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Systematic review

# Effect of Ventilatory Modes and Respiratory Support Strategies on Objectively Measured Sleep in Critically Ill Adults: A Systematic Review

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Abstract

Background: Critically ill adults receiving ventilatory support sleep poorly. Their sleep is fragmented, with little slow-wave or rapid eye movement (REM) sleep. This review evaluated the effect of ventilatory modes and respiratory support strategies on objectively measured sleep in critically ill adults. Methods: Following PRISMA 2020, PubMed, Scopus, and Web of Science were searched from inception to October 31, 2026. Two authors independently screened records, extracted data, and assessed risk of bias with RoB 2 and ROBINS-I. Findings were synthesized narratively by comparison type. Results: Eleven studies (194 patients) met the inclusion criteria, all using polysomnography. Assist-control and pressure-controlled ventilation improved sleep efficiency, deep sleep, or continuity compared with pressure support ventilation, particularly in acute-on-chronic respiratory failure, and prevented pressure support-related central apneas. Proportional assist and neurally adjusted ventilatory assist improved REM sleep and fragmentation in two trials, whereas proportional assist with load-adjustable gain factors showed no benefit in two others. Automatically adjusted pressure support matched assist-control ventilation. Ventilatory assistance increased sleep compared with unassisted breathing in two of three studies, and ventilator type during noninvasive ventilation did not change sleep architecture. Seven studies raised some concerns and three carried high risk of bias. Conclusion: Nocturnal settings that prevent over-assistance, central apneas, and ineffective efforts, especially assist-control or pressure-controlled ventilation, improve objectively measured sleep in selected critically ill adults. Larger trials with ICU-adapted sleep scoring are required.

**Keywords:** Critical illness; Mechanical ventilation; Noninvasive ventilation; Polysomnography; Pressure support ventilation; Patient-ventilator asynchrony; Sleep

## Introduction

Sleep in critically ill adults who require mechanical ventilation differs profoundly from normal sleep, and continuous 24-hour polysomnography (PSG) in such patients identified no individual with normal sleep (1). Total sleep time varies widely among intensive care unit (ICU) patients, and 57% of sleep occurs during daytime hours, which reflects loss of the normal sleep-wake rhythm (2). Sleep in the ICU consists mostly of stages 1 and 2 with scant slow-wave sleep (SWS) and rapid eye movement (REM) sleep, and the median duration of an uninterrupted sleep bout is only three minutes (3). Atypical electroencephalography (EEG) patterns that defy standard scoring rules are frequent in ventilated patients and complicate sleep measurement (1). Sleep deprivation during critical illness has been linked to delirium, impaired immunity, respiratory muscle dysfunction, and delayed physical and psychological recovery (4).

Environmental noise explains only a small share of this disruption, accounting for 11.5% of arousals and 17% of awakenings in one PSG study (2). Illness severity, sedative and analgesic drugs, patient-care activities, light exposure, and ventilatory support act together to fragment sleep in ventilated patients (5). Patient-ventilator asynchrony and ineffective triggering add further arousals during assisted breathing (4). Mechanical ventilation exerts favorable or harmful effects on sleep depending on the patient population, the mode, and the settings applied, since over-assistance promotes central apneas and under-assistance raises respiratory effort (6).

Several physiological studies have compared assist-control ventilation (ACV), pressure support ventilation (PSV), proportional assist ventilation (PAV), and neurally adjusted ventilatory assist (NAVA) using PSG in ventilated patients (6). A Cochrane review of non-pharmacological interventions identified six trials of ventilator modes, reported that their results did not consistently agree, and examined these trials alongside earplugs, eye masks, music, and other measures (7). Data on noninvasive ventilation (NIV), ventilator type, and assisted versus unassisted breathing remain scattered across small physiological reports (5, 6).

Sleep loss is a recognized barrier to physical and psychological recovery after critical illness, which

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makes nocturnal ventilator management a practical target for intervention (4). A focused synthesis of how each respiratory support strategy influences objectively measured sleep is still lacking for bedside decisions (6, 7). Therefore, this systematic review evaluated the effect of ventilatory modes, ventilator settings, and respiratory support strategies on objectively measured sleep in critically ill adults (5, 6).

## Methods

### Design and eligibility criteria

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. Eligible studies enrolled adults (≥18 years) in an ICU or post-ICU step-down unit who received invasive or noninvasive ventilatory support, compared at least two ventilatory modes, assist levels, ventilator types, or support strategies, including ventilation versus unassisted breathing, and measured sleep objectively with PSG, EEG, actigraphy, or bispectral index. Randomized, crossover, and comparative observational studies published in English were eligible. Studies of healthy volunteers, home ventilation, children, pharmacological sleep interventions, or subjective sleep measures alone, and reviews or abstracts, were excluded.

### Information sources and search

PubMed, Scopus, and Web of Science were searched from inception to October 31, 2026. The PubMed strategy was: ("Sleep"[MeSH] OR sleep* OR polysomnograph* OR actigraph*) AND ("Respiration, Artificial"[MeSH] OR "Noninvasive Ventilation"[MeSH] OR "mechanical ventilation" OR "pressure support" OR "assist-control" OR "proportional assist" OR "neurally adjusted" OR "high-flow nasal") AND ("Critical Illness"[MeSH] OR "Intensive Care Units"[MeSH] OR "critically ill"). Equivalent syntax was applied in Scopus (TITLE-ABS-KEY) and Web of Science (TS).

### Study selection

Two authors independently screened titles and abstracts and then full texts, resolving disagreements by consensus or through a third author. The search yielded 1,315 records (PubMed n = 412; Scopus n = 538; Web of Science n = 365). After removal of 486 duplicates, 829 records were screened and 781 were excluded. Of 48 reports sought, 2 were not retrieved and 46 full texts were assessed. Thirty-five were excluded for no objective sleep measure (n = 11), no comparison of ventilatory strategies (n = 9), pharmacological or sedation intervention (n = 6), healthy volunteers or home ventilation (n = 5), and review, letter, or abstract only (n = 4), leaving 11 included studies (Figure 1).

### Data extraction and outcomes

Two authors independently extracted design, population, sample size, sedation status, compared strategies, sleep measurement method, recording window, and outcomes on a piloted form. Primary outcomes were sleep efficiency, total sleep time (TST), and fragmentation index (arousals and awakenings per hour of sleep), and secondary outcomes were SWS, REM sleep, central apneas, and asynchrony. Data were recorded as reported (median and range or mean and standard deviation).

### Risk of bias and synthesis

Two authors independently applied RoB 2, including its crossover variant, to randomized and crossover studies (Table 1) and ROBINS-I to the non-randomized study. Disagreements were resolved by discussion. Heterogeneity in modes, settings, recording windows, and outcome reporting precluded meta-analysis, so findings were

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synthesized narratively by comparison type following the Synthesis Without Meta-analysis guideline.

## Results

### Study characteristics

Eleven studies published between 2002 and 2013 analyzed 194 patients, with sample sizes from 11 to 26 (Table 2) (8-18). Ten were interventional comparisons, eight with explicit randomization of mode order or allocation (9, 10, 12, 14-18). One study compared ventilated and spontaneously breathing patients in a step-down unit (13). All studies measured sleep with full PSG over windows ranging from two-hour periods to 24 hours (8, 13, 17).

### Risk of bias

Among ten randomized or crossover studies, seven raised some concerns and three carried high risk of bias, mainly from unclear allocation of mode order, period effects within one night, post-randomization exclusions, and unreported scorer blinding (8, 11, 16). Two studies balanced day and night recording periods across modes, which lowered concern about period effects (14, 17). The observational study carried serious risk of confounding, since group membership was not assigned and illness severity independently predicted sleep abnormalities (13).

### Backup-rate modes versus PSV

Sleep fragmentation was greater during PSV than during ACV, at 79 ± 7 versus 54 ± 7 arousals and awakenings per hour, and six of 11 patients developed central apneas on PSV (8). In acute-on-chronic respiratory failure, ACV reduced wakefulness and increased stage 3 and 4 sleep compared with PSV of 6 cmH2O (Table 3) (10). Pressure-controlled ventilation (PCV) raised sleep efficiency from 37% to 63% compared with low-level PSV and increased REM sleep from 0% to 6.5% (16). In conscious non-sedated patients, ACV, clinically adjusted PSV, and automatically adjusted PSV produced similar REM sleep and fragmentation, although central apneas occurred only during the PSV modes (12). Among patients with central apneas, added dead space during PSV reduced fragmentation from 83 ± 12 to 44 ± 6 events per hour (8).

### Proportional and neurally adjusted modes versus PSV

PAV reduced arousals from 16 to 9 per hour and increased REM sleep (9% vs 4%), while asynchronies fell from 53 to 24 per hour and correlated with arousals (9). NAVA increased REM sleep from 4.5% to 16.5% and reduced fragmentation from 40 to 16 events per hour, eliminating the ineffective efforts and central apneas recorded during PSV (14). In patients with good synchrony on PSV, PAV with load-adjustable gain factors (PAV+) and PSV produced similar sleep quality, and periodic breathing emerged mainly at high assist with either mode (11). In patients selected for asynchrony on PSV, PAV+ improved synchrony while producing slightly greater fragmentation and less REM sleep (0.0% vs 5.8%) (17).

### Assisted versus unassisted breathing and ventilator type

In tracheostomized patients with prolonged weaning, low-level PSV increased TST from 132 to 183 minutes compared with spontaneous breathing, without significant changes in sleep architecture or fragmentation (18). During acute hypercapnic respiratory failure, sleep time and quality were greater during NIV sessions than during unassisted breathing (15). In a step-down unit, sleep quantity and quality did not differ between tracheostomized ventilated patients and spontaneously breathing patients (13). Dedicated NIV ventilators and ICU ventilators produced similar

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sleep architecture, although dedicated devices generated more ineffective efforts (34 vs 2 per hour of sleep) (15).

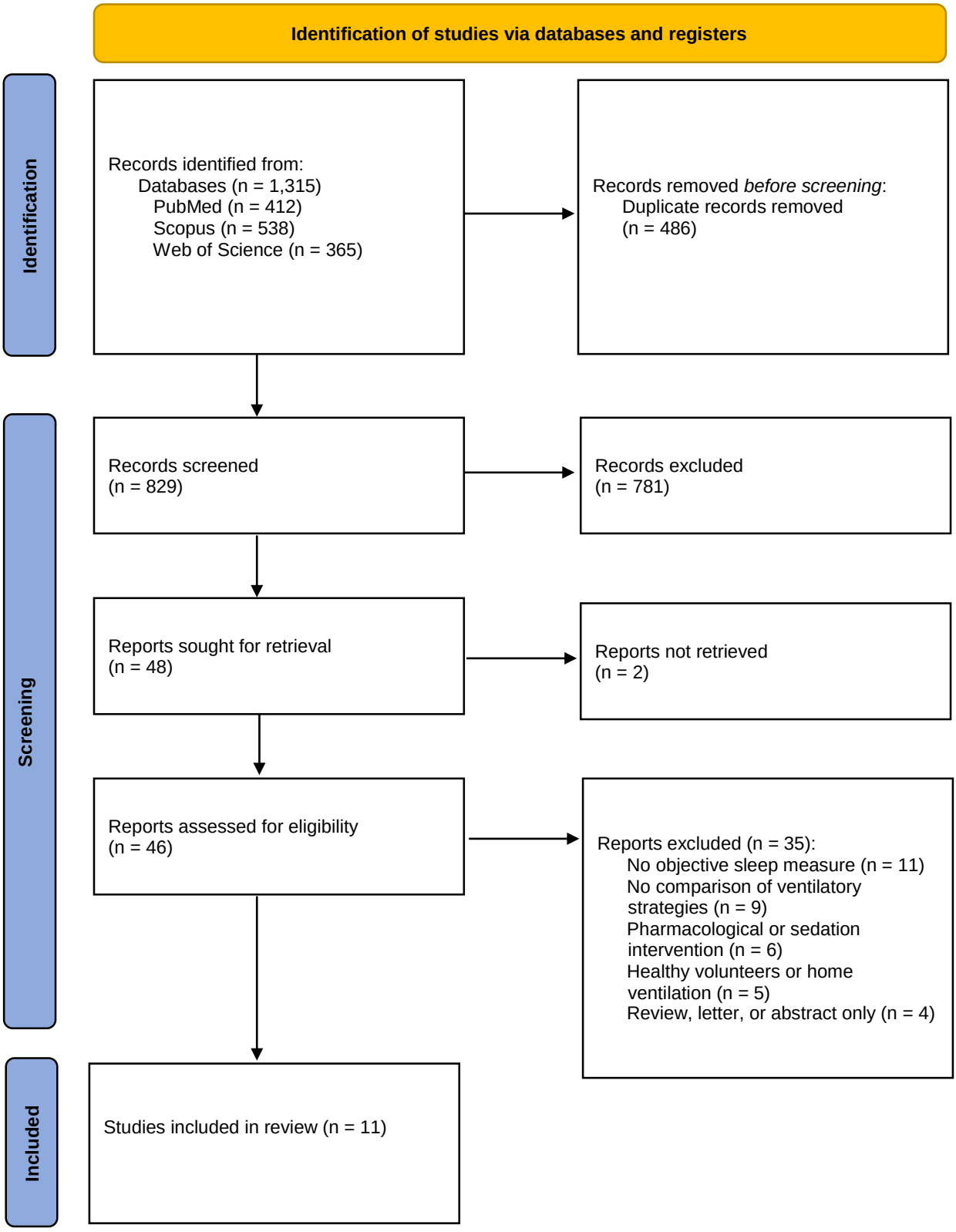



*Figure 1: PRISMA flow chart*

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**Table 1. Risk of bias of randomized and crossover studies (RoB 2)**

| Study | D1 | DS | D2 | D3 | D4 | D5 | Overall |
|---|---|---|---|---|---|---|---|
| Parthasarathy 2002 | SC | SC | L | L | SC | SC | H |
| Bosma 2007 | L | SC | L | L | SC | SC | SC |
| Toublanc 2007 | L | SC | L | L | SC | SC | SC |
| Alexopoulou 2007 | SC | SC | L | L | SC | SC | H |
| Cabello 2008 | L | SC | L | L | SC | SC | SC |
| Delisle 2011 | L | L | L | L | SC | SC | SC |
| Córdoba-Izquierdo 2013 | L | NA | L | L | SC | SC | SC |
| Andréjak 2013 | L | SC | L | SC | SC | SC | H |
| Alexopoulou 2013 | L | L | L | L | SC | SC | SC |
| Roche-Campo 2013 | L | SC | L | L | SC | SC | SC |

D1, randomization process; DS, period and carryover effects; D2, deviations from intended interventions; D3, missing outcome data; D4, measurement of the outcome; D5, selection of the reported result; L, low; SC, some concerns; H, high; NA, not applicable (parallel design). ROBINS-I (Fanfulla 2011): serious risk, driven by confounding.

**Table 2. Characteristics of the included studies**

| Study | Design | Population | Comparison | PSG window |
|---|---|---|---|---|
| Parthasarathy 2002 (8) | Crossover | Invasive MV, n = 11 | ACV vs PSV vs PSV with dead space | 2-h periods |
| Bosma 2007 (9) | RCO | Weaning, n = 13 | PSV vs PAV | 22:00-08:00, two nights |
| Toublanc 2007 (10) | RCO | Acute-on-chronic RF, n = 20 | ACV vs PSV 6 cmH2O | 22:00-06:00 |
| Alexopoulou 2007 (11) | Crossover | Sedated, n = 11; non-sedated, n = 9 | PAV+ vs PSV, two assist levels | One or two nights |
| Cabello 2008 (12) | RCO | Non-sedated invasive MV, n = 15 | ACV vs cPSV vs aPSV | Three 6-h periods |
| Fanfulla 2011 (13) | Observational | Step-down unit; MV, n = 10; SB, n = 11 | MV vs SB | 24 h |
| Delisle 2011 (14) | RCO | Non-sedated weaning, n = 14 | NAVA vs PSV | Four 4-h periods |
| Córdoba-Izquierdo 2013 (15) | Randomized parallel | Hypercapnic RF on NIV, n = 24 | ICU vs dedicated ventilator; NIV vs SB | 16:00-09:00 |

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| Study | Design | Population | Comparison | PSG window |
|---|---|---|---|---|
| Andréjak 2013 (16) | RCO | Acute-on-chronic RF, n = 26 | PCV vs PSV 6 cmH2O | 22:00-06:00 |
| Alexopoulou 2013 (17) | RCO | Asynchrony on PSV, n = 14 | PAV+ vs PSV | 24 h |
| Roche-Campo 2013 (18) | RCO | Tracheostomized, prolonged weaning, n = 16 | Low-level PSV vs SB | Two 5-h periods |

**Table 3. Main sleep outcomes of the included studies**

| Study | Key sleep findings | Direction |
|---|---|---|
| Parthasarathy 2002 (8) | Fragmentation 79 vs 54 events/h (PSV vs ACV); central apneas with PSV | Favors ACV |
| Bosma 2007 (9) | Arousals 16 vs 9/h; REM 4% vs 9% (PSV vs PAV) | Favors PAV |
| Toublanc 2007 (10) | Less wakefulness and more stage 3-4 sleep with ACV | Favors ACV |
| Alexopoulou 2007 (11) | Similar sleep quality; periodic breathing at high assist | Neutral |
| Cabello 2008 (12) | Similar REM and fragmentation across ACV, cPSV, and aPSV | Neutral |
| Fanfulla 2011 (13) | No difference between MV and SB | Neutral |
| Delisle 2011 (14) | REM 4.5% vs 16.5%; fragmentation 40 vs 16 events/h (PSV vs NAVA) | Favors NAVA |
| Córdoba-Izquierdo 2013 (15) | Similar sleep by ventilator type; better during NIV than SB | Favors NIV over SB |
| Andréjak 2013 (16) | Sleep efficiency 63% vs 37%; REM 6.5% vs 0% (PCV vs PSV) | Favors PCV |
| Alexopoulou 2013 (17) | Less REM (0.0% vs 5.8%) and slightly more fragmentation with PAV+ | Favors PSV |
| Roche-Campo 2013 (18) | TST 183 vs 132 min (MV vs SB); similar fragmentation | Favors MV |

## Discussion

This review found that ventilator modes with a backup rate or controlled delivery, namely ACV and PCV, improved nocturnal sleep compared with PSV in several crossover studies (8, 10, 16). In healthy volunteers, periodic breathing during PSV develops predictably once assistance lowers carbon dioxide tension below the apneic threshold during sleep (19). Critically ill patients with heart failure reproduced this mechanism, and a backup rate or added dead space improved sleep continuity (8). A meta-analysis of four trials (67 patients) confirmed higher sleep efficiency with PCV than PSV (mean difference 15.6%) and fewer apneic events (20). The PADIS guideline accordingly suggests ACV rather

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than PSV at night to improve sleep, as a conditional recommendation based on low-quality evidence (21).

Proportional and neurally adjusted modes produced discordant results across the included trials (9, 11, 14, 17). PAV and NAVA improved sleep when PSV generated frequent asynchrony, ineffective efforts, or central apneas, which identifies these events as the main targets of benefit (9, 14). PAV+ failed to improve sleep despite better synchrony in a cohort dominated by chronic obstructive pulmonary disease, indicating that synchrony alone does not determine sleep quality (17). Clinically and automatically titrated PSV matched ACV in conscious non-sedated patients, which suggests that careful titration removes much of the mode effect (12). The PADIS panel made no recommendation on adaptive modes, reflecting this heterogeneity (21).

Ventilatory assistance increased sleep time compared with unassisted breathing in tracheostomized and NIV-treated patients, whereas no difference appeared in a step-down population (13, 15, 18). Nocturnal reconnection to the ventilator during weaning therefore appears reasonable, provided settings avoid over-assistance (11, 18). This matters because abnormal EEG patterns and poor sleep during NIV were associated with late NIV failure in hypercapnic patients (22). Atypical sleep and absent REM sleep during difficult weaning were associated with longer weaning duration (23). Lower levels of full wakefulness before a spontaneous breathing trial were also associated with trial failure (24).

A meta-analysis of 13 trials, eight of which tested ventilator modes, reported that timed modes improved sleep quantity compared with spontaneous modes (25). The Cochrane review rated the overall evidence for non-pharmacological interventions as low or very low quality and found inconsistent ventilator-mode trials (7). The present review adds separate analysis of invasive, noninvasive, and unassisted comparisons and of mechanisms such as central apneas (12, 15, 18).

Samples of 11 to 26 patients and recording windows of two to 24 hours limit precision and generalizability (8, 13, 16). Standard scoring fails in many ventilated patients, with atypical sleep forming 85% of recorded data in one cohort (26). Conventional scoring was not feasible in 28% of conscious non-sedated ICU patients, which supports adding atypical sleep and pathological wakefulness to future outcome sets (27). No eligible study tested high-flow nasal oxygen, helmet NIV, or recent closed-loop modes, and most enrolled stable patients during weaning (8-18). Research priorities from the American Thoracic Society include standardized ICU sleep measurement and adequately powered intervention trials (28).

**Conclusion**

Ventilatory mode and settings influence objectively measured sleep in critically ill adults. Assist-control and pressure-controlled ventilation at night improved sleep efficiency and deep sleep compared with pressure support, mainly in patients with acute-on-chronic respiratory failure or central apneas. Proportional and neurally adjusted modes improved sleep when pressure support produced frequent ineffective efforts, whereas proportional assist with load-adjustable gain factors did not. Ventilatory assistance during sleep generally increased sleep time compared with unassisted breathing. Nocturnal settings that avoid over-assistance and asynchrony are a practical sleep-promoting measure, and larger multicenter trials with ICU-adapted sleep scoring are needed to confirm patient-centered benefits.

**List of Abbreviations**

ACV: assist-control ventilation; aPSV: automatically adjusted pressure support ventilation; cPSV:

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clinically adjusted pressure support ventilation; EEG: electroencephalography; ICU: intensive care unit; MV: mechanical ventilation; NAVA: neurally adjusted ventilatory assist; NIV: noninvasive ventilation; PADIS: Pain, Agitation/Sedation, Delirium, Immobility, and Sleep Disruption; PAV: proportional assist ventilation; PAV+: proportional assist ventilation with load-adjustable gain factors; PCV: pressure-controlled ventilation; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PSG: polysomnography; PSV: pressure support ventilation; RCO: randomized crossover; REM: rapid eye movement; RF: respiratory failure; RoB 2: Risk of Bias 2 tool; ROBINS-I: Risk Of Bias In Non-randomized Studies of Interventions; SB: spontaneous breathing; SWS: slow-wave sleep; TST: total sleep time.

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