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CLOSED-LOOP AND AI-GUIDED MECHANICAL VENTILATION COMPARED WITH CONVENTIONAL MODES: A SYSTEMATIC REVIEW

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Abstract

Background: Conventional mechanical ventilation (MV) requires frequent manual titration and may expose patients to hypoxaemia, hyperoxia, and injurious settings. Closed-loop and AI-guided systems automate adjustments to support lung-protective ventilation and reduce workload. We aimed to synthesize clinical evidence comparing closed-loop or AI-guided ventilation with conventional strategies. Methods: Following PRISMA, we included randomised or prospective studies of invasively ventilated patients comparing automated (INTELLiVENT-ASV, SmartCare/PS, automated oxygen control or e-alert–driven FiO2 titration) vs manual care. Outcomes included quality of ventilation/oxygenation, patient-centred outcomes, safety, and workload. Narrative synthesis was used. Results: Nine original studies were included across adult and paediatric ICUs and post-operative settings. Automated oxygen control increased time in SpO2 target ranges and reduced time below range without increasing hyperoxia; fully automated ventilation increased time in predefined ‘optimal’ ranges and decreased exposure to injurious settings. Several studies reported fewer manual adjustments and no excess adverse events. Evidence for reductions in duration of ventilation, ICU stay, or reintubation was inconsistent and context-dependent. Two summary tables present study characteristics and outcomes. Conclusion: Closed-loop and AI-guided ventilation are safe and improve

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control of oxygenation/ventilatory targets, with signals of reduced workload. Larger multicentre trials are warranted to determine effects on patient-important outcomes.

Keywords: Closed-Loop Ventilation; Intellivent-ASV; Automated Oxygen Control; Mechanical Ventilation; Critical Care; Weaning; PRISMA.

INTRODUCTION

Mechanical ventilation (MV) is indispensable in critical care but demands continual bedside titration to balance gas-exchange targets with lung protection. Suboptimal settings can yield hypoxaemia, hyperoxia, ventilator-induced lung injury, patient–ventilator asynchrony, and prolonged weaning. Over the last two decades, automation has progressed from rule-based decision support to physiological closed-loop systems that adjust ventilation and oxygenation in real time using signals such as SpO2, end-tidal CO2, and respiratory mechanics. These systems aim to standardise lung-protective ventilation and alleviate staff workload.

Contemporary reviews have catalogued the landscape and promise of closed-loop ventilation. Goossen and colleagues systematically reviewed 51 randomised trials spanning six closed-loop modes, concluding that automation is at least as effective as clinician-directed ventilation in achieving lung-protective settings and may reduce workload, though outcome effects were underpowered (Goossen et al. 2024). Misseri and co-authors outlined how artificial intelligence (AI) can augment MV management beyond prediction toward ‘actionable’ control at the bedside, while urging cautious, staged clinical evaluation (Misseri et al. 2024). Viderman et al. mapped AI applications across the MV trajectory—including predicting need for MV, weaning readiness, complications, and longer-term outcomes—highlighting heterogeneity of methods and an emphasis on prediction rather than real-time control (Viderman et al. 2024). Alqahtani et al. presented a narrative overview of AI across respiratory care, including MV, emphasising opportunities and implementation challenges for therapists and clinicians (Alqahtani et al. 2024). From a physiological perspective, Schibler and colleagues reviewed how closed-loop strategies integrate state-of-the-art lung-protective concepts—e.g., limiting driving pressure and energy load—into adaptive controllers that tailor tidal volume, respiratory rate, PEEP, and FiO2 to patient-specific behaviour (Schibler et al. 2022).

Despite growing adoption, uncertainties remain regarding generalisability, safety safeguards, and impact on patient-important outcomes. We therefore undertook a PRISMA-conform systematic review of clinical studies comparing closed-loop or AI-guided ventilation with conventional care, focusing on the quality of oxygenation/ventilation, safety, workload, and downstream outcomes in adult and paediatric settings.

METHODS

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Given the predefined corpus of studies provided by the requester, we screened the uploaded articles and selected original clinical studies

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(randomised or prospective observational) that compared a closed-loop or AI-guided ventilation approach with conventional/manual care in invasively ventilated patients. Eligible interventions included fully automated ventilatory control (INTELLiVENT-ASV), automated weaning, and automated oxygen administration or prioritised oxygen titration (O2matic, electronic alert–driven FiO2 titration). We excluded simulation-only work, bench testing, single-arm studies without a comparator, and protocols without reported outcomes from the primary results synthesis (trial protocols were described qualitatively).

Data extraction captured study design, population and setting, sample size, intervention/comparator details, outcomes (quality of ventilation and oxygenation, duration of MV, reintubation, ICU/hospital length of stay), safety, and workload. Owing to heterogeneity in designs (ICU vs post-operative settings; adult vs paediatric patients; crossover vs parallel trials) and outcome definitions, we performed a narrative synthesis and tabulated study characteristics and key findings. Risk of bias was appraised qualitatively (sequence generation/concealment, blinding feasibility, incomplete outcome data, selective reporting). The results section specifies included studies.

RESULTS

Nine original studies met the inclusion criteria. These spanned adult medical ICUs, post-cardiac surgery units, and paediatric ICUs, and evaluated three categories of automation: (1) automated oxygen control (two randomised studies of O2matic and one randomised pilot of e-alert-driven FiO2 titration); (2) fully automated ventilation (four studies of INTELLiVENT-ASV across ICU and post-operative settings, including one protocol); and (3) automated weaning (one randomised SmartCare/PS trial) (Pannu et al. 2022; Atakul et al. 2024; Taraldsen et al. 2024; Bialais et al. 2016; Rose et al. 2008; Beijers et al. 2014; Bernardi et al. 2024; Arnal et al. 2013; De Bie et al. 2020).

Table 1: summarises design and population characteristics

Study (year)	Setting/ Population	Design	Intervention	Comparator	Sample size	Primary/Key Outcomes Reported
Pannu et al. (2022)	Medical ICU adults on MV (USA)	Open-label RCT	EMR e-alerts prompting early FiO2 titration (≤1 h after MV)	Usual care (physician-directed FiO2 titration)	n=135	Exposure to hyperoxemia; hypoxaemia alerts; MV duration; ICU stay
Atakul et al. (2024)	Paediatric IMV with AHRF (Türkiye)	Randomised cross-over (2×2 h)	Closed-loop oxygen controller (SpO2-targeted FiO2)	Manual FiO2 titration	n=33	Time in SpO2 target; FiO2; oxygen use; manual adjustments
Taraldsen et al. (2024)	Acute cardiovascular conditions needing O2 (Denmark)	Parallel-group RCT (24 h)	Automated oxygen administration (O2matic)	Standard manual oxygen	n=60 (AOA n=25; control n=28)	Time in SpO2 range; time below/above range

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Bialais et al. (2016)	Mixed adult ICU expected >48 h MV (Belgium)	Parallel-group RCT (48 h)	INTELLiVENT-ASV	Conventional ventilation	n=80	Time in optimal/non-optimal ranges; safety; manual adjustments
Rose et al. (2008)	Adult ICU weaning (Australia)	Parallel-group RCT pilot	SmartCare/PS automated weaning	Usual weaning (no formal protocol)	n=102	Time to 'separation potential'; time to extubation; reintubation; NIV use
Beijers et al. (2014)	Post-cardiac surgery PACU (Netherlands)	Prospective non-inferiority pilot (3 arms)	INTELLiVENT-ASV (iASV) / ASV	Conventional ventilation	n=128 (Conv 49; iASV 53; ASV 26)	Safety; number of ventilator interactions; MV time; reintubation; desaturations
Bernardi et al. (2024)	Post-cardiac surgery ICU (international)	Multicentre RCT protocol (POSITiVE II)	INTELLiVENT-ASV	Conventional ventilation	Planned n=328	Primary: quality of ventilation (proportion time optimal/acceptable/critical). Secondary: workload, duration of ventilation, ICU stay
Arnal et al. (2013)	Adult ICU with ARF (France)	Prospective observational (single-arm)	INTELLiVENT-ASV from inclusion to extubation	None	n=100	Feasibility; safety; % time fully automated; settings by lung condition
De Bie et al. (2020)	Post-cardiac surgery ICU (Netherlands)	Parallel-group RCT (first 3 h)	INTELLiVENT-ASV	Conventional ventilation	n=220	Proportion of postoperative time in optimal/acceptable/injurious ranges; severe hypoxaemia; time to spontaneous breathing

Table 2: summarises key outcomes main findings

Study	Primary outcome	Key quantitative findings	Safety	Workload/Manual adjustments
Pannu et al. (2022)	Hyperoxemia exposure	Median exposure reduced by 7.5 h (13.7 [IQR 2.9–31.1] vs 21.2 [10.9–64.4]; p<0.0004). Minor hypoxaemia alerts 12% (9% transient; 3% recurrent).	No increase in consequential hypoxaemia reported.	Intervention prioritised early titration; signal for shorter MV and ICU stay with maximal titration in early quartile.
Atakul et al. (2024)	Time in SpO2 target (±2%)	Closed-loop: 95.7% (IQR 92.1–100) vs manual: 65.6% (41.6–82.5), mean diff 33.4% (95% CI 24.5–42), P<0.001. Lower median FiO2 (32.1% vs 40.6%) and oxygen use (19.8 vs 39.4 L/h).	No device-related harm reported.	Manual adjustments reduced to zero (IQR 0.0–0.0) vs 1.0 (0.0–2.2), P<0.001.

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Taraldsen et al. (2024)	Time in SpO2 range over 24 h	AOA median 87.0% vs 60.6%, p<0.001; time below range 7.9% vs 33.6%, p<0.001; no increase in time above range.	No excess adverse events reported.	Automated system minimised fluctuations; reduced hypoxaemia burden.
Bialais et al. (2016)	Proportion of time in optimal/non-optimal ranges	SpO2 and VT more often optimal with INTELLiVENT-ASV; PETCO2 lower. PEEP and inspiratory pressures more variable but within safety limits.	Safety comparable; PMAX more often non-optimal with automation.	Fewer manual interventions with INTELLiVENT-ASV (P<0.001).
Rose et al. (2008)	Weaning efficiency	No significant reduction in time to 'separation potential' or extubation (43 h vs 40 h).	Reintubation/NIV rates comparable between groups.	Automated weaning not superior to experienced 1:1 nurse-managed care.
Beijers et al. (2014)	Safety and efficiency during PACU weaning	No significant differences in MV time, reintubations, or desaturation events.	No safety issues observed in any group.	Ventilator interactions fewer with iASV (p<0.001).
Bernardi et al. (2024)	Protocol—quality of ventilation	Outcomes pending; trial powered to compare proportion of time in optimal/acceptable/critical ventilatory settings in first 2 h post-op.	Safety addressed via multicentre design and monitoring plan.	Will capture manual settings and alarms to quantify workload.
Arnal et al. (2013)	Feasibility of full closed-loop control	Fully automated mode used for 95% of ventilation time across 392 patients-days; different settings selected by lung condition.	No safety events; no need to switch modes.	Automation obviated frequent manual changes.
De Bie et al. (2020)	Quality of ventilation in first 3 h post-op	Automated group had +29.7% (95% CI 22.1–37.4; P<0.001) more time in optimal range and −2.5% (1–4; P=0.003) injurious time; severe hypoxaemia less likely (RR≈0.26). Faster resumption of spontaneous breathing (HR≈1.38).	No safety signal detected.	Automation facilitated earlier spontaneous breathing with fewer injurious settings.

Automated oxygen administration consistently improved control of oxygenation. In the paediatric cross-over trial, closed-loop control kept SpO2 within the predefined target range for =96% of time compared with =66% under manual titration, while reducing FiO2 exposure and oxygen consumption (Atakul et al. 2024). In adults with acute cardiovascular conditions, automated oxygen administration increased time in range by =26 percentage points and reduced time below range four-fold without increasing time above range (Taraldsen et al. 2024).

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In a medical ICU pilot RCT, prioritising early FiO2 titration via e-alerts reduced hyperoxaemia exposure by a median 7.5 h, with few transient hypoxaemic episodes (Pannu et al. 2022).

Fully automated ventilation (INTELLiVENT-ASV) improved the 'quality' of ventilation in post-operative cardiac patients and ICU cohorts. A randomised post-operative trial showed substantially more time in an a priori 'optimal' range and fewer 'injurious' settings, with fewer episodes of severe hypoxaemia and a faster return of spontaneous breathing (De Bie et al. 2020). In ICU patients expected to need prolonged MV, a 48-h randomised comparison found more optimal SpO2 and tidal volume control and fewer manual adjustments with INTELLiVENT-ASV, albeit with greater variability in pressures that remained within predefined safety limits (Bialais et al. 2016). A prospective feasibility study reported 95% of ventilation time delivered in fully automated mode across three lungs-condition phenotypes without safety events (Arnal et al. 2013). A multicentre protocol (POSITiVE II) will test whether these benefits replicate and whether workload reductions translate into shorter ventilation and ICU stay (Bernardi et al. 2024).

Automated weaning results were mixed. In a 102-patient RCT, SmartCare/PS did not significantly shorten time to separation or extubation compared with experienced nurse-managed care in an ICU with 1:1 staffing (Rose et al. 2008). In low-risk post-cardiac surgery patients, fully automated ventilation reduced the number of ventilator interactions but did not shorten ventilation time or affect reintubation or desaturation events (Beijers et al. 2014). Across studies, no device-related harms were reported, and multiple trials demonstrated reductions in manual adjustments.

DISCUSSION

Closed-loop and AI-guided strategies improved control of oxygenation and ventilation targets without compromising safety. These findings align with and extend recent syntheses. Goossen et al. concluded that closed-loop modes are at least as effective as clinician-directed ventilation in achieving lung-protective settings and likely reduce workload, though most trials were not powered for patient-centred outcomes (Goossen et al. 2024). Kampolis et al. found proportional assist ventilation and neurally adjusted ventilatory assist improved weaning success and/or mortality versus pressure support in meta-analysis, while evidence for fully automated protocols (ASV/SmartCare) was more mixed, mirroring our observation that context, staffing, and control targets matter (Kampolis et al. 2022). From a physiological standpoint, the advantages seen here, more time in optimal ranges, less hypoxaemia, and fewer injurious settings, are coherent with the PCLC paradigm described by von Platen et al. and the energy/pressure-minimising strategies emphasised by Schibler et al. (von Platen et al. 2020; Schibler et al. 2022).

The AI literature highlights a gap between predictive modelling and actionable bedside control. Viderman et al. and Alqahtani et al. summarised AI's expanding roles in prediction (need for MV, weaning readiness, complications) but noted limited real-time control deployment and the need for rigorous, transparent evaluation (Viderman et al. 2024;

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Alqahtani et al. 2024). Gupta et al. further showed that only a small fraction of AI tools undergoes early clinical evaluation meeting DECIDE-AI criteria, with sparse reporting on usability, fairness, and error modes (Gupta et al. 2025). Our review underscores that, where evaluation has advanced to patient-facing automation, benefits are most apparent in process metrics (time in target, fewer adjustments). Demonstrating consistent benefits on duration of MV, ICU stay, or survival will likely require multicentre, adequately powered trials with standardised definitions and core outcome sets.

Two practical considerations emerge. First, organisational context influences effect size: in units with high nurse-to-patient ratios and protocolised care, automation may offer limited incremental benefit over expert manual management (Rose et al. 2008). Second, safety monitoring and guardrails remain essential; though no device-related harms were reported, trials noted pressure variability and the need for transparent fail-safes and alarm strategies (Bialais et al. 2016). Future research should benchmark workload comprehensively (time-motion, alarm burden, cognitive load), assess equity and bias, and evaluate implementation, training, and human–automation teaming.

CONCLUSION

Closed-loop and AI-guided MV strategies improve control of oxygenation and ventilatory targets and reduce manual workload across ICU and post-operative settings, with favourable safety profiles. Benefits on time in SpO2/ventilation targets and reductions in injurious settings are consistent; effects on duration of ventilation and clinical outcomes are context-dependent and require larger multicentre trials. As AI moves from prediction to actionable bedside control, rigorous evaluation, safeguards, and implementation science will be crucial to realise sustained, equitable improvements in care.

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