RESUSCITATION 215 (2025) 110764

Available online at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Clinical paper

Influence of different ventilation strategies during cardiopulmonary resuscitation on the return of spontaneous circulation in out-of-hospital cardiac arrest: a retrospective study from the German resuscitation registry

Pia Turowski[a,*], *Katharina Fetz*[a,c], *Jan-Thorsten Gräsner*[a,b], *Stephan Seewald*[a,b], *Jan Wnent*[a,b]

Abstract

Aim: To evaluate the association of different intra-arrest ventilation strategies with return of spontaneous circulation (ROSC), hospital admission, and 24-h survival among adult OHCA patients.

Methods: This retrospective cross-sectional study analyzed data from the German Resuscitation Registry. Adult patients (≥18 years) with non-traumatic out-of-hospital cardiac arrest (OHCA) between March 2016 and March 2023 were included if they received CPR, endotracheal intubation during CPR, and had a documented ventilation strategy. Four ventilation modes were compared: Intermittent Positive Pressure Ventilation (IPPV), Chest Compression Synchronized Ventilation (CCSV), biphasic positive airway pressure (BIPAP), and manual bag-valve ventilation (Manually). ROSC observed ($ROSC_{obs}$) was compared with expected ROSC ($ROSC_{exp}$) based on the ROSC after cardiac arrest score (RACA). Secondary outcomes were hospital admission status and 24-hour survival.

Results: Among 3,195 patients (IPPV: 1,865; CCSV: 194; BIPAP: 81; Manually: 1,055), ROSC occurred in 44 % (IPPV), 40 % (CCSV), 49 % (BIPAP), and 39 % (Manually). IPPV showed a significant positive deviation from $ROSC_{exp}$ (+2.7 %, $p = 0.0005$). No other strategy reached statistical significance. Patients ventilated with CCSV had a lower rate of admission with ROSC (24 %) and higher rates of admission under ongoing CPR (34 %). In the manual bag-valve ventilated group more patients died on scene (59 %).

Conclusion: Respirator controlled ventilation with IPPV modestly but significantly exceeded expected ROSC rates in patients with non-traumatic OHCA. CCSV, the mode designed specifically for ventilation during CPR, does not seem to be superior to manual bag-valve ventilation. Randomized controlled trials are needed to refine mechanical ventilation strategies in CPR.

Keywords: Cardiopulmonary resuscitation, Ventilation, IPPV, CCSV, BIPAP

Introduction

Out-of-hospital cardiac arrest (OHCA) is a time-critical medical emergency with persistently high mortality. In Germany, the incidence is approximately 65 cases per 100,000 population annually, affecting more than 50,000 individuals each year. Despite improvements in emergency medical services (EMS) and bystander training, only 10–12 % of patients survive to hospital discharge.[1,2] Enhancing interventions during cardiopulmonary resuscitation (CPR), particularly those related to airway management and ventilation, may offer further potential to improve outcomes.

High-quality chest compressions that are prompt, continuous, and minimally interrupted form the cornerstone of effective CPR.

* Corresponding author at: Institute for Emergency Medicine, University Hospital Schleswig-Holstein, Campus Kiel, Arnold-Heller-Straße 3, Building 808, Kiel 24105 Germany.

E-mail address: pia.turowski@uksh.de (P. Turowski).

https://doi.org/10.1016/j.resuscitation.2025.110764

Received 27 June 2025; Received in Revised form 27 July 2025; Accepted 28 July 2025

These must not be compromised by ventilation strategies. Ventilation during CPR serves two critical objectives: to ensure adequate oxygenation and to eliminate carbon dioxide. If insufficient, hypoxia and acidosis may worsen; if excessive, ventilation can elevate intrathoracic pressure, impede venous return, reduce coronary perfusion, and impair return of spontaneous circulation (ROSC). Animal studies have shown that excessive ventilation during CPR is associated with reduced ROSC rates.[3]

In addition to immediate effects during resuscitation, the mode of ventilation may also influence post-resuscitation morbidity. Among OHCA survivors who require prolonged mechanical ventilation, nearly half develop acute respiratory distress syndrome (ARDS) within 48 h.[4] This supports the early application of lung-protective strategies—even during CPR—to prevent secondary ventilator-associated lung injury.

German guidelines for the management of acute respiratory failure and prehospital airway care recommend mechanical ventilators over manual bag-valve ventilation in out-of-hospital settings.[5,6] Historically, volume-controlled ventilation predominated but has increasingly been replaced by pressure-controlled modes.[7] Nonetheless, manual bag-valve ventilation remains common practice in prehospital CPR. Once an advanced airway is in place, current guidelines advise using a tidal volume of 6–7 ml/kg at a rate of 10 breaths per minute.[8] Ventilation modes such as intermittent positive pressure ventilation (IPPV) and biphasic positive airway pressure (BIPAP) are now frequently used in the prehospital setting. However, high-quality evidence on intra-arrest ventilation remains sparse, and guideline recommendations are still limited.[8,9]

A novel strategy—Chest Compression Synchronized Ventilation (CCSV)—has been specifically developed for use during CPR and is currently implemented in over 150 emergency services and hospitals.[10] CCSV delivers a brief, pressure-controlled ventilation pulse synchronized with each chest compression, aiming to preserve intrathoracic pressure gradients and enhance forward blood flow. Preclinical studies suggest that CCSV may improve gas exchange and hemodynamics by leveraging the mechanical effects of chest compressions.[11–13] Despite its theoretical advantages, clinical data on the effectiveness of CCSV in improving survival outcomes remain lacking.

In this study, we investigate the association between ventilation strategies and clinical outcomes in a large cohort of OHCA patients recorded in the German Resuscitation Registry. Specifically, we assess whether any mode of ventilation, including CCSV, is associated with improved rates of ROSC, hospital admission, or short-term survival. To our knowledge, this is the first large-scale clinical evaluation of CCSV compared to conventional ventilation strategies during real-world prehospital resuscitation.

Methods

Study design and setting

This retrospective cross-sectional study is based on anonymized patient data from the German Resuscitation Registry (GRR), which systematically collects information on cardiac arrests across Germany. Data are entered voluntarily by participating EMS and hospitals. Quality is ensured through automated plausibility checks and feedback mechanisms. Twenty EMS centers additionally documented ventilation strategies used during CPR. The study was approved by the Ethics Committee of the Medical Faculty at the Christian-Albrechts-University of Kiel (D493/23) and the scientific advisory board of the GRR (2023-03).

Study population

All adult patients (≥18 years) recorded in the GRR who experienced a non-traumatic OHCA between March 16, 2016, and March 30, 2023, were screened for inclusion. Eligible patients had initiated CPR, underwent endotracheal intubation during performing CPR, and had a documented ventilation strategy. Patients were excluded if they were under 18 years of age, had a traumatic cause of arrest, underwent airway management without secured airway or after ROSC, or had missing data on ventilation mode or the ROSC after cardiac arrest score (RACA) (Fig. 1).

Data collection and definitions

From the GRR, we extracted demographic data (age, sex), arrest characteristics (location, witnessed status, bystander CPR, suspected cause), initial ECG rhythm, EMS arrival times, airway management details, and outcomes (ROSC, hospital admission, 24-hour survival, discharge status). Ventilation strategies were classified into four groups based on the documented mode used between endotracheal intubation and the end of CPR:

- Intermittent Positive Pressure Ventilation (IPPV)
- Chest Compression Synchronized Ventilation (CCSV)
- Biphasic Positive Airway Pressure (BIPAP)
- Manual bag-valve ventilation (Manually)

The primary outcome was ROSC at any time, defined as sustained palpable pulse or measurable blood pressure after resuscitation efforts. Secondary outcomes included hospital admission with or without ROSC, death at the scene, and 24-hour survival.

Expected ROSC calculation

To adjust for confounders and case mix, the Return of Spontaneous Circulation After Cardiac Arrest (RACA) score was used to estimate the expected ROSC probability. This score quantifies independent risk factors for each patient based on sex, age, location of arrest, initial rhythm, etiology, bystander CPR, witnessed status, and EMS response time.[14] It was developed as a quality control tool to evaluate different therapy strategies in OHCA and has been re-evaluated and validated in several countries since its inception.[15–17] The observed ROSC ($ROSC_{obs}$) was then compared to expected ROSC ($ROSC_{exp}$) for each ventilation group.

Statistical analysis

Descriptive statistics were used to summarize patient characteristics and outcomes. Categorical variables are presented as frequencies and percentages; continuous variables as means with standard deviations or medians with interquartile ranges, as appropriate. Group comparisons for categorical variables were conducted using the chi-square test. The paired *t*-test was used to assess the mean difference between $ROSC_{obs}$ and $ROSC_{exp}$ within each ventilation group. A p-value of < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS (IBM Corp., Version 29.0.1.0(171)).

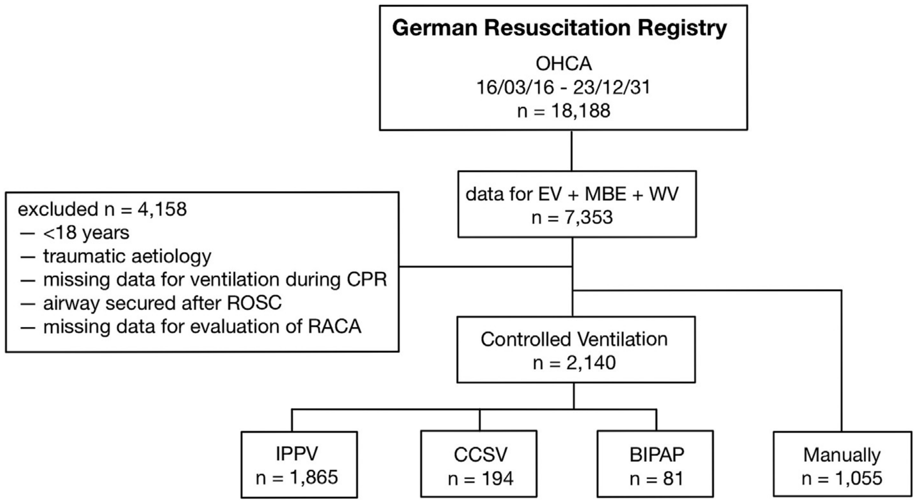

Fig. 1 – Flowchart of Enrolment. OHCA, out of hospital cardiac arrest; EV, prehospital treatment dataset; MBE, dataset on ventilation, WV, post resuscitation care dataset; CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation; RACA, ROSC after cardiac arrest score; IPPV, Intermittent Positive Pressure Ventilation; CCSV, Chest Compression Synchronized Ventilation; BIPAP; Biphasic Positive Airway Pressure; Manually; manual ventilation with a bag-valve system.

Results

A total of 18,188 OHCA cases were recorded in the GRR between March 16, 2016, and March 30, 2023. Of these, 7,353 patients underwent resuscitation and had documented ventilation data after securing the airway. After applying exclusion criteria (age < 18 years, traumatic etiology, intubation after ROSC, missing ventilation data, or missing RACA score), 3,195 cases were included in the final analysis (IPPV: 1,865; CCSV: 194; BIPAP: 81; Manually: 1,055).

Baseline characteristics are presented in Table 1. The CCSV group included a higher proportion of male patients, while the BIPAP group included a relatively larger proportion of females. The manually ventilated group had the highest mean age. Witnessed arrest and initial shockable rhythm were most common in the BIPAP and CCSV groups. Bystander CPR, telephone-assisted CPR and the use of a mechanical CPR device were more frequently documented in the CCSV group. Median time to ROSC following airway management was shortest in the BIPAP group.

Twenty study centers contributed data. Six centers used CCSV and accounted for 66 % (2,111) of included cases. These centers also contributed nearly all BIPAP cases. Among CCSV-using centers, 72 % of patients received respirator-controlled ventilation during CPR, compared to 57 % in centers not using CCSV. In one of the 20 study centres, all patients were treated with respirator-controlled ventilation during CPR (Table 2).

Return of spontaneous circulation

ROSC was achieved in 44 % of patients in the IPPV group, 40 % in the CCSV group, 49 % in the BIPAP group, and 39 % in the Manually group. Differences between groups did not reach statistical significance ($\chi^2(3) = 7.908$, $p = 0.046$, n.s.). Observed ROSC ($ROSC_{obs}$) exceeded expected values ($ROSC_{exp}$) in the IPPV, BIPAP, and Manually groups. In contrast, $ROSC_{obs}$ in the CCSV group was slightly below $ROSC_{exp}$.

A statistically significant mean difference between $ROSC_{obs}$ and $ROSC_{exp}$ was observed only in the IPPV group (IPPV: $t = 3.4729$, $p = 0.0005$). Other groups did not show statistically significant differences (CCSV: $t = 0.0866$, $p = 0.9310$; BIPAP: $t = 0.7925$, $p = 0.4293$; Manually: $t = 1.2633$, $p = 0.2066$) (Fig. 2).

Hospital admission and short-term survival

A total of 1,598 patients were admitted to hospital. Patients in the CCSV group had significant lower rates of admission with ROSC (24 %) compared to other groups and higher rates of admission under ongoing CPR (34 %). Admission rates with ROSC were highest in the BIPAP group (37 %), followed by IPPV (34 %) and Manually (29 %). In the Manually group, significant more patients died on scene (59 %) compared to all other groups.

Data on survival and discharge were incomplete with documentation available for only 889 patients. Twenty-four-hour survival was significant less in in the CCSV group (36 %) compared to the other groups (IPPV (55 %), BIPAP (58 %), Manually (54 %).

Full data including center contributions and subgroup analyses are presented in Tables 1–3 and visualized in Figs. 1 and 2.

Discussion

In this retrospective study, mechanical ventilation with IPPV resulted in a significantly higher rate of return of spontaneous circulation (ROSC) than expected according to the confounder-adjusted RACA score. The BIPAP group showed a similar trend, although not statistically significant, likely due to the small sample size. Overall ROSC rates did not differ significantly between groups. However, patients in the CCSV group were significantly less likely to be admitted with ROSC and more likely to arrive under ongoing CPR. Accordingly, a higher 24-hour mortality was observed, although this outcome was not documented for all hospitalized patients. These findings highlight the need for prospective, randomized controlled trials: first,

Table 1 – Characteristics of the different ventilation strategy groups.

	IPPV	CCSV	BIPAP	Manually
n	1,865	194	81	1,055
Sex				
Male	1,249/ 67 %	144/ 74 %	47/ 58 %	712/ 67 %
Female	616/ 33 %	50/ 26 %	34/ 42 %	343/ 33 %
Age				
MW+/-SD/Min-Max	69+/-15/20–98	69+/-14/26–97	69+/-16/20–98	71+/-14/21–99
>/= 80 years	498/ 27 %	46/ 24 %	22/ 27 %	343/ 33 %
Initial ECG				
VF	471/ 25 %	61/ 31 %	30/ 37 %	231/ 22 %
PEA	395/ 21 %	44/ 23 %	13/ 16 %	243/ 23 %
Asystole	999/ 54 %	89/ 46 %	38/ 47 %	581/ 55 %
Witnessed				
None	817/ 44 %	90/ 46 %	29/ 36 %	488/ 46 %
Lay person	885/ 47 %	91/ 47 %	42/ 52 %	479/ 45 %
Professional	163/ 9 %	13/ 7 %	10/ 12 %	88/ 8 %
Bystander CPR	922/ 49 %	115/ 59 %	45/ 56 %	478/ 45 %
Telephone guided CPR	572/ 31 %	89/ 46 %	30/ 37 %	311/ 29 %
Mechanical CPR	373/ 20 %	86/ 44 %	14/ 17 %	140/ 13 %
Difficult airway				
Change of procedure	139/ 7 %	21/ 10 %	5/ 6 %	57/ 5 %
Intubation difficult > 1	182/ 10 %	29/ 15 %	5/ 6 %	163/ 15 %
Coniotomy	2/ 0,1%	0	0	3/ 0,3%
Ventilation time*until				
ROSC	10 (6/ 18)	14 (6/ 19)	8 (5/ 14)	10 (5/ 15)
Termination of CPR	23 (15/ 31)	24 (15/ 34)	22 (15/ 40)	20 (14/ 29)
Admission to hospital	42 (31/ 55)	49 (38/ 56)	49 (35/ 56)	51 (36/ 60)

IPPV, Intermittent Positive Pressure Ventilation; CCSV, Chest Compression Synchronized Ventilation; BIPAP, Biphasic Positive Airway Pressure; Manually, manual bag-valve ventilation; VF, ventricular fibrillation; PEA, pulseless electrical activity; CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation; *Ventilation time (in minutes) (median, 25th/75th percentile) following intubation during ongoing CPR is presented as median with 25th and 75th percentiles.

Table 2 – Ventilation modes and proportion of modes used within the study centres.

study centres	patients	IPPV	CCSV	BIPAP	Manually
n	3,195	1,865	194	81	1,055
A	529	427/ 81 %	50/ 9 %	21/ 4 %	31/ 6 %
B	444	369/ 83 %	35/ 8 %	26/ 6 %	14/ 3 %
C	252	39/ 15 %	67/ 27 %	5/ 2 %	141/ 56 %
D	213	43/ 20 %	24/ 11 %	17/ 8 %	129/ 61 %
E	34	28/ 82 %	6/ 18 %	–	–
F	639	348/ 54 %	12/ 2 %	9/ 1 %	270/ 42 %
centres using CCSV (*n* = 6)	2,111	1,254/ 59 %	194/ 9 %	78/ 4 %	585/ 28 %
other centres (*n* = 14)	1,084	611/ 56 %	–	3/ 0 %	470/ 43 %

IPPV, Intermittent Positive Pressure Ventilation; CCSV, Chest Compression Synchronized Ventilation; BIPAP, Biphasic Positive Airway Pressure; Manually, manual bag-valve ventilation.

to assess whether BIPAP offers benefits beyond the widely established IPPV mode, and second, to clarify whether CCSV, despite its conceptual advantages, performs no better than manual ventilation with a bag-valve device.

Our findings support previous data suggesting improved ROSC with mechanical ventilation over manual bag-valve ventilation during CPR.[18] Both IPPV and BIPAP are well-established ventilation modes with a long safety track record, even though evidence for their use specifically during CPR remains limited. In contrast, CCSV, a newer modality developed specifically for use during chest compressions, must demonstrate not only safety but also superiority. In our study, the CCSV group showed more frequent hospital admissions under ongoing CPR and had the highest rate of mechanical CPR use, yet this did not result in better early outcomes such as ROSC or 24-hour survival. This suggests that the decision to terminate resuscitation may have been postponed until hospital arrival in this group. Conversely, manual ventilation was associated with more prehospital termination and fewer hospital admissions under ongoing CPR, per-

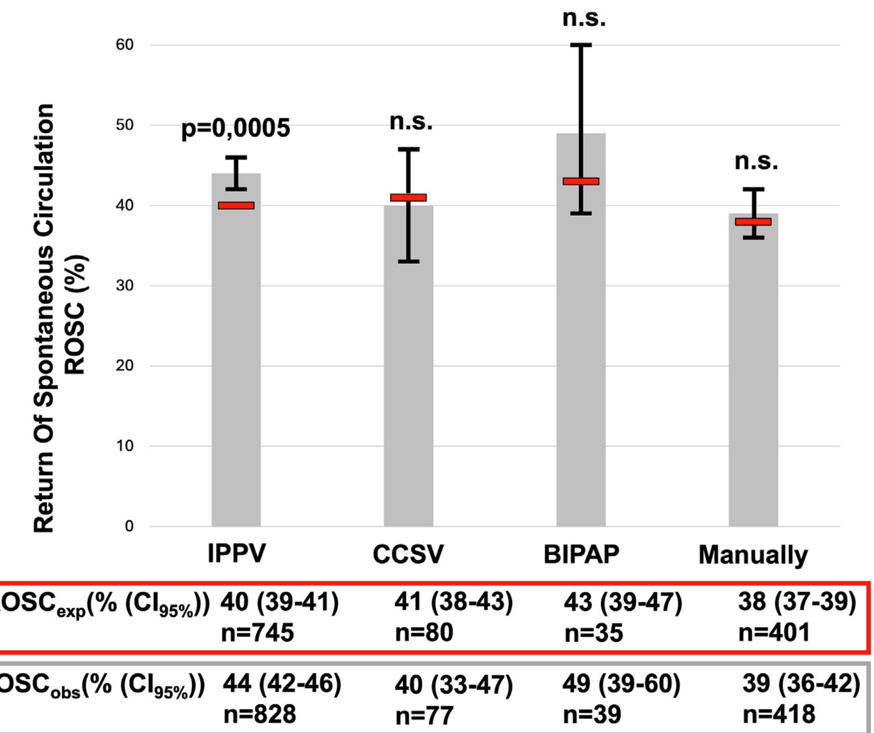

Fig. 2 – Return of spontaneous circulation (ROSC). $ROSC_{exp}$, return of spontaneous circulation after cardiac arrest score (RACA) (red horizontal bars); $ROSC_{obs}$, ROSC observed any time (mean as grey vertical columns, 95% confidence interval); IPPV, Intermittent Positive Pressure Ventilation; CCSV, Chest Compression Synchronized Ventilation; BIPAP, Biphasic Positive Airway Pressure; Manually, manual bag-valve ventilation; Ventilation with IPPV was associated with significantly higher ROSC rates compared to RACA-predicted outcomes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3 – Early outcome within the different ventilation strategy groups.

	IPPV	CCSV	BIPAP	Manually	p-value
n	1,865	194	81	1,055	
Death on scene	862/ 46 %	82/ 42 %	29/ 36 %	624/ 59 % [a]	0.001
Admission to hospital					
With ROSC	627/ 34 % [b]	47/ 24 % [b]	30/ 37 %	305/ 29 %	
With ongoing CPR	376/ 20 %	65/ 34 % [d]	22/ 27 %	126/ 12 % [c]	
24 h Survival[#]	279 (527) 55 %	28 (78) 36 %	11 (20) 58 %	142 (264) 54 %	0.009
Discharge alive[#]	106 (527) 20 %	13 (78) 17 %	6 (20) 30 %	51 (264) 19 %	n.s.
Deaths within 24hrs[§]	1,110/ 60 %	132/ 68 %	38/ 47 %	746/ 71 %	–

IPPV, Intermittent Positive Pressure Ventilation; CCSV, Chest Compression Synchronized Ventilation; BIPAP, Biphasic Positive Airway Pressure; Manually, manual bag-valve ventilation; ROSC, return of spontaneous circulation; CPR, cardiopulmonary resuscitation.

[a] statistically significant compared to all other groups.

[b] significantly higher in the IPPV group compared to the CCSV group, no significant differences when compared to the other groups.

[c] significantly fewer patients admitted to hospital compared to all other groups.

[d] significantly more patients admitted to hospital with ongoing CPR compared to IPPV and Manually ventilated groups, but without significance versus BIPAP.

[#] outcome data for patients admitted to hospital were only available for 889 patients (group-specific numbers in brackets).

[§] documented deaths of all 3195 patients included in the study.

haps reflecting a more definitive field-based decision-making approach.

The choice of ventilation strategy was left to the clinical judgment of the attending physician, which may have introduced selection bias. Moreover, physician preference for new technology in promising cases could have contributed to skewed distribution.

Although the CCSV group had the highest rates of layperson and telephone-assisted CPR, it also showed the lowest rate of admission to hospital with ROSC and 24-hour survival. This may suggest a potential disadvantage associated with this ventilation strategy is underscored due to different baseline data. However, a direct causal interpretation of any single characteristic is difficult due to multiple confounding factors. Given the small and heterogeneous group sizes, simple group comparisons have limited validity. To adjust for relevant baseline differences, we used the RACA score, which quantifies key predictors of ROSC for each patient individually. Comparing observed with expected ROSC thus provides a more reliable basis for evaluating ventilation effects. Notably, only in the CCSV group ROSC observed was lower than expected.

Experimental and preclinical studies in porcine models suggest that CCSV may improve oxygenation and perfusion by harnessing thoracic pressure dynamics during compressions.[11–13,19,20] However, these investigations differ substantially in both duration and clinical setting from the real-world circumstances of out-of-hospital cardiac arrest and conclusions about patient outcomes should be drawn with caution. Notably, CCSV's high-frequency ventilation may risk hyperventilation and alkalosis,[11] with potential consequences for organ perfusion and long-term outcomes.[21] One animal study reported higher rates of pneumothorax in CCSV compared to manual ventilation, possibly due to repeated rapid increases in airway pressure and simultaneous thoracic compression.[22] Given that nearly half of OHCA survivors develop ARDS within 48 h,[4] any additional pulmonary injury could critically impact survival.

While BIPAP requires active adjustment of ventilatory parameters and may suggest operator expertise, its distribution across centers using CCSV, where mechanical ventilation was already prevalent, makes operator skill an unlikely explanation for the observed intergroup differences. Still, manual ventilation was used in 33 % of cases, despite guideline recommendations favoring transport ventilators once the airway is secured.[23] Practical constraints, such as equipment load and deployment logistics, may explain the ongoing reliance on bag-valve systems. In Belgium, nearly 90 % of OHCA cases were managed with manual ventilation, yet mechanical ventilation was associated with better ROSC.[18]

The persistently high rate of suboptimal manual ventilation during CPR observed in this and other studies remains concerning, especially considering its frequent use as a first-line approach. Implementation of quality assurance measures and real-time feedback may help improve manual ventilation performance, particularly in prehospital settings. In addition, emergency equipment planning should ensure that transport ventilators are readily available, preconfigured for CPR use, and with sufficient battery life and ease of use under field conditions to maintain stable tidal volume, respiratory rate, and oxygenation as soon as possible during CPR and during patient transfer.

The patient cohort analyzed here is representative of non-traumatic OHCA in Germany. However, our analysis was limited to the specific subgroup of patients with a secured airway during CPR, excluding those with early ROSC, early cessation of CPR, or mask ventilation. As a result, the absolute ROSC and survival rates are not directly comparable to those of the overall OHCA population. Despite the variety of ventilation modes investigated, survival rates remained low across groups. This likely reflects the complexity of out-of-hospital cardiac arrest scenarios, in which multiple factors beyond ventilation, including time to first compression, underlying etiology, and quality of bystander CPR, critically influence outcome. Future research should aim to integrate ventilation strategies with optimized overall resuscitation bundles to improve early outcomes.

Nonetheless, several limitations apply. This was a retrospective analysis with physician-determined ventilation strategy. Group sizes were unequal, particularly for BIPAP. The German two-tiered EMS system, with physicians present at the scene, limits generalizability to other systems. Ventilation was not continuously monitored or recorded, and unmeasured factors likely influenced survival. Among all evaluated outcomes, only the RACA-adjusted comparison between observed and expected ROSC offers a robust way to account for these confounders.

Current guidelines emphasize high-quality, minimally interrupted chest compressions. Ventilation must support this principle and avoid both hypoventilation and hyperventilation, which may compromise outcomes.[23] An ideal CPR ventilator would be lightweight, preconfigured with lung-protective settings, and able to deliver consistent tidal volumes and pressures. Mechanical ventilation offers the added benefit of freeing personnel and providing reliable feedback on delivered volumes and pressures.

Determining the optimal ventilatory approach during and after CPR is challenging due to rapidly changing cardiorespiratory physiology. Capnography alone may be insufficient. Detailed monitoring of inspiratory and expiratory volumes, as well as continuous recording of ventilation parameters, is crucial for future studies.[24] Further, reliable data are lacking on the technical performance of different ventilators during patient transfer, particularly under battery operation, which might affect oxygenation and ventilation quality. Randomized controlled trials employing real-time monitoring during CPR and the immediate post-ROSC period are urgently needed.[24–27] Until then, early intubation followed by normoventilation using a trusted, well-monitored mechanical ventilation mode remains a pragmatic strategy.

Conclusion

This study suggests that respirator-controlled ventilation with IPPV is associated with improved ROSC compared to predicted rates in patients with non-traumatic OHCA. CCSV, despite its theoretical benefits, did not outperform manual bag-valve ventilation. Future randomized controlled trials are essential to refine mechanical ventilation strategies during CPR and determine the optimal mode for patient outcomes.

Conflict of interest

J.-T. Gräsner, J. Wnent, S. Seewald, K. Fetz and P. Turowski are employees of the Institute for Emergency Medicine at the University Hospital Schleswig-Holstein. The Institute has received consulting grants from WEINMANN Emergency Medical Technology GmbH& Co. KG, 22525 Hamburg, Germany. WEINMANN Emergency Medical Technology had no influence on the design, analysis and interpretation of the data.

Declaration of AI and AI-assisted technology in the writing process

No AI or AI-assisted technology was used in the writing process. Thereafter AI was used to assist with translation and to refine language. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Pia Turowski: Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Katharina Fetz:** Writing – review & editing, Validation, Formal analysis. **Jan-Thorsten Gräsner:** Writing – review & editing, Validation, Supervision, Conceptualization. **Stephan Seewald:** Writing – review & editing, Validation, Formal analysis. **Jan Wnent:** Writing – review & editing, Validation, Supervision, Formal analysis, Conceptualization.

Funding

Open access funding enabled and organized by Projekt DEAL.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We like to thank all paramedics and emergency physicians that collected data for this study.

The manuscript including the related data and figures has not been published previously and is not under consideration elsewhere.

Author details

[a]Institute for Emergency Medicine, University Hospital Schleswig-Holstein, Campus Kiel, Arnold-Heller-Straße 3, Building 808, Kiel 24105, Germany[b]Department of Anesthesiology and Intensive Care Medicine, University Hospital Schleswig-Holstein, Campus Kiel, Arnold-Heller-Straße 3, Building 12, Kiel 24105, Germany [c]Faculty of Health, Institute for Research in Operative Medicine, University Witten/ Herdecke, Building 38, 51109 Cologne, Germany

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