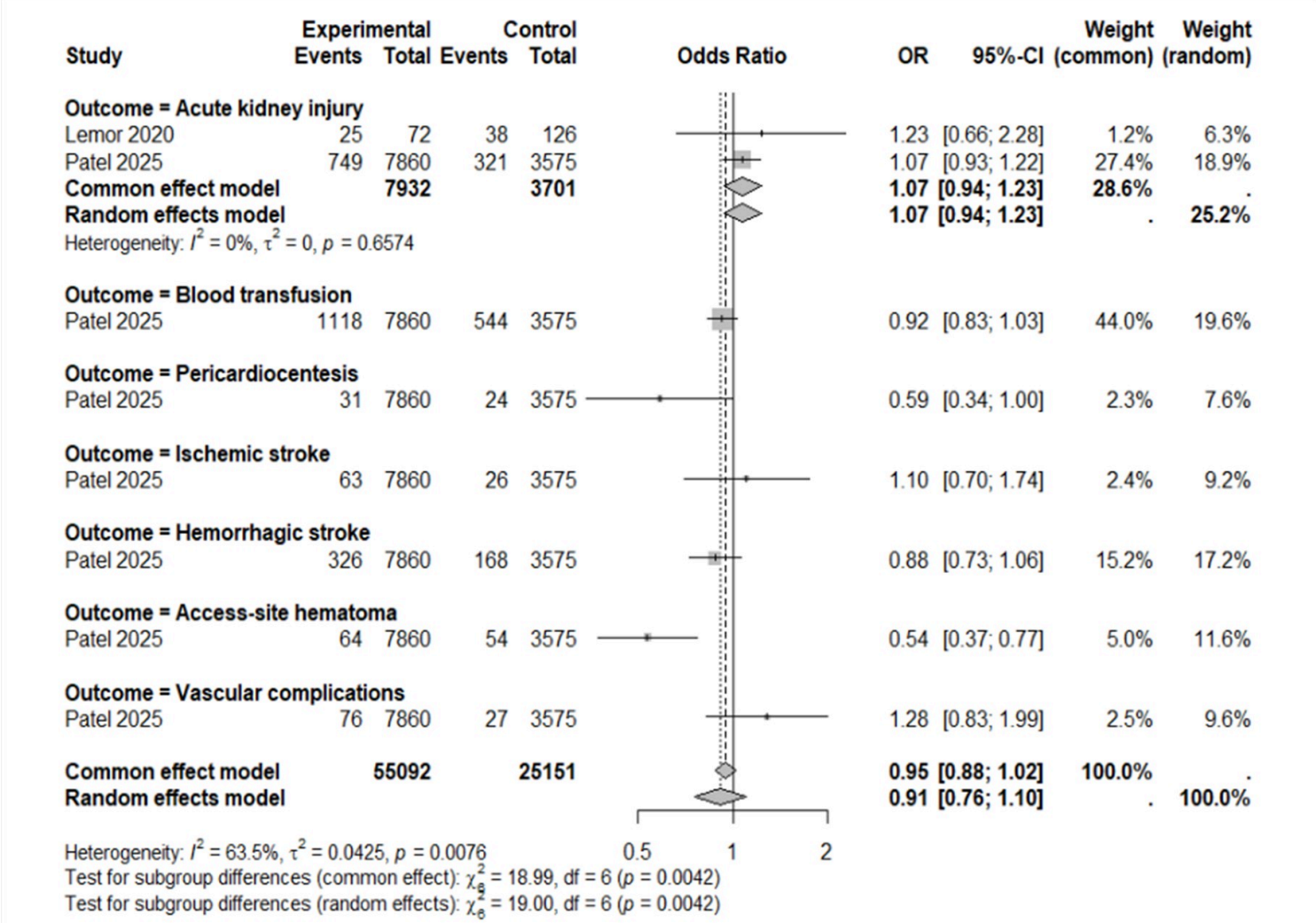


Figure 4

Forest plot of renal and safety outcomes; Forest plot comparing renal and safety outcomes between culprit-only/incomplete revascularization and multivessel/complete revascularization in patients with acute myocardial infarction complicated by cardiogenic shock receiving Impella or pLVAD support. Outcomes were analyzed according to predefined safety subgroups, including acute kidney injury, blood transfusion, pericardiocentesis, ischemic stroke, hemorrhagic stroke, access-site hematoma, and vascular complications. Odds ratios (ORs) were pooled using the Mantel–Haenszel method. Squares represent study-specific effect estimates, with square size proportional to study weight; horizontal lines indicate 95% confidence intervals (CIs); diamonds represent pooled estimates.

Supplementary Files

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- Appendix.docx