

## REVIEW ARTICLE

# Chest Compression Synchronized Mechanical Ventilation Modes for Cardiac Arrest; A Scoping Review

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**Abstract:** **Introduction:** Chest Compression Synchronized Ventilation (CCSV) is a novel approach aimed at optimizing gas exchange and hemodynamics during cardiopulmonary resuscitation (CPR). However, its clinical value, safety profile and implementation barriers remain unclear. This study aimed to systematically synthesize existing evidence on the use of CCSV during cardiac arrest in animals and humans. **Methods:** We conducted a scoping review and systematically searched five databases (Medline, Embase, CENTRAL, Scopus, Web of Science) up to May 2025. Studies investigating CCSV or mechanically related ventilation strategies during cardiac arrest were included regardless of study design, language or publication date. Data were charted for study characteristics, outcomes and adverse events. **Results:** Thirty-two studies published between 1980 and 2025 were included. Most were animal studies (n=19), primarily conducted in pigs, with limited human data (n=10). CCSV showed positive effects on arterial oxygenation, carbon dioxide clearance, and hemodynamic parameters as well as cerebral oxygenation compared to conventional ventilation modes. Adverse events such as pneumothorax and lung injury were inconsistently reported. **Conclusion:** Available data on CCSV suggests potential physiological benefits during CPR, particularly in experimental settings. Human data remain scarce, and larger, prospective human trials are essential to evaluate clinical effectiveness, guide implementation, and assess risks compared to conventional ventilation strategies.

**Keywords:** Cardiac arrest; Cardiopulmonary resuscitation; Ventilation; Chest compression; review

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## 1. Introduction

Current European Resuscitation Council (ERC) guidelines on Advanced Life Support (ALS) recommend uninterrupted chest compressions with asynchronous ventilation. However, more precise recommendations regarding ventilation parameters beyond respiratory rate and oxygen concentration, the use of mechanical ventilators and specific ventilation modes during cardiopulmonary resuscitation (CPR) are

lacking (1). American Heart Association provides recommendations regarding tidal volume and respiratory rate and discourages the use of simultaneous compression and ventilation (2) based on a study by Krischer et al. However, this study has to be viewed with caution in this context as it describes chest compression at a rate of 40/min with synchronized ventilation with 80 mmHg of airway pressure (simultaneous compression-ventilation; SC-V) (3). Various ventilation modes or variations thereof are described during CPR (4). In an opinion survey in 54 countries, Cordioli et al. report volume-controlled ventilation as the most common ventilation mode, followed by pressure-controlled ventilation, and continuous positive pressure ventilation (5).

The idea of ventilation applied simultaneously with chest compressions was first described by Chandra et al. They ex-

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explored a so called “new CPR” (40 compressions per minute, simultaneous ventilation with 60-110 cmH<sub>2</sub>O airway pressure) in eleven patients after conventional means of resuscitation had failed in 1980. During “new CPR” they observed higher carotid flow and higher pressure in the radial artery (6). In this context, the study of Krischer et al. has to be referenced, evaluating a synchronized compression-ventilation technique at a rate of 40/min with at 80 mmHg of airway pressure resulting in a 11% lower survival rate in non-traumatic cardiac arrests (3).

Regarding the superiority of manual or mechanical ventilation during CPR, literature is conflicting: CPR results in oscillations in airway pressures and can cause reversed air flow during inspiratory and expiratory ventilation phases (7). This can cause deviations from parameters set on the ventilator (8) and problems due to trigger-related issues (9). Whatever the ventilation technique is, a measurement of ventilation parameters as a form of feedback is recommended (10) to ensure ventilation quality, which may be more challenging during manual ventilation because additional devices are needed. A recent clinical study on Chest Compression Synchronized Ventilation (CCSV) suggests that the intervention may be effective in maintaining gas exchange during CPR (11) and the mode seems to be in use internationally in the absence of international recommendations.

A comprehensive overview of published literature on CCSV, and thus a descriptive summary of the current knowledge base along with relevant gaps for future research is lacking. We, therefore, conducted a scoping review to provide an overview of clinical and pre-clinical studies of CCSV during cardiac arrest.

## 2. Methods

For the present review we used the following definitions of common ventilation modes:

- Intermittent positive pressure ventilation (IPPV): IPPV describes a conventional volume-controlled ventilation mode. A set tidal volume is applied with a set ventilation rate. Additionally, the application of positive end-expiratory pressure (PEEP) is possible. Maximum airway pressure can be limited by the ventilator (12,13).

- Bi-Level Positive Airway Pressure Ventilation (BiPAP): BiPAP ventilation is characterized by two different, predefined pressure levels (P<sub>low</sub> and P<sub>high</sub>), cycled at ventilation rate. It allows for pressure-controlled ventilation, while simultaneously permitting spontaneous breathing with pressure support in any ventilation phase. Synchronization of mandatory and spontaneous ventilation is regulated by the ventilator. This mode is available in a variety of commercial ventilators. However, nomenclature might differ between companies (14).

- Chest Compression Synchronized Ventilation (CCSV, WEINMANN, Emergency Medical Technology GmbH + Co. KG, Hamburg, Germany): CCSV is a ventilation mode specifically designed for CPR. Expiratory airflow caused by chest

compression is used as a signal to trigger pressure-controlled mechanical ventilation at 40 mbar or 60 mbar immediately. Therefore, air is pushed inside the patient simultaneous to chest compression (with the same rate). PEEP can be necessary for correct triggering. This mechanism is proposed to result in increased intrathoracic pressure concentrated at the heart and in further consequence, positive hemodynamic effects such as increased mean arterial pressure. However, data in humans is currently limited (15).

### 2.1. Study design and setting

This scoping review collected publications on CCSV during cardiac arrest in animals and humans. A scoping review was selected as the most appropriate methodology because the aim was to explore the scope, range, and nature of the available literature on CCSV (or similar ventilation forms), rather than to assess the effectiveness of interventions or aggregate outcome data (16,17). This review is solely based on published literature, no primary patient data were accessed at any time. It was conducted according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR).

We operationally defined CCSV, Cardiopulmonary Ventilation (CPV), Simultaneous Compression Ventilation (SCV), and Automatic Compression Synchronous Ventilation (ACSV) as ventilation techniques characterized by the temporal coordination of mechanical ventilation with chest compressions with or without external synchronization mechanisms. Inclusion was based on this shared principle rather than specific ventilatory pressures or device settings, allowing for heterogeneity in pressure parameters, while maintaining focus on the core intervention concept for this scoping review.

Our protocol was designed according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR), (18) following these key features:

Sample: Humans and animals during cardiac arrest

Phenomenon of Interest: Ventilation with CCSV during cardiac arrest

Design: Structured literature research with predefined search strategy

Evaluation: Patient-centered outcomes (Return of spontaneous circulation (ROSC), survival to hospital discharge, 30-day survival, neurological outcome); changes in vital signs and laboratory measurements (Partial pressure of oxygen (PO<sub>2</sub>), carbon dioxide (PCO<sub>2</sub>), pH, blood pressures, peripheral oxygen saturation (SpO<sub>2</sub>), regional tissue oxygenation (rSO<sub>2</sub>), biomarkers of neuroinflammation); and adverse events (Ventilator-associated lung injury (VALI), pneumothorax, histological changes in lung tissue). Research Type: All literature published in peer-reviewed journals was eligible for inclusion. All years and all languages were included as long as there was an English abstract. There was no restriction of publications regarding time of publication.

## 2.2. Search strategy and evidence selection

We performed a systematic search of Medline, Embase, Central, Web of Science and Scopus databases on March 3rd 2025, with an update on May 25th 2025. The search strategy was designed by an information specialist (BH) and further refined within the research team. The full strategy for all databases can be found in Table 1.

Search results were analyzed for eligibility in a two-step process: First, duplicates were removed, and titles and abstracts were evaluated by two independent reviewers. Conflicts were resolved by consensus. Secondly, the full texts of eligible sources were retrieved and assessed in the same multi-reviewer process. Excluded sources were documented with justification. In the event of duplicate search results for previously published abstracts and their associated articles, the abstracts were excluded. Additionally, references of included sources were searched for relevant publications and screened in the same manner. Rayyan (Rayyan.ai) and Zotero 7.0.7 (Corporation for Digital Scholarship) were used for evidence selection.

## 2.3. Data extraction and analysis

Data extraction was performed on the included full text results. The data charting form was extended during pilot testing and included bibliography information, country, type of literature, ventilation forms, study design and setting, population size, and interventions and outcomes, as well as funding sources and features described above (patient centered outcomes, changes in vitals and lab values, adverse events) in the final operational version. Descriptive statistics were performed with R 4.4.1 (R Foundation for Statistical Computing, Vienna, Austria). Due to the considerable heterogeneity in study designs, outcome measures, and reporting formats, no effect sizes were calculated, in accordance with the descriptive and exploratory aims of this scoping review.

## 3. Results

### 3.1. Screening

The structured search yielded a total of 1,292 results. After removal of duplicates, 753 records were screened for eligibility. Initially 97.4% of the abstracts were classified concordantly (Cohen's Kappa: 0.77). All conflicts could be resolved by agreement. The process resulted in 50 reports eligible for further examination. Nineteen records were excluded due to lack of relation to the topic of interest. Additionally, in three cases abstracts and their associated articles published afterwards were found independently, resulting in the exclusion of the abstract. One abstract was published twice and therefore excluded once. In three cases the full-texts could not be retrieved, limiting data extraction to abstracts in these cases (19–21). Seven additional reports were identified by manual research. Of these, five were included in the review after full-text screening. In total, 32 studies were included in the review (Figure 1).

### 3.2. Characteristics of selected sources

A total of 32 reports published between 1980 and 2025 were included in the review and further assessed: Twenty-three reports (72%) focused on CCSV directly, seven reports (22%) described other ventilation modes or experimental ventilation protocols during chest compression (3,6,19,22–25) and two (6%) explored protocols for ventilation between compressions (26,27). Most reports originated from Germany (n=15, 47%), USA (n=4, 13%), or China (n=3, 9%). The majority of studies were designed as randomized controlled trials (n=13, 41%) (3,11,19–21,27–34) and conducted in animals (pigs; n=18, 58%) (19,23,24,27–41). Nine studies (28%) report outcomes in humans (3,6,11,21,25,26,42–44), one (3%) in human cadavers (20), and another one (3%) was conducted on manikins (45). Of note, one case report (42), one editorial (46), and one review (46) resulted from the database search. To estimate the resource setting, the reports originating from respective countries have been categorized according to the World Bank classifications (47) (Table 2).

### 3.3. Outcome parameters

Fourteen reports (44%) (11,19,21–23,29,30,32–34,36,39,40,44) included blood gas analysis results (arterial pO<sub>2</sub> and pCO<sub>2</sub> in all fourteen cases, and venous pO<sub>2</sub> and pCO<sub>2</sub> in only three cases(32,36,44) (9%)) as outcome measures. Hemodynamics were evaluated in 14 reports (44%) (19,22–24,26,27,29,31–34,37,39,48). Regarding hemodynamic features, various different endpoints were described: Aside from systolic, diastolic, and mean arterial blood pressure (6,22,23,29,32–34,37,39), coronary perfusion pressure (19,34), stroke volume (19), ejection fraction (19), cardiac output (23,27), coronary (22) or carotid flow (6,19,22,24,27,31), aortic pressure and right atrial pressure (22–24,27,34), central venous pressure (23,32,37,39), and SpO<sub>2</sub> (26), as well as end tidal CO<sub>2</sub> (etCO<sub>2</sub>) (19,26,29,34) were assessed. Cerebral oxygenation (rSO<sub>2</sub>) was assessed in three studies (31,34,35) (9%) and neuroinflammation was evaluated in another one (28) (3) Patient outcomes were reported in nine studies (28%) (3,11,25,31,34,40,42–44), and adverse events, especially lung injuries, were discussed in six studies (19%) (3,23,27,29,33,41) [Autopsy by predefined protocol – details not reported (3) / rib fractures, damage to the heart and lungs including abrasions, edema, ecchymosis, rupture of lung tissue (23) / pulmonary lacerations, edema, bullae, hemorrhage or injury to thoracic cavity (27) / incidence of pneumothorax (29)/diffuse alveolar hemorrhage, epithelia destruction, (hemo)pneumothorax (33)/emphysema, intraparenchymal cysts, congestion, interstitial thickening, alveolar hemorrhage and exudates (41)].

### 3.4. Various compression synchronized ventilation protocols

While 23 studies dealt with CCSV in particular (11,21,28–37,39–45,49–52), nine studies described differ-

ent but mechanistically related compression synchronized ventilation algorithms (3,19,22–27,48).

Ventilation simultaneous with chest compressions aside from CCSV was explored by seven studies (22%; three human (3,25,48) and four animal studies(19,22–24); airway pressure ranged from 20 cmH<sub>2</sub>O to 136 cmH<sub>2</sub>O). In one study, synchronized ventilation was limited to a frequency of 10/minute (25).

Schaller et al. focused on automatic ventilation during decompression at a rate of 100/min in seven cases of out-of-hospital cardiac arrest (OHCA) in Munich, Germany (26), and Olasveengen et al. explored ventilation between chest compressions as well (27).

### **3.5. Reported effects of synchronized ventilation on studied outcomes**

Study populations and major outcomes are summarized in Tables 3 and 4.

#### **3.5.1 Clinical outcomes**

Beneficial effects of CCSV on cerebral TNF mRNA levels in pigs were reported by Renz et al. (28). High rates of ROSC with CCSV and aortic balloon occlusion were observed in pigs by Xu et al. (34).

The use of CPV (AIR LIQUIDE MEDICAL SYSTEMS SA, Antony, France; respiratory rate of 10/min, inspiratory pressure of 20 cmH<sub>2</sub>O and a PEEP of 5 cmH<sub>2</sub>O; magnification of intrathoracic pressure) was found to be associated with higher rates of ROSC in humans in a retrospective analysis of the Belgian cardiac arrest registry by Malinverni et al. (25). In contrast, Krischer et al. reported better survival rates to hospital admission and hospital discharge for conventional CPR compared with simultaneous compression and ventilation (at a rate of 40/min with an airway pressure of 80mmHg) in humans (3). A recent, non-randomized study comparing CCSV, IPPV, and bag ventilation during OHCA by Hernández-Tejedor et al. showed a non-significant trend towards higher rates of ROSC and favorable neurological survival (Cerebral Performance Category (CPC) 1 or 2) for patients ventilated with CCSV (44).

#### **3.5.2 Hemodynamics**

Chandra et al. demonstrated improved carotid blood flow in animals and humans (22,48) and radial artery pressure in humans (48) during synchronized ventilation and compression when compared to conventional CPR. They also showed a correlation between lateral pleural pressure and aortic pressure and proposed it as a main determinant for blood flow during CPR in animals (24). Similarly, Kill et al. reported improved mean arterial and coronary perfusion pressures with CCSV (37), and mean arterial pressure for CCSV in comparison to IPPV (32,39) or BiPAP (32) in pig models. Additionally, they were able to show improved cerebral oxygen saturation for CCSV when compared to IPPV (35). Similar results for cerebral oxygen saturation in pigs were reported by Xu et al. (34) and Hu et al. (31). The latter also demonstrated an improved carotid flow with CCSV when compared to IPPV, as

well as lower lactate levels (31). On the other hand, Kopra et al. observed that CCSV had no effects on arterial blood pressure in comparison to bag-valve ventilation also in a pig model (29). Only minimally improved hemodynamic effects of synchronized (between compressions) compared to unsynchronized manual ventilation at a rate of 10/min were observed by Olasveengen et al. also in a pig model (27). Hou et al. showed an increase in central venous pressure in the simultaneous compression ventilation subgroup (at a ventilation rate of 60/min) when compared to standard CPR in pigs (23).

#### **3.5.3 Gas exchange**

The majority of studies reported on gas exchange parameters (19,21–23,29,30,32–34,36,39,40,44). Kill et al. showed adequate oxygenation as well as decarboxylation with CCSV during CPR (36) and better performance compared to IPPV and BiPAP (32). An association of higher paO<sub>2</sub> with CCSV compared to IPPV was also described by Renz et al., Xu et al., Kill et al., and Dersch et al. (33,34,39,40). The same effect was observed by Kopra et al. in comparison to bag-valve ventilation (29). Manegold et al. described an additional benefit of the combination of aortic occlusion and CCSV regarding pO<sub>2</sub>, pCO<sub>2</sub>, and pH (30). An improved paO<sub>2</sub> was also described by Cao et al. in an Automatic Compression Synchronous Ventilation (ACSV; 3ml/kg tidal volume, respiratory rate 100/min) group compared to IPPV (19).

However, Hou et al. reported more a rapid deterioration of pH, paO<sub>2</sub>, and paCO<sub>2</sub> in the simultaneous compression ventilation subgroup (at a rate of 60/min) compared to standard CPR (23). CCSV was associated with smaller deviations from ventilator presets (tidal volumes, peak airway pressures) when compared to IPPV and BiPAP in manikins as reported by Speer et al. (45).

In humans, Schaller et al. observed maximum etCO<sub>2</sub> values below 44 mmHg during synchronized ventilation between compressions (26). Only two recently published studies examined the effects of CCSV on gas exchange in humans (11,44). Oh et al. randomized OHCA patients upon hospital arrival at a single center and allocated them to either IPPV or CCSV ventilation group and compared arterial pO<sub>2</sub> and pCO<sub>2</sub>. Of 343 cases presenting at the hospital, 144 were randomized, but only 30 patients (15 in each group) were successfully included with initial and follow-up blood gas analyses. They were able to show a significant increase in pO<sub>2</sub> in the CCSV group and less marked, non-significant increase in the IPPV group; however, they failed to show a significant difference between ventilation groups (CCSV and IPPV). A significant decrease in pCO<sub>2</sub> in the CCSV group was demonstrated (11). It has to be noted that prehospital care of these OHCA patients was not standardized and not included in the analysis. In a non-randomized prospective study on OHCA patients (100 patients ventilated with CCSV, 145 ventilated with IPPV, and 276 with bag ventilation), Hernández-Tejedor et al. showed a significant increase in paO<sub>2</sub> for patients ventilated with CCSV (7 blood samples) compared to

IPPV (32 samples) and bag ventilation (24 samples). Arterial pH and  $\text{paCO}_2$  did not differ significantly. It has to be mentioned that arterial blood gas samples were not mandatory in this study. In venous blood samples, a non-significant trend towards higher  $\text{pCO}_2$  in patients with bag ventilation compared to mechanically ventilated patients was observed (44).

### 3.5.4 Adverse events

Data on adverse events were conflicting. Kopra et al. described a significantly higher prevalence of pneumothorax in the CCSV subgroup compared to bag-valve ventilation in pigs.(29) Renz et al. observed higher epithelial damage associated with CCSV in pigs (33). On the other hand, the rates of lung injuries in pigs were comparable between CCSV and IPPV as shown by Dersch et al. (41) and between synchronized and unsynchronized groups in the study by Olasveengen et al. (27). Kill et al. reported no adverse events of CCSV in OHCA in humans (43).

## 4. Discussion

After reviewing numerous studies, it must be concluded that data on CCSV in humans are still scarce, but there is more evidence available from animal studies.

Improved oxygenation in terms of  $\text{paO}_2$  is generally described for CCSV when compared to IPPV, BiPAP, or manual ventilation during cardiac arrest (32–34,36,39,40). Beneficial effects of CCSV on oxygenation was also described in humans (11,44). Despite the extremely high ventilation rate, an adequate decarboxylation avoiding hypercarbia is specifically suggested for CCSV (32,36). Hemodynamic assessments during CPR are generally in favor of CCSV: beneficial effects on mean arterial (32,37,39) and coronary perfusion pressures (37) as well as carotid flow, and lower lactate concentrations (31) have been described. Additionally, cerebral oxygenation, as a combined endpoint for oxygenation and hemodynamics, seems to be favorable during CCSV (31,34,35).

However, despite these numerous physiological parameters, data on patient outcomes are scarce. Moreover, data on adverse events, especially lung injuries including pneumothorax due to the high ventilation pressures, are currently limited and conflicting, and may differ between animals and humans. Of note, no adverse events were described in an OHCA cohort of 34 human patients in Germany (43). Additional safety data from larger prospective trials in humans are needed to clarify this.

It must also be mentioned that a large number of reports originate from Germany and the majority of these from the research group of Kill et al. (an overview of funding / sponsoring is given in Table 3).

A considerable proportion of studies focused on gas exchange or hemodynamic values, which may be relevant physiological outcome measures serving as surrogate markers and are useful to understand mechanistic aspects of an intervention, but do not necessarily provide information about the effect of CCSV on survival outcomes. This is further aggravated by the scarcity of prospective clinical data on

CCSV. Therefore, further clinical observational studies and ultimately (multicenter) randomized controlled trials reporting core outcome data along with rigorous safety monitoring are needed to provide reliable data on the effectiveness of CCSV during CPR (53). Other aspects, e.g. the impact of specialized ventilation modes such as CCSV on the management of human and team resources, especially in a prehospital setting and the general availability (and utilization) of specialized ventilation modes for CPR, remain yet to be explored.

## 5. Limitations

We found a considerable diversity of reported endpoints, especially hemodynamic outcomes, throughout the included studies. Additionally, the applied ventilation parameters varied largely, and some authors described and compared specific experimental ventilation protocols rather than standardized or commercialized ventilation modes. Therefore, comparability is limited and must be assessed cautiously. The importance of a common terminology regarding intra-arrest ventilation was also highlighted recently by Segond et al. (54).

With the intention to provide a broad overview of the current literature, we included studies examining other protocols besides pure CCSV, e.g. CPV and SC-V, as well. Of course, direct comparability is not given in these cases and results have to be analyzed cautiously. Also, three full-texts could not be retrieved and were, therefore, not assessed.

Another important point is the potential for selective reporting bias, particularly in studies funded by device manufacturers. Although we attempted to report this risk by including an overview of funding / sponsoring information if available, the information provided was sometimes incomplete or inconsistent, which limits transparency. Industry-sponsored studies may be more likely to report favorable outcomes, which could influence the overall perception of the efficacy of synchronized ventilation. This potential bias should be considered when interpreting our findings and highlights the need for independent investigator-initiated studies.

## 6. Conclusions

CCSV is a novel and specialized approach for intra-arrest ventilation. Data from animal and human studies report improvements of physiological parameters during CPR, but direct data on patient outcomes are still scarce. Prospective clinical trials in humans comparing the effectiveness of CCSV to other ventilation modes and manual ventilation are required.

## 7. Declarations

### 7.1. Acknowledgments

None.

## 7.2. Author contributions

Roman Brock: Conceptualization, Data curation, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing

Christoph Veigl: Data curation, Investigation, Writing – original draft, Writing – review & editing

Andrea Kornfehl: Data curation, Investigation, Writing – review & editing

Johannes Wittig: Validation, Writing – original draft, Writing – review & editing

Sabine Heider: Data curation, Investigation, Writing – review & editing

Karina Tapinova: Data curation, Investigation, Methodology, Writing – review & editing

Erwin Snijders: Data curation, Investigation, Writing – review & editing

Sabine Dunkl: Data curation, Investigation, Writing – review & editing

Daniel Grassmann: Data curation, Investigation, Writing – review & editing

Birgit Heller: Data curation, Investigation, Methodology, Resources, Validation, Writing – review & editing

Mario Krammel: Data curation, Investigation, Writing – review & editing

Sebastian Schnaubelt: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

## 7.3. Data availability

The assessed data are available upon reasonable request to the corresponding author.

## 7.4. Conflict of Interest

Johannes Wittig declares research grants from Aarhus University Research Foundation, Riisfort Fonden and the Laerdal Foundation. Sebastian Schnaubelt declares research grants by the ZOLL foundation, the Laerdal foundation, and Weinmann Medical, is ILCOR EIT Task Force member, ERC Advanced Life Support Science and Education Committee member, and Vice-Chair of the Austrian Resuscitation Council (ARC). All other authors declare that, apart from their displayed affiliations, they have no conflict of interest.

The authors declare that no commercial entity, including manufacturers of ventilation devices, influenced the conduct or conclusions of this scoping review. All interpretations and statements presented are solely those of the authors.

## 7.5. Funding

None.

## 7.6. Using artificial intelligence chatbots

During the preparation of this work the authors used DeepL and ChatGPT for translation and grammatical optimization. After using these services, the authors reviewed and edited

the content as needed and take full responsibility for the content of the publication.

## 7.7. Preprint statement

This manuscript is previously published as a preprint on Medrxiv: <https://www.medrxiv.org/content/10.1101/2025.05.28.25328471v1.full>.

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**Table 1:** Search strategy for different databases

<b>PubMed Central</b>		
#	Query	Results
1	"chest compression synchronized ventilat*".ti,ab,kw.	3
2	"chest compression synchronised ventilat*".ti,ab,kw.	0
3	CCSV.ti,ab,kw.	5
4	1 or 2 or 3	6
5	exp Cardiopulmonary Resuscitation/	1743
6	("Cardiopulmonary Resuscitation*" or "Cardio pulmonary Resuscitation*" or "cardiopulmonary reanimation*" or "cardio pulmonary reanimation*" or CPR or "basic life support*" or "advanced life support*" or "cardiac life support*" or "cardiovascular life support*" or "chest compression*" or "cardiac massage*" or "heart massage*" or "mouth to mouth Resuscitation*").ti,ab,kw.	4671
7	5 or 6	5012
8	4 and 7	4
9	exp Positive-Pressure Respiration/	3924
10	("positive pressure ventilat*" or "positive pressure respirat*").ti,ab,kw.	2136
11	("pressure controlled ventilat*" or "pressure controlled respirat*").ti,ab,kw.	443
12	(simultaneous adj2 (ventilat* or respirat*)).ti,ab,kw.	10
13	("synchronized ventilat*" or "synchronized respirat*").ti,ab,kw.	19
14	((new or novel) adj3 (ventilat* or respirat*)).ti,ab,kw.	564
15	9 or 10 or 11 or 12 or 13 or 14	6355
16	7 and 15	118
17	exp Heart Arrest/	3068
18	("heart arrest*" or "cardiac arrest*" or Asystol* or "Cardiopulmonary Arrest*" or "cardio pulmonary arrest*" or "circulation arrest*" or "circulatory arrest*" or "heart standstill*").ti,ab,kw.	6087
19	17 or 18	7223
20	16 and 19	37
21	8 or 20	39
<b>Embase</b>		
No.	Query	Results
#22	#8 OR #21	571
#21	#17 AND #20	564
#20	#18 OR #19	165702
#19	'heart arrest*:ti,ab,kw OR 'cardiac arrest*:ti,ab,kw OR asystol*:ti,ab,kw OR 'cardiopulmonary arrest*:ti,ab,kw OR 'cardio pulmonary arrest*:ti,ab,kw OR 'circulation arrest*:ti,ab,kw OR 'circulatory arrest*:ti,ab,kw OR 'heart standstill*:ti,ab,kw	100026
#18	'heart arrest'/exp	147187
#17	#7 AND #16	1152
#16	#9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15	93867
#15	((new OR novel) NEAR/3 (ventilat* OR respirat*)):ti,ab,kw	6999
#14	'synchronized ventilat*:ti,ab,kw OR 'synchronized respirat*:ti,ab,kw	128
#13	(simultaneous NEAR/2 (ventilat* OR respirat*)):ti,ab,kw	311
#12	'pressure controlled ventilat*:ti,ab,kw OR 'pressure controlled respirat*:ti,ab,kw	1012
#11	'positive pressure ventilat*:ti,ab,kw OR 'positive pressure respirat*:ti,ab,kw	11552
#10	'pressure controlled ventilation'/exp	842
#9	'positive pressure ventilation'/exp	84013
#8	#4 AND #7	20
#7	#5 OR #6	57879
#6	'cardiopulmonary resuscitation*:ti,ab,kw OR 'cardio pulmonary resuscitation*:ti,ab,kw OR 'cardiopulmonary reanimation*:ti,ab,kw OR 'cardio pulmonary reanimation*:ti,ab,kw OR cpr:ti,ab,kw OR 'basic life support*:ti,ab,kw OR 'advanced life support*:ti,ab,kw OR 'cardiac life support*:ti,ab,kw OR 'cardiovascular life support*:ti,ab,kw OR 'chest compression*:ti,ab,kw OR 'cardiac massage*:ti,ab,kw OR 'heart massage*:ti,ab,kw OR 'mouth to mouth resuscitation*:ti,ab,kw	57495
#5	'advanced cardiac life support'/de	901
#4	#1 OR #2 OR #3	39
#3	ccsv:ti,ab,kw	37
#2	'chest compression synchronised ventilat*:ti,ab,kw	1
#1	'chest compression synchronized ventilat*:ti,ab,kw	18
<b>Medline</b>		
#	Query	Results
1	"chest compression synchronized ventilat*".ti,ab,kf.	8
2	"chest compression synchronised ventilat*".ti,ab,kf.	0
3	CCSV.ti,ab,kf.	26
4	1 or 2 or 3	28
5	exp Cardiopulmonary Resuscitation/	23914

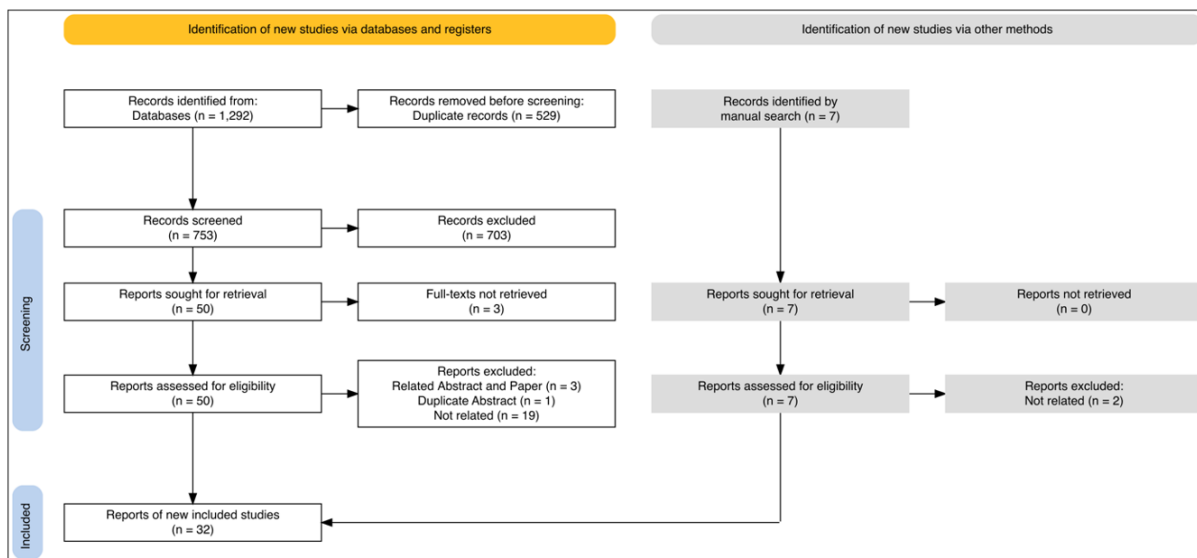
**Table 1:** Search strategy for different databases

6	("Cardiopulmonary Resuscitation*" or "Cardio pulmonary Resuscitation*" or "cardiopulmonary reanimation*" or "cardio pulmonary reanimation*" or CPR or "basic life support*" or "advanced life support*" or "cardiac life support*" or "cardiovascular life support*" or "chest compression*" or "cardiac massage*" or "heart massage*" or "mouth to mouth Resuscitation*").ti,ab,kf.	36730
7	5 or 6	45269
8	4 and 7	8
9	exp Positive-Pressure Respiration/	30316
10	("positive pressure ventilat*" or "positive pressure respirat*").ti,ab,kf.	7882
11	("pressure controlled ventilat*" or "pressure controlled respirat*").ti,ab,kf.	719
12	(simultaneous adj2 (ventilat* or respirat*)).ti,ab,kf.	237
13	("synchronized ventilat*" or "synchronized respirat*").ti,ab,kf.	89
14	((new or novel) adj3 (ventilat* or respirat*)).ti,ab,kf.	5234
15	9 or 10 or 11 or 12 or 13 or 14	39638
16	7 and 15	519
17	exp Heart Arrest/	59233
18	("heart arrest*" or "cardiac arrest*" or Asystol* or "Cardiopulmonary Arrest*" or "cardio pulmonary arrest*" or "circulation arrest*" or "circulatory arrest*" or "heart standstill*").ti,ab,kf.	63190
19	17 or 18	91110
20	16 and 19	217
21	8 or 20	219
	<b>Scopus</b>	
#	Query	Results
1	TITLE-ABS-KEY ( ( "chest compression synchronized ventilat*" ) )	9
2	TITLE-ABS-KEY ( ( "chest compression synchronised ventilat*" ) )	9
3	TITLE-ABS-KEY ( ( ccsv ) )	56
4	1 OR 2 OR 3	59
5	TITLE-ABS-KEY ( ( "Cardiopulmonary Resuscitation*" OR "Cardio pulmonary Resuscitation*" OR "cardiopulmonary reanimation*" OR "cardio pulmonary reanimation*" OR cpr OR "basic life support*" OR "advanced life support*" OR "cardiac life support*" OR "cardiovascular life support*" OR "chest compression*" OR "cardiac massage*" OR "heart massage*" OR "mouth to mouth Resuscitation*" ) )	58954
6	4 AND 5	9
7	TITLE-ABS-KEY ( ( "positive pressure ventilat*" OR "positive pressure respirat*" ) )	27576
8	TITLE-ABS-KEY ( ( "pressure controlled ventilat*" OR "pressure controlled respirat*" ) )	1331
9	TITLE-ABS-KEY ( ( ( simultaneous ) near/2 ( ventilat* OR respirat* ) ) )	137
10	TITLE-ABS-KEY ( ( "synchronized ventilat*" OR "synchronized respirat*" ) )	125
11	TITLE-ABS-KEY ( ( ( new OR novel ) near/3 ( ventilat* OR respirat* ) ) )	887
12	7 OR 8 OR 9 OR 10 OR 11	29692
13	5 AND 12	641
14	TITLE-ABS-KEY ( ( "heart arrest*" OR "cardiac arrest*" OR asystol* OR "Cardiopulmonary Arrest*" OR "cardio pulmonary arrest*" OR "circulation arrest*" OR "circulatory arrest*" OR "heart standstill*" ) )	120603
15	13 AND 14	287
16	6 OR 15	289
	<b>Web of Science</b>	
#	Search Query	Results
1	TS=("chest compression synchronized ventilat*")	10
2	TS=("chest compression synchronised ventilat*")	0
3	TS=(CCSV)	43
4	#1 OR #2 OR #3	46
5	TS=("Cardiopulmonary Resuscitation*" or "Cardio pulmonary Resuscitation*" or "cardiopulmonary reanimation*" or "cardio pulmonary reanimation*" or CPR or "basic life support*" or "advanced life support*" or "cardiac life support*" or "cardiovascular life support*" or "chest compression*" or "cardiac massage*" or "heart massage*" or "mouth to mouth Resuscitation*")	47494
6	#4 AND #5	10
7	TS=("positive pressure ventilat*" or "positive pressure respirat*")	9905
8	TS=("pressure controlled ventilat*" or "pressure controlled respirat*")	765
9	TS=((simultaneous) NEAR/2 (ventilat* or respirat*))	623
10	TS=("synchronized ventilat*" or "synchronized respirat*")	91
11	TS=((new or novel) NEAR/3 (ventilat* or respirat*))	8986
12	#7 OR #8 OR #10 OR #9 OR #11	20071
13	#5 AND #12	485
14	TS=("heart arrest*" or "cardiac arrest*" or Asystol* or "Cardiopulmonary Arrest*" or "cardio pulmonary arrest*" or "circulation arrest*" or "circulatory arrest*" or "heart standstill*")	76050
15	#13 AND #14	172
16	#15 OR #6	174

**Table 2:** Income classification table according to the World Bank classification (47) (In two cases, the country could not be determined due to missing full-text)

Country	Income	East Asia & Pacific (N=5)	Europe & Central Asia(N=21)	North America (N=4)	Overall (N=30)
China	Upper middle income	3 (60)	0	0	3 (10)
Taiwan, China	High income	1 (20)	0	0	1 (3)
Korea	High income	1 (20)	0	0	1 (3)
Belgium	High income	0	1 (5)	0	1 (3)
Finland	High income	0	1 (5)	0	1 (3)
France	High income	0	1 (5)	0	1 (3)
Germany	High income	0	15 (71)	0	15 (50)
Ireland	High income	0	1 (5)	0	1 (3)
Norway	High income	0	1 (5)	0	1 (3)
Spain	High income	0	1 (5)	0	1 (3)
United States	High income	0	0	4 (100)	4 (13)

Data are presented as number (%).



**Figure 1:** Flow diagram of the screening and inclusion/exclusion process.

**Table 3:** Overview of study populations and funding sources, classified into animal and human studies and ordered by year of publication

Title	First Author	Year	Population	Funding
Comparison of ventilation modes in non-traumatic out-of-hospital cardiac arrest: SYMEVECA phase 2	Hernández-Tejedor, A.	2025	Human (n=521)	None
Effectiveness of Chest Compression-Synchronized Ventilation in Patients with Cardiac Arrest	Oh, Y.T.	2025	Human (n=30)	Hallym University Research Fund
Intra-Arrest-Ventilation in Human Cadavers	Unknown*	2024	Human cadavers	Unknown
Evaluation of the effectiveness of Chest Compression Synchronized Ventilation in cardiac arrest patients	Unknown*	2023	Human	Unknown
Fully Automated Cardiopulmonary Resuscitation - a Bridge to ECMO	van der Velde, J.	2023	Human (n=1)	Not reported
Out of hospital cardiac arrest ventilation using Cardiopulmonary Ventilation is associated with increased incidence of return of spontaneous circulation	Malinverni, S.	2023	Human (n=1936)	Not reported
Continuous chest compressions with a simultaneous triggered ventilator in the Munich Emergency Medical Services: a case series	Schaller, S.J.	2019	Human (n=7)	Not reported
Mechanical positive pressure ventilation during resuscitation in out-of-hospital cardiac arrest with chest compression synchronized ventilation (CCSV)	Kill, C.	2019	Human (n=34)	Not reported
Comparison of prehospital conventional and simultaneous compression-ventilation cardiopulmonary resuscitation	Krischer, JP.	1989	Human (n=994)	National Heart, Lung and Blood Institute
Simultaneous chest compression and ventilation at high airway pressure during cardiopulmonary resuscitation	Chandra, N.	1980	Human (n=11)	National Heart, Lung and Blood Institute
Mechanical Ventilation During Resuscitation: how Manual Chest Compressions Affect a Ventilator's Function	Speer, T.	2017	Manikin (n=90)	Weinmann Emergency
Chest compression synchronized ventilation is associated with improved oxygenation but also with increased incidence of pneumothoraces in an experimental CPR model	Kopra, J.	2024	Pig (n=30)	Sigrid Jusélius Foundation, device by Weinmann Emergency
Lung tissue injury and hemodynamic effects of ventilations synchronized or unsynchronized to continuous chest compressions in a porcine cardiac arrest model.	Olasveengen, T.	2024	Pig (n=20)	Oslo Cardiopulmonary Resuscitation Research (OSCAR) Network, Laerdal Foundation, Jahres Fund
The study on the effect of automatic compression synchronous ventilation mode on cardiopulmonary resuscitation in pigs	Cao, G.	2024	Pig (n=12)	Research and Development Program of China, Natural Science Foundation of China, Natural Key Zhejiang Provincial Key Research and Development Program
Analysis of cerebral Interleukin-6 and tumor necrosis factor alpha patterns following different ventilation strategies during cardiac arrest in pigs	Renz, M.	2023	Pig (n=35)	German Research foundation, devices by Weinmann Emergency
Influence of aortic occlusion during non-trauma resuscitation on gas exchange in a pig model with chest compression synchronized ventilation	Manegold, R.	2023	Pig (n=9)	Not reported
Synchronized ventilation during resuscitation in pigs does not necessitate high inspiratory pressures to provide adequate oxygenation	Renz, M.	2023	Pig (n=15)	University Medical Center Mainz, German Research Foundation, devices by Weinmann Emergency and Stryker
Efficacy of chest compression synchronized ventilation on brain tissue oxygenation in a porcine cardiopulmonary resuscitation model	Hu, H.	2022	Pig (n=10)	Hangzhou Science and Technology Bureau project
The combination of chest compression synchronized ventilation and aortic balloon occlusion improve the outcomes of cardiopulmonary resuscitation in swine	Xu, J.	2022	Pig (n=31)	Natural Science Foundation of China, Zhejiang Provincial Key Research, Zhejiang Provincial Welfare Scientific Research Project of China
Cerebral oxygenation during resuscitation: Influence of the ventilation modes Chest Compression Synchronized Ventilation (CCSV) or Intermittent Positive Pressure Ventilation (IPPV) and of vasopressors on cerebral tissue oxygen saturation	Kill, C.	2015	Pig (n=32)	Not reported
Chest Compression Synchronized Ventilation versus Intermittent Positive Pressure Ventilation during Cardiopulmonary Resuscitation in a Pig Model	Kill, C.	2015	Pig (n=12)	German governmental grant, Weinmann Emergency

**Table 3:** Overview of study populations and funding sources, classified into animal and human studies and ordered by year of publication

Title	First Author	Year	Population	Funding
Mechanical ventilation during cardiopulmonary resuscitation with intermittent positive-pressure ventilation, bilevel ventilation, or chest compression synchronized ventilation in a pig model	Kill, C.	2014	Pig (n=24)	German governmental grant, Weinmann Emergency
Resuscitation with mechanical ventilation: The effects of Chest Compression Synchronized Ventilation (CCSV) or Intermitted Positive Pressure Ventilation (IPPV) on lung injury in a pig model	Dersch, W.	2013	Pig (n=22)	Not reported
Resuscitation and mechanical ventilation with Chest Compression Synchronized Ventilation (CCSV) or Intermitted Positive Pressure Ventilation (IPPV): Influence on gas exchange and return of spontaneous circulation in a pig model Category: CPR Systems	Dersch, W.	2012	Pig (n=44)	Not reported
Chest compression synchronized ventilation during CPR: Influence of a novel ventilator mode on gas exchange in a pig model	Kill, C.	2011	Pig (n=7)	Not reported
Chest compression synchronized ventilation during cpr: Influence on haemodynamics in a pig model	Kill, C.	2011	Pig (n=7)	Not reported
Chest compression synchronized ventilation during CPR: Technical solution and flow-volume curves of a novel ventilator mode	Dietz, F.	2011	Pig (n=7)	Not reported
Comparison of conventional and simultaneous compression-ventilation cardiopulmonary resuscitation in piglets	Hou, S.-H.	1994	Pig (n=20)	Provincial Taipei Hospital
Augmentation of carotid flow during cardiopulmonary resuscitation by ventilation at high airway pressure simultaneous with chest compression	Chandra, N.	1981	Pig (n=6), dog (n=21), baboon (n=1)	National Heart, Lung, and Blood Institute
Contrasts between intrathoracic pressures during external chest compression and cardiac massage	Chandra, N.	1981	Pig (n=4), dog (n=3), baboon (n=1)	National Heart, Lung, and Blood Institute

\*Missing authors due to missing full-text.

**Table 4:** Overview of included studies, study design, populations and main outcome

Title	First Author	Year	Population	Design	Major results
Comparison of ventilation modes in non-traumatic out-of-hospital cardiac arrest: SYMEVECA phase 2	Hernández-Tejedor, A.	2025	Human (n=521)	Prospective quasi-experimental non-randomized study	Trend towards better oxygenation and higher rates of ROSC and favorable neurological outcome with CCSV paO <sub>2</sub> : CCSV: 229.5 ± 183.5, IPPV: 103.6 ± 82.6, Bag-ventilation: 149.6 ± 116.4 paCO <sub>2</sub> : CCSV: 75.6 ± 18.1; IPPV: 73.6 ± 27.7 ; Bag-ventilation: 85.1 ± 38.3 mmHg CPC 1-2: CCSV: 16%; IPPV: 12.4%; Bag-ventilation: 9.4%
Effectiveness of Chest Compression-Synchronized Ventilation in Patients with Cardiac Arrest	Oh, Y.T.	2025	Human (n=30)	RCT	Improved oxygenation with CCSV delta paO <sub>2</sub> : CCSV: 76.1 [22.8; 260.3]; IPPV: 8.8 [1.6; 113.9] delta paCO <sub>2</sub> : CCSV: 10.3 [18.3; 2.7]; IPPV: 11.5 [36.5; 5.6]
Intra-Arrest-Ventilation in Human Cadavers	Unknown	2024	Human cadavers	Comparative study	Unknown
Evaluation of the effectiveness of Chest Compression Synchronized Ventilation in cardiac arrest patients	Unknown	2023	Human	RCT	Unknown
Fully Automated Cardiopulmonary Resuscitation - a Bridge to ECMO	van der Velde, J.	2023	Human (n=1)	Case report	Case report
Out of hospital cardiac arrest ventilation using Cardiopulmonary Ventilation is associated with increased incidence of return of spontaneous circulation	Malinverni, S.	2023	Human (n=1936)	Retrospective analysis	CPV associated with higher probability of ROSC OR 1.52 (1.12-2.07)
Continuous chest compressions with a simultaneous triggered ventilator in the Munich Emergency Medical Services: a case series	Schaller, S.J.	2019	Human (n=7)	Case series	No hyperventilation etCO <sub>2</sub> <45mmHg
Mechanical positive pressure ventilation during resuscitation in out-of-hospital cardiac arrest with chest compression synchronized ventilation (CCSV)	Kill, C.	2019	Human (n=34)	Retrospective analysis	No serious adverse events occurred Admission with ROSC n = 21 (61.8%), 24 h survival n = 12 (35.3%), discharged alive n = 5 (14.7%)
Comparison of prehospital conventional and simultaneous compression-ventilation cardiopulmonary resuscitation	Krischer, JP.	1989	Human (n=994)	RCT	Lower survival to hospital admission and survival to discharge with simultaneous compression-ventilation, no difference in GCS Survival to hospital admission: Control: 26.2%; Intervention 19% Percentage discharged alive: Control: 43.4%; Intervention 34.2% mean GCS 24h post admission: Control: 8.1, Intervention 8.4
Simultaneous chest compression and ventilation at high airway pressure during cardiopulmonary resuscitation	Chandra, N.	1980	Human (n=11)	Prospective interventional study	Improved carotid flow and radial artery pressures during simultaneous compression-ventilation mean systolic radial artery pressure: control: 40.6±4.4; new CPR: 53.1±3.9 mm Hg MAP: control: 33.3±4.2; new CPR: 45.9±3.5 mm Hg carotid flow index: new CPR/control: 252% (113-643%)
Mechanical Ventilation During Resuscitation: how Manual Chest Compressions Affect a Ventilator's Function	Speer, T.	2017	Manikin (n=90)	Randomized trial	During simulated CPR, CCSV worked best with preset parameters, without exceeding the maximum pressure preset compared to IPPV and BiPAP Median tidal volume IPPV with a preset of 450ml: 399 (386/411) ml Median inspiratory pressure BiLevel with a preset of 19 hPa: 22.0 (19.7/25.6) hPa Median inspiratory pressure CCSV with a preset of 60 hPa: 55.2 (52.6/56.7) hPa

**Table 4:** Overview of included studies, study design, populations and main outcome

Title	First Author	Year	Population	Design	Major results
Chest compression synchronized ventilation is associated with improved oxygenation but also with increased incidence of pneumothoraces in an experimental CPR model	Kopra, J.	2024	Pig (n=30)	RCT	Higher PO <sub>2</sub> , lower etCO <sub>2</sub> in CCSV, comparable systolic and mean arterial pressure, higher incidence of pneumothoraces with CCSV PaO <sub>2</sub> : CCSV: 490 (86–570) ; control: 304 (109–379) Pneumothorax: CCSV: n=12; control: n=3 time x group interaction term for systolic blood pressure: 0.11
Lung tissue injury and hemodynamic effects of ventilations synchronized or unsynchronized to continuous chest compressions in a porcine cardiac arrest model.	Olasveengen, T.	2024	Pig (n=20)	RCT	Comparable hemodynamics and lung injury in synchronized and unsynchronized ventilation Gross lung tissue injury: synchronized: 0/10; unsynchronized: 4/10 Traumatic bullae: synchronized: 4cm; unsynchronized: 3 cm ROSC: synchronized 5/10; unsynchronized: 3/10 Aortic Pressure: synchronized 86 ± 16; unsynchronized: 93 ± 11 Coronary Perfusion Pressure: synchronized 81 ± 17; Unsynchronized: 87 ± 11 Cerebral Perfusion Pressure: synchronized 76 ± 16; unsynchronized: 85 ± 12 Carotid Blood Flow: synchronized 158 ± 13; unsynchronized: 178 ± 41 Cardiac output: synchronized 3.1 ± 0.6; unsynchronized: 3.0 ± 0.4
The study on the effect of automatic compression synchronous ventilation mode on cardiopulmonary resuscitation in pigs	Cao, G.	2024	Pig (n=12)	RCT	Higher PaO <sub>2</sub> with ACSV
Analysis of cerebral Interleukin-6 and tumor necrosis factor alpha patterns following different ventilation strategies during cardiac arrest in pigs	Renz, M.	2023	Pig (n=35)	RCT	Positive impact on the TNFalpha levels post-resuscitation TNFα Hippocampus: IPPV: 0.12 ± 0.049; CCSV: 0.048 ± 0.01 TNFα Cortex: IPPV: 0.13 ± 0.092; CCSV: 0.092 ± 0.04
Influence of aortal occlusion during non-trauma resuscitation on gas exchange in a pig model with chest compression synchronized ventilation	Manegold, R.	2023	Pig (n=9)	RCT	REBOA improved gas exchange Mean pO <sub>2</sub> : Control: 105 mmHg REBOA: 114mmHg
Synchronized ventilation during resuscitation in pigs does not necessitate high inspiratory pressures to provide adequate oxygenation	Renz, M.	2023	Pig (n=15)	RCT	Increased epithelial destruction and higher PaO <sub>2</sub> with CCSV, comparable mean arterial pressures Epithelial Destruction points: IPPV 3.31 (0.58); SV 20 mbar 3.37 (0.50); CCSV 40 mbar 3.61 (0.53) MAP: IPPV-BLS: 32.94 (5.93) ALS: 38.18 (6.09); SV 20 mbar BLS: 31.17 (5.70) ALS: 37.57 (32.02); CCSV 40 mbar BLS: 33.07 (3.91) ALS: 33.45 (13.93) paO <sub>2</sub> : IPPV BLS: 212.72 (229.76) ALS: 209.80 (200.77); SV 20 mbar BLS: 162.94 (79.54) ALS: 162.30 (141.76); CCSV 40 mbar BLS: 306.55 (254.98) ALS: 145.73 (160.93) paCO <sub>2</sub> : IPPV BLS: 62.94 (19.71) ALS: 54.56 (25.75); SV 20 mbar BLS: 67.14 (23.82) ALS: 74.90 (33.16); CCSV 40 mbar BLS: 53.46 (27.52) ALS: 60.76 (30.52) Efficacy of chest compression synchronized ventilation on brain tissue oxygenation in a porcine cardiopulmonary resuscitation model Hu, H. 2022 Pig (n=10) RCT Lower lactate levels and higher carotid flow and cerebral saturation in the CCSV group Lactate levels: 4 min CCSV: 8.33 ± 0.14 IPPV: 9.27 ± 0.16; 7 min CCSV: 8.68 ± 0.18 IPPV: 9.64 ± 0.17; 30 min CCSV: 9.24 ± 0.33 IPPV: 10.99 ± 0.46 Cerebral oxygen saturation: 1 h CCSV: 58.62 ± 0.85 IPPV: 54.88 ± 1.22; 2 h CCSV: 57.52 ± 0.70 IPPV: 54.64 ± 0.95; 3 h CCSV: 59.40 ± 0.48 IPPV: 56.52 ± 0.77; 4 h CCSV: 61.84 ± 0.88 IPPV: 56.46 ± 1.86

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Title	First Author	Year	Population	Design	Major results
The combination of chest compression synchronized ventilation and aortic balloon occlusion improve the outcomes of cardiopulmonary resuscitation in swine	Xu, J.	2022	Pig (n=31)	RCT	Improved ventilatory and hemodynamic efficacy and probability of ROSC in the combination of CCSV and ABO ROSC: IPPV: 5/10; CCSV: 5/7; IPPV+ABO: 6/7; CCSV+ABO: 7/7 paO <sub>2</sub> 4min: IPPV: 115 ± 44; CCSV: 433 ± 61; IPPV+ABO: 105 ± 58; CCSV+ABO: 372 ± 123 paO <sub>2</sub> 7min: IPPV: 107 ± 51; CCSV: 466 ± 69; IPPV+ABO: 103 ± 78; CCSV+ABO: 412 ± 107 paCO <sub>2</sub> 4min: IPPV: 38 ± 7; CCSV: 23 ± 4; IPPV+ABO: 42 ± 13; CCSV+ABO: 30 ± 12 paCO <sub>2</sub> 7min: IPPV: 37 ± 9; CCSV: 25 ± 11; IPPV+ABO: 37 ± 11; CCSV+ABO: 28 ± 12 Coronary perfusion pressure (trend): CCSV+ABO/IPPV+ABO > CCSV > IPPV rSO <sub>2</sub> (trend): CCSV/CCSV+ABO > IPPV+ABO > IPPV cerebral blood flow (trend): CCSV+ABO/IPPV+ABO > CCSV > IPPV
Cerebral oxygenation during resuscitation: Influence of the ventilation modes Chest Compression Synchronized Ventilation (CCSV) or Intermittent Positive Pressure Ventilation (IPPV) and of vasopressors on cerebral tissue oxygen saturation	Kill, C.	2015	Pig (n=32)	Interventional study	Improved ScO <sub>2</sub> with CCSV ScO <sub>2</sub> 6min: IPPV 38% (30/45); CCSV 46% (36/49) ScO <sub>2</sub> 10min: 43% (36/50); CCSV 51% (37/62) ScO <sub>2</sub> 12 min: 54% (43/60); CCSV 59% (36/74)
Chest Compression Synchronized Ventilation versus Intermittent Positive Pressure Ventilation during Cardiopulmonary Resuscitation in a Pig Model	Kill, C.	2015	Pig (n=12)	RCT	Improved PaO <sub>2</sub> and mean arterial pressure with CCSV paO <sub>2</sub> kPa: IPPVfirst: 19.6 (13.9/36.2) ; IPPVlast: 22.7(5.4/36.9) ; CCSVA: 48.9(29.0/58.2) ; CCSVB: 54.0 (43.8/64.1); CCSVC: 46.0 (20.2/58.4) MAP mmHg: IPPVfirst: 42.5 (33.4/47.5); IPPVlast: 22.4 (18.4/29.9); CCSVA: 40.1 (34.4/44) mmHg; CCSVB: 39.2 (34.5/45.6); CCSVC: 37 (29.5/42.2)
Mechanical ventilation during cardiopulmonary resuscitation with intermittent positive-pressure ventilation, bilevel ventilation, or chest compression synchronized ventilation in a pig model	Kill, C.	2014	Pig (n=24)	RCT	Highest mean arterial pressure and oxygenation in the CCSV group paO <sub>2</sub> , 4min, torr: IPPV 143 (76/256); Bilevel 261 (109/386); CCSV 598 (471/650) paO <sub>2</sub> , 13min, torr: IPPV 262 (81/340); Bilevel: 236 (86/364); CCSV 634 (115/693) Arterial pressure, end inspiratory, mmHg: IPPV 28.0 (25.0/29.6); Bilevel 29.1 (25.6/37.1); CCSV 32.7 (30.4/33.4) arterial pressure, end expiratory, mmHg: IPPV 27.9 (24.4/30.0); Bilevel: 28.7 (24.2/36.5); CCSV 27.0 (24.5/27.7)
Resuscitation with mechanical ventilation: The effects of Chest Compression Synchronized Ventilation (CCSV) or Intermittent Positive Pressure Ventilation (IPPV) on lung injury in a pig model	Dersch, W.	2013	Pig (n=22)	Interventional study	Ventilation with CCSV and IPPV during resuscitation causes only minor lung tissue injury Emphysematous changes: CCSV 1(1/2); IPPV 1.5(1/2); Intraparenchymal cysts: CCSV 1(1/1), IPPV 1(1/1); Interstitial congestion: CCSV 1(1/2); IPPV 1(1/1.75); Interstitial thickening: CCSV 2(2/3); IPPV 2(1/2.75) Alveolar hemorrhage: CCSV 1(1/2); IPPV 1(1/2); Organization of alveolar exudates: CCSV 1(1/1); IPPV 1(1/1)
Resuscitation and mechanical ventilation with Chest Compression Synchronized Ventilation (CCSV) or Intermittent Positive Pressure Ventilation (IPPV): Influence on gas exchange and return of spontaneous circulation in a pig model Category: CPR Systems	Dersch, W.	2012	Pig (n=44)	Interventional study	CCSV increases oxygenation and avoids hypercarbia ROSC: CCSV n=15; IPPV n=20 PaCO <sub>2</sub> , 8min, mmHg: CCSV 44 (35–49); IPPV 58 (53–66) PaCO <sub>2</sub> , 12min, mmHg: CCSV 41 (32–50); IPPV 60 (52–75) PaO <sub>2</sub> , 8min, mmHg: CCSV 317 (175–492), IPPV 88 (55–122) PaO <sub>2</sub> , 12min, mmHg: CCSV 383 (132–456); IPPV 97 (68–155)
Chest compression synchronized ventilation during CPR: Influence of a novel ventilator mode on gas exchange in a pig model	Kill, C.	2011	Pig (n=7)	Interventional study	Adequate oxygenation and decarboxylation with CCSV PaO <sub>2</sub> : baseline 91 (85/94) mmHg; 10min CPR: 634 (115/693) mmHg PaCO <sub>2</sub> : baseline 40 (39/42) mmHg, 10min CPR: 26 (18/29) mmHg

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Title	First Author	Year	Population	Design	Major results
Chest compression synchronized ventilation during cpr: Influence on haemodynamics in a pig model	Kill, C.	2011	Pig (n=7)	Interventional study	Improved mean arterial pressure during CPR with CCSV MAP, 13min CPR with and without CCSV, mmHg: 32.7 (30.4/33.4) vs. 27.0 (24.5/27.7) MAP, 17min CPR with and without CCSV, mmHg: 61.8 (58.3/67.9) vs. 47.8 (46.6/48.9)
Chest compression synchronized ventilation during CPR: Technical solution and flow-volume curves of a novel ventilator mode	Dietz, F.	2011	Pig (n=7)	Interventional study	CCSV was correctly triggered in 98.6% of the compressions
Comparison of conventional and simultaneous compression-ventilation cardiopulmonary resuscitation in piglets	Hou, S.-H.	1994	Pig (n=20)	Interventional study	Increased barotrauma and worse blood gases with simultaneous compression-ventilation PCO <sub>2</sub> > 50mmHg after 20min in SCV-CPR PO <sub>2</sub> significantly higher with C-CPR Rib fracture: C-CPR 2/10, SCV-CPR 2/9 Lungs heavier and edematous with SCV-CPR Petechial ecchymosis in the lungs: C-CPR 3/10, SCV-CPR 6/9 Formation of bullae: C-CPR 0/10, SCV-CPR 4/10 Rupture of bullae: C-CPR 0/10, SCV-CPR 1/10
Augmentation of carotid flow during cardiopulmonary resuscitation by ventilation at high airway pressure simultaneous with chest compression	Chandra, N.	1981	Pig (n=6), dog (n=21), baboon (n=1)	Interventional study	Improved carotid and coronary blood flow with simultaneous ventilation-compression Mean carotid flow: C-CPR 5.1 +- 1.08 ml/ min; SCV-CPR 18.7 +- 4.7 ml/min Coronary flow rate: C-CPR 1.1 +- 0.5 ml/min; SCV-CPR 3.7 +- 0.5 ml/min
Contrasts between intrathoracic pressures during external chest compression and cardiac massage	Chandra, N.	1981	Pig (n=4), dog (n=3), baboon (n=1)	Interventional study	Atrial and aortic pressures comparable, equaled the change in pleural pressure; elevation of intrathoracic pressure determines the blood flow during CPR

RCT: randomized clinical trial; ROSC: Return of spontaneous circulation; CCSV: Chest Compression Synchronized Ventilation; CPC: Cerebral Performance Category; CPV: Cardiopulmonary Ventilation; OR: Odds ratio; GCS: Glasgow coma scale; CPR: Cardiopulmonary resuscitation; MAP: Mean arterial pressure; ALS: Advanced Life Support; BLS: Basic Life Support; ABO: Aortic balloon occlusion; SCV-CPR: CPR with simultaneous chest compression and ventilation at high airway pressure; REBOA: resuscitative endovascular balloon occlusion of the aorta; BiPAP: Bi-Level Positive Airway Pressure Ventilation.