


REVIEW ARTICLE

# Does Autopulse Mechanical chest compression improve outcomes after cardiac arrest? A systemic review and meta-analysis

Qasem Ahmed Almulihi<sup>1\*</sup> , Asaad Suliman Shujaa<sup>2</sup>, Bader Jameel Aldossary<sup>1</sup>, Mohammad Ibrahim Faya Assiri<sup>1</sup>, Abdullah Ahmed T. Al Bahrani<sup>3</sup>, Shahd Ali Al Rashed<sup>4</sup>, Fawaz Hassan Alali<sup>5</sup>, Abdullah Ali Alaithan<sup>5</sup>, Ghanem Mohammed Aldubayyan<sup>5</sup>, Mohammed Ali Alaithan<sup>6</sup>, Hussain Ali AlBakhite<sup>7</sup>, Yaser Mohammed Hussain Alsultan<sup>8</sup>, Huda Saud Mohammed Al Nemer<sup>9</sup>, Fatimah Saud Alfaraj<sup>10</sup>, Ayub Salman Mohammed Alabdullah<sup>11</sup>

## ABSTRACT

**Background:** Cardiac arrest remains a critical global health challenge, necessitating effective interventions to improve outcomes. Autopulse Mechanical chest compression (CC) has emerged as a potential adjunct to conventional manual cardiopulmonary resuscitation (M-CPR). This study aimed to comprehensively investigate the association between Autopulse use and various outcomes following cardiac arrest.

**Methods:** A thorough literature review was conducted using PubMed, Embase, Scopus, Google Scholar, CINAHL, and the Cochrane Library. Articles were evaluated for eligibility according to predefined criteria. The collected data was synthesized, and the findings were subsequently presented.

**Results:** Sixteen studies were included in the study. A synthesis of diverse studies revealed nuanced perspectives on Autopulse Mechanical CC. Enhanced cardiopulmonary resuscitation success and improved survival rates in out-of-hospital cardiac arrest were demonstrated, while potential drawbacks were suggested, warranting scrutiny of device design and implementation strategies. Meta-analyses on the return of spontaneous circulation favored Autopulse, indicating a statistically significant advantage over M-CPR (relative risk 1.43, 95% CI 1.07-1.92). Complication analyses showed no significant difference (relative risk 1.11, 95% CI 0.93-1.33), emphasizing comparable safety profiles. Patient survival rates exhibited variations, with Autopulse demonstrating higher rates in some studies, but nuances were observed in 30-day survival and hospital discharge rates.

**Conclusion:** Autopulse Mechanical CC holds promise as a supplementary strategy in cardiac arrest resuscitation. However, complexities arose in longer-term outcomes, highlighting the need for contextual considerations.

**Keywords:** Cardiac arrest, cardiopulmonary resuscitation, device, meta-analysis.

## Introduction

Cardiac arrest stands as a critical medical emergency, necessitating prompt intervention to optimize patient outcomes [1]. For more than five decades, cardiopulmonary resuscitation (CPR) has stood as a well-known and acknowledged emergency intervention in instances of cardiac arrest [2,3]. The cornerstone of CPR involves manual chest compressions (CCs), a procedure

**Correspondence to:** Qasem Ahmed Almulihi

\*ER Department, King Fahad University Hospital, AlKhobar, Saudi Arabia.

**Email:** qasem.almulihi@hotmail.com

*Full list of author information is available at the end of the article.*

**Received:** 02 January 2024 | **Accepted:** 03 January 2024



integral to restoring circulation [4]. Annually, in the United Kingdom, around 35,000 individuals experience an in-hospital cardiac arrest, with a mere 18.4% surviving until discharge from the hospital [5]. The caliber of CCs is a crucial factor that can be modified to influence survival rates after a cardiac arrest [6]. However, challenges associated with the consistency and efficacy of manual compressions have prompted exploration into alternative methods to enhance resuscitative efforts.

Despite the crucial role of CPR in cardiac arrest management, conventional manual CCs present inherent limitations. Variability in compression depth, rate, and interruptions can compromise the effectiveness of resuscitation efforts, leading to suboptimal outcomes. Over the last few decades, researchers have persisted in investigating the ideal depth and rate of CCs. As a result, the American Heart Association has advocated that CCs be conducted at a depth ranging from 5 to 6 cm and at a frequency between 100 and 120 compressions per minute, as indicated in its CPR Guidelines [7]. The quest for improved resuscitation strategies has given rise to innovative technologies, among which Autopulse Mechanical CC has garnered attention.

During the early 2000s, the US Food and Drug Administration approved two mechanical compression devices, namely AutoPulse and LUCAS, aiming to address the challenges associated with manual CCs. The AutoPulse device is characterized as a load-distributing band (LDB) mechanism featuring broadband that encircles the chest wall. This band is automated to alternate between shortening and lengthening, facilitating the provision of compressions. The Autopulse system introduces a mechanized approach to CCs, aiming to address the limitations associated with manual techniques. This automated system is designed to deliver consistent and high-quality CCs, potentially overcoming challenges encountered during manual CPR (M-CPR) [8].

While several studies have investigated the use of Autopulse in the context of cardiac arrest, the existing literature reveals a landscape marked by varying methodologies and, at times, conflicting findings. Recent randomized clinical trials (RCTs) did not show enhanced patient survival rates with mechanical CPR compared to M-CPR controls [9,10]. This observation is consistent with recent systematic reviews and meta-analyses [11,12]. Unfortunately, some studies even indicated that mechanical compressions might be linked to higher instances of injuries compared to M-CPR, potentially influencing survival outcomes [13,14].

In light of the inconsistencies in the current literature, the systematic review and meta-analysis will provide a comprehensive and evidence-based assessment of Autopulse's impact on post-cardiac arrest outcomes. By clearly understanding the existing evidence, this study endeavors to contribute valuable insights to clinical practitioners and researchers, informing future resuscitation strategies and fostering improved patient care.

### ***Research objectives***

The primary objectives are to synthesize the current state of evidence regarding the association between the

utilization of Autopulse Mechanical CC and enhanced outcomes, including but not limited to survival rates, return of spontaneous circulation (ROSC), quality of CPR, complications and adverse events, duration of resuscitation, cost-effectiveness, and neurological outcomes.

### ***Research question***

Is the use of Autopulse Mechanical CC associated with improved outcomes, such as survival rates, ROSC, quality of CPR, complications and adverse events, duration of resuscitation, cost-effectiveness, and neurological outcomes, compared to conventional manual CCs in patients who have experienced cardiac arrest?

## **Methodology**

### ***Search strategy***

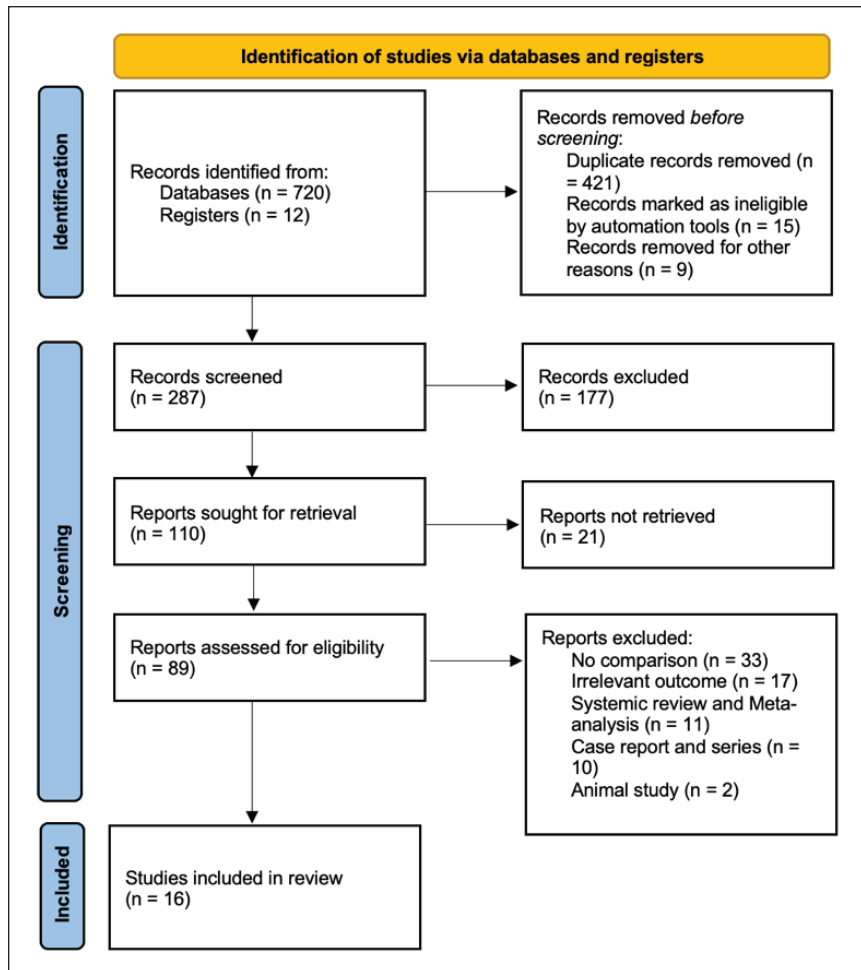
A pre-established protocol was employed, adhering to the guidelines outlined in the preferred reporting items for systematic reviews and metaanalyses (PRISMA) statement, ensuring transparency and replicability in our literature search and synthesis (Figure 1). The review protocol has been duly registered in Inplasy under the registration number INPLASY202410002. We conducted a comprehensive search across multiple databases, namely PubMed, Embase, Scopus, Google Scholar, CINAHL, and the Cochrane Library, encompassing articles published up to December 2023. Within all electronic databases, we implemented a meticulously designed search strategy, querying the following key terms (in the title/abstract, keywords, and their associated MeSH subheadings) with appropriate constraints: “CPR” AND “out-of-hospital cardiac arrests (OHCA)” AND “AutoPulse devices” AND “ROSC.” To further ensure completeness, we meticulously examined the reference lists of the included studies and relevant reviews identified through our search. We also explored available gray literature, thus striving for comprehensive coverage and saturation in our investigation.

### ***Data collection and analysis***

Data selection and extraction were carried out collaboratively by pairs of autonomous reviewers, with the findings subsequently validated by a third reviewing author. Any disparities that arose were subject to thorough discussion and resolution through team consensus. In presenting the outcomes in this systematic review, the authors diligently adhered to the prescribed recommendations outlined in the quality of reporting of the meta-analysis statement. Information was collected from each study using a form and a database created explicitly for this study, utilizing a Microsoft Excel spreadsheet. Data extracted included article information (Author, year of publication, study design, study setting, country, sample size, and results/outcome).

### ***Eligibility criteria***

In our study, we considered specific criteria for inclusion:



**Figure 1.** PRISMA 2020 flow diagram for new systematic reviews, which included searches of databases and registers only [29]

We focused on research involving adults, specifically those aged 18 years or older, who had experienced cardiac arrests outside of a hospital setting.

These studies compared the outcomes of utilizing AutoPulse devices versus manual CCs.

We did not limit our selection to any particular language or country; studies from any linguistic background and countries with advanced emergency medical services (EMSs) services were eligible for inclusion.

Excluded from consideration were case reports, narrative reviews, commentaries, letters, abstracts, studies that used mannequins or animals, and investigations involving mechanical devices other than AutoPulse for resuscitation.

Our interest centered on patients in nontraumatic situations who received CCs through mechanical devices, while the control group consisted of similar patients receiving manual CCs. This approach allowed us to comprehensively assess the effectiveness of AutoPulse compared to manual methods in OHCA scenarios.

### Statistical analyses

We selected ROSC lasting 20 minutes or more following resuscitation in OHCA as the primary outcome. Our rationale was that this outcome most directly reflects

the immediate effects of CPR. Long-term outcomes, such as survival until discharge and neurological results, were more likely influenced by post-resuscitation care. Cohen's *d* was chosen as the statistical measure of the effect size. To assess heterogeneity among studies, we computed  $I^2$ , where values of 25%, 50%, and 75% denoted mild, moderate, and substantial heterogeneity, respectively. In this meta-analysis, log [odds ratio (OR)] and SE were considered the optimal approach. Review Manager 5.4 was employed for the meta-analysis, calculating the OR to measure the association between the intervention and control outcomes. A random-effect model was utilized, and a significance threshold of a *p*-value of 0.05 was adopted.

### Risk of bias assessment

The included studies were thoroughly assessed using the Cochrane Quality Rating Scale and the Newcastle Ottawa Scale (NOS) adopted by Zhu et al. [11] RCTs were assessed using the Cochrane scale, which evaluates random sequence generation, randomized concealment, blinding procedures, and outcome description (Tables 1 and 2). The NOS scale was applied for observational studies, considering criteria such as cohort/case selection, comparability between groups, and outcome/exposure

**Table 1.** Cochrane quality scale for randomized controlled studies.

Study	Allocation generation	Allocation concealment	Blinding of participants	Blinding of assessors	Outcome complete	Outcome selective	Other biases
Koster et al. [15]	Low	Low	Unclear	Unclear	Moderate	Unclear	Unclear
Gao et al. [16]	Low	High	Unclear	Unclear	Moderate	Unclear	Unclear
Hallstrom et al. [4]	Moderate	Moderate	Unclear	Unclear	Moderate	Unclear	Unclear
Wik et al. [9]	Moderate	Low	Unclear	Unclear	Moderate	Unclear	Unclear

**Table 2.** NOS quality scale for observational studies.

Study	Selection	Comparability	Exposure/ Outcome
Primi et al. [17]	2	1	0
Spiro et al. [18]	2	1	1
Krep et al. [19]	2	0	2
Omori et al. [20]	2	2	1
Gorący et al. [21]	3	2	2
Hayashida et al. [22]	4	2	1
Zeiner et al. [23]	4	2	1
Jennings et al. [24]	4	2	1
Steinmetz et al. [25]	4	2	1
Ong et al. [26]	3	2	1
Hock Ong et al. [27]	4	2	1
Kim et al. [28]	4	2	1

reporting, with a potential score of 9 stars (represented as points). A study could be awarded a maximum of 4 stars for the Selection category, three stars for the outcome/exposure category, and a maximum of 2 stars for comparability.

## Results

### Results of the search

In the systematic review and meta-analysis process, an initial search yielded 732 records. Following the removal of 421 duplicates and another 30 records for various reasons, 287 citations were left for title and abstract screening. Two independent reviewers evaluated these citations, excluding 177 based on pre-established inclusion and exclusion criteria. Efforts to retrieve the full texts for the remaining 110 citations resulted in 21 needing to be attainable. The 89 articles that were accessed underwent a thorough eligibility assessment, which led to the exclusion of 74 for reasons such as lack of comparison groups (34 articles), irrelevance of outcomes (17), being systematic reviews or meta-analyses themselves (11), case reports or series (10), and animal studies (2). After this comprehensive screening process, 16 studies were deemed suitable for inclusion in the final systematic review and meta-analysis.

### Study characteristics

This study included 16 studies (Table 3). These articles, published between 2006 and 2023, employed diverse study designs, including prospective RCTs prospective multicenter observational studies, phased prospective cohorts, retrospective case-control studies, and cohort

studies. The research settings varied, covering both in-hospital and out-of-hospital scenarios across different countries, such as China, Poland, the USA, Canada, Japan, Singapore, Australia, Korea, the Netherlands, Germany, Italy, the UK, and Austria. The sample sizes ranged from 18 to 12,901 participants. The observational studies were of moderate to high quality, while the risk of bias in the included studies was generally unclear (Tables 1 and 2).

### Results of included studies

In a prospective randomized controlled trial conducted by Gao et al. [16], the impact of AutoPulse compared to manual CC for CPR in OHCA patients was assessed. The researchers concluded that using AutoPulse enhances the success of CPR and improves survival rates among individuals experiencing OHCA. However, they noted that further evaluation is needed to determine its effectiveness in strengthening cerebral performance. In a randomized controlled trial conducted by Hallstrom et al. [4], the study compared resuscitation outcomes in OHCA cases where an automated LDB cardiopulmonary resuscitation (LDB-CPR) device was incorporated into standard EMS care, as opposed to M-CPR. The findings led the authors to conclude that the utilization of an automated LDB-CPR device was linked to poorer neurological outcomes and indicated a tendency toward decreased survival compared to M-CPR. They further suggested that additional evaluation is necessary, mainly focusing on the design of the device and the strategies for its implementation. Research conducted by Hayashida et al. [22] aimed to establish a connection between mechanical cardiopulmonary resuscitation (mCPR) administered in the emergency department (ED) and subsequent clinical outcomes. The study's findings revealed that the application of mCPR in the ED correlated with reduced probabilities of achieving positive clinical outcomes following nontraumatic OHCA in adults. In a retrospective observational study conducted by Kim et al. [28], the research aimed to explore prognostic variations between AutoPulse and LUCAS for adult patients experiencing OHCA. The study's conclusion indicated no substantial improvement in the ROSC or survival rates with the use of LUCAS compared to AutoPulse in either subgroup. Furthermore, the study suggested that the in-hospital use of LUCAS might have an adverse impact on survival compared to AutoPulse.

In an observational study conducted by Gorący et al. [21], the efficacy of AutoPulse in patients with shock-resistant ventricular fibrillation was investigated. The study revealed that shock-resistant ventricular fibrillation

**Table 3.** Study descriptor table.

Author (s)	Year of publication	Study design	Setting	Country	Sample size	Results
Gao et al. [16]	2016	Prospective RCT	In hospital	China	133	The ROSC rate of patients with OHCA was significantly higher in the AutoPulse CPR group than in the M-CPR group (44.9% vs. 23.4%; $p = 0.009$ ). The 24-hour survival rate of OHCA patients was significantly higher in the AutoPulse CPR group than in the M-CPR group (39.1% vs. 21.9%; $p = 0.03$ ). The hospital discharge rate of the patients with OHCA was significantly higher in the AutoPulse CPR group than in the M-CPR group (18.8% vs. 6.3%; $p = 0.03$ ).
Goraćy et al. [21]	2022	Prospective multicenter observational study	Out of hospital	Poland	18	The coronary intervention was continued during mechanical resuscitation in 50.0% of patients, 60% of patients survived the procedure, and 27.8% of the patients survived.
Hallstrom et al. [4]	2006	RCT	Out of hospital	USA and Canada	1,071	No difference existed in the primary endpoint of survival to 4 hours between the M-CPR group and the LDB-CPR group overall ( $N = 1071$ ; 29.5% vs. 28.5%; $p = 0.74$ ) or among the primary study population ( $n = 767$ ; 24.7% vs. 26.4%, respectively; $p = 0.62$ ). However, among the primary population, survival to hospital discharge was 9.9% in the M-CPR group and 5.8% in the LDB-CPR group ( $p = 0.06$ , adjusted for covariates and clustering).
Hayashida et al. [22]	2017	Prospective observational	Out of hospital	Japan	6,537	Multivariate analyses revealed that mCPR was associated with a decreased likelihood of survival to hospital discharge [adjusted odds ratio (AOR), 0.40; 95% confidence interval (CI), 0.20-0.78; $p = 0.005$ ], ROSC (AOR, 0.71; 95% CI, 0.53-0.94; $p = 0.018$ ), and hospital admission (AOR, 0.57; 95% CI, 0.40-0.80; $p = 0.001$ ).
Ong et al. [27]	2012	Phased prospective cohort	Out of hospital	Singapore	1,101	The rate of survival to hospital discharge tended to be higher in the LDB-CPR phase (LDB 3.3% vs. Manual 1.3%; AOR, 1.42; 95% CI, 0.47-4.29). There were more survivors in the LDB group with cerebral performance category (CPC) 1 (good) (Manual 1 vs. LDB 12, $p = 0.01$ ). Overall performance category 1 (good) was Manual 1 versus LDB 10, $p = 0.06$ .
Jennings et al. [24]	2012	Retrospective case-control	Out of hospital	Australia	286	Survival to the hospital was achieved in 26% (17/66) of cases receiving A-CPR compared with 20% (43/220) of controls receiving C-CPR and the propensity score-[AOR (95% CI)] was 1.69 (0.79, 3.63).
Kim et al. [28]	2019	Retrospective observational	Out of hospital	Korea	820	LUCAS showed lower survival than AUTOPULSE (OR, 0.23; 95% CI, 0.06-0.84), although it showed no significant association with ROSC. Percutaneous coronary intervention (OR, 6.30; 95% CI, 1.53-25.95) and (target temperature management; OR, 7.30; 95% CI, 2.27-23.49) were the independent factors for survival.
Koster et al. [15]	2017	RCT	In hospital	Netherlands	374	The primary outcome was serious or life-threatening visceral resuscitation-related damage, assessed blind by post-mortem computed tomography scan and/or autopsy or by clinical course until discharge. The primary outcome was observed in 12 of 103 AutoPulse patients (11.6%), 8 of 108 LUCAS patients (7.4%), and 8 of 126 controls (6.4%). Rate difference AutoPulse - control: +5.3% (95% CI - 2.2% to 12.8%), $p = 0.15$ . Rate difference LUCAS - control +1.0% (95% CI - 5.5% to 7.6%), $p = 0.75$ .
Krep et al. [19]	2007	Prospective observational study	Out of hospital	Germany	46	In 25 patients (54.3%) ROSC was achieved, 18 patients (39.1%) were admitted to the intensive care unit (ICU), and 10 patients (21.8%) were discharged from ICU. End-tidal capnography showed significantly higher $etCO_2$ values in patients with ROSC than in patients without ROSC. No injuries were detected after the use of the AutoPulse-CPR.

*Continued*

Author (s)	Year of publication	Study design	Setting	Country	Sample size	Results
Omori et al. [20]	2013	RCT	In hospital	Japan	92	ROSC and survival to hospital discharge were increased in the AutoPulse group compared to the M-CPR group [ROSC, 30.6% (15 patients) vs. 7.0% (3 patients)]; survival to hospital discharge, 6.1% (3 patients) vs. 2.3% (patient)]. In multivariate analysis, the factors associated with ROSC were the use of AutoPulse (OR, 7.22; $p = 0.005$ ) and patients aged $\leq 65$ years (OR, 0.31; $p = 0.042$ ).
Ong et al. [26]	2006	Phased prospective cohort	Out of hospital	USA	783	Patients in the M-CPR and LDB-CPR phases were comparable except for a faster response time interval (mean difference, 26 seconds) and more EMS-witnessed arrests (18.7% vs. 12.6%) with LDB. Rates for ROSC and survival were increased with LDB-CPR compared with M-CPR (for ROSC, 34.5%; 95% CI, 29.2%-40.3% vs. 20.2%; 95% CI, 16.9%-24.0%; AOR, 1.94; 95% CI, 1.38-2.72; for survival to hospital admission, 20.9%; 95% CI, 16.6%-26.1% vs. 11.1%; 95% CI, 8.6%-14.2%; AOR, 1.88; 95% CI, 1.23-2.86; and for survival to hospital discharge, 9.7%; 95% CI, 6.7%-13.8% vs. 2.9%; 95% CI, 1.7%-4.8%; AOR, 2.27; 95% CI, 1.11-4.77).
Primi et al. [17]	2023	Retrospective propensity-score-based study	Out of hospital	Italy	12,901	The rates of ROSC (15% vs. 23%, $p < 0.001$ ) and 30-day survival (6% vs. 14%, $p < 0.001$ ) were lower in the mechanical CPR group. After correction for confounders, Autopulse [OR 2.1, 95%CI (1.6-2.8), $p < 0.001$ ] and LUCAS [OR 2.5, 95%CI (1.7-3.6), $p < 0.001$ ] significantly increased the probability of ROSC, and Autopulse significantly increased the probability of 30-day survival compared to M-CPR [HR 0.9, 95%CI (0.8-0.9), $p = 0.005$ ].
Spiro et al. [18]	2015	Cohort study	In hospital	UK	285	AutoPulse-CPR registry: 285 patients suffered IHCA, 25 received A-CPR. Survival to hospital discharge following C-CPR was 28/260 (11%) and 7/25 (28%) following A-CPR. A-CPR supported invasive procedures in nine patients, two of whom had A-CPR-dependent circulation during transfer to the catheter lab.
Steinmetz et al. [25]	2008	Retrospective case-control	Out of hospital	Denmark	791	30-day survival increased after the implementation from 31/372 (8.3%) to 67/419 (16%), $p = 0.001$ . ROSC at hospital admission, as well as survival to hospital discharge, were obtained in a significantly higher proportion from 23.4% to 39.1%, $p < 0.0001$ , and from 7.9% to 16.3%, $p = 0.0004$ , respectively. Treatment after implementation was confirmed as a significant predictor of better 30-day survival in a logistic regression analysis.
Wik et al. [9]	2014	RCT	Out of hospital	USA	4,219	Sustained ROSC (ED admittance), 24-hour survival, and hospital discharge (unknown for 12 cases) for iA-CPR compared to M-CPR were 600 (28.6%) versus 689 (32.3%), 456 (21.8%) versus 532 (25.0%), 196 (9.4%) versus 233 (11.0%) patients, respectively. The AOR of survival to hospital discharge for iA-CPR compared to M-CPR, was 1.06 (95% CI 0.83-1.37), meeting the criteria for equivalence. The 20 minutes CPR fraction was 80.4% for iA-CPR and 80.2% for M-CPR.
Zeiner et al. [23]	2015	Retrospective case-control	Out of hospital	Austria	948	Patients who received mechanical CC had a significantly worse neurological outcome - measured in the CPC - than the manual CC group (56.8% vs. 78.6%, $p = 0.009$ ). Patients receiving mechanical cc were significantly younger, more were male, and were more likely to have bystander CPR and an initially shock-able ECG rhythm. No difference in the quality of CPR might explain the worse outcome in mechanical cc patients.

was indicative of a probable coronary component contributing to the cardiac arrest. Consequently, the authors concluded that AutoPulse proves to be beneficial in facilitating resuscitation efforts, contributing to a reduction in the time taken to reach the hospital. In a retrospective case-control study conducted by Jennings et al. [24], the rates of survival between conventional cardiopulmonary resuscitation (C-CPR) and automated CPR (A-CPR) using AutoPulse were compared in adults following OHCA. The findings indicated that the utilization of A-CPR led to a higher rate of survival in the hospital in comparison to C-CPR. However, there was a tendency for a lower survival rate to hospital discharge with A-CPR, although these associations did not achieve statistical significance. In a randomized controlled trial conducted by Koster et al. [15], the study focused on assessing the safety of mechanical CC and identifying potential excess damage when compared with manual CC. The researchers concluded that, in the case of LUCAS, there was no evidence to suggest a significant increase in severe or life-threatening visceral damage compared to manual CC. However, in the case of AutoPulse, the study indicated that a definitive conclusion regarding the occurrence of significantly more severe or life-threatening visceral damage compared to manual CC could not be excluded. In a survey conducted by Krep et al. [19], the effectiveness, safety, and practicability of the new automated LDB resuscitation device, AutoPulse, in OHCA were evaluated. The authors concluded that the AutoPulse system proves to be an effective and safe mechanical CPR device that is beneficial in the context of OHCA CPR. Furthermore, the study suggested that A-CPR devices may assume a growing significance in CPR practices in the future, as they ensure the provision of continuous CCs of a consistent quality.

In a study conducted by Omori et al. [20], the efficacy of AutoPulse on cardiopulmonary arrest (CPA) patients during helicopter transport was investigated. The authors found that using AutoPulse in helicopters significantly improved the rate of ROSC in CPA patients. As a result, the utilization of automated CC devices, such as AutoPulse, may be recommended, especially for CPA patients being transported by helicopters. In a study by Ong et al. [26], a comparison of resuscitation outcomes was conducted before and after an urban EMS system transitioned from M-CPR to LDB CPR. The authors concluded that implementing a resuscitation strategy involving LDB-CPR on EMS ambulances is linked with enhanced survival to hospital discharge in adults experiencing out-of-hospital nontraumatic cardiac arrest. In another study conducted by Hock Ong et al. [27], the objective was to compare resuscitation outcomes before and after the transition from M-CPR to LDB CPR. The authors concluded that implementing a resuscitation strategy involving LDB-CPR in an ED setting was associated with improved neurologically intact survival upon discharge in adults experiencing prolonged, nontraumatic cardiac arrest. In a study conducted by Primi et al. [17], the investigation aimed to assess whether the choice of mechanical chest compressor could impact the likelihood of ROSC and 30-day survival in patients experiencing OHCA when compared to standard M-CPR. The

authors concluded that mechanical chest compressors can potentially increase the ROSC rate, particularly in prolonged resuscitation cases. They also highlighted the distinctiveness of the devices, emphasizing that their varied performances could significantly influence patient outcomes. Notably, the load-distributing-band device was identified as the only mechanical chest compressor capable of positively affecting 30-day survival.

In a prospective cohort study conducted by Spiro et al. [18], the primary objectives were to evaluate the proficiency of healthcare staff in using A-CPR during a cardiac arrest scenario at baseline, after re-training, and over time through scenario-based training. In addition, the study aimed to investigate the clinical experience of A-CPR at their institution over 2 years, specifically focusing on details such as invasive cardiac procedures performed, encountered challenges, resuscitation rates, and in-hospital outcomes as recorded in the AutoPulse-CPR Registry. The authors reported that A-CPR demonstrated the potential to offer excellent hemodynamic support and enable concurrent invasive cardiac procedures. Furthermore, they noted the presence of a significant learning curve when integrating A-CPR into clinical practice. In a randomized controlled trial conducted by Steinmetz et al. [25], the findings indicated that introducing new resuscitation guidelines was linked to an enhancement in 30-day survival rates following OHCA. In a study conducted by Wik et al. [9], a comparison between integrated automated LDB CPR (iA-CPR) and high-quality M-CPR was undertaken to ascertain whether they were equivalent, superior, or inferior in terms of survival to hospital discharge. The authors concluded that iA-CPR led to statistically equivalent survival rates to hospital discharge compared to high-quality M-CPR. In a retrospective case-control study conducted by Zeiner et al. [23], the findings revealed that, despite providing high-quality CPR in both manual and mechanical CC groups, patients who received mechanical CCs experienced significantly worse outcomes. Based on the study results, the expected advantages of a higher compression ratio and a more consistent compression depth offered by mechanical CC devices were deemed uncertain.

### ***Return of spontaneous circulation***

The meta-analysis comparing the ROSC between Autopulse Mechanical CC and M-CPR reveals a significant pooled effect with a relative risk of 1.43 (95% CI 1.07-1.92). However, notable heterogeneity is observed ( $Tau^2 = 0.14$ ,  $Chi^2 = 49.79$ ,  $df = 7$ ,  $p < 0.00001$ ;  $I^2=86\%$ ), indicating variability across the included studies. The forest plot demonstrates a significant overall effect with a  $Z$  value of 2.39 ( $p = 0.02$ ), suggesting a favorable impact of Autopulse over M-CPR on achieving ROSC (Figure 2). It is essential to acknowledge the high heterogeneity, and further exploration of contributing factors may be warranted. Despite this, the findings underscore the potential benefit of Autopulse in enhancing the likelihood of achieving ROSC in the context of cardiac arrest. Meanwhile, the funnel plot indicated the publication bias of the review was acceptable (Figure 3).

## Hospital discharge

Table 4 summarizes the percentage of hospital discharge across selected studies comparing Autopulse Mechanical CC to M-CPR. Notably, the studies included in the meta-analysis revealed varying outcomes.

## Survival rates

Table 5 presents the 24-hour patient survival rates and 30-day survival rates from selected studies, comparing outcomes between Autopulse Mechanical CC and M-CPR.

## Complications and adverse events

The meta-analysis comparing complications between Autopulse Mechanical CC and M-CPR reveals a relative risk of 1.11 (95% CI 0.93-1.33). The forest plot demonstrates no significant heterogeneity ( $\text{Chi}^2 = 0.77$ ,  $\text{df} = 3$ ,  $p = 0.86$ ;  $I^2 = 0$ ), indicating consistent findings across studies. The test for the overall effect yields a Z value of 1.17 ( $p = 0.24$ ), suggesting no statistically significant difference in complications between Autopulse and M-CPR (Figure 4). These findings emphasize the comparable safety profiles of Autopulse and M-CPR in terms of rib breakage and chest complications. Meanwhile, the funnel plot indicated the publication bias of the review was acceptable (Figure 5).

## Discussion

The primary aim of this systematic review and meta-analysis was to investigate the association between the use of Autopulse Mechanical CC and various outcomes following cardiac arrest. The comprehensive research question guiding this study was: “Is the use of Autopulse Mechanical CC associated with improved outcomes, such as survival rates, ROSC, quality of CPR, complications and adverse events, duration of resuscitation, cost-effectiveness, and neurological outcomes, compared to conventional manual CCs in patients who have experienced cardiac arrest? Our investigation spanned diverse studies, and the critical findings shed light on the multifaceted impact of Autopulse Mechanical CC on post-cardiac arrest outcomes.

In a prospective randomized controlled trial by Gao et al. [16], Autopulse was associated with enhanced CPR success and improved survival rates in OHCA. However, a call for further evaluation, explicitly focusing on cerebral performance, was noted. Conversely, findings from Hallstrom et al. [4] suggested poorer neurological outcomes and a potential decrease in survival with an automated LDB CPR device, warranting additional scrutiny of device design and implementation strategies. Notably, studies by Kim et al. [28] and Gorący et al. [21] revealed nuanced perspectives, indicating no substantial improvement in outcomes with specific devices and highlighting the benefits of Autopulse in facilitating resuscitation efforts, especially in particular contexts. Furthermore, the synthesis of evidence, ranging from Koster et al. [15] to Spiro et al. [18], provided insights into safety, practicability, and proficiency, offering a comprehensive view of Autopulse Mechanical CC’s role in the continuum of care. The meta-analysis of the ROSC between Autopulse Mechanical CC and M-CPR reveals a compelling narrative favoring Autopulse. The pooled effect with a relative risk of 1.43 (95% CI 1.07-1.92) signifies a statistically significant advantage of Autopulse over M-CPR in facilitating ROSC. This finding aligns with the overarching goal of enhancing crucial resuscitation milestones. However, it is essential to acknowledge the observed heterogeneity ( $I^2 = 86\%$ ) across the studies, indicating potential variability in outcomes.

Turning our attention to the meta-analysis comparing complications between Autopulse Mechanical CC and M-CPR, a crucial facet of our findings emerges. The analysis, encapsulated by a relative risk of 1.11 (95% CI 0.93-1.33), signifies a nuanced aspect of the safety profile associated with these two resuscitation approaches. The forest plot provides reassuring insights, revealing no significant heterogeneity ( $I^2 = 0$ ), indicating consistent findings across studies. The test for the overall effect, with a Z value of 1.17 ( $p = 0.24$ ), suggests no statistically significant difference in complications between Autopulse and M-CPR. Delving into the critical aspect of patient survival rates, our synthesis of studies provides valuable insights into the comparative performance of Autopulse Mechanical CC and M-CPR. Noteworthy findings from Gao et al. [16] reveal a notable difference

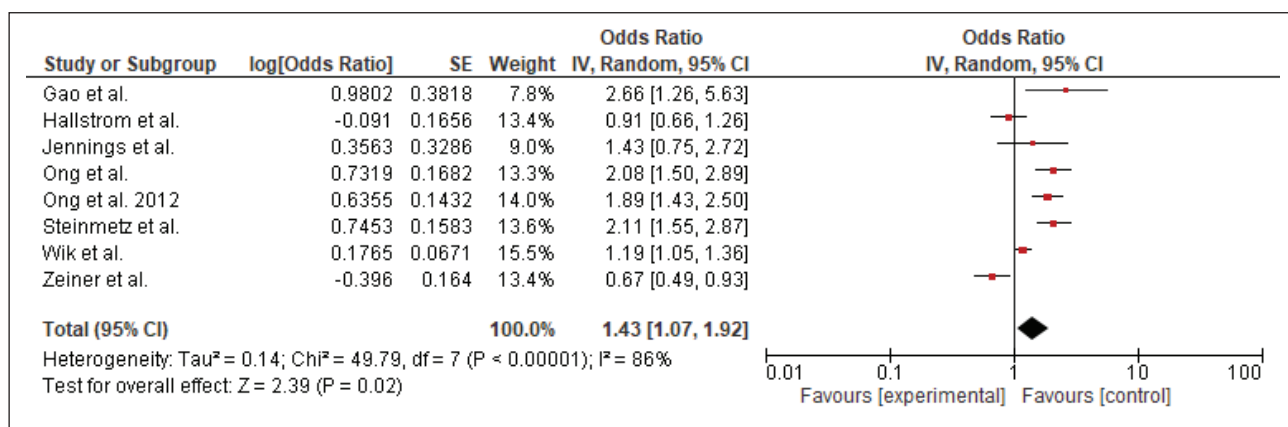


Figure 2. Meta-analysis of ROSC.

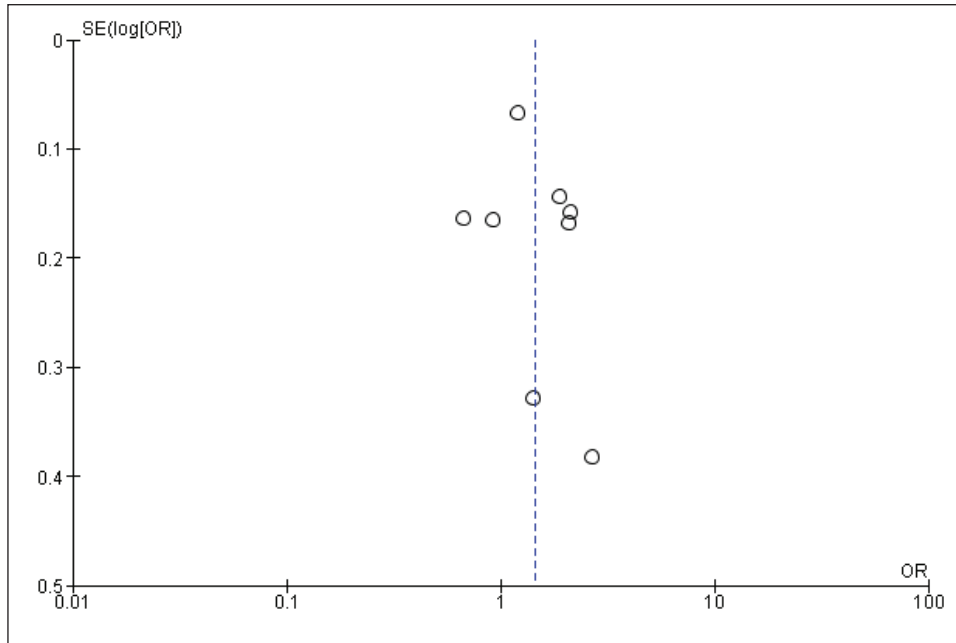


Figure 3. Funnel plot of ROSC.

Table 4. Hospital discharge rates for Autopulse versus M-CPR.

Studies	Autopulse	M-CPR
Gao et al. [16]	18.8%	6.3%
Hayashida et al. [22]	2.5%	2.6%
Jenning et al. [24]	3%	7%
Ong et al. [26]	9.71%	2.88%
Ong et al. [27]	3.3%	1.3%
Spiro et al. [18]	28%	11%
Wik et al. [9]	9.4%	11%

Table 5. Survival rates: Autopulse versus manual CC.

Studies	Autopulse	Manual
<b>The 24-hour patient survival rate</b>		
Gao et al. [16]	39.1%	21.9%
Jenning et al. [24]	26%	20%
Wik et al. [9]	21.8%	25.0%
<b>30-day survival rate</b>		
Primi et al. [17]	6%	14%
Steinmetz et al. [25]	16%	

in the 24-hour patient survival rate, with Autopulse exhibiting a substantially higher rate of 39.1% compared to 21.9% for M-CPR.

Similarly, the study by Jennings et al. [24] underscores a survival advantage for Autopulse with a 26% rate compared to 20% for M-CPR. Contrasting results from Wik et al. [9] show Autopulse at 21.8% and M-CPR at 25.0%, indicating nuanced variations across studies. Regarding the 30-day survival rate, findings from Primi et al. [17] highlight a divergence in outcomes, with Autopulse demonstrating a 6% survival rate compared to 14% for M-CPR. Steinmetz et al. [25] also contribute

to the discussion with a 16% survival rate, offering a comprehensive view of the temporal dimension in survival outcomes.

An integral aspect of our comparative analysis involves exploring hospital discharge rates between Autopulse Mechanical CC and M-CPR. Across various studies, distinct patterns emerge, shedding light on the complexities of patient outcomes. Examining Gao et al. [16], the study demonstrates a substantial disparity in hospital discharge rates, with Autopulse showing an 18.8% discharge rate compared to 6.3% for M-CPR. In contrast, Hayashida et al. [22] and Jennings et al. [24] reveal more nuanced differences, highlighting Autopulse rates of 2.5% and 3%, respectively, against M-CPR rates of 2.6% and 7%. Ong et al. [26] and Hock Ong et al. [27] contribute to the discourse with their findings, indicating higher hospital discharge rates for Autopulse at 9.71% and 3.3%, respectively, compared to M-CPR rates of 2.88% and 1.3%. Spiro et al. [18] further emphasize the potential impact of Autopulse with a substantial discharge rate of 28%, compared to 11% for M-CPR. Finally, Wik et al. [9] showcase a nuanced perspective, with Autopulse at 9.4% and M-CPR at 11%.

Our analysis aligns with prior studies, notably the findings of Gao et al. [16] and Jennings et al. [24], indicating higher 24-hour patient survival rates with Autopulse than with M-CPR. This consistency suggests a potential trend towards improved immediate survival outcomes when utilizing Autopulse. Conversely, Wik et al. [9] present a divergence, reporting a higher 24-hour survival rate with M-CPR. Such variations may be attributed to differences in study populations, resuscitation settings, or the quality of CPR provided. The 30-day survival rates, as highlighted by Primi et al. [17], exhibit a divergence, indicating lower rates with Autopulse than with M-CPR. This discrepancy prompts a closer examination of the specific patient populations, intervention protocols, and potentially nuanced

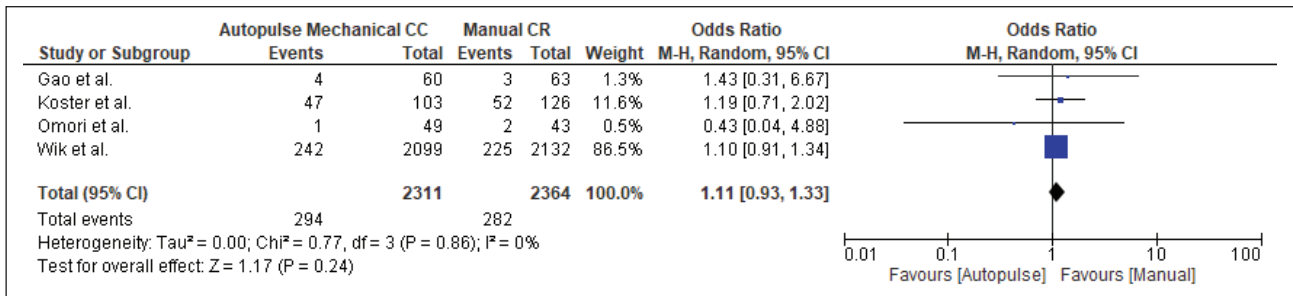


Figure 4. Complications and adverse events.

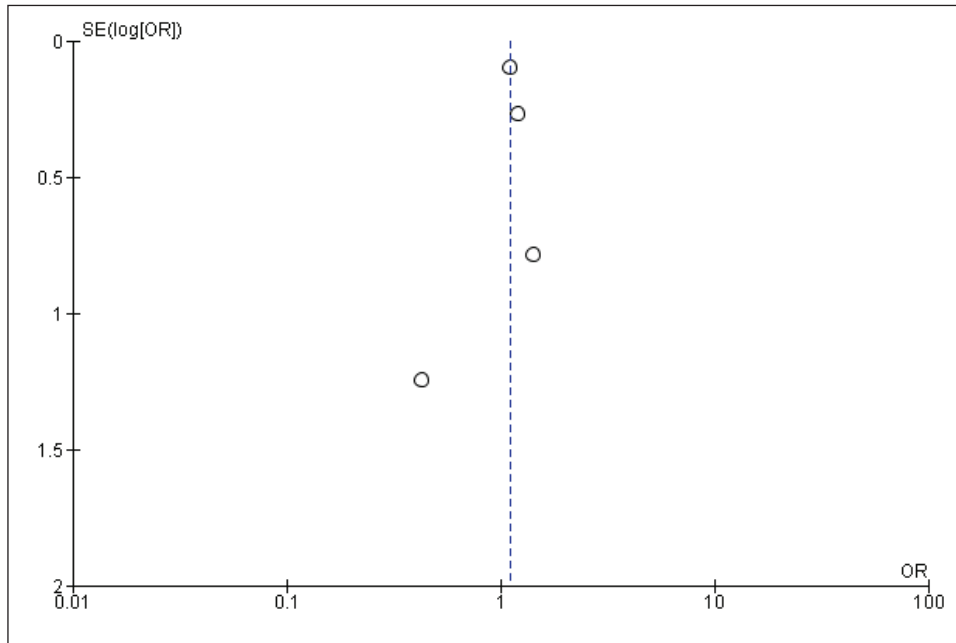


Figure 5. Funnel plot complications and adverse events.

factors influencing longer-term survival. Hospital discharge rates demonstrate notable variability across studies. While Gao et al. [16] and Spiro et al. [18] align with our findings, emphasizing higher hospital discharge rates with Autopulse, other studies, such as Jennings et al. [24] and Ong et al. [27], report lower rates for Autopulse compared to M-CPR. These divergences may be rooted in differences in healthcare systems, pre-existing comorbidities, or varying resuscitation strategies employed.

Our meta-analytical results on ROSC and complications align with the existing literature, emphasizing the potential advantage of Autopulse in achieving ROSC without a significant increase in complications [11,30]. Seven comprehensive analyses, including the most recent by Sheraton et al. [31], collectively suggest that mechanical CC should not replace M-CPR. However, it holds promise as a supplemental treatment within a broader strategy for treating CA patients. A nationwide population-based observational study in South Korea by Kim et al. [32] echoes these sentiments, reporting comparable survival to discharge between mechanical CPR devices and M-CPR in OHCA patients. However, a notable caveat emerges when considering in-hospital use of the AutoPulse device, which is associated with a significant reduction in survival compared to M-CPR. These findings underscore the

importance of nuanced considerations, acknowledging that the impact of mechanical CPR may vary based on the specific clinical context.

The contradictory results from the most recent study inject an element of complexity into the existing body of evidence. It is crucial to note that while presenting fresh insights, this study has limitations that may impact the reliability of its findings. This realization emphasizes the ongoing evolution of research and guidelines in the field, necessitating a cautious interpretation of conflicting data. The observed outcome variations may be attributed to several factors, including differences in study designs, patient populations, and implementation strategies. Variances in the quality of CPR provided by healthcare professionals, device familiarity, and regional disparities in EMS may contribute to the divergent findings. Our findings underscore the need to carefully consider Autopulse Mechanical CC's role within a broader resuscitation strategy. While immediate survival benefits are evident, the nuances in longer-term outcomes and hospital discharge rates warrant caution. Future research should focus on refining strategies, exploring context-specific benefits, and addressing conflicting findings to guide more effective clinical decision-making. This meta-analysis contributes to the evolving knowledge on

mechanical CC, aligning with recent meta-analyses that position it as a supplementary, not replacement, strategy in treating cardiac arrest.

## Conclusion

This study revealed diverse outcomes across various studies. Notably, Autopulse demonstrated enhanced CPR success and improved survival rates in OHCA, aligning with the overarching goal of enhancing resuscitation milestones. However, the nuanced perspectives from different studies, including contradictory findings and divergent survival rates, underscored the complexity of Autopulse's impact. The meta-analysis on ROSC favored Autopulse, highlighting its statistically significant advantage over M-CPR. However, the observed heterogeneity across studies emphasizes the need for a nuanced interpretation of these findings. Exploring complications, patient survival rates, and hospital discharge rates provided valuable insights, stressing the need for tailored approaches. Consistency with prior studies, such as higher 24-hour patient survival rates with Autopulse, suggests a potential trend in immediate survival benefits. However, 30-day survival and hospital discharge rate variations underscored the importance of contextual factors and intervention protocols.

In light of the findings, Autopulse Mechanical CC emerges as a valuable tool within a broader resuscitation strategy, offering immediate benefits but requiring careful consideration of contextual factors. Future research should focus on refining strategies, exploring context-specific benefits, and addressing conflicting findings to guide more effective clinical decision-making. This meta-analysis contributes to the evolving knowledge of mechanical CC, emphasizing its role as a supplementary strategy in treating cardiac arrest.

## List of Abbreviations

A-CPR	Automated CPR
C-CPR	Conventional cardiopulmonary resuscitation
CPR	Cardiopulmonary resuscitation
iA-CPR	Integrated automated load-distributing band
LDB-CPR	Load-distributing band cardiopulmonary resuscitation
LUCAS	Lund University Cardiopulmonary Assist System
mCPR	Mechanical cardiopulmonary resuscitation
OHCA	Out-of-hospital cardiac arrest
ROSC	Return of spontaneous circulation

## Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this article.

## Funding

None.

## Consent to participate

Not applicable.

## Ethical approval

Not applicable.

## Author details

Qasem Ahmed Almulihi<sup>1</sup>, Asaad Suliman Shujaa<sup>2</sup>, Bader Jameel Aldossary<sup>1</sup>, Mohammad Ibrahim Faya Assiri<sup>1</sup>,

Abdullah Ahmed T. Al Bahrani<sup>3</sup>, Shahd Ali Al Rashed<sup>4</sup>, Fawaz Hassan Alali<sup>5</sup>, Abdullah Ali Alaithan<sup>5</sup>, Ghanem Mohammed Aldubayyan<sup>5</sup>, Mohammed Ali Alaithan<sup>6</sup>, Hussain Ali Albakhite<sup>7</sup>, Yaser Mohammed Hussain Alsultan<sup>8</sup>, Huda Saud Mohammed Al Nemer<sup>9</sup>, Fatimah Saud Alfaraj<sup>10</sup>, Ayub Salman Mohammed Alabdullah<sup>11</sup>

1. ER Department, King Fahad University Hospital, AlKhobar, Saudi Arabia
2. Consultant and Program Director of Residency Program, Emergency Department, Johns Hopkins Aramco Healthcare Centre, Dahrhan, Saudi Arabia
3. Royal College of Surgeons in Ireland, Dublin, Ireland
4. School of Medicine, University of Galway, Galway, Ireland
5. College of Medicine, Imam Abdulrahman Bin Faisal University, AlKhobar, Saudi Arabia
6. College of Medicine, Qassim University, Al Qassim, Saudi Arabia
7. Prince Saud Bin Jalawi Hospital, Al-Ahsa, Saudi Arabia
8. Alkhobar PHC Network-MOH, AlKhobar, Saudi Arabia
9. Jubail General Hospital, Al Jubail, Saudi Arabia
10. Service Resident, Maternity and Children's Hospital, Dammam, Saudi Arabia
11. Alahsa Middle Health Sector, Al-Ahsa, Saudi Arabia

## References

1. Edelson DP, Litzinger B, Arora V, Walsh D, Kim S, Lauderdale DS, et al. Improving in-hospital cardiac arrest process and outcomes with performance debriefing. *Arch Intern Med.* 2008;168(10):1063–9.
2. Jude JR, Kouwenhoven WB, Knickerbocker GG. Cardiac arrest: report of application of external cardiac massage on 118 patients. *JAMA.* 1961;178(11):1063–70.
3. Kouwenhoven WB, Jude JR, Knickerbocker GG. Closed-chest cardiac massage. *JAMA.* 1960;173(10):1064–7.
4. Hallstrom A, Rea TD, Sayre MR, Christenson J, Anton AR, Mosesso VN Jr, et al. Manual chest compression vs use of an automated chest compression device during resuscitation following out-of-hospital cardiac arrest: a randomized trial. *JAMA.* 2006;295(22):2620–8. <https://doi.org/10.1001/jama.295.22.2620>
5. Nolan JP, Soar J, Smith GB, Gwinnutt C, Parrott F, Power S, et al. Incidence and outcome of in-hospital cardiac arrest in the United Kingdom National Cardiac Arrest Audit. *Resuscitation.* 2014;85(8):987–92.
6. Stiell IG, Brown SP, Nichol G, Cheskes S, Vaillancourt C, Callaway CW, et al. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? *Circulation.* 2014;130(22):1962–70.
7. Panchal AR, Bartos JA, Cabañas JG, Donnino MW, Drennan IR, Hirsch KG, et al. Part 3: adult basic and advanced life support: 2020 American Heart Association guidelines for Cardiopulmonary Resuscitation and emergency cardiovascular care. *Circulation.* 2020;142(16\_Suppl\_2):S366–468.
8. Bronstein R, Segal D. Modularity of CHIP/LDB transcription complexes regulates cell differentiation. *Fly.* 2011;5(3):1001063.
9. Wik L, Olsen JA, Persse D, Sterz F, Lozano M Jr, Brouwer MA, et al. Manual vs. integrated automatic load-distributing band CPR with equal survival after out-of-hospital cardiac arrest. The randomized CIRC

- trial. *Resuscitation*. 2014;85(6):741–8. <https://doi.org/10.1016/j.resuscitation.2014.03.005>
10. Smekal D, Johansson J, Huzevka T, Rubertsson S. A pilot study of mechanical chest compressions with the LUCAS™ device in cardiopulmonary resuscitation. *Resuscitation*. 2011;82(6):702–6.
  11. Zhu N, Chen Q, Jiang Z, Liao F, Kou B, Tang H, et al. A meta-analysis of the resuscitative effects of mechanical and manual chest compression in out-of-hospital cardiac arrest patients. *Crit Care*. 2019;23(1):100. <https://doi.org/10.1186/s13054-019-2389-6>
  12. Liu M, Shuai Z, Ai J, Tang K, Liu H, Zheng J, et al. Mechanical chest compression with LUCAS device does not improve clinical outcome in out-of-hospital cardiac arrest patients: a systematic review and meta-analysis. *Medicine*. 2019;98(44):e17550.
  13. Baubin M, Sumann G, Rabl W, Eibl G, Wenzel V, Mair P. Increased frequency of thorax injuries with ACD-CPR. *Resuscitation*. 1999;41(1):33–8.
  14. Wik L. Automatic and manual mechanical external chest compression devices for cardiopulmonary resuscitation. *Resuscitation*. 2000;47(1):7–25.
  15. Koster RW, Beenen LF, van der Boom EB, Spijkerboer AM, Tepaske R, van der Wal AC, et al. Safety of mechanical chest compression devices AutoPulse and LUCAS in cardiac arrest: a randomized clinical trial for non-inferiority. *Eur Heart J*. 2017;38(40):3006–13. <https://doi.org/10.1093/eurheartj/ehx318>
  16. Gao C, Chen Y, Peng H, Chen Y, Zhuang Y, Zhou S. Clinical evaluation of the AutoPulse automated chest compression device for out-of-hospital cardiac arrest in the northern district of Shanghai, China. *Arch Med Sci*. 2016;12(3):563–70. <https://doi.org/10.5114/aoms.2016.59930>
  17. Primi R, Bendotti S, Currao A, Sechi GM, Marconi G, Pamploni G, et al. Use of mechanical chest compression for resuscitation in out-of-hospital cardiac arrest-device matters: a propensity-score-based match analysis. *J Clin Med*. 2023;12(13):4429. <https://doi.org/10.3390/jcm12134429>
  18. Spiro JR, White S, Quinn N, Gubran CJ, Ludman PF, Townend JN, et al. Automated cardiopulmonary resuscitation using a load-distributing band external cardiac support device for in-hospital cardiac arrest: a single centre experience of AutoPulse-CPR. *Int J Cardiol*. 2015;180:7–14. <https://doi.org/10.1016/j.ijcard.2014.11.109>
  19. Krep H, Mamier M, Breil M, Heister U, Fischer M, Hoefft A. Out-of-hospital cardiopulmonary resuscitation with the AutoPulse system: a prospective observational study with a new load-distributing band chest compression device. *Resuscitation*. 2007;73(1):86–95. <https://doi.org/10.1016/j.resuscitation.2006.08.027>
  20. Omori K, Sato S, Sumi Y, Inoue Y, Okamoto K, Uzura M, et al. The analysis of efficacy for AutoPulse™ system in flying helicopter. *Resuscitation*. 2013;84(8):1045–50. <https://doi.org/10.1016/j.resuscitation.2013.01.014>
  21. Gorący J, Stachowiak P, Krejczy A, Piątek P, Gorący I. Efficacy of AutoPulse for mechanical chest compression in patients with shock-resistant ventricular fibrillation. *Int J Environ Res Public Health*. 2022;19(5):2557. <https://doi.org/10.3390/ijerph19052557>
  22. Hayashida K, Tagami T, Fukuda T, Suzuki M, Yonemoto N, Kondo Y, et al. Mechanical cardiopulmonary resuscitation and hospital survival among adult patients with nontraumatic out-of-hospital cardiac arrest attending the emergency department: a prospective, multicenter, observational study in Japan (SOS-KANTO [Survey of Survivors after Out-of-Hospital Cardiac Arrest in Kanto Area] 2012 Study). *J Am Heart Assoc*. 2017;6(11):e007420. <https://doi.org/10.1161/JAHA.117.007420>
  23. Zeiner S, Sulzgruber P, Datler P, Keferböck M, Poppe M, Lobmeyr E, et al. Mechanical chest compression does not seem to improve outcomes after out-of-hospital cardiac arrest. A single-centre observational trial. *Resuscitation*. 2015;96:220–5. <https://doi.org/10.1016/j.resuscitation.2015.07.051>
  24. Jennings PA, Harriss L, Bernard S, Bray J, Walker T, Spelman T, et al. An automated CPR device compared with standard chest compressions for out-of-hospital resuscitation. *BMC Emerg Med*. 2012;12:8. <https://doi.org/10.1186/1471-227X-12-8>
  25. Steinmetz J, Barnung S, Nielsen SL, Risom M, Rasmussen LS. Improved survival after an out-of-hospital cardiac arrest using new guidelines. *Acta Anaesthesiol Scand*. 2008;52(7):908–13. <https://doi.org/10.1111/j.1399-6576.2008.01657.x>
  26. Ong ME, Ornato JP, Edwards DP, Dhindsa HS, Best AM, Ines CS, et al. Use of an automated, load-distributing band chest compression device for out-of-hospital cardiac arrest resuscitation. *JAMA*. 2006;295(22):2629–37. <https://doi.org/10.1001/jama.295.22.2629>
  27. Hock Ong ME, Fook-Chong S, Annathurai A, Ang SH, Tiah L, Yong KL, et al. Improved neurologically intact survival with the use of an automated, load-distributing band chest compression device for cardiac arrest presenting to the emergency department. *Crit Care*. 2012;16(4):R144. <https://doi.org/10.1186/cc11456>
  28. Kim HT, Kim JG, Jang YS, Kang GH, Kim W, Choi HY, et al. Comparison of in-hospital use of mechanical chest compression devices for out-of-hospital cardiac arrest patients: AUTOPULSE vs LUCAS. *Medicine*. 2019;98(45):e17881. <https://doi.org/10.1097/MD.00000000000017881>
  29. PRISMA. PRISMA statement. 2020. Available from: <http://www.prisma-statement.org/>
  30. Li H, Wang D, Yu Y, Zhao X, Jing X. Mechanical versus manual chest compressions for cardiac arrest: a systematic review and meta-analysis. *Scand J Trauma Resusc Emerg Med*. 2016;24:10. <https://doi.org/10.1186/s13049-016-0202-y>
  31. Sheraton M, Columbus J, Surani S, Chopra R, Kashyap R. Effectiveness of mechanical chest compression devices over manual cardiopulmonary resuscitation: a systematic review with meta-analysis and trial sequential analysis. *West J Emerg Med*. 2021;22(4):810–9. <https://doi.org/10.5811/westjem.2021.3.50932>
  32. Kim W, Ahn C, Kim IY, Choi HY, Kim JG, Kim J, et al. Prognostic impact of in-hospital use of mechanical cardiopulmonary resuscitation devices compared with manual cardiopulmonary resuscitation: a nationwide population-based observational study in South Korea. *Medicina (Kaunas, Lithuania)*. 2022;58(3):353. <https://doi.org/10.3390/medicina58030353>