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Ventilation parameters during adult cardiopulmonary resuscitation: a systematic review

Nicholas J. Johnson[a,*], *Guillaume Debaty*[b], *Betty Y. Yang*[c], *Ari Moskowitz*[d], *Ian Drennan*[e], *Jimena del Castillo*[f], *Theresa Olasveengen*[g], *Katherine M. Berg*[h], *Laurie J. Morrison*[i], *Janet E. Bray*[j,k], *on behalf of the International Liaison Committee on Resuscitation Basic and Advanced Life Support Task Forces*[†]

Abstract

Background: Effective ventilation during cardiopulmonary resuscitation (CPR) is challenging, with limited evidence to guide optimal rates, volumes, and other parameters. This systematic review, part of the continuous evidence evaluation process for the International Liaison Committee on Resuscitation, examined whether specific tidal volumes, respiratory rates, inspiratory times, or positive end-expiratory pressure (PEEP) improve outcomes.

Methods: Studies of adults in any setting (in-hospital or out-of-hospital cardiac arrest) receiving ventilation were included if they compared specific tidal volumes, respiratory rates, inspiratory times, or PEEP. MEDLINE, EMBASE, and CENTRAL were searched from inception to November 10, 2025. Risk of bias was assessed using RoB 2.0 and ROBINS-I; certainty of evidence was evaluated with GRADE. Registered in PROSPERO (CRD420251070065).

Results: Of 3021 records, 11 studies (3 randomized trials, 8 observational) met eligibility criteria. Certainty of evidence was very low, limited by bias, inconsistency, indirectness, and imprecision. Due to heterogeneity, results were reported narratively using Synthesis Without Meta-Analysis (SWiM) guidelines. Ventilation rates showed mixed associations with neurological, survival, and return of spontaneous circulation (ROSC) outcomes; some studies indicated harm with lower ventilation rates. Most found no differences between higher and lower tidal volumes, although very low tidal volumes were associated with worse outcomes in some studies. When impedance-detected ventilations occurred in $\geq$50% of chest compression pauses during 30:2 CPR, survival and ROSC were higher.

Conclusion: Evidence on optimal ventilation during CPR is inconsistent and of very low certainty. Very low ventilation rates and tidal volumes may be harmful. Future research should use robust designs to define evidence-based ventilation targets.

Keywords: Cardiopulmonary resuscitation, Heart arrest, Ventilation, Bag valve mask ventilation, Tidal volume

Introduction

Cardiac arrest (CA) is a life-threatening event that leads to immediate tissue hypoxia and acidemia, resulting in irreversible organ damage if not promptly addressed. Early and high-quality cardiopulmonary resuscitation (CPR)—encompassing effective chest compressions, timely defibrillation, and effective ventilation—is critical for survival. Among these components, ventilation plays a vital role; however, evidence to guide effective ventilation strategies during CA remains limited.

Studies in animal models indicate an early, dynamic deterioration of oxygen and acid-base status following CA.[1,2] Both animal and human studies demonstrate that ventilation parameters during

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[*] Corresponding author at: Associate Professor and Section Head of Critical Care, Department of Emergency Medicine, Division of Pulmonary, Critical Care, and Sleep Medicine, University of Washington/Harborview Medical Center, 325 9th Avenue, Box 359702, Seattle, WA 98104-2499, United States.
E-mail address: nickj45@uw.edu (N.J. Johnson).
@NickJohnsonMD (N.J. Johnson)

[†] The members of the International Liaison Committee on Resuscitation Basic and Advanced Life Support Task Forces are listed in Acknowledgments at the end of the article.

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CA are associated with outcomes, although the ideal approach has yet to be defined.[3–5] Early studies documented adverse hemodynamic consequences related to hyperventilation, while more recent research highlights potentially ineffective ventilation in a substantial proportion of patients.[1,4,6–9] Both hypo- and hyperventilation have been associated with worse outcomes, though results are mixed and best practices are not well-defined.[1,4,6,10–12] Further, there is growing recognition that respiratory complications are common after CA and contribute substantially to morbidity and mortality.[13] Over half of resuscitated CA patients develop acute respiratory distress syndrome (ARDS), a severe form of lung injury; these patients are less likely to survive and recover neurologically.[14,15] While injurious ventilation practices such as large tidal volumes and high pressures are known risk factors for ARDS, the effects of ventilation strategies during CPR—for example, bag size used for ventilation and tidal volume—remain insufficiently understood.[13,14,16–19].

The International Liaison Committee on Resuscitation (ILCOR) has reviewed several aspects of ventilation practices and makes the following treatment recommendations: for adult cardiac arrest patients, deliver each breath over about 1 s with ~600 mL tidal volume to achieve chest rise and use a compression–ventilation ratio of 30:2.[20] Most of these recommendations are based on very low quality or indirect evidence. Recent studies underscore several key gaps in our knowledge: lung inflation appears to occur infrequently during CPR, hyperventilation and hypotenventilation are common, and optimal ventilation rates, volumes, and inspiratory times to balance oxygen delivery and systemic hemodynamics have not been well established.[1,11] This updated ILCOR systematic review aims to synthesize the existing evidence on ventilation parameters during CA to clarify their effects on outcomes and identify knowledge gaps to guide future research.

Methods

The systematic review was conducted by the ILCOR Basic Life Support (BLS), Advanced Life Support (ALS), and Pediatric Life Support (PLS) Task Forces. It was registered on the International Prospective Register of Systematic Reviews (PROSPERO: CRD420251070065) and followed ILCOR processes and the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting framework (Supplement 1).[21] The systematic review complied with a prespecified plan written by members of the above ILCOR Task Forces (Supplement 2). After hierarchical selection of studies for inclusion and consultation with the BLS and ALS, the PLS Task Force decided to complete a separate systematic review abstracting data from eligible studies enrolling only children, so pediatric studies were not ultimately included in this systematic review.

We applied data screening steps and a standard data abstraction form available on Covidence (https://www.covidence.org). Data collection forms, extracted data, and analytic code can be made available via a request to the authors. Conflict of interest was managed in accordance with ILCOR guidelines. Where a reviewer was an author of a particular paper, the decision to include that study and data abstraction were undertaken by other members of the review group.

Eligibility criteria

The research question was structured using the Population, Intervention, Comparator, Outcome, Study designs, and Timeframe (PICOST) framework (Table 1). For initial screening, the population was adults or children in any setting (out-of-hospital or in-hospital) in cardiac arrest receiving ventilation. Clinical outcomes that were identified by the writing group a priori as critical were return of spontaneous circulation (ROSC), survival and survival with favorable neurologic outcome at discharge, 30 days or longer, with a preference for outcomes listed in the ILCOR Core Outcome Set for Cardiac Arrest (COSCA).[22] After data abstraction, four critical and important outcomes were selected based on outcomes available in the included studies: survival with favorable neurologic outcome, survival at discharge or 30 days, ROSC, and pH.

Ventilation rate was defined as the number of breaths delivered per minute. Tidal volume was defined as the volume of air or oxygen delivered with each positive pressure breath (typically in L or ml) measured or calculated by any means, including spirometry and thoracic impedance. Tidal volume could be measured during inspiration, exhalation, or both. Inspiratory time was defined as the duration over which a breath is delivered (typically seconds). When exact measurements of tidal volume were not available, the insufflated tidal volume was inferred based on manufacturer specifications in studies comparing differently sized ventilation bags. Positive end-expiratory pressure (PEEP) was defined as positive airway pressure administered during the exhalation phase.

Information sources and search strategy

The search strategy was developed with the assistance of an information specialist from University of Oslo. Key search terms and the search strategy are provided in the Supplemental Materials. After review by the ILCOR Task Forces, the search strategy was run on October 14, 2024 and updated on November 11, 2025. Articles for review were obtained through Ovid MEDLINE(R), EMBASE and Cochrane Database of Systematic Reviews and Cochrane Central Register of Controlled Trials (CENTRAL). Additional citations were searched through hand search of the reference list of included studies following the initial review.

Selection process

All citations were uploaded into Covidence for screening and duplicates were removed. The authors (NJ, GD, BY, AM, GdC) reviewed all titles and abstracts against inclusion and exclusion criteria; each title was reviewed by two authors with a third resolving any conflicts. After initial screening, all potential eligible full texts were retrieved and further reviewed by two of the five authors (NJ, GD, BY, AM, GdC) against the same eligibility criteria. Whenever there was uncertainty about a potentially eligible study, the final decisions were achieved by discussion and consensus.

Data abstraction

Data were abstracted by authors (NJ, GD, BY, AM, GdC) using standardized data abstraction forms and all data were checked for accuracy by co-authors (NJ, LM, JB). The following information was abstracted for each included study: year and origin of publication, study design, population and number of included patients, intervention, comparator, outcomes, clinical setting, limitations, ethical consideration, conflict of interest, main findings, if reported.

Table 1 – Summary of inclusion criteria for articles.

PICOST	Description
Population	Adults receiving assisted ventilation during cardiac arrest
Intervention	Ventilation with a specific tidal volume, respiratory rate, inspiratory time, and/or positive end-expiratory pressure
Comparison	Any other tidal volume, respiratory rate, inspiratory time, and/or positive end-expiratory pressure or combination of these parameters
Outcomes	Any clinical outcome, including but not limited to ROSC, survival and survival with favorable neurologic outcome at discharge, 30 days or longer, duration of mechanical ventilation, oxygenation, blood gas parameters, progression to ARDS, barotrauma, ICU and hospital length of stay, with a preference for outcomes listed in the ILCOR COSCA
Study Design	RCTs and non-randomized studies (non-randomized controlled trials, interrupted time series, controlled before-and-after studies, cohort studies) are eligible for inclusion. Only studies that included a study comparator were included. Mannequin and animal studies will not be included
Timeframe	All years

ROSC: Return of spontaneous circulation, ARDS: acute respiratory distress syndrome, ICU: intensive care unit, ILCOR: International Liaison Committee on Resuscitation, COSCA: Core Outcome Set for Cardiac Arrest, RCTs: Randomized controlled trials.

Risk of bias assessment

Five authors (NJ, GD, BY, AM, GdC) initially assessed each study for risk of bias with each study reviewed by two authors with a third resolving conflicts. Risk of bias was assessed using the Cochrane Risk of Bias 2.0 (RoB 2.0) tool for randomized control trials (RCTs) and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool for non-randomized trials.[23,24] Any discrepancies were presented to the writing group and resolved through discussion and consensus. The level of certainty for the generated evidence was determined by the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) methodology.[25] This approach ranks the certainty of evidence at one of four levels, ranging from very low to high. GRADE tables were developed using GRADEpro GDT software (https://www.gradepro.org/).

Synthesis methods

Studies were assessed for clinical (i.e., participants, interventions, and outcomes) and methodological (i.e., study design or risk of bias) and statistical heterogeneity. Meta-analysis was planned, however heterogeneity (clinical, methodological) was deemed too substantial and a narrative synthesis was conducted guided by the SWiM reporting guidelines and narrative synthesis methods.[26] Interpretation of the synthesis was by discussion within the research team and resuscitation science experts from the ILCOR BLS, ALS, and PLS Task Forces.[27] Cochrane RevMan was used for data analysis.

Results

We screened 3021 titles and abstracts, identifying 11 eligible studies in 6257 adults; three were pilot RCTs and eight were observational studies (Fig. 1, Table 2).[1,10,11,16,28–34] Two observational studies were secondary analyses of RCT data.[10,11] These investigations evaluated ventilation rate, tidal volume, and impedance-detected chest rise during CPR. The overall certainty of evidence for all outcomes were judged to be very low, reflecting substantial risk of bias, inconsistency, indirectness, and imprecision (Fig. 2). Data primarily arose from observational out-of-hospital cardiac arrest (OHCA) studies and pilot OHCA RCTs involving heterogeneous patient populations, differing airway management strategies (with and without advanced airway or mechanical ventilators, and various measurement methods). No study compared distinct PEEP levels or inspiratory times.

Ventilation rate

Two studies ($N = 1347$) evaluated survival with favorable neurological outcome (Table 2).[10,33] One retrospective OHCA cohort ($N = 337$) found no difference in neurological survival between ventilation rates >10 vs. ≤10 breaths/min.[33] In a Pragmatic Airway Resuscitation Trial (PART) sub-analysis ($n = 1010$), duration of ventilation with rates of >12–16 breaths/min were associated with improved neurological survival compared to 6–12 breaths/min (adjusted odds ratio [aOR] 1.36, 95% confidence interval [95CI]: 1.01–1.84).[10] For survival to hospital discharge, the PART subanalysis found duration of ventilation with rates <6 breaths/min was associated with worse survival (aOR 0.79, 95CI: 0.72–0.87), while >16–20 breaths/min (aOR 1.12, 95CI: 0.98–1.41) was not associated with surgical, and >12–16 breaths/min (aOR 1.23, 95CI: 1.07–1.40), and >20 breaths/min (aOR 1.22, 95CI: 1.06–1.41) were associated with improved odds of survival.[10] The OHCA retrospective cohort showed no significant difference in survival between >10 vs. ≤10 breaths/min. ROSC findings ($n = 1701$, 5 studies) were mixed.[10,28,29,31,33] A retrospective cohort ($N = 337$) found no difference in ROSC comparing >10 vs. ≤10 breaths/min.[33] In the PART subanalysis, >12–16 breaths/min were associated with higher ROSC odds (aOR 1.09, 95CI: 1.04–1.15), while <6 breaths/min were associated with lower odds (aOR 0.96, 95CI: 0.94–0.99).[10] An IHCA cohort using capnography found each 2 breaths/min increase associated with improved ROSC (aOR 1.15, 95CI: 1.04–1.28), with modeled optimal rate of 27 breaths/min.[29] One OHCA study using capnography found no significant association with ROSC.[28] One small RCT ($n = 46$) comparing 10 vs. 20 breaths/min found no significant pH difference between groups.[31]

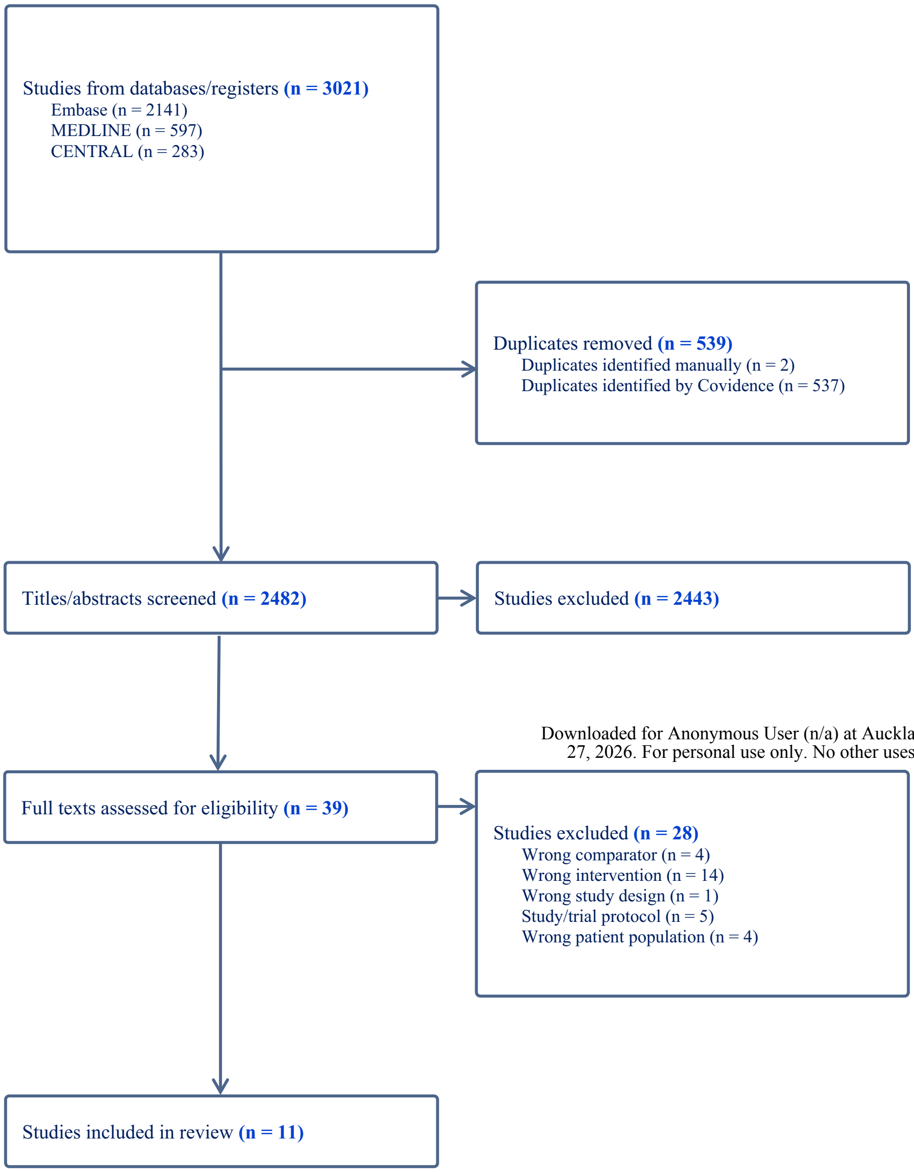


Fig. 1 – PRISMA flowchart.

Tidal volume

Two observational OHCA studies (*n* = 2026) found no difference in neurological survival or survival to discharge when comparing insufflation volumes estimated by small (manufacturer estimated tidal volume: 450 mL) vs. large (750 mL) ventilation bags.[16,34] In the larger cohort (*n* = 1994), small-bag use was not associated with neurological survival or survival to discharge.[16] In a smaller study using spirometry (*n* = 32), neurological survival was not directly reported; survival to discharge did not differ significantly between small and large bags.[34]

For the critical outcome of ROSC, two small RCTs (total *n* = 77) found no consistent effect of higher tidal volumes: one pilot trial (500 mL vs. 1000 mL) reported ROSC in 30% vs. 0% (unadjusted OR 0.00, 95CI: 0.00–1.39), while another trial (bag ventilation median 267 mL vs. mechanical ventilation median 507 mL) found no significant difference.[30,32] In the large OHCA cohort, the estimated insufflation volume generated by small-bag use was associated with lower adjusted odds of ROSC (aOR 0.74, 95CI: 0.61–0.91). In the smaller spirometry study, ROSC did not differ significantly.[16]

One RCT found lower mean pH with 500 mL tidal volume than with 1000 mL (mean 7.01 ± 0.10 vs. 7.20 ± 0.20, $p = 0.03$).[30] Two other studies (one RCT, one observational) found no significant difference in pH between higher and lower tidal volumes.[16,32]

Impedance-detected ventilations

Two post-hoc analyses of data from the Resuscitation Outcomes Consortium's Continuous Chest Compressions trial (*n* = 2528; 30:2 CPR without advanced airway) found that ≥50% of chest compression pauses with impedance-detected lung inflation were associated with improved outcomes.[1,11] Of note, data from the first study, a single site pilot including 560 patients, were also apparently used in the larger (*N* = 1976) multi-site one. (Table 2) For neurologically intact

Table 2 – Summary of included studies and key results.

	Author Year	Country	Study Design	Population	Sample Size	Intervention	Comparison	Outcome(s)	Result
Ventilation Rate	Benoit 2019	USA	Retrospective cohort	Adult OHCA, AA or BMV	314	8-10 breaths/min	< 8 or >10 breaths/min	ROSC	aOR 1.17 [95CI: 0.35-3.93]
	Jaffe 2025	USA	Secondary prospective	Adult IHCA	222	>12 breaths/min	6–12 breaths/min	ROSC	45% vs 24% (p=0.009)
	Prause 2023	Austria	Pilot RCT	Adult OHCA, AA + MV	46	20 breaths/min	10 breaths/min	ROSC pH	48% vs 52% (p=0.44) 6.89 vs 6.83 (p=0.8)
	Vissers 2019	Belgium	Retrospective cohort	Adult OHCA, AA	337	≤10 breaths/min	>10 breaths/min	Neurologically intact survival Survival to discharge	aOR 0.59 [95% CI: 0.19–1.87] aOR 0.91 [95CI: 0.30–2.7]
	Wang 2022	USA	Secondary analysis RCT	Adult OHCA, AA	1010	Duration of <6 or>12 breaths/min	Duration of 6–12 breaths/min)	Neurologically intact survival Survival to discharge ROSC	>12: aOR 1.36 [1.01–1.84]; <6: no benefit >12: aOR 1.23 [1.07–1.40]; <6: aOR 0.79 [0.72–0.87] >12: aOR 1.09 [1.04–1.15]; <6: aOR 0.96 [0.94–0.99]
Tidal Volume	Langhelle 2000	Norway	Pilot RCT	lt OHCA, AA +	17	Vt 500 ml	Vt 1000 ml	ROSC pH	3/9 (33%) vs 0/8 (0%) 7.01±0.1 vs 7.2±0.2 (p=0.03)
	Shin 2024	South Korea	Pilot RCT	Adult OHCA, AA + MV/BV	60	Mechanical ventilator (median Vt 460 ml)	Bag ventilation (median Vt 267 ml)	ROSC pH	57% vs 43% (p=0.3) 6.9 vs 6.9
	Snyder 2019	USA	Retrospective cohort	Adult OHCA, AA	1994	Small bag (expected Vt 450 ml)	Large bag (expected 750 ml)	Survival to discharge ROSC pH	aOR 0.79 [95CI: 0.57–1.09] aOR 0.74 [95 CI: 0.61–0.91] 7.09 vs 7.06
	Yang 2022	USA	Prospective observational study	Adult OHCA, AA	32	Small bag (383 ml)	Large bag (422 ml)	Neurologically intact survival Survival to discharge ROSC	17% vs 10% (p=0.71) 33% vs 10% (p=0.9) 45% vs 67% (p=0.98)
Impedance	Chang 2019	USA	Retrospective observational cohort	Adult OHCA 30:2 CPR BMV	560	Ventilation waveforms in <50% compression pauses	≥50% compression pauses	Neurologically intact survival Survival to discharge ROSC	aOR 4.14 [1.14–15.1] aOR 2.13 [0.83–5.47] aOR 2.84 [1.47–5.48]
	Idris 2023	USA	Retrospective observational cohort	Adult OHCA 30:2 CPR BMV	1979	Ventilation waveforms in <50% compression pauses	≥50% compression pauses	Neurologically intact survival Survival to discharge ROSC	aRR 2.8 [1.8–4.3] aRR 2.2 [1.6–3.0] aRR 1.3 [1.2–1.6]

USA: United States of America; AA: advanced airway; BMV: bag-mask ventilation; MV: mechanical ventilation; BV: bag ventilation; ROSC: Return of Spontaneous Circulation, OHCA: out-of-hospital cardiac arrest, IHCA: in-hospital cardiac arrest, ml: milliliter, Vt: tidal volume; aOR: adjusted odds ratio; aRR: adjusted risk ratio; 95CI: 95% confidence interval.

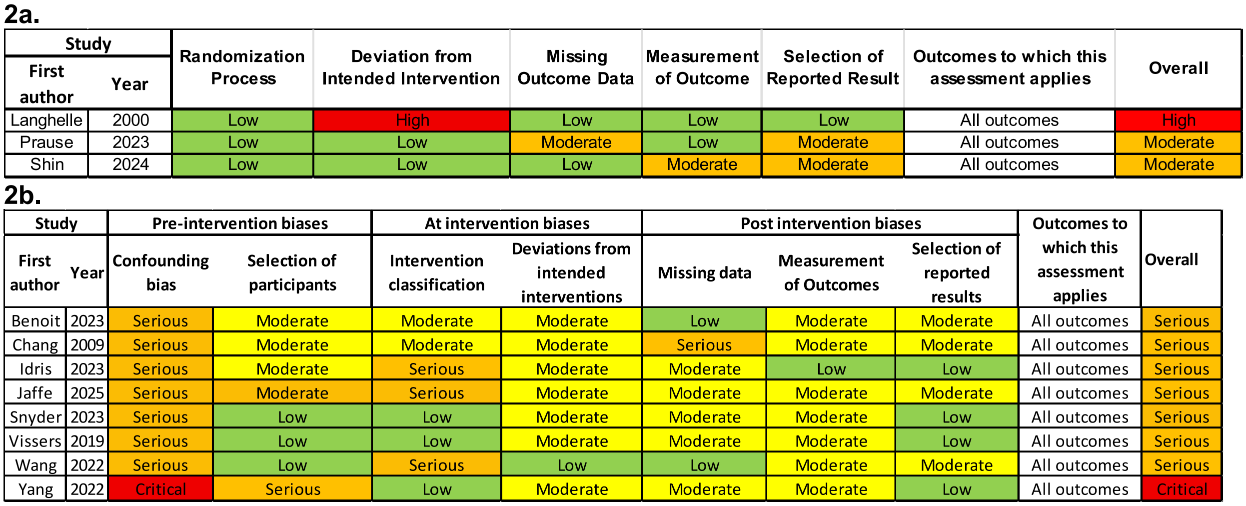
survival, both studies showed association with achieving ≥50% of pauses containing impedance-detected lung inflation. In one study (*n* = 560), the aOR was 4.14 (95CI: 1.14–15.1), and in the other (*n* = 1976), aOR was 2.80 (95CI: 1.80–4.30). For survival to hospital discharge, the first study was not statistically significant, while the second demonstrated a significant association (aOR 2.20, 95CI: 1.60–3.00). Both studies found an association between lung inflation and ROSC.

Discussion

This review examined three RCTs and eight observational studies, encompassing 6257 adult cardiac arrest patients, to evaluate ventilation parameters during cardiac arrest. Across this body of literature, ventilation rate, tidal volume, and ventilations detected by transthoracic impedance were the main parameters assessed.[1,4,6,10,11] The certainty of evidence was rated very low, reflecting serious risk of bias, heterogeneity in populations and interventions, imprecision, and indirectness. Variation in definitions, thresholds, terminology, and measurement techniques across studies was substantial. There is support for standardized terminology and reporting around ventilation during cardiac arrest, but these were not consistently applied to the included studies.[35]

Our interpretation must be placed in historical context. The 2005 ILCOR treatment recommendation focused on ventilation was grounded solely in observational studies and extrapolation from animal and healthy volunteer models, with concerns at the time focused primarily on potential harm from hyperventilation, largely based on a single small study with both human and animal data.[4,6,36] In contrast, more recent observational data have documented frequent hypoventilation, especially in the absence of an advanced airway, and associations between inadequate ventilation and worse outcomes.[1,2,10,11,16] These conflicting findings likely reflect heterogeneity in patient populations (e.g., in-hospital vs. out-of-hospital arrests), ventilation methods (manual vs. mechanical), airway strategies, and study designs. In most included studies, ventilations were delivered via advanced airways (supraglottic devices or endotracheal tubes), and this review does not address decisions around airway device choice, feedback utilization, or integration with chest compressions, topics addressed in separate systematic reviews and consensus on science summaries.[37–39]

Evidence on optimal ventilation rate is largely observational, with one small RCT reporting no statistically significant difference between higher and lower ventilation rates for ROSC rates.[31] Observational findings are inconsistent. Older studies, several of which were not included in this review due to lack of comparisons or reporting of critical or important outcomes; primarily report harm associated with high ventilation rates.[4,6] More recent work describes frequent hypoventilation and possible associations between higher rates and improved survival, particularly in patients with advanced airways.[1,10,11,33] Potential explanations include differences in patient populations, the mode of ventilation delivery, and evolving CPR practices focusing on continuous high quality CPR. Variation in airway devices (bag-mask ventilation, supraglottic airway, tracheal intubation) was substantial in the included studies. Given that effective ventilation with a bag-valve-mask requires skill and often multiple rescuers, there is a strong case for exploring methods to improve delivery and training or feedback tools; this remains an important area for future research. The Task Forces noted insufficient evidence



2a.

Study		Randomization Process	Deviation from Intended Intervention	Missing Outcome Data	Measurement of Outcome	Selection of Reported Result	Outcomes to which this assessment applies	Overall
First author	Year							
Langhelle	2000	Low	High	Low	Low	Low	All outcomes	High
Prause	2023	Low	Low	Moderate	Low	Moderate	All outcomes	Moderate
Shin	2024	Low	Low	Low	Moderate	Moderate	All outcomes	Moderate

2b.

Study		Pre-intervention biases		At intervention biases		Post intervention biases			Outcomes to which this assessment applies	Overall
First author	Year	Confounding bias	Selection of participants	Intervention classification	Deviations from intended interventions	Missing data	Measurement of Outcomes	Selection of reported results		
Benoit	2023	Serious	Moderate	Moderate	Moderate	Low	Moderate	Moderate	All outcomes	Serious
Chang	2009	Serious	Moderate	Moderate	Moderate	Serious	Moderate	Moderate	All outcomes	Serious
Idris	2023	Serious	Moderate	Serious	Moderate	Moderate	Low	Low	All outcomes	Serious
Jaffe	2025	Serious	Moderate	Serious	Moderate	Moderate	Moderate	Moderate	All outcomes	Serious
Snyder	2023	Serious	Low	Low	Moderate	Moderate	Moderate	Low	All outcomes	Serious
Vissers	2019	Serious	Low	Low	Moderate	Moderate	Moderate	Low	All outcomes	Serious
Wang	2022	Serious	Low	Serious	Low	Low	Moderate	Moderate	All outcomes	Serious
Yang	2022	Critical	Serious	Low	Moderate	Moderate	Moderate	Low	All outcomes	Critical

Fig. 2 – Risk of bias assessments in randomized controlled trials (a) and non-randomized studies (b).

especially around an upper rate limit and concluded that current data primarily support avoiding hypoventilation rather than targeting higher rates.

Tidal volume, whether inferred insufflation volume based on bag size or directly measured, was not associated with a clear survival or neurological benefit.[16,30,32,34] Physiologic principles and indirect evidence support targeting tidal volumes sufficient to maintain oxygenation and CO_2 clearance while avoiding excessive volumes that might impede venous return or precipitate lung injury. However, none of the included RCTs was powered to assess critical outcomes such as favorable neurological survival or survival to discharge, and both randomized and observational data were inconclusive. The lack of standardization in measurement and terminology, exacerbated by infrequent direct measurement of tidal volumes, absence of data on inspiratory time and PEEP, and limited mechanistic insight, remains a major barrier to evidence-based recommendations. Chest rise remains the most common clinical proxy for adequacy of ventilation volume in many settings, but older data indicate that chest rise in non-arrest situations can occur at tidal volumes as low as 180 ml, which is likely below physiologically ideal thresholds, underscoring the limitations of visual assessment during ongoing CPR.[40] The absence of pulmonary-specific outcomes (e.g., barotrauma, ARDS), which are known complications of cardiac arrest, also limits interpretation of potential harms.[13–15] Additionally, the lack of signal for tidal volume could stem from the crudeness of measurement methods (e.g., using bag size as proxy or limitations with measurement tools), physiologic tolerances to a relatively wide range of delivered volumes, or insufficient statistical power.

A consistent signal favoring impedance-detected ventilation in $\geq$50% of compression pauses across large observational datasets, while not definitive, reinforces the importance of assessing ventilation adequacy during CPR. However, these data represent retrospective analysis of impedance data. Previous work by this group suggests that an impedance deflection of $\geq$0.5 Ohm correlates with a tidal volume of at least 250 ml in healthy volunteers, but whether this relationship exists in patients undergoing CPR is less clear.[1] The more consistent association between impedance-detected ventilation and improved outcomes in observational datasets may reflect a true physiologic benefit of ensuring adequate lung inflation, or it may be a surrogate marker of overall resuscitation quality (e.g., optimized team performance, effective airway management). Further, whether ventilation monitoring tools like impedance or other feedback devices could inform ventilation practices in real-time is not clear, but this remains an area where further investigation is needed.[37]

Limitations

Ventilation metrics, when reported, were typically averaged over the entire resuscitation, obscuring dynamic changes. This averaging approach may overlook important temporal relationships between ventilation parameters and patient physiology. Further, interplay between ventilation parameters is likely, complex, and not well-captured in the existing studies. Tidal volume was rarely directly measured, and other potentially relevant parameters were largely absent from the literature. The scarcity of granular data appears to be partly driven by the limited availability of precise measurement tools during emergency care, resulting in reliance on imperfect proxies, which may not accurately capture true physiological values. Blood gas data were inconsistently reported, most often after ROSC, limiting mechanistic interpretation. No studies addressed special populations such as pregnancy. We assumed that ventilation bag size correlates with delivered tidal volume, which may not always be true. In one study, tidal volume was measured and indeed correlated with ventilation bag size, but in another large observational, tidal volume was not directly measured.[16,34]

Future directions

Taken together, it is striking how little high-quality data exist on such a fundamental component of CPR. Addressing these evidence gaps will require adequately powered, multicenter randomized trials assessing ventilation rate, tidal volume, inspiratory time, airway pressures, and PEEP during cardiac arrest, with neurologically-intact survival as the primary outcome. Precise thresholds for “higher” and “lower” ventilation rates should be defined for specific settings and populations (e.g., in-hospital vs. out-of-hospital arrests). Studies should explore how ventilation strategies differ when advanced airways are used compared with bag-mask ventilation. Mechanistic work is needed to clarify ventilation-related changes in intrathoracic pressure, airway closure, oxygenation, and CO_2 clearance during compressions, using continuous physiologic monitoring rather than post-ROSC sampling. Targeted subgroup analyses by etiology, arrest rhythm, and patient characteristics are essential for nuanced recommendations. The integration of ventilation monitoring and feedback devices could prove valuable, but they require formal evaluation.[37]

Conclusion

Ventilation during cardiac arrest is a critical but understudied component of resuscitation. Current evidence on optimal ventilation rate, tidal volume, and other parameters remains limited, inconsistent, and of very low certainty. While observational evidence supports ensuring ventilation effectiveness, findings are inconsistent and susceptible to bias. Future work should focus on establishing physiologically and clinically meaningful targets, supported by rigorous multicenter trials, so that recommendations are grounded in evidence capable of improving clinical outcomes.

CRediT authorship contribution statement

Nicholas J. Johnson: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Guillaume Debaty:** Writing – review & editing, Methodology, Investigation, Data curation. **Betty Y. Yang:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Ari Moskowitz:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Ian Drennan:** Writing – review & editing, Supervision, Methodology, Investigation. **Jimena del Castillo:** Writing – review & editing, Methodology, Investigation, Data curation. **Theresa Olasveengen:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Katherine M. Berg:** Writing – review & editing, Supervision, Methodology, Investigation. **Laurie J. Morrison:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Janet E. Bray:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

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Declaration of competing interest

Nicholas Johnson and Betty Yang receive funding from the American Heart Association for studies examining ventilation during CPR. Guillaume Debaty received funding from the University of Grenoble Alps for studies on cadavers examining ventilation during CPR. Ian Drennan receives funding from Zoll for a study examining real-time ventilation feedback and a trial on ventilation. The remaining authors declared no conflict of interest related to this work. JEB is an Editor of Resuscitation Plus. JEB and LM are members of the Editorial Board of Resuscitation.

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Non-author Task Force member collaborators

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BLS: Micheal Bradfield, Steven C. Brooks, Rebecca E. Cash, Sung Phil Chung, Julie Considine, Katie N. Dainty, Vihara Dassanayake, Maya Dewan, Bridget Dicker, Natasha Dodge, Fredrik Folke, Carolina Malta Hansen, Takanari Ikeyama, Anthony Lagina, George Lukas, Siobhan Masterson, Peter T. Morley, Ziad Nehme, Tatsuya Norii, Gavin D. Perkins, Helen Pocock, Violetta Raffay, Giuseppe Ristagno, Aloka Samantaray, Federico Semeraro, Baljit Singh, Christopher M. Smith, Michael A. Smyth, Anastasia Spartinou, Christian Vaillancourt.

ALS: Bernd W. Böttiger, Yew Woon Chia, Keith Couper, Conor Crow, Sonia D'Arrigo, Charles Deakin, Shannon M. Fernando, Rakesh Garg, Asger Granfeldt, Brian Grunau, Karen G. Hirsch, Mathias J. Holmberg, Peter Kudenchuk, Eric J. Lavonas, Carrie Leong, Neville Lok, Robert W. Neumar, Tonia Nicholson, Nikolaos Nikolaou, Jerry P. Nolan, Brian O'Neil, Shinichiro Ohshimo, Michael Parr, Claudio Sandroni, Tommaso Scquizzato, Markus Skrifvars, Jasmeet Soar, Michelle Welsford, Carolyn Zelop.

Appendix A. Supplementary material

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Author details

on behalf of the International Liaison Committee on Resuscitation Basic and Advanced Life Support Task Forces[†][a]*Department of Emergency Medicine & Division of Pulmonary, Critical Care, and Sleep Medicine, University of Washington, Seattle, WA, United States* [b]*Univ. Grenoble Alpes, Emergency Department and Mobile Intensive Care Unit, CNRS, UMR 5525, VetAgro Sup, Grenoble INP, TIMC, 38000 Grenoble, France* [c]*Department of Emergency Medicine, University of Texas, Southwestern, Dallas, TX, United*

States[d]Division of Critical Care Medicine, Montefiore Medical Center, Bronx, NY, United States[e]Interdepartmental Division of Critical Care, Department of Medicine, University of Toronto; Institute of Health Policy, Management, and Evaluation, Dalla Lana School of Public Health, University of Toronto; Ornge Air Ambulance and Critical Care Transport; Department of Emergency Services and Sunnybrook Research Institute, Sunnybrook Health Sciences Centre, United States [f]Hospital General Universitario Gregorio Marañón, Madrid, Spain[g]Department of Anesthesia and Intensive Care Medicine, Oslo University Hospital, and Institute of Clinical Medicine, University of Oslo, Norway [h]Center for Resuscitation Science and Department of Medicine, Beth Israel Deaconess Medical Center, Boston, MA, United States [i]Division of Emergency Medicine, Department of Medicine, University of Toronto; Department of Emergency Services, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada [j]School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia [k]Prehospital, Resuscitation and Emergency Care Research Unit (PRECRU), School of Nursing, Midwifery and Paramedicine, Curtin University, Bentley, Australia

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