Efficacy of mechanical against manual method in cardiopulmonary resuscitation for out-of-hospital cardiac arrest: A meta-analysis

XINQING ZHU and JUN FU

Department of Emergency Medicine, Shandong Provincial Third Hospital, Shandong University, Jinan, Shandong 250031, P.R. China

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Abstract. Out-of-hospital cardiac arrest (OHCA) remains a leading cause of mortality worldwide, with the efficacy of cardiopulmonary resuscitation (CPR) methods playing a crucial role in patient outcomes. The present study aimed to compare the effectiveness of mechanical and manual CPR in OHCA, focusing on three outcomes: Return of spontaneous circulation (ROSC), survival to admission and survival till discharge. A comprehensive meta-analysis was conducted, incorporating 39 studies for ROSC, 28 for survival to admission, and 30 for survival till discharge, totalling 144,430, 130,499 and 162,088 participants, respectively. The quality of evidence was evaluated using the GRADE approach, assessing risk of bias, inconsistency, indirectness, imprecision and publication bias. Statistical analysis included pooled odds ratios (ORs) with 95% confidence intervals (CIs) and sensitivity analyses. For ROSC, the pooled OR was 1.09 (95% CI: 0.92-1.29), demonstrating no significant difference between mechanical and manual CPR. Survival to admission favoured mechanical CPR with a pooled OR of 1.25 (95% CI: 1.09-1.43). No conclusive difference was found for survival till discharge, with a pooled OR of 0.79 (95% CI: 0.61-1.02). Substantial heterogeneity was observed across outcomes. Evidence of potential publication bias was noted, particularly in the survival to admission outcome. The overall quality of evidence was graded as very low, mainly due to high heterogeneity and indirectness of evidence. The study suggests that mechanical CPR may improve short-term outcomes such as survival to admission in patients with OHCA but does not demonstrate a significant long-term survival benefit over manual CPR.

Correspondence to: Dr Jun Fu, Department of Emergency Medicine, Shandong Provincial Third Hospital, Shandong University, 11 Wuyingshan Middle Road, Tianqiao, Jinan, Shandong 250031, P.R. China
E-mail: fujun202310@163.com

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Introduction

Cardiac arrest remains one of the most urgent medical emergencies worldwide, with out-of-hospital cardiac arrest (OHCA) presenting a particular challenge due to its unpredictable nature and the need for immediate intervention (1). The American Heart Association reports that over 350,000 OHCAs occur in the United States annually (2) with similar higher burden in Europe (3), with survival rates significantly impacted by the quality and timeliness of cardiopulmonary resuscitation (CPR) administered.

CPR, a lifesaving technique crucial in the management of cardiac arrest, has traditionally been performed manually (4). Manual CPR, involving rhythmic chest compressions and ventilations, aims to maintain circulatory flow and oxygenation until advanced care can be provided (4). However, the effectiveness of manual CPR can be limited by various factors, including the physical endurance of the rescuer, consistency in compression depth and rate, and interruptions during patient transfer or transport (5).

In recent years, mechanical CPR devices have emerged as a potential solution to these limitations. These devices are designed to deliver consistent, uninterrupted chest compressions and are increasingly being used in pre-hospital settings (6). Proponents of mechanical CPR argue that these devices offer several advantages over manual methods, including the ability to provide high-quality compressions over prolonged periods, reduced rescuer fatigue, and greater consistency in compression depth and rate (7). Additionally, mechanical devices potentially reduce interruptions in chest compressions, a factor closely linked to improved survival rates in cardiac arrest cases (7).

However, the adoption of mechanical CPR in OHCA scenarios has been met with mixed responses from the medical community. While some studies suggest improved outcomes with mechanical CPR (8,9), others indicate no significant difference or even inferior results compared with manual methods (10,11). This discrepancy raises critical questions about the comparative effectiveness of these two approaches, particularly in the context of OHCA where every second counts.

Several factors necessitate a comparative analysis between these two methods. First, the choice between mechanical and manual CPR can significantly impact patient outcomes, particularly in terms of survival to hospital discharge and long-term survival (8-11). Second, understanding the relative benefits and limitations of each method can inform training protocols and guidelines for emergency medical services (EMS). Finally, with the evolving landscape of pre-hospital emergency care and the continuous development of new CPR technologies, it is crucial to periodically reassess and update best practice recommendations.

The objective of the present meta-analysis was to comprehensively evaluate and compare the effectiveness of mechanical and manual CPR methods in improving survival outcomes in patients experiencing OHCA.

Materials and methods

Eligibility criteria of participants. Studies conducted in participants aged ≥18 years who had OHCA were included.

Intervention and control group. Studies comparing the mechanical CPR using any device against manual mode of CPR were eligible.

Outcomes. Return of spontaneous circulation (ROSC), survival till admission, survival till discharge.

Design of the study. Studies of any of the following designs: Randomized controlled trials (RCTs), quasi-experimental trials, non-randomized studies or any form of interventional trials with comparison group were eligible.

Exclusion criteria. To ensure the robustness and relevance of the present meta-analysis, the following exclusion criteria were applied:

Animal studies. Studies conducted on animals were excluded to focus exclusively on human data.

Case reports and series. Individual case reports or case series were excluded as they do not provide comparative data between mechanical and manual CPR.

Studies with insufficient data. Studies that did not report sufficient data on the outcomes of interest (ROSC, survival to admission, and survival till discharge) were excluded.

Overlapping data. Duplicate publications or studies with overlapping data were carefully screened, and only the most comprehensive or recent study was included.

Information sources and search strategy. The search strategy employed a comprehensive approach to identify relevant studies, utilizing databases such as PubMed (https://pubmed.ncbi.nlm.nih.gov/), Scopus (https://www.scopus.com/home.uri), Cochrane library (https://www.cochranelibrary.com/), Google Scholar (https://scholar.google.com/), (ScienceDirect) https://www.sciencedirect.com/and Web of Science (https://clarivate.com), along with the references of the included studies. A combination of the following terms was used, including 'Mechanical CPR', 'Manual CPR', 'Cardiopulmonary resuscitation', 'Out-of-hospital cardiac arrest', 'Prehospital CPR', 'Randomized Controlled Trial', 'Autopulse' and 'LUCAS-2'. The time limit of the search started from the inception of each of the databases till December 2023. There were no restrictions in terms of language during the search.

Search strategy in PubMed was as follows: ['Mechanical CPR' (All Fields) OR 'Mechanical Cardiopulmonary Resuscitation' (All Fields) OR 'Mechanical Chest Compression' (All Fields) OR 'Autopulse' (All Fields) OR 'LUCAS-2'(All Fields)] AND ['Manual CPR'(All Fields) OR 'Manual Cardiopulmonary Resuscitation'(All Fields) OR 'Manual Chest Compression'(All Fields)] AND ['Out-of-Hospital Cardiac Arrest'(All Fields) OR 'Prehospital Cardiac Arrest'(All Fields) OR 'OHCA'(All Fields) OR 'Cardiac Arrest'(All Fields)].

Study screening process. Two independent researchers thoroughly reviewed the literature, initially assessing the relevance of each study by examining its title, abstract and essential key words. Subsequently, they obtained the full-text versions of articles for a more detailed evaluation. The suitability of these studies for inclusion in the analysis was determined based on pre-established criteria. In cases where inconsistencies or disagreements arose regarding the selection of a study, the two researchers worked together to discuss and resolve these differences through consensus. If consensus could not be reached, a third-party expert, who was not an author of the present study but had expertise in the field, was consulted to provide an independent assessment and resolve the disagreement. This process ensured the methodological integrity and reliability of the study selection process. To ensure methodological integrity, the entire review process was documented following the PRISMA guidelines (12).

Data extraction. The principal investigator meticulously gathered critical data from the selected studies, recording fundamental details such as extraction date, study titles and author names. Key methodological elements were also noted, including the design of each study, participant demographics, and the specific context in which the study was conducted. Particular attention was paid to recording the number of participants in each arm of the studies, along with the baseline and final outcome measures, and the criteria used for including or excluding participants. Information about interventions, comparison groups, and the length of follow-up periods was systematically logged. This included details of primary and secondary outcomes, the timing of evaluations, and other factors crucial for assessing the quality of the studies. To maintain the accuracy of the data collection process, a second researcher rigorously cross-checked the extracted information against the original reports, ensuring the reliability of the compiled data.

Risk of bias assessment. The assessment of study quality was conducted by two evaluators using two specific bias assessment instruments. For RCTs, they employed the Cochrane Collaboration's Risk of Bias 2 tool, (13) which evaluates potential biases across several domains. These domains include the process of randomization, deviations from the planned interventions, the handling of missing outcome data, the measurement of outcomes, and the selection of reported results. For non-randomized studies, the reviewers used the Risk Of Bias In non-randomized studies-of interventions (ROBINS-I) tool (14). This tool focuses on biases related to confounding factors, selection of participants, classification of interventions, deviations from intended interventions, missing data, outcome measurements, and the reporting of results. Based on these evaluations, studies were classified into categories indicating 'low', 'high', or 'some concerns' regarding their risk of bias. This categorization ensured a thorough and rigorous quality appraisal of the evidence gathered.

Statistical analysis. The statistical analysis for the present study was performed using STATA, version 14.2. (StataCorp LP). As all the outcomes were measured in binary terms, the pooled odds ratio (OR) was computed along with a 95% CI, based on the frequency of events in both intervention and control groups, offering a comparative perspective on the effectiveness of interventions.

A random-effects model was applied, utilizing the inverse variance method to accommodate variations across the included studies (15). To evaluate heterogeneity, or the variability in results across studies, several methods were used: Visual inspection of forest plots to observe CI overlaps, chi-square tests, and the I^2 statistic, the latter quantifying the proportion of total variation due to differences between studies.

For assessing publication bias, several techniques were employed. Egger's test was used to detect asymmetry in the data, indicative of potential bias. Funnel plots provided a visual assessment of bias, plotting the treatment effects measured in the studies against their precision. The Doi plot and Luis Furuya Kanamori (LFK) index were also utilized to further explore and quantify potential publication bias (16). The LFK index between -1 to +1 indicate no publication bias (perfect symmetry), while between -1 to -2 or +1 to +2 indicate minor asymmetry, while value less than -2 and more than +2 indicate major asymmetry (16). To address and minimize the impact of publication bias, the trim and fill method was utilized in addition to traditional methods. The trim and fill analysis were conducted using a random-effects model to adjust for the detected publication bias.

Subgroup analysis was performed based on study design and type of mechanical device to identify any variations in outcomes related to different study methodologies. Sensitivity analysis was performed to assess the robustness of the estimates by excluding high risk of bias studies. Leave-one out sensitivity analysis was also conducted to assess the single-study effects for each of the outcomes.

GRADE assessment. The Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) approach plays a crucial role in assessing the quality of evidence in healthcare research (17). This method employs five key domains to evaluate the strength and reliability of evidence. Each domain addresses specific aspects of the studies under consideration, providing a comprehensive overview of their credibility (17).

Risk of bias assessment. This domain examines the extent to which the study design and implementation minimize biases. It considers factors such as randomization, blinding, and the completeness of outcome data. Studies with a high risk of bias are considered less reliable and can result in downgrading the quality of evidence.

Inconsistency. Inconsistency refers to the degree of variation in the results across different studies. Significant heterogeneity in outcomes can indicate underlying differences in study populations, interventions, or methodologies, leading to questions about the applicability of results. A high level of inconsistency may lead to a lower GRADE rating.

Indirectness. This domain assesses the extent to which the evidence directly applies to the population, intervention, comparator, and outcomes of interest in the specific research question. Studies with high indirectness, meaning their focus or methods diverge significantly from the research question, are less likely to contribute to a high-quality evidence base.

Imprecision. Imprecision evaluates the confidence in the effect estimates provided by the evidence. It takes into account the sample size, confidence intervals (CIs), and the number of events. Studies with wide CIs or small sample sizes are considered imprecise, potentially leading to a downgrade in the quality of evidence.

Publication bias. This domain investigates the presence of selective publication of studies, often those with positive findings. Tools such as funnel plots, Egger's test and other statistical methods are used to assess this bias. Evidence of publication bias can significantly affect the trustworthiness of the evidence pool and may result in lowering the GRADE.

By meticulously evaluating each of these domains, the GRADE approach provides a systematic and transparent method to assess the quality of evidence. This rigorous process ensures that healthcare recommendations are based on the most reliable and relevant information available.

Results

Search results. Overall, a total of 2,993 studies were obtained from PubMed, Scopus, Cochrane library, Google Scholar, ScienceDirect and Web of Science. A total of 182 studies were initially found eligible based on reading of title and abstract and the full texts were obtained for these studies. Finally, 50 studies were eligible after reading full text and included in analysis (Fig. 1) (18-67).

Characteristics of included studies. The present meta-analysis encompassed 50 studies with varied designs including 11 RCTs, 15 prospective cohorts and 24 retrospective cohorts or case-controls. The total sample size across these studies ranged significantly, from as few as 17 participants in the smallest study to as numerous as 80,690 in the largest. Geographically, the majority of studies were conducted in the United States, with significant contributions from European and Asian countries. The most commonly used mechanical CPR devices were the LUCAS and Autopulse systems, which were predominant across these studies. The studies exhibited diverse levels of risk of bias: 17 with a high risk, 26 with a low risk, and 7 with some concerns (Table I).

ROSC. A total of 39 studies with 144,430 participants have compared the effectiveness of mechanical against manual CPR on ROSC amongst patients with OHCA. Pooled OR

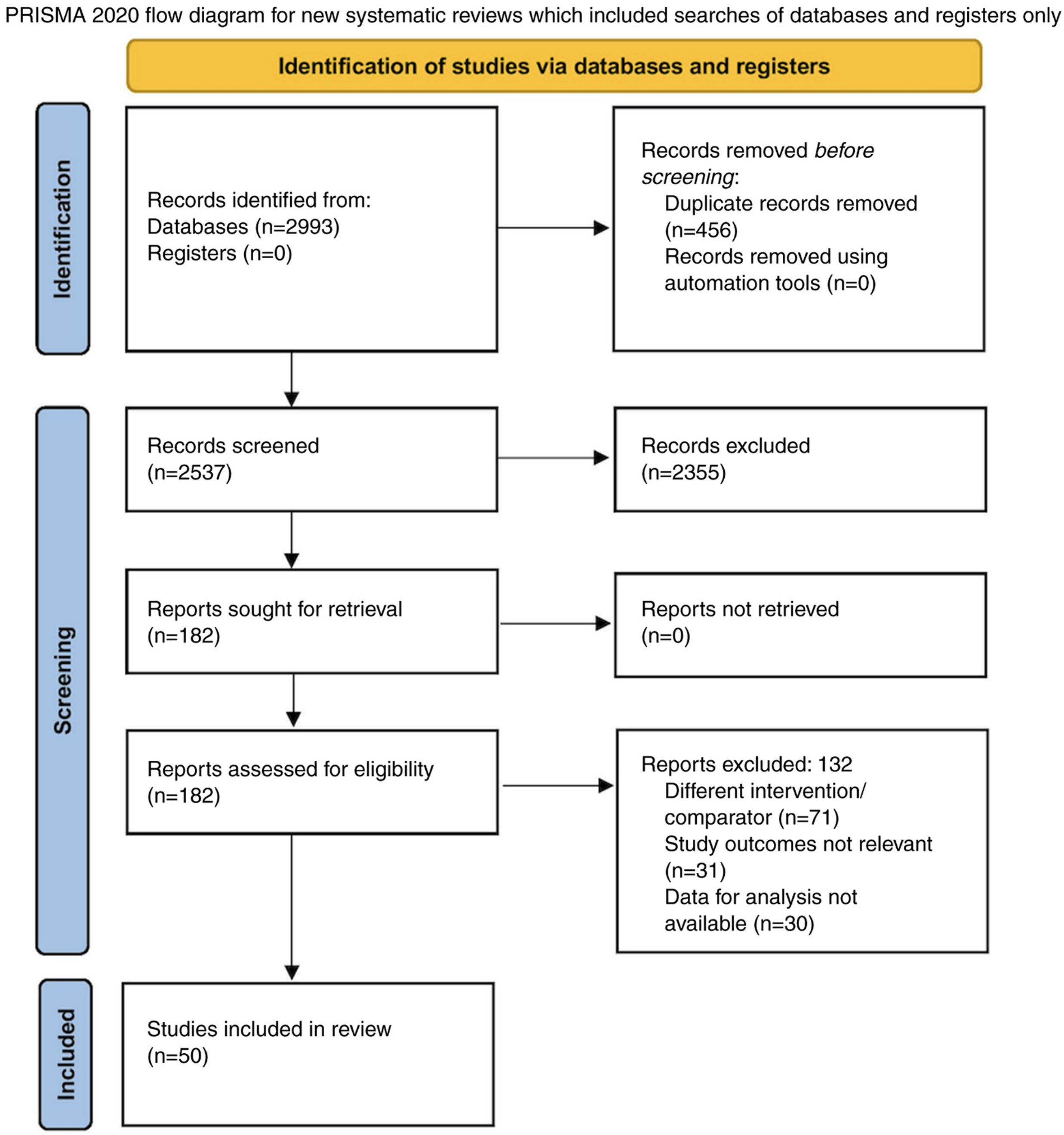

Figure 1. PRISMA flowchart.

was 1.09, with 95% CI ranging from 0.92 to 1.29 (Fig. 2). The analysis demonstrated a non-significant overall effect (P=0.31), suggesting that there is no conclusive difference between mechanical and manual CPR on ROSC. There was substantial heterogeneity among the studies, as evidenced by an I^2 value of 95.3%. Subgroup analysis based on study design did not reveal any difference in the extent and direction of the pooled effect size (Fig. S1). The pooled estimates from both RCTs and non-RCTs revealed non-significant difference between mechanical and manual CPR in terms of ROSC. Subgroup analysis based on type of mechanical device revealed that the Autopulse subgroup had the most pronounced effect with an OR of 1.63 (95% CI: 1.20 to 2.22; Fig. S2).

Funnel plot (Fig. S3) revealed an asymmetrical plot, indicating the possibility of publication bias. Egger's test was performed to confirm these findings and it was found that the coefficient for the slope is -0.21 with a standard error of 0.09. This slope coefficient represents the relationship between the effect sizes and their precision (inversely related to the standard error). A negative coefficient suggests a trend where smaller studies (with larger standard errors) tend to report larger effect sizes. The P=0.02, which is less than the conventional threshold of 0.05, indicating that the relationship is statistically significant. This suggests that there is evidence of small-study effects in the data.

The bias coefficient (intercept) is 1.56 with a standard error of 0.97, and a P=0.12. This P≥0.05, indicating that the bias coefficient is not statistically significant. This means that while

Table I. Characteristics of the included studies (N=50).

Author and Year	Study design	Country	Nation wide Study	Sample Size (overall)	Sample size in mechanical CPR	Sample size in manual CPR	Type of mechanical device	CPR guideline	Risk of bias	(Refs)
Ahn *et al*, 2023	Prospective cohort	Korea	No	3,519	2,759	760	NR	NR	Low	(43)
Anantharaman *et al*, 2017	Cluster RCT	Singapore	No	1,191	302	889	LUCAS	2010 ILCOR	Some concerns	(44)
Axelsson *et al*, 2006	Prospective cohort	Sweden	No	210	105	105	LUCAS	2000 AHA	Low	(23)
Axelsson *et al*, 2013	Retrospective cohort	Sweden	No	1,165	702	463	LUCAS	NR	High	(29)
Buckler *et al*, 2016	Retrospective cohort	USA	No	80,690	17,625	63,065	NR	NR	High	(21)
Canakci *et al*, 2021	Non-RCT		No	178	47	131	LUCAS-2	NR	Low	(63)
Casner *et al*, 2005	Retrospective cohort	USA	No	162	69	93	Autopulse	NR	Low	(49)
Chen *et al*, 2021	Retrospective cohort	Taiwan	No	552	279	273	LUCAS	2015 AHA	High	(48)
de Wilde *et al*, 2008	Prospective	Netherlands	No	220	102	118	LUCAS	NR	Low	(58)
Dickinson *et al*, 1998	RCT	USA	No	17	7	10	Thumper	NR	High	(27)
Gao *et al*, 2016	Cluster RCT	China	No	133	69	64	Autopulse	2010 AHA	Some concerns	(24)
Halhalli *et al*, 2020	Retrospective	Turkey	No	818	473	345	LUCAS	NR	High	(47)
Hallstrom *et al*, 2006	Cluster RCT	USA and Canada	No	767	394	373	Autopulse	2000 AHA	Some concerns	(34)
Hardig *et al*, 2017	RCT	Sweden	No	757	374	383	LUCAS	NR	Low	(42)
Hayasida *et al*, 2017	Prospective	Japan	No	6,537	918	5,619	LUCAS and Autopulse	NR	Low	(36)
Jennings *et al*, 2012	Retrospective cohort	Australia	No	286	66	220	Autopulse	NR	High	(20)
Jin *et al*, 2019	Retrospective	China	Yes	493	214	279	NR	NR	Low	(52)
Jung *et al*, 2019	Prospective cohort	Korea	Yes	31,011	2,357	28,654	Autopulse/ LUCAS	NR	Low	(37)
Karasek *et al*, 2020	Prospective	Czech Republic	No	278	144	134	LUCAS	NR	High	(33)
Kim *et al*, 2024	Multi-center observational	Korea	Yes	842	421	421	NR	NR	Low	(45)
Lairet *et al*, 2005	Retrospective review	USA	No	406	49	357	Autopulse	NR	High	(56)
Lin *et al*, 2015	Retrospective cohort	Taiwan	No	404	216	188	Life-Stat 1008	NR	Low	(26)

Table I. Continued.

Author and Year	Study design	Country	Nation wide Study	Sample Size (overall)	Sample size in mechanical CPR	Sample size in manual CPR	Type of mechanical device	CPR guideline	Risk of bias	(Refs)
Liu *et al*, 2016	RCT	China	No	71	33	38	LUCAS	NR	Low	(62)
Lu *et al*, 2010	RCT	China	No	150	76	74	Thumper modal 1007	NR	Some concerns	(67)
Mastenbrook *et al*, 2022	Retrospective	USA	No	264	190	74	LUCAS-2	NR	Low	(46)
Maule *et al*, 2007	Retrospective cohort	Belgie	No	290	150	140	LUCAS	NR	High	(53)
Morozov *et al*, 2012	Retrospective	Russia	No	472	398	74	Autopulse	NR	Low	(61)
Newberry *et al*, 2018	Retrospective cohort	USA	No	2,999	763	2,236	LUCAS	NR	Low	(41)
Ong *et al*, 2006	Prospective cohort	USA	No	777	278	499	Autopulse	NR	Low	(54)
Ong *et al*, 2012	Prospective cohort	Singapore	No	1,011	552	459	Autopulse	NR	High	(30)
Ornato *et al*, 2005	Retrospective	USA	No	1,086	79	1,007	Autopulse	NR	Low	(57)
Paradis *et al*, 2009	Retrospective cohort	USA	Yes	1,020	729	291	Autopulse	NR	Low	(59)
Perkins *et al*, 2015	Cluster RCT	United Kingdom	No	4,471	1,652	2,819	LUCAS	2005/2010 ERC	Some concerns	(40)
Primi *et al*, 2023	Retrospective	Italy	No	4,292	2,146	2,146	LUCAS, Autopulse, Easypulse	NR	High	(51)
Rubertsson *et al*, 2014	RCT	Sweden, United Kingdom, Netherlands	No	2,589	1,300	1,289	LUCAS	2005 ERC	High	(39)
Saleem *et al*, 2022	Retrospective	Israel	No	107	62	45	LUCAS	NR	Low	(66)
Satterlee *et al*, 2013	Retrospective cohort	USA	No	572	498	74	LUCAS	NR	High	(28)
Savastano *et al*, 2019	Prospective cohort	Italy	No	1,401	235	1,166	Autopulse	NR	Low	(32)
Schmidbauer *et al*, 2017	Prospective cohort	Sweden	Yes	13,922	6,961	6,961	LUCAS	2010 ERC	Low	(50)
Seewald *et al*, 2019	Retrospective cohort	Germany	Yes	17,957	872	17,085	LUCAS/ Autopulse	NR	High	(18)
Smekal *et al*, 2011	RCT	Sweden	No	148	75	73	LUCAS	2000 ERC	Some concerns	(19)

Table I. Continued.

Author and Year	Study design	Country	Nation wide Study	Sample Size (overall)	Sample size in mechanical CPR	Sample size in manual CPR	Type of mechanical device	CPR guideline	Risk of bias	(Refs)
Steinmetz *et al*, 2008	Retrospective case-control	Denmark	No	419	77	342	Autopulse	NR	Low	(31)
Swanson *et al*, 2006	Retrospective review	USA	No	876	269	607	Autopulse	AHA 2000	High	(55)
Takayama *et al*, 2023	Retrospective	Japan	No	1,101	319	782	LUCAS-3	2015 or 2020 AHA and ERC Guidelines	Low	(64)
Tantarattana-pong *et al*, 2022	Retrospective cohort	Thailand	No	168	32	136	LUCAS-3	2015 AHA	Low	(25)
Truhlar *et al*, 2010	Prospective	Czech Republic	No	30	19	11	LUCAS/ Autopulse	NR	Low	(60)
Ujvárosy *et al*, 2018	Retrospective cohort	Hungary	No	287	55	232	LUCAS	NR	High	(22)
Viniol *et al*, 2020	Retrospective	Germany	No	64	32	32	Autopulse	Recomm-endations of the European Council for Resusci-tation	Low	(65)
Wik *et al*, 2014	RCT	Norway	No	4,231	2,099	2,132	Autopulse	2005 ERC/ AHA	Low	(35)
Zeiner *et al*, 2015	Prospective cohort	Austria	No	938	283	655	LUCAS/ Autopulse	NR	Low	(38)

CPR, cardiopulmonary resuscitation; NR, not reported; RCT, randomized controlled trial; ILCOR, International Liaison Committee on Resuscitation Guidelines; AHA, American Heart Association; ERC, European Resuscitation Council.

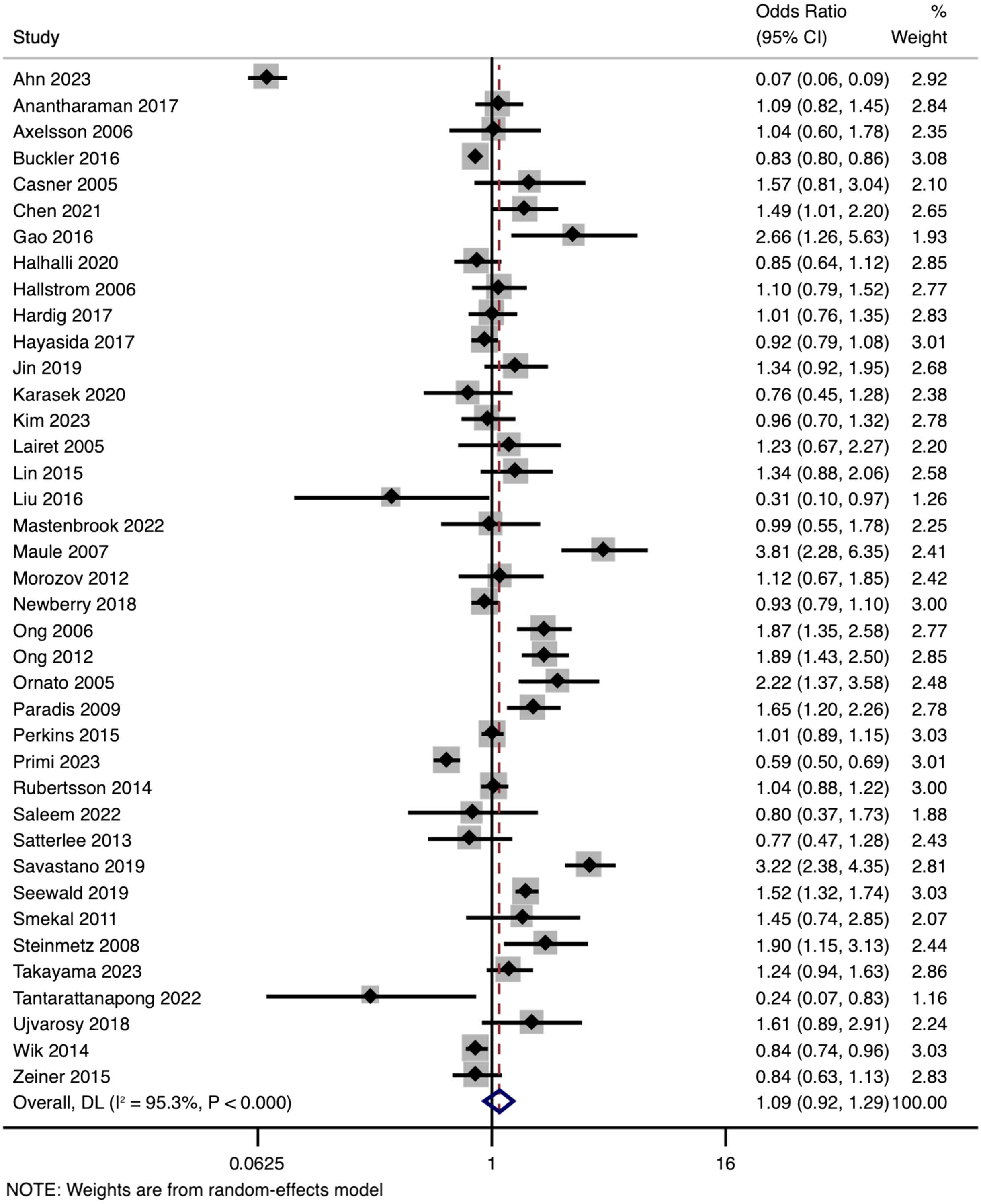

Figure 2. ROSC in Out-of-Hospital Cardiac Arrest: Comparison of Mechanical vs. Manual CPR. This figure presents a forest plot comparing the OR and 95% CI for ROSC among patients receiving mechanical CPR vs. manual CPR. The pooled OR and overall effect size are demonstrated, indicating no significant difference between the two methods. CI, confidence interval; ROSC, return of spontaneous circulation; OR, odds ratio; CPR, cardiopulmonary resuscitation.

there is a trend for smaller studies to report larger effects, it is not strong enough to conclusively indicate publication bias. The overall P-value for the test of no small-study effects is 0.12. This is above the conventional alpha level of 0.05, suggesting that there is no significant evidence of small-study effects. However, since the value is relatively close to 0.05, it warrants cautious interpretation and suggests a possible but not definitive presence of small-study effects.

Since the funnel plot and Egger's test provided inconclusive evidence, Doi plot and LFK index was performed to obtain conclusive evidence on publication bias. The Doi plot (Fig. S4) revealed major asymmetry which was further confirmed by higher LFK index of 2.62. Using the trim and fill method, the adjusted random-effects pooled estimate of the effect size (ES) shifted to 0.835 (95% CI: 0.712 to 0.979, P=0.027; Fig. S5). This suggests that after adjusting for publication

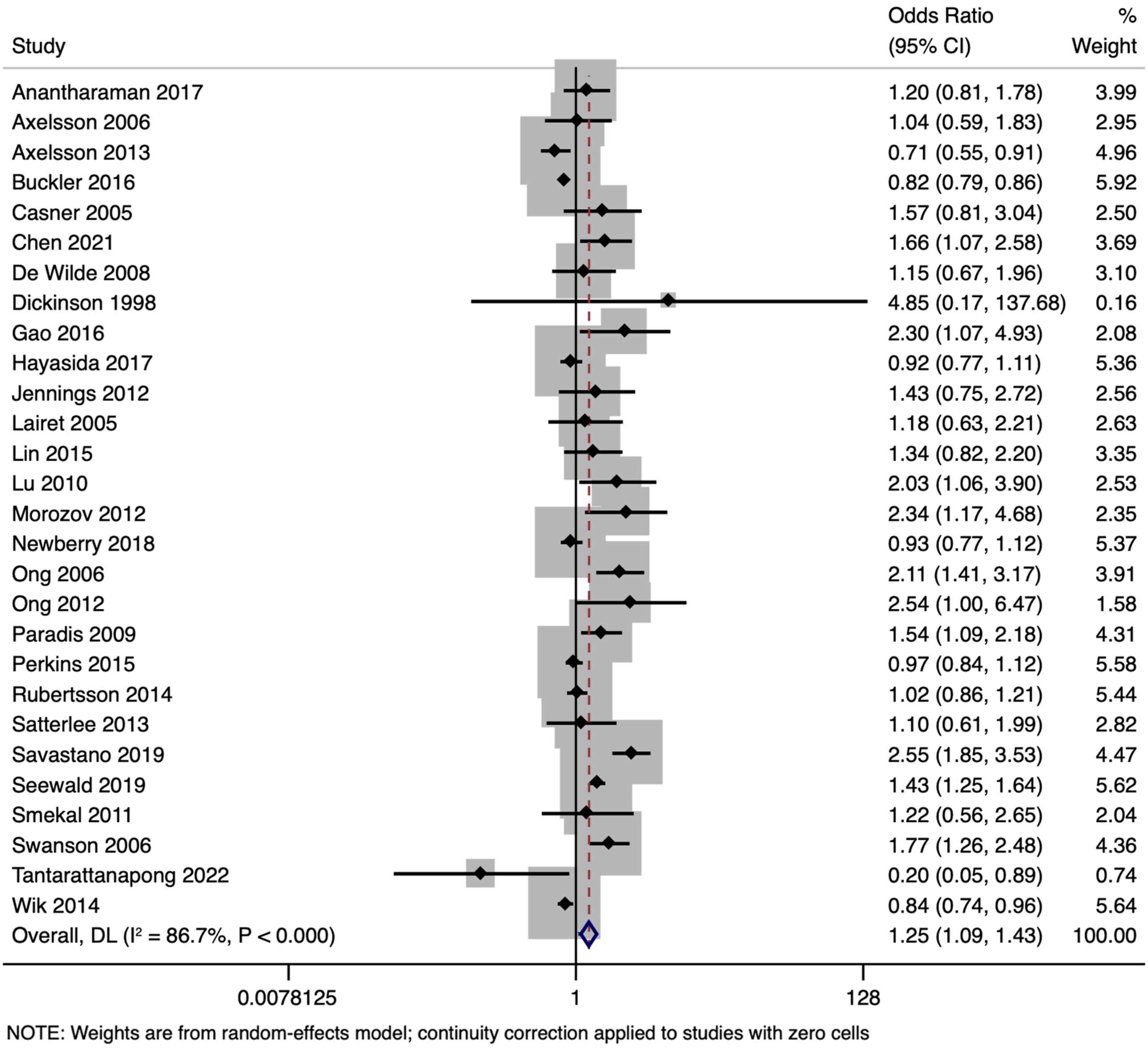

Figure 3. Survival to Admission in Out-of-Hospital Cardiac Arrest: Effectiveness of mechanical vs. manual CPR. This figure demonstrates a forest plot of the pooled odds ratio and 95% CI for survival to hospital admission. The analysis demonstrates a significant positive effect of mechanical CPR compared with manual CPR. CPR, cardiopulmonary resuscitation; CI, confidence interval.

bias, the results indicate a significant effect, highlighting the potential impact of publication bias on the initial analysis. The leave-one out sensitivity analysis and exclusion of high risk of bias studies did not reveal any significant change either in the form of magnitude or the direction of association.

Survival to admission. A total of 28 studies with 130,499 participants have compared the effectiveness of mechanical against manual CPR on survival till admission amongst patients with OHCA. Pooled OR was 1.25, with 95% CI ranging from 1.09 to 1.43 (Fig. 3). The analysis demonstrated a significant overall effect (P=0.001), suggesting that there is a significant positive effect of mechanical against manual CPR on survival to admission. There was substantial heterogeneity among the studies, as evidenced by an I^2 value of 86.7%. Subgroup analysis based on study design revealed a significant difference in the extent and direction of the pooled ES (Fig. S6). The pooled estimates from RCTs did not demonstrate a significant effect (pooled OR=1.06; 95% CI: 0.90 to 1.26), while non-RCTs revealed significant difference between mechanical and manual CPR (pooled OR=1.30; 95% CI: 1.07 to 1.57). Subgroup analysis based on type of mechanical device (Fig. S7) revealed that the Autopulse subgroup revealed a significantly positive effect, with an OR of 1.7, within CI of 1.21 to 2.37.

Funnel plot (Fig. S8) revealed a clear asymmetrical plot with Egger's test confirming the presence of publication bias with highly significant P<0.001. The Doi plot (Fig. S9) revealed major asymmetry which was further confirmed by higher LFK index=5.79. Using the trim and fill method, the adjusted random-effects pooled estimate of the ES shifted to 1.096 (95% CI: 0.963 to 1.248, P=0.164) (Fig. S10). The leave-one out sensitivity analysis and exclusion of high risk of bias did not reveal any significant change either in the form of magnitude or the direction of association.

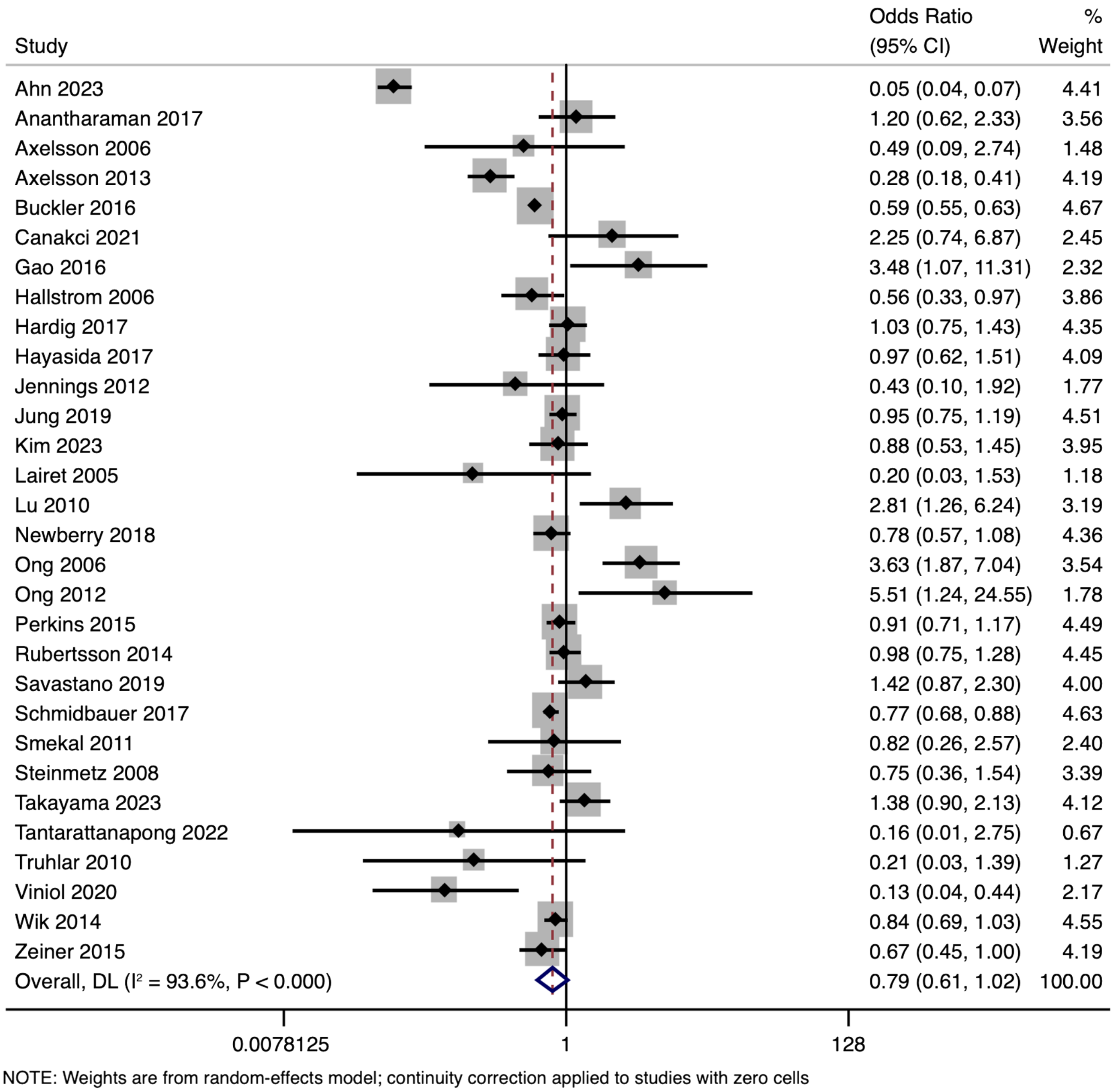

Figure 4. Survival till discharge in Out-of-Hospital Cardiac Arrest: Comparative analysis of mechanical vs. manual CPR. This figure illustrates a forest plot comparing the odds ratios and 95% CIs for survival until discharge. The results indicate no conclusive difference between mechanical and manual CPR in long-term survival. CPR, cardiopulmonary resuscitation; CI, confidence interval.

Survival till discharge. A total of 30 studies with 162,088 participants have compared the effectiveness of mechanical against manual CPR on survival till discharge amongst patients with OHCA. Pooled OR was 0.79, with 95% CI ranging from 0.61 to 1.02 (Fig. 4). The analysis demonstrated a non-significant overall effect (P=0.08), suggesting that there is no conclusive difference between mechanical and manual CPR on survival till discharge. There was substantial heterogeneity among the studies, as evidenced by an I^2 value of 93.6%. Subgroup analysis based on study design revealed a significant difference in the extent and direction of the pooled ES (Fig. S11). The pooled estimates from RCTs did not demonstrate a significant effect (pooled OR=0.99; 95% CI: 0.81 to 1.22), while non-RCTs revealed significant difference between mechanical and manual CPR (pooled OR=0.67; 95% CI: 0.48 to 0.94). Subgroup analysis based on type of mechanical device (Fig. S12) revealed that LUCAS subgroup was the only one showing statistically significant difference, with an OR of 0.78 (95% CI: 0.61 to 0.99).

Funnel plot (Fig. S13) demonstrated a symmetrical plot with Egger's test showing the absence of publication bias with non-significant P=0.37. The Doi plot (Fig. S14) demonstrated minor asymmetry which was further confirmed by higher LFK=1.33. The leave-one out sensitivity analysis and exclusion of high risk of bias did not reveal any significant change either in the form of magnitude or the direction of association.

GRADE assessment results. The GRADE assessment of the present study for the three outcomes studied, began with an initial classification of the evidence as 'low quality'. This starting point was chosen due to the inclusion of observational studies, which inherently carry a higher risk of bias compared with RCTs.

Risk of bias. A significant concern in the analysis of the present study was the risk of bias. For some of the studies, this risk was deemed high, leading to a downgrade in the quality of evidence to 'very low'. The high risk of bias in these studies stemmed from methodological issues that could potentially affect the validity of their findings.

Indirectness of evidence. Another critical factor was the indirectness of the evidence, particularly concerning the study design as there is inclusion of different study designs in the review. However, appropriate subgroup analysis was performed and separate estimates are provided and hence, there is no need to downgrade based on indirectness of the evidence.

Imprecision. For the outcome of survival until admission, there was no imprecision observed. The CIs were robust, and there was no crossing of the null value, which meant that there was no need for a downgrade in this domain. However, for the other two outcomes-ROSC and survival until discharge-the CIs did cross the null value. This crossing indicated a level of imprecision, necessitating a single downgrade in the quality of evidence for these outcomes.

Heterogeneity. All outcomes exhibited significant heterogeneity. While the subgroup analysis explained some of this variability, it did not account for all of it. This unexplained heterogeneity led to a further downgrade in the quality of evidence.

Publication bias. Finally, the assessment of the present study revealed the presence of publication bias across all outcomes. This bias was evidenced by the Egger's test results and visual inspection of the funnel plots. The presence of publication bias introduces a systematic error that could skew the overall findings, leading to a further downgrade in the quality of evidence.

Overall quality of evidence. Considering these factors, the overall quality of the evidence for all three outcomes was determined to be 'very low'. The cumulative impact of the high risk of bias in some studies, the imprecision in certain outcomes, the significant heterogeneity, and the presence of publication bias all contributed to this final assessment. The 'very low' quality rating indicates that there is substantial uncertainty about the accuracy of the effect estimates for these outcomes.

Discussion

The present meta-analysis, encompassing a comprehensive examination of the effectiveness of mechanical vs. manual CPR in patients with OHCA, offers critical insights into three primary outcomes: ROSC, survival to admission and survival till discharge. For ROSC, 39 studies involving 144,430 participants indicated no statistically significant difference between mechanical and manual CPR. This finding suggests that mechanical CPR does not confer a significant advantage over manual CPR in improving the likelihood of ROSC in OHCA. The substantial heterogeneity observed and the inconclusive evidence of publication bias further complicate the interpretation of this outcome.

For ROSC, previous reviews on this topic has also reported no significant difference between mechanical and manual CPR, consistent with the findings of the present study (8-11). However, the present analysis adds to the existing body of knowledge by incorporating a larger sample size and more recent studies, providing a more comprehensive overview. The absence of a significant difference between mechanical and manual CPR in achieving ROSC can be attributed to several factors. Mechanical CPR devices are designed to deliver consistent, uninterrupted chest compressions, theoretically offering an advantage over manual CPR, where fatigue and variability in compression quality are concerns (7). However, the transition from manual to mechanical CPR involves a pause, potentially negating the benefits of consistency. Furthermore, the mechanical nature of these devices may not adequately adjust to individual patient anatomies or the dynamic physiological conditions during resuscitation, possibly impacting their efficacy (68).

In terms of survival to admission, 28 studies with 130,499 participants revealed a significant positive effect of mechanical CPR over manual CPR. This result is of particular interest as it indicates a potential advantage of mechanical CPR in the initial stages post-resuscitation. However, the high heterogeneity and the clear evidence of publication bias identified necessitate cautious interpretation. The findings of the present study for survival to admission were in line with several previous reviews (8-11,69) that did identify a significant advantage of mechanical over manual CPR in the early post-resuscitation period.

The observed advantage of mechanical CPR in improving survival to admission could be due to the sustained and consistent quality of compressions, particularly important during transport and in prolonged resuscitation efforts where manual CPR effectiveness may wane due to rescuer fatigue. Mechanical CPR ensures a constant compression depth and rate, which are critical in the early stages of cardiac arrest management (7). This consistency could lead to improved coronary perfusion and short-term outcomes, such as survival to admission.

For survival till discharge, data from 30 studies involving 162,088 participants did not reveal a conclusive difference between the two CPR methods. This outcome aligns with the findings for ROSC, suggesting that the long-term benefits of mechanical CPR in improving survival rates may not be significantly different from manual methods (8-11,69).

The lack of a significant difference in survival till discharge between mechanical and manual CPR suggests that while mechanical devices may offer short-term benefits, these do not necessarily translate into long-term survival advantages. This outcome might reflect the multifactorial nature of long-term survival post-cardiac arrest, where factors such as the quality of post-resuscitation care, underlying health conditions, and the initial cause of the cardiac arrest play significant roles (70,71).

The variations in findings across different studies and outcomes can be attributed to several factors. The type of mechanical CPR device used, the training and experience of the personnel administering CPR, and the specific circumstances of each cardiac arrest incident (such as the location and cause of arrest) are all likely to influence outcomes. Additionally, the high degree of heterogeneity observed in the present study and others underscores the complexity of comparing mechanical and manual CPR across diverse clinical settings and populations. The alignment of the present study and deviation from previous literature highlight the ongoing debate and the need for further research in this field. The mixed results across different outcomes suggest that the effectiveness of mechanical vs. manual CPR may vary depending on the specific context and metrics of success being measured.

Strengths and limitations of the study. The present meta-analysis included a substantial number of studies and participants, enhancing the statistical power and generalizability of the findings. By incorporating both RCTs and non-RCTs, the study provided a broad overview of the existing evidence. The use of advanced statistical tools such as Egger's test, Doi plot and LFK index added robustness to the present study's assessment of publication bias and data synthesis. However, significant heterogeneity was observed among the studies, potentially impacting the consistency and applicability of the findings. Indications of publication bias, particularly in some outcomes, could have skewed the results. Differences in the types of mechanical CPR devices used and variations in manual CPR technique across studies may have influenced the outcomes. Most studies focused on immediate or short-term outcomes, with less emphasis on long-term survival.

The high heterogeneity observed in the present meta-analysis can be attributed to several factors. The present analysis included a mix of RCTs, quasi-experimental trials, non-randomized studies, and observational studies. The methodological differences across these study designs contribute to heterogeneity. Various mechanical CPR devices, such as LUCAS and AutoPulse, were used across the studies. These devices have different operational mechanisms and efficacy, which could lead to variability in outcomes. Differences in the demographics and clinical characteristics of study populations, such as age, comorbidities and initial cardiac arrest rhythms, can significantly affect the results and contribute to heterogeneity. The context in which CPR was administered, including pre-hospital settings vs. in-hospital settings, and variations in EMS protocols, can also influence the outcomes and add to heterogeneity. Variability in the definitions and measurements of outcomes, such as ROSC, survival to admission and survival till discharge, across different studies, can lead to inconsistencies in the results. A significant number of included studies exhibited a high risk of bias.

This high risk of bias could influence the reliability and validity of the findings and should be considered when interpreting the results. The presence of publication bias, particularly in the survival to admission outcome, is a significant concern in this meta-analysis. Publication bias can lead to an overestimation of the effectiveness of mechanical CPR due to the preferential publication of studies with positive results. This bias impacts the study's conclusions by potentially skewing the overall effect estimates and reducing the reliability of the findings. Another limitation of the present review is that the authors focussed mainly on the short-term outcomes, while the long-term outcomes were not considered for the review.

The GRADE approach was used to assess the quality of evidence, and the very low quality of evidence for all outcomes raises questions about the strength of the recommendations that can be made based on this analysis. The implications of this low-quality evidence on clinical practice are significant. The very low quality of evidence suggests that there is substantial uncertainty about the effect estimates, making it difficult to draw definitive conclusions or provide strong clinical recommendations. Clinicians should be cautious when interpreting these findings and consider them as part of a broader clinical context that includes individual patient circumstances, available resources and other relevant clinical guidelines.

To overcome these limitations and enhance the evidence base, future studies should aim to standardize study designs and methodologies. Conducting more RCTs with similar protocols can help reduce heterogeneity and provide more robust evidence. Studies should aim to use the same type of mechanical CPR device or, at the very least, provide detailed descriptions and comparisons of the devices used. This will help in improved understanding of the efficacy of specific devices. Ensuring homogeneity in study populations by setting clear inclusion and exclusion criteria can help minimize variability. Stratifying results based on key demographic and clinical characteristics can also provide more nuanced insights. Adopting standardized definitions and measurement criteria for outcomes across studies can reduce discrepancies and improve the comparability of results.

Implications for clinical practice and research. Given the very low quality of evidence and the significant heterogeneity observed in this meta-analysis, translating these findings into clinical practice requires careful consideration. The variability in study designs, populations and intervention protocols complicates the generalizability of the results. Despite these limitations, some suggestions can be made regarding the potential contexts in which mechanical CPR might be preferred over manual CPR. Mechanical CPR may be more effective during prolonged resuscitation efforts where consistent, high-quality compressions are critical, and rescuer fatigue is a significant concern. During patient transport, mechanical CPR can provide continuous and consistent chest compressions, which are challenging to maintain manually. It can be used in situations where limited personnel is available to perform high-quality manual CPR, mechanical devices can ensure the delivery of effective compressions, in settings with well-trained staff in high-performance CPR may observe less difference between manual and mechanical methods, but in less controlled environments, mechanical CPR might offer more consistent results.

Given the current evidence, clinicians should weigh these factors and consider individual patient circumstances, available resources, and existing clinical guidelines when deciding between mechanical and manual CPR. Further research with higher-quality studies is needed to provide more definitive recommendations and to improve understanding of the specific contexts in which mechanical CPR may be most beneficial. Future studies should report the training level uniformly in their trials, ensuring that the reviews can undertake separate subgroup analysis based on training level of the healthcare providers. Finally, the current review focusses exclusively on short term outcomes, and hence the future reviews can focus on the long-term outcomes between these interventions.

Given the variability in outcomes, a personalized approach to CPR, considering patient-specific factors such as the underlying cause of arrest and physiological differences, is crucial. Since the long-term survival benefits of mechanical CPR are not significantly different from manual CPR, emphasis should also be placed on the quality of post-resuscitation care, including advanced cardiac life support and critical care management.

Further studies should explore the physiological and biomechanical mechanisms behind the effectiveness of different CPR methods to enhance understanding and improve techniques. Research should also focus on the development and testing of new CPR technologies, including more advanced mechanical devices that can better adapt to patient-specific needs and resuscitation scenarios.

The present study underscored the complexity of CPR methods in OHCA and the importance of context in choosing between mechanical and manual CPR. It highlights the need for ongoing research and training in both methods, ensuring that healthcare providers are equipped to make the best decisions for their patients. Ultimately, the goal is to improve the outcomes of OHCA patients, making every second and every action count in these critical situations.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

XZ and JF made substantial contributions to the conception and design of the present study, the acquisition, analysis and interpretation of data for the present meta-analysis. Both authors drafted the work and revised it critically for important intellectual content. Both authors read and approved the final manuscript and confirm the authenticity of all the raw data.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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