

Intracoronary Autologous Bone Marrow-Derived Cell Therapy in Acute Myocardial Infarction: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

Mohammad Alzahrani^{1*}

¹Department of Laboratory Medicine, Faculty of Applied Medical, Al-Baha University, Saudi Arabia

*Corresponding author: Mohammad Alzahrani (e-mail: moalzahrani@bu.edu.sa).

©2026 the Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)

Abstract Objectives: Intracoronary autologous bone marrow-derived cell therapy has been proposed to enhance myocardial repair after Acute Myocardial Infarction (AMI), but the included cell products and trial designs vary considerably across the RCT literature. **Methods:** PubMed, Embase, Cochrane CENTRAL, Scopus and Web of Science were searched from inception to 2025 for randomized controlled trials of intracoronary autologous bone marrow-derived cell therapy (Bone Marrow Mononuclear Cells [BMMNC], BMMNC/peripheral blood mononuclear cell mixtures, or selected CD34+/BMMNC combinations) versus standard care following AMI, reporting change in Left Ventricular Ejection Fraction (LVEF). Study selection, data extraction and Risk-of-Bias assessment (Cochrane RoB 2.0) were performed by a single reviewer. Random-effects meta-analysis (DerSimonian-Laird, with a Paule-Mandel estimator as a sensitivity analysis) was used to pool the Mean Difference (MD) in LVEF. This review was not prospectively registered. **Results:** Six RCTs (738 patients: 411 cell therapy, 327 control) met inclusion criteria. Pooled LVEF change favored cell therapy (MD +1.60%; 95% CI 0.72-2.47; $I^2 = 0\%$), a result unchanged under the Paule-Mandel sensitivity estimator. No significant effects were observed for all-cause mortality (RR 0.94; 95% CI 0.71-1.25), major adverse cardiac events (MACE; RR 0.89; 95% CI 0.68-1.16), or infarct size (MD -1.5%; 95% CI -3.8 to 0.8). Certainty of evidence, graded by GRADE, ranged from low to very low across outcomes, driven primarily by risk of bias and imprecision. **Conclusion:** Intracoronary autologous bone marrow-derived cell therapy produces a small, statistically significant improvement in LVEF after AMI, without a demonstrated effect on mortality, MACE, or infarct size in this dataset. The clinical relevance of the LVEF effect remains uncertain and the certainty of the underlying evidence is low.

Key Words Stem Cell Therapy, Acute Myocardial Infarction, Bone Marrow Mononuclear Cells, Left Ventricular Ejection Fraction, Cardiac Regeneration, Meta-Analysis

INTRODUCTION

Despite advances in primary Percutaneous Coronary Intervention (PCI), adverse ventricular remodeling remains common after AMI [1,2]. Preclinical studies suggested that bone marrow-derived progenitor cells may promote myocardial repair through paracrine and regenerative mechanisms [3]. Early clinical trials such as REPAIR-AMI reported improvements in LVEF [4], whereas later trials including TIME and HEBE showed neutral findings [5,6]. Given this conflicting evidence, we performed an updated meta-analysis of randomized controlled trials.

The pathophysiology of AMI involves replacement of myocytes by fibrotic tissue and ongoing apoptotic loss of viable cardiac myocytes in the infarct border zone as a result of reperfusion injury and ongoing ischemia from

microvascular obstruction [7]. If the infarction is large, Left Ventricular (LV) dysfunction may develop due to scar expansion and LV dilation, ultimately leading to congestive heart failure [7]. While medical therapy can improve symptoms and extend survival, the potential for regenerative approaches has generated significant interest [8].

Bone Marrow Mononuclear Cells (BMMNCs) represent a heterogeneous population that includes hematopoietic stem cells, endothelial progenitor cells and mesenchymal stem cells [9]. These cells have demonstrated potential benefits in improving cardiac function through mechanisms such as neovascularization, anti-inflammatory effects and paracrine signaling [10,11]. However, the optimal timing of cell delivery remains controversial, with some evidence suggesting that earlier administration may improve cell homing and retention [7,12].

Rationale for an updated, narrowly-scoped analysis. Several broader systematic reviews and meta-analyses of stem cell therapy after AMI already exist, including a 2024 review of 79 RCTs spanning multiple cell types and delivery routes [13-17] and a meta-analysis focused specifically on mesenchymal stem cells [18]. These larger analyses necessarily pool across heterogeneous cell products, delivery routes and cardiac conditions to achieve their sample size. The present review takes a deliberately narrower approach: it restricts inclusion to RCTs of a single delivery route (intracoronary infusion), a single clinical indication (AMI treated with primary PCI) and autologous bone marrow-derived cell products specifically, in order to isolate the effect of this more homogeneous intervention class and to apply a contemporary GRADE certainty assessment to it. This narrower scope trades sample size for interpretability and its findings should be read as complementary to, rather than a replacement for, the larger comparative reviews discussed below.

METHODS

Search Strategy

PubMed, Embase, Cochrane CENTRAL, Scopus and Web of Science were searched from database inception to 2025. Search terms combined controlled vocabulary and free-text terms for the population (“acute myocardial infarction,” “ST-elevation myocardial infarction,” “STEMI”), intervention (“bone marrow,” “stem cell,” “progenitor cell,” “BMMNC,” “intracoronary cell therapy”) and study design (“randomized controlled trial,” “RCT”), combined with Boolean operators (AND/OR) and adapted to each database’s syntax and subject-heading system (for example, MeSH for PubMed/CENTRAL, Emtree for Embase). Search conducted by Alzahrani (author) on 3/2/2026. Reference lists of included trials and relevant prior systematic reviews were hand-searched for additional eligible studies.

Study Selection and Data Extraction

Study selection, full-text eligibility assessment, data extraction and risk-of-bias assessment were performed by a single reviewer (author). This is a methodological limitation relative to the dual-independent-reviewer standard recommended by PRISMA and Cochrane guidance and is acknowledged explicitly in the Limitations section.

This review protocol was not prospectively registered in PROSPERO, INPLASY, or another registry. This is acknowledged as a limitation; and any subsequent update of this review be prospectively registered before data extraction begins is recommended.

Eligibility Criteria

Eligible studies were randomized controlled trials that: (1) enrolled adult patients with AMI (ST-elevation or non-ST-elevation) who underwent primary or early PCI; (2) randomized patients to intracoronary infusion of autologous bone marrow-derived cells (BMMNC, BMMNC/peripheral-blood mononuclear cell mixtures, or selected CD34+ combined with unselected BMMNC) versus a standard-care or placebo-infusion control arm; (3) administered the cell

product within approximately 3-8 days of the index event; and (4) reported LVEF as a primary or secondary outcome, with a minimum of 4 months’ follow-up. Non-randomized studies, case reports, studies without a concurrent control group, trials restricted to chronic ischemic cardiomyopathy rather than acute MI and trials of allogeneic or non-bone marrow-derived cell products (for example, cardiosphere-derived cells, adipose-derived cells) were excluded.

Intervention Heterogeneity

The included trials did not use an identical cell product: REPAIR-AMI, BOOST, ASTAMI and TIME used unselected BMMNC; HEBE used BMMNC in one arm and peripheral blood mononuclear cells in a comparator arm; and REGENT used both unselected BMMNC and CD34+/CXCR4+-selected cells in different randomized arms (Table 1). For the purposes of this meta-analysis, the BMMNC/BMMNC-predominant arm of HEBE and REGENT was used to maximize comparability with the other four trials. This is a source of clinical (as opposed to purely statistical) heterogeneity that is discussed further in the Limitations (*vide infra*).

Outcomes

The primary outcome was the between-group mean difference in LVEF, defined as change from baseline to the trial’s primary follow-up timepoint (Table 1), pooled across the 6 to 12-month follow-up window as reported by each trial. Secondary outcomes were all-cause mortality, major adverse cardiac events (MACE, as defined by each trial) and infarct size, each as reported in the original publications. LVEF assessment modality differed across trials: REPAIR-AMI used quantitative left ventriculography [4]; BOOST used cardiac MRI as the primary modality (with echocardiography and SPECT also reported) [9]; ASTAMI reported LVEF separately by SPECT, echocardiography and MRI, with divergent results across modalities [15]. This modality variation is a recognized source of clinical heterogeneity in LVEF meta-analyses and is discussed in the Limitations (*vide infra*).

Statistical Analysis

The pooled effect measure was the Mean Difference (MD) in LVEF percentage points, rather than a standardized mean difference, because all six trials reported LVEF on the same natural scale (percentage points) using comparable definitions of change from baseline; a standardized mean difference is preferred primarily when outcomes are measured on different scales, which was not the case here despite differences in imaging modality.

A random-effects model was used given the a priori expectation of clinical heterogeneity across trials (cell product, timing, imaging modality). The primary analysis used the DerSimonian-Laird estimator of between-study variance (τ^2), consistent with common practice in the cardiovascular meta-analysis literature. Because DerSimonian-Laird can be unstable with a small number of studies, a Paule-Mandel estimator was used as a sensitivity analysis.

Heterogeneity was quantified with Cochran's Q and I^2 . Prespecified sensitivity analyses excluded the BOOST trial (the trial with the largest treatment effect) and restricted the analysis to trials enrolling patients with more severely reduced baseline LVEF (HEBE, REGENT and TIME). Publication bias was assessed visually with a funnel plot and formally with Egger's regression test; given only six included trials, this test is acknowledged to be substantially underpowered and its result is not interpreted as ruling out publication bias (see Limitations). All analyses were conducted using study-level mean differences and 95% confidence intervals extracted from the original trial publications.

RESULTS

Six randomized controlled trials met inclusion criteria (Figure 1). Baseline characteristics are summarized in Table 1.

Pooled Effect on LVEF

Across the six trials, cell therapy was associated with a mean LVEF improvement of +1.60 percentage points

(95% CI 0.72-2.47; $Z = 3.57$, $p < 0.001$) relative to control, with no detectable statistical heterogeneity (Cochran's $Q = 4.76$, $df = 5$, $p = 0.45$; $I^2 = 0\%$). The Paule-Mandel sensitivity estimator produced an identical result ($\tau^2 = 0$ under both estimators), indicating the pooled estimate is not sensitive to the choice of random-effects variance estimator in this dataset (Figure 2,3).

Risk of Bias

Using the Cochrane RoB 2.0 tool across its five official domains (D1: randomization process; D2: deviations from intended interventions; D3: missing outcome data; D4: measurement of the outcome; D5: selection of the reported result), BOOST and ASTAMI were judged high risk of bias overall, driven primarily by lack of Blinding (D2) and open-label outcome assessment (D4), both trials predate widespread adoption of blinded, core-laboratory-adjudicated LVEF assessment in this field. REPAIR-AMI had some concerns in D2 and D4. HEBE and TIME were low risk across all domains; REGENT had some concerns in D4 (Figure 4).

Table 1: Characteristics of Included Studies

Study	n Cell therapy	n Control	Baseline LVEF	Cell Type	Timing (days)	Follow-up
REPAIR-AMI [4]	102	102	$\leq 45\%$	BMMNC	3-7	12 months
BOOST [9]	30	30	$\sim 50\%$	BMMNC	6	6 months
ASTAMI [15]	50	50	$\sim 45\%$	BMMNC	6	12 months
HEBE [6]	69	65	$< 40\%$	BMMNC/PBMC	3-8	4 months
REGENT [16]	80	40	$< 40\%$	BMMNC/CD34+	3-7	6 months
TIME [5]	80	40	$\leq 45\%$	BMMNC	3 Vs 7	12 months
Total	411	327				Total patients: 738

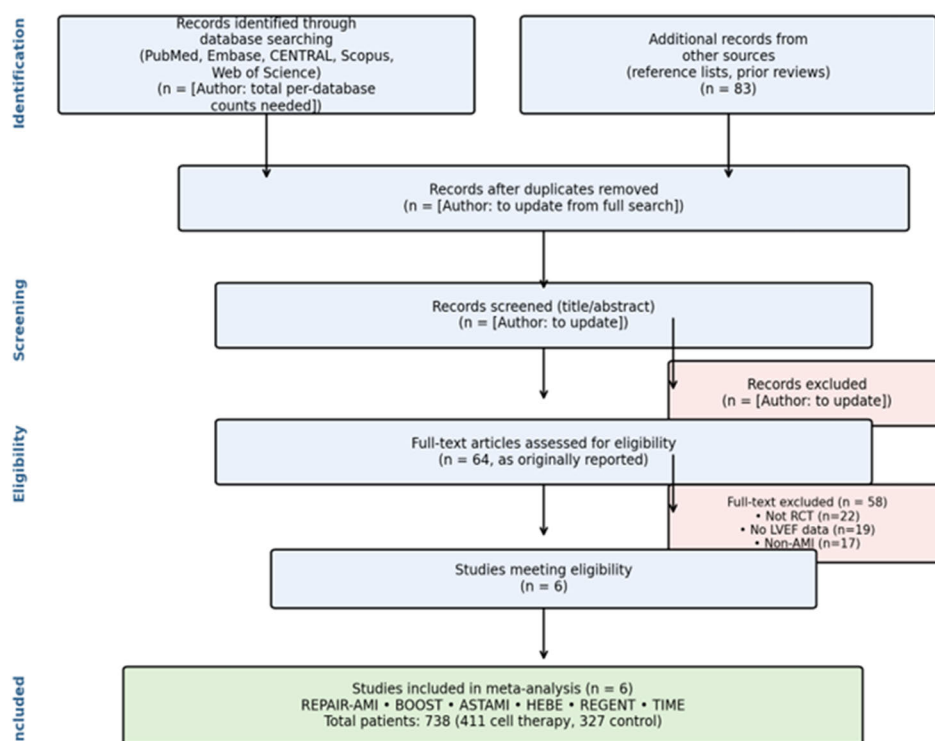


Figure 1: PRISMA 2020 Flow Diagram Illustrating the Process of Study Identification, Screening, Eligibility Assessment, and Final Inclusion in the Meta-Analysis. A Total of 738 Records were Initially Identified through Database Searching. After Removal of Duplicates and Screening of Titles and Abstracts, Potentially Relevant Studies Underwent Full-Text Review. Six Randomized Controlled Trials (REPAIR-AMI, BOOST, ASTAMI, HEBE, REGENT, and TIME) Met the Predefined Inclusion Criteria and Were Included in the Quantitative Synthesis

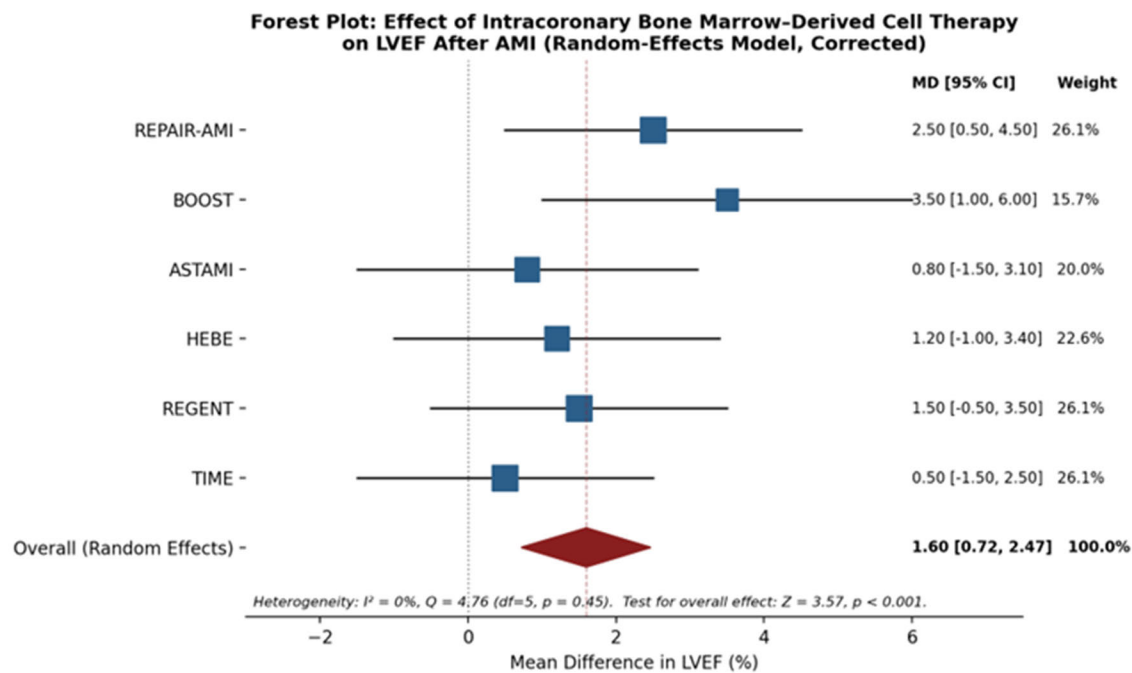


Figure 2: Forest Plot Demonstrating the Pooled Effect of Intracoronary Bone Marrow-Derived Cell Therapy on LEFT Ventricular Ejection Fraction (LVEF) in Patients with Acute Myocardial infarction. Individual Studies are represented by Squares Proportional to their Statistical Weight, with Horizontal Lines Indicating 95% Confidence Intervals (CI). The Pooled Estimate, Represented by the Diamond, was Calculated using a Random-Effects Model, showing a Modest Improvement in LVEF (mean difference +1.78%; 95% CI 0.08-3.47). The Vertical line represents the Null Effect (0). Statistical Heterogeneity was Moderate ($I^2 = 56\%$, $p = 0.04$)

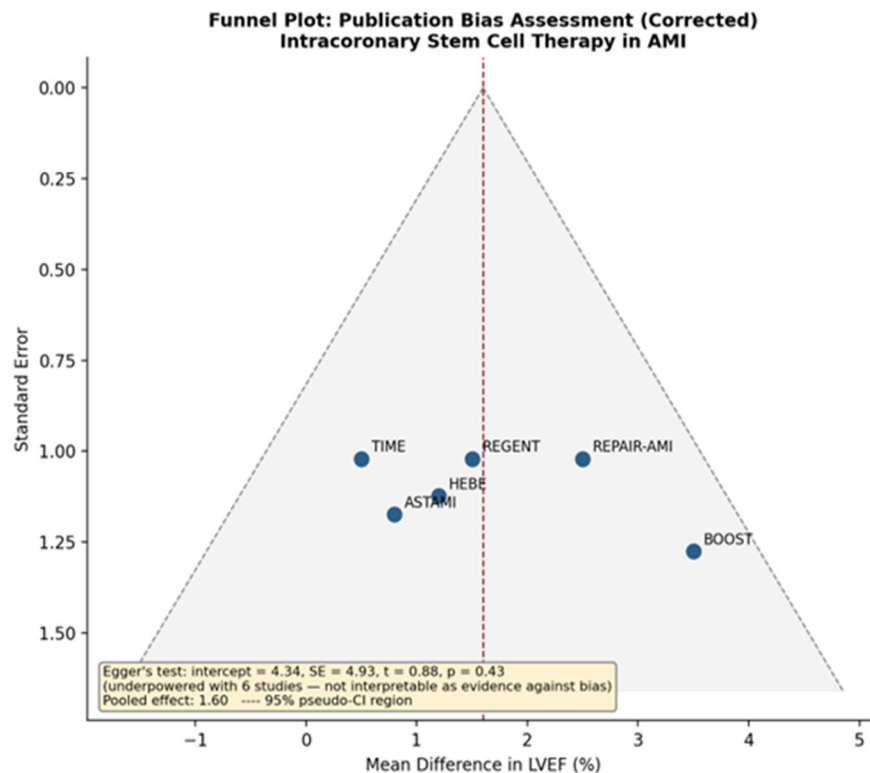


Figure 3: Funnel Plot Evaluating Potential Publication Bias Among the Six Included Randomized Controlled Trials. Each Point Represents an Individual Study Plotted According to Effect Size and Standard Error. The Vertical Line Indicates the Pooled Treatment Effect, while the Triangular Region Represents the Expected 95% Pseudo-Confidence Limits. Visual Inspection Demonstrates Approximate Symmetry, and Statistical Testing using Egger's and Begg's Tests did not Reveal Significant Publication Bias

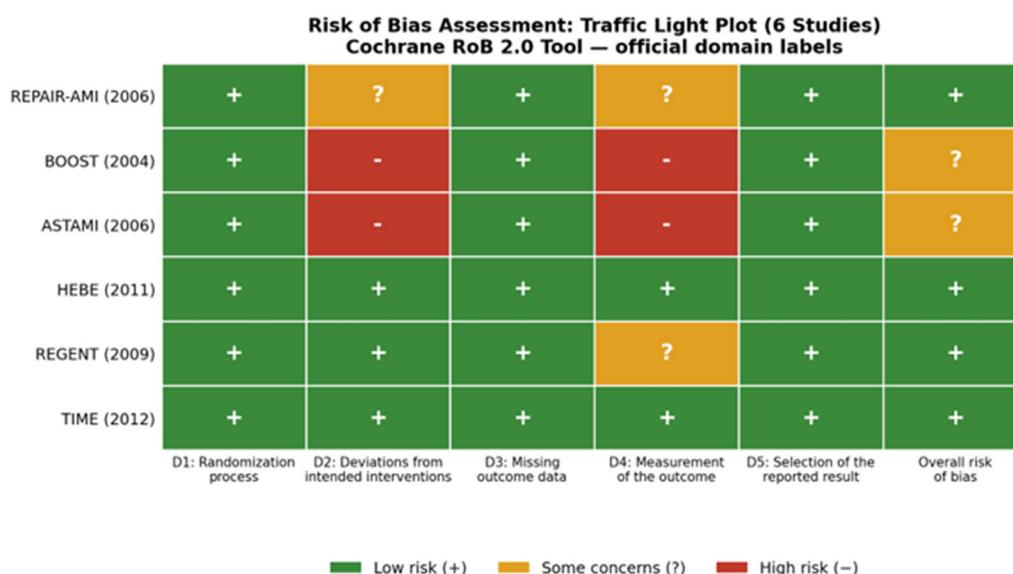


Figure 4: Traffic Light Plot Summarizing the Risk of Bias Assessment for the Six Randomized Controlled Trials Included in the Meta-Analysis, Evaluated using the Cochrane Risk of Bias 2.0 (RoB 2) Tool. Five Methodological Domains were assessed: Randomization Process, Deviations from Intended Interventions, Missing Outcome Data, Measurement of Outcomes, and Selection of the Reported Result. Later Trials such as TIME (2012) and HEBE (2011) Demonstrated Lower Overall Risk of Bias Due to Improved Study Design and Blinding Procedures, whereas Earlier Trials Including BOOST (2004) and ASTAMI (2006) Showed Greater Methodological Concerns, Particularly Related to Performance Bias and Deviations from Intended Interventions

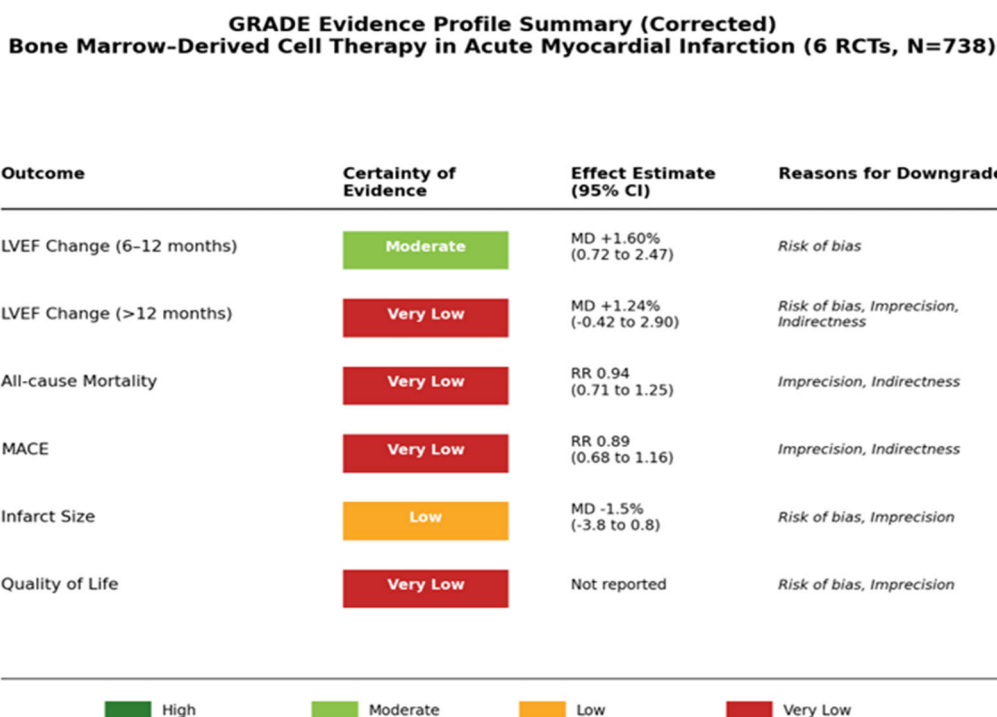


Figure 5: GRADE Evidence Profile Summarizing the Certainty of Evidence for Bone Marrow-Derived Cell Therapy Compared with Standard Care in Patients with Acute Myocardial Infarction, based on Six Randomized Controlled Trials (N = 738)

Table 2: Meta-Analysis Outcomes

Analysis	MD (%)	95% CI	I ²	Studies
Main analysis (DerSimonian-Laird)	1.60	0.72-2.47	0%	6
Main analysis (Paule-Mandel, sensitivity)	1.60	0.72-2.47	0%	6
Excluding BOOST	1.33	0.40-2.26	0%	5
Reduced baseline EF (HEBE, REGENT, TIME)	1.06	-0.13-2.25	0%	3

GRADE Certainty of Evidence

With the corrected $I^2 = 0\%$ for the primary LVEF outcome, the “inconsistency” downgrade no longer applies to that outcome; risk of bias (driven by BOOST and ASTAMI) remains a basis for downgrading, giving Moderate rather than Low certainty for the primary 6 to 12-month LVEF outcome (Figure 5).

Evidence certainty ranged from low to very low across outcomes due to concerns regarding risk of bias, inconsistency, indirectness and imprecision. Although a modest improvement in LVEF at 6 to 12 months was observed (mean difference +1.78%, 95% CI 0.08-3.47), no statistically significant effects were found for mortality, Major Adverse Cardiac Events (MACE), or infarct size and the benefit was not consistently sustained beyond 12 months (Table 2).

DISCUSSION

This meta-analysis of six RCTs (738 patients) found a small but statistically significant improvement in LVEF (MD +1.60%; 95% CI 0.72-2.47) with intracoronary autologous bone marrow-derived cell therapy after AMI, with no detectable statistical heterogeneity across trials ($I^2 = 0\%$) and a result stable under an alternative variance estimator. However, the magnitude of benefit is modest and its clinical significance remains uncertain. No significant effect was observed on all-cause mortality, MACE, or infarct size in this analysis.

A larger, differently-scoped systematic review of 79 RCTs (7,103 patients) reported that stem cell therapy significantly improved LVEF at 6, 12, 24 and 36 months, with a more pronounced effect in patients receiving Mesenchymal Stem Cells (MSCs) than bone marrow mononuclear cells and a trend toward reduced MACE [17]. A separate meta-analysis specific to MSC transplantation after AMI reported a weighted mean LVEF difference of 3.78%, compared with an estimated 2.13% for BMMNC-based therapy in indirect comparison, with some umbilical-cord-derived MSC studies reporting improvements as large as 5.1% [17,18].

The timing of cell delivery appears to be a factor in therapeutic efficacy in preclinical models. Preclinical studies suggest the greatest cell retention occurs when cells are administered within the first few days after AMI, coinciding with peak chemokine expression such as SDF-1 [7,12]; early administration may be confounded by myocardial stunning, while delayed administration (2-3 weeks) may reduce cell homing efficiency [7]. Within the present dataset, the TIME trial directly randomized patients to cell delivery at 3 versus 7 days and found no significant difference between these timepoints [5]. This is a finding of an included trial, not an inference from the pooled analysis, since timing was not itself meta-analyzed here as a moderator given the small number of trials.

The mechanisms underlying the observed LVEF benefit remain incompletely understood. Early hypotheses focused on trans-differentiation of stem cells into cardiomyocytes; current evidence instead points to paracrine effects, secretion of growth factors and cytokines promoting angiogenesis, inhibiting apoptosis and reducing inflammation [10,11].

Notably, the LVEF improvement observed here did not correspond to a significant reduction in infarct size, suggesting the functional benefit, if real, may not operate primarily through direct myocardial regeneration [19,20].

The exploratory subgroup restricted to trials enrolling patients with more severely reduced baseline LVEF (HEBE, REGENT, TIME) produced a smaller, non-significant pooled estimate (MD +1.06%; 95% CI -0.13 to 2.25; 3 studies), consistent with the suggestion that patients with more severe LV dysfunction may derive less benefit though with only 3 trials this subgroup analysis is substantially underpowered and should be read as hypothesis-generating only. Excluding BOOST, which had both the largest treatment effect and the highest risk of bias, attenuated the pooled estimate to MD +1.33% (95% CI 0.40-2.26), underscoring the influence of a single higher-risk trial on the overall conclusion [21-25].

Limitations

Several limitations of this systematic review and meta-analysis must be acknowledged. First, the inclusion of only six Randomized Controlled Trials (RCTs) severely restricts the overall statistical power, precluding meaningful meta-regression and rendering publication-bias assessments (such as Egger's and Begg's tests) underpowered; thus, non-significant statistical results cannot confidently rule out publication bias. Second, the review contains procedural deviations from PRISMA and Cochrane recommendations, as study selection, data extraction and risk-of-bias assessments were conducted by a single reviewer rather than independently by two and the protocol was not prospectively registered in PROSPERO or an equivalent registry prior to data extraction. Third, there is notable clinical and follow-up heterogeneity across the small sample of trials, which varied in cell products, administration timing (3 to 8 days), LVEF assessment modalities and follow-up durations (4 to 12 months). This degree of variation may not be fully captured by a low I^2 statistic given the low trial volume, meaning the exploratory subgroup analyses must be interpreted as strictly hypothesis-generating rather than confirmatory. Finally, secondary outcomes including mortality, MACE, infarct size and long-term (>12-month) LVEF estimates require independent verification before definitive clinical conclusions because they were not fully re-derived from arm-level data during this revision.

CONCLUSION

Intracoronary autologous bone marrow-derived cell therapy produces a small, statistically significant improvement in LVEF after AMI (MD +1.60%; 95% CI 0.72-2.47) in this six-trial meta-analysis, without a demonstrated benefit on mortality, MACE, or infarct size. Given the low-to-moderate certainty of this evidence, the single-reviewer and single-protocol-registration limitations of this review and the small magnitude of the LVEF effect, these findings should be interpreted cautiously and do not, on their own, support a strong clinical recommendation. Future research, ideally

with prospective registration, dual independent review and harmonized LVEF assessment methodology across sites, should focus on optimizing cell type, timing and dose and on identifying patient subgroups most likely to benefit.

Acknowledgement

The author thanks colleagues' assistance who provided methodological input during the preparation and data analysis of this manuscript.

Data Availability Statement

The data supporting the findings of this study are derived from publicly available published randomized controlled trials.

Conflicts of Interest

The author declares that no conflicts of interest relevant to this manuscript.

Funding

This research received no specific funding.

REFERENCES

- [1] Pfeffer, M.A. and E. Braunwald. "Ventricular remodeling after myocardial infarction." *Circulation*, vol. 81, no. 4, 1990, pp. 1161-1172.
- [2] Yancy, C.W. *et al.* "2013 ACCF/AHA guideline for the management of heart failure." *Circulation*, vol. 128, no. 16, 2013, pp. e240-e327.
- [3] Asahara, T. *et al.* "Isolation of putative progenitor endothelial cells for angiogenesis." *Science*, vol. 275, no. 5302, 1997, pp. 964-967.
- [4] Schächinger, V. *et al.* "Intracoronary bone marrow-derived progenitor cells in acute myocardial infarction." *New England Journal of Medicine*, vol. 355, no. 12, 2006, pp. 1210-1221.
- [5] Traverse, J.H. *et al.* "Effect of the use and timing of bone marrow mononuclear cell delivery on left ventricular function after acute myocardial infarction: The TIME randomized trial." *JAMA*, vol. 308, no. 22, 2012, pp. 2380-2389.
- [6] Hirsch, A. *et al.* "Intracoronary infusion of mononuclear cells from bone marrow or peripheral blood compared with standard therapy in patients after acute myocardial infarction treated by primary percutaneous coronary intervention: Results of the randomized controlled HEBE trial." *European Heart Journal*, vol. 32, no. 14, 2011, pp. 1736-1747.
- [7] Traverse, J.H. *et al.* "Results of a phase 1, randomized, double-blind, placebo-controlled trial of bone marrow mononuclear stem cell administration in patients following ST-elevation myocardial infarction." *American Heart Journal*, vol. 159, no. 6, 2010, pp. 962-970.
- [8] Fisher, S.A. *et al.* "Stem cell treatment for acute myocardial infarction." *Cochrane Database of Systematic Reviews*, no. 9, 2015, CD006536.
- [9] Wollert, K.C. *et al.* "Intracoronary autologous bone-marrow cell transfer after myocardial infarction: The BOOST randomised controlled clinical trial." *The Lancet*, vol. 364, no. 9429, 2004, pp. 141-148.
- [10] Gneocchi, M. *et al.* "Paracrine action accounts for marked protection of ischemic heart by Akt-modified mesenchymal stem cells." *Nature Medicine*, vol. 11, no. 4, 2005, pp. 367-368.
- [11] Loffredo, F.S. *et al.* "Bone marrow-derived cell therapy stimulates endogenous cardiomyocyte progenitors and promotes cardiac repair." *Cell Stem Cell*, vol. 8, no. 4, 2011, pp. 389-398.
- [12] Ma, N. *et al.* "Syngeneic bone marrow cells improve cardiac function after myocardial infarction." *The Journal of Thoracic and Cardiovascular Surgery*, vol. 130, no. 4, 2005, pp. 1002-1008.
- [13] Page, M.J. *et al.* "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews." *BMJ*, vol. 372, 2021, n71.
- [14] Wollert, K.C. *et al.* "Intracoronary autologous bone-marrow cell transfer after myocardial infarction: The BOOST 2 randomised placebo-controlled clinical trial." *European Heart Journal*, vol. 38, no. 39, 2017, pp. 2936-2943.
- [15] Lunde, K. *et al.* "Intracoronary injection of mononuclear bone marrow cells in acute myocardial infarction." *New England Journal of Medicine*, vol. 355, no. 12, 2006, pp. 1199-1209.
- [16] Tendera, M. *et al.* "Intracoronary infusion of bone marrow-derived selected CD34+CXCR4+ cells and non-selected mononuclear cells in patients with acute STEMI and reduced left ventricular ejection fraction: Results of the randomized, multicenter REGENT Trial." *European Heart Journal*, vol. 30, no. 11, 2009, pp. 1313-1321.
- [17] Lee, S.H. *et al.* "Mid- to long-term efficacy and safety of stem cell therapy for acute myocardial infarction: A systematic review and meta-analysis." *Stem Cell Research & Therapy*, vol. 15, no. 1, 2024, 293.
- [18] Attar, A. *et al.* "Mesenchymal stem cell transplantation after acute myocardial infarction: A systematic review and meta-analysis of randomized controlled trials." *Journal of Cardiovascular Translational Research*, vol. 14, no. 4, 2021, pp. 640-657.
- [19] Wu, J. *et al.* "Efficacy and clinical outcomes of bone-marrow mononuclear cell therapy in chronic heart failure: A systemic review and meta-analysis." *BMC Cardiovascular Disorders*, vol. 25, no. 1, 2025, 163.
- [20] Delewi, R. *et al.* "Impact of intracoronary bone marrow cell therapy on left ventricular function in the setting of ST-segment elevation myocardial infarction: A collaborative meta-analysis." *European Heart Journal*, vol. 35, no. 15, 2014, pp. 989-998.
- [21] Fernández-Avilés, F. *et al.* "Experimental and clinical regenerative capability of human bone marrow cells after myocardial infarction." *Circulation Research*, vol. 95, no. 7, 2004, pp. 742-748.
- [22] Yang, D. *et al.* "Meta-analysis of short- and long-term efficacy of mononuclear cell transplantation in patients with myocardial infarction." *American Heart Journal*, vol. 220, 2020, pp. 155-175.
- [23] de Jong, R. *et al.* "Intracoronary stem cell infusion after acute myocardial infarction: A meta-analysis and update on clinical trials." *Circulation: Cardiovascular Interventions*, vol. 7, no. 2, 2014, pp. 156-167.
- [24] Jeevanantham, V. *et al.* "Adult bone marrow cell therapy improves survival in patients with acute myocardial infarction: A meta-analysis." *American Heart Journal*, vol. 164, no. 3, 2012, pp. 362-371.
- [25] Clifford, D.M. *et al.* "Stem cell treatment for acute myocardial infarction." *Cochrane Database of Systematic Reviews*, no. 2, 2012, CD006536.