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Physiological and clinical effects of selected airway clearance techniques in mechanically ventilated adult ICU patients: a systematic review and synthesis without meta-analysis

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Abstract

Background and objectives: Secretion retention is common in invasively mechanically ventilated ICU patients. Airway clearance techniques (ACTs) are widely used, although their physiological and clinical effects remains uncertain. We aimed to evaluate the physiological and clinical effects of selected ACTs in invasively mechanically ventilated adult ICU patients.

Methods: This systematic review was registered in PROSPERO (CRD42025631124) and conducted according to PRISMA guidelines. We searched MEDLINE, Embase, and the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and PEDro up to 20 March 2025. Studies evaluating ventilator hyperinflation, PEEP–ZEEP technique, expiratory rib-cage compression (ERCC), or mechanical insufflation–exsufflation (MI-E) in mechanically ventilated adults were included. We assessed risk of bias using the Cochrane Risk of Bias tool for randomized studies and Joanna Briggs Institute tools for observational studies and case series. The primary outcome was secretion clearance (e.g., sputum weight or volume). Secondary outcomes included clinical outcomes (mortality, duration of invasive mechanical ventilation, ICU length of stay), safety (adverse events during ACTs), and respiratory complications related to impaired airway clearance (gas-exchange impairment, increased work of breathing, and ventilator-associated pneumonia).

Results: Forty-six studies including 1,884 patients were analysed. Secretion clearance was the most frequently reported outcome. Several studies reported greater secretion clearance with ACTs compared with standard care or suctioning alone, although findings varied across techniques, comparisons, and outcome definitions. ERCC, MI-E, and hyperinflation techniques were associated with increased secretion clearance in some studies, whereas results for PEEP–ZEEP technique were inconsistent. Effects on respiratory mechanics, oxygenation, and clinical outcomes were variable and predominantly short-term.

Clinically relevant respiratory complications and patient-centred outcomes were inconsistently reported. No clear effect was observed on mortality, duration of mechanical ventilation, or ICU length of stay. No major adverse events were reported.

Conclusion: Selected ACTs may improve short-term secretion clearance in invasively ventilated ICU patients. However, the evidence is largely limited to surrogate physiological outcomes and is of low certainty for clinically meaningful outcomes, whose effects remain uncertain. Further high-quality studies using standardized outcome definitions and robust safety reporting are required.

List of abbreviations

ACT = airway clearance techniques

Cdyn = dynamic compliance

Cst = static compliance of the respiratory system

ERCC = expiratory rib-cage compression

f/Vt = respiratory rate to tidal volume ratio

HR = heart rate

ICU = intensive care unit

LOS = length of stay

MAP = mean arterial pressure

MD = mean difference

MHI = manual hyperinflation

MI-E = mechanical insufflation–exsufflation

MV = mechanical ventilation

NRSI = non-randomized study of interventions

PaCO2 = arterial partial pressure of carbon dioxide

PaO2/FiO2 = the ratio of arterial oxygen partial pressure to fraction of inspired oxygen

PEEP-ZEEP = Positive End-Expiratory Pressure – Zero End-Expiratory Pressure

Pplat = plateau pressure

PPeak = peak airway pressure

RCT = randomized controlled trial

RR = risk ratio

SMD = standardized mean difference

SpO2 = peripheral oxygen saturation

VAP = ventilator-associated pneumonia

VCO2 = carbon dioxide production

VHI-MHI = ventilator hyperinflation and manual hyperinflation

Vt = tidal volume

Introduction

Secretion retention is a clinically relevant problem in adults receiving invasive mechanical ventilation (MV) (1). The presence of an artificial airway, impaired mucociliary clearance, reduced cough effectiveness, inadequate humidification, and respiratory muscle weakness may promotes mucus accumulation, leading to atelectasis, hypoxaemia, infection, and ventilator-associated pneumonia (VAP) (2). These complications contribute to delayed weaning and extubation failure (3). In a pivotal multicentre cohort, ineffective cough and abundant secretions were independent predictors of reintubation, while intensive care unit (ICU)-acquired weakness further impaired airway clearance capacity during the first week after extubation (4). The burden of secretion retention is amplified in specific subgroups, including older adults and individuals with chronic obstructive pulmonary disease, heart failure, renal dysfunction or neurological impairment, who exhibit a reduced physiological reserve and are particularly vulnerable to secretion-related complications (5, 6). In these populations, impaired airway clearance may initiate a cascade leading to prolonged mechanical ventilation, increased infection risk, and poorer clinical outcomes (7, 8).

A wide range of airway clearance techniques (ACTs) is used in mechanically ventilated ICU patients, including suctioning strategies, humification systems, nebulised therapies, oscillatory devices, intrapulmonary percussive ventilation, manual techniques, and ventilator-based approached (9).

Among these, selected ACTs, such as manual or ventilator hyperinflation (MHI, VHI), PEEP–ZEEP manoeuvres (10), expiratory rib-cage compression (ERCC), and mechanical insufflation–exsufflation (11), are specifically designed to enhance expiratory flow bias, mobilize secretions, optimise ventilation distribution, or facilitate cough assistance (9, 12). Despite their widespread use, clinical practice remains variable across and within countries (9, 13). Surveys consistently report differences in indications, treatment intensity, and preferred modalities, often influenced by local expertise, resource availability, and clinician preference rather than high-quality comparative evidence (13-15).

Previous systematic reviews have mainly evaluated single techniques, particulary hyperinflation strategies such as MHI and VHI (16-18), and have predominantly focused on short-term physiological outcomes. Consequently, clinicians still lack a structured synthesis comparing selected ACTs commonly used to promote secretion mobilization in invasively ventilated adults.

Moreover, methodological limitations, including small sample sizes, heterogeneous protocols, short follow-up periods, and inconsistent reporting of patient-centred outcomes, limit the interpretation and clinical applicability of the currrent evidence.

Recent international efforts to develop consensus-based recommendations further highlight the uncertainty and variability surrounding ACT use in mechanically ventilated ICU patients (19).

Therefore, this systematic review aimed to evaluate the physiological effects, clinical outcomes, and safety of selected ACTs (ERCC, MI-E, PEEP-ZEEP manoeuvres, and MHI/VHI) in invasively mechanically ventilated adults, with a specific focus on secretion clearance, respiratory physiology, and clinically relevant patient-centred outcomes.

Methods

This is a systematic review, performed following the guidelines outlined in the Cochrane Handbook for Systematic Reviews of Interventions (20) and the reporting according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (checklist included in Online Resource 1). The protocol was registered on PROSPERO (CRD42025631124).

Selection criteria

Type of studies

In this systematic review, we considered randomized controlled trials (RCTs), crossover studies, and non-randomized studies of interventions (NRSIs), evaluating the physiological parameters and clinical effectiveness of ACTs in invasively mechanically ventilated adult ICU patients.

We excluded pilot, case reports, systematic reviews, protocols, and conference or meeting abstracts only.

Population

We included adults (over 18 years old) receiving invasive mechanical ventilation in the ICU, irrespective of underlying diagnosis, disease severity, or clinical phenotype. Eligible populations included medical and surgical patients with acute critical illness (e.g., cardiopulmonary arrest, neurological injury, acute respiratory failure). Studies enrolling mixed populations were included when data for the target population were clearly identifiable. Studies focusing on patients with primary neuromuscular disorders and studies involving pediatric populations were excluded.

Interventions

The review included studies addressing one of the four ACTs (ERCC, MI-E, PEEP-ZEEP maneuvers, and VHI-MHI) alone or in combination with other treatments such as conventional physiotherapy or suctioning. We considered studies that compared one of the four ACTs (either standalone or combined) to any other intervention, including non-ACTs, usual care, suctioning, no intervention. The selection of these techniques was guided by their consistent representation in existing narrative and scoping reviews of airway clearance in invasively ventilated patients and by the availability of primary clinical studies examining their application in this population (9, 13).

Outcome measure

Primary outcome

Secretion retention/clearance: assessed using physiological indicators such as sputum weight or sputum (gr) volume.

Secondary outcomes

Secondary outcomes were grouped into clinically relevant domains, given the heterogeneity of outcome definitions across studies.

Clinical outcomes included mortality, duration of invasive mechanical ventilation, and ICU length of stay

Safety outcomes included adverse events occurring during airway clearance techniques (ACTs) (e.g., desaturation, hemodynamic instability, endotracheal tube obstruction, ventilator-related events).

Respiratory complications related to impaired airway clearance included:

- Gas-exchange impairment, assessed using PaO_2/FiO_2, $PaCO_2$, and SpO_2
- Increased work of breathing, assessed using physiological and ventilatory parameters (e.g., VCO_2, tidal volume, peak airway pressure and plateau pressure, driving pressure, respiratory system compliance, f/Vt, heart rate, and mean arterial pressure)
- Ventilator-associated pneumonia

Search Strategy

Our systematic review commenced with a comprehensive search across the following databases: MEDLINE, Embase, Web of Science, the Cochrane Central Register of Controlled Trials (CENTRAL), and Pedro-up to 20 March 2025. The search strategy adapted for each database is reported in **Supplementary Table A**. The search strategy was developed using Medical Subject Headings (MeSH) and relevant text-words. No restrictions were applied to publication date to ensure a comprehensive search, while only English-language studies were considered for eligibility. This restriction was applied due to methodological feasibility considerations and to ensure accurate interpretation of physiological and ventilatory outcomes reported in the included studies. Moreover, we also hand-searched the reference lists of included previous systematic reviews. The duplicates were removed using EndNote version 20.6 (Clarivate, Philadelphia, PA, USA).

Screening process

The screening was conducted by two independent authors (MC and GT) blinded to each other's assessment, using the Rayyan Intelligent Systematic Review tool (https://www.rayyan.ai/) (21). All titles, abstracts, and full texts were screened for appropriateness. Any conflicts among the reviewers were resolved by a third reviewer (VR) until a consensus was achieved. All reviewers responsible for study selection were physiotherapists with over 10 years of experience in critical care and respiratory management, as well as expertise in research methodology, ensuring a rigorous and informed selection process.

Data extraction

Two reviewers (MC and GT) independently extracted data from each included study using a predefined Excel form. A third author (VR) checked all extracted data.

Extracted variables included study characteristics (year of publication, first author, country), participant characteristics (age, sex distribution, comorbidities, comorbidity burden (e.g., Charlson Comorbidity Index when available), and disease severity (e.g., SAPS II, APACHE II). Baseline respiratory status was also collected, including PaO_2/FiO_2, and details of the airway clearance intervention (expiratory rib-cage compression, ERCC; MI-E; PEEP-ZEEP and VHI-MHI), including duration, dosing and the healthcare professional delivering the intervention. Comparator characteristics were also collected, including the nature, duration, and frequency of the comparison intervention.

Outcome-related data included the outcomes assessed in each study, the measurement instruments used, and the corresponding numerical results. Disagreements were resolved through discussion, with involvement of a third reviewer when necessary.

Assessment of risk of bias in included studies

Two reviewers (MC and VR) performed the risk of Bias utilizing the Cochrane Risk of Bias 1 (RoB1) (22) or Joanna Briggs Institute (JBI) Critical Appraisal tools (23) for observational studies and case series (24), as appropriate. Disagreements between the two authors were resolved through discussion with additional reviewers (MJDF and CC), resulting in a final consensus.

Statistical analysis

When the information was not directly available from data extraction, it was calculated if possible. Results were summarized using descriptive statistics and counts, and percentages were reported for categorical variables.

A meta-analysis using a random-effects model was planned to pool similar studies regarding participants, interventions, comparisons, and outcomes if the data were available. Mean differences (MDs) for continuous outcomes measured with the same metrics or standardized mean differences (SMDs) for outcomes measured with different metrics with 95% CIs were calculated, as well as risk ratios (RRs) with 95% CIs for adverse events and mortality. Statistical heterogeneity was assessed by visual inspection of the forest plot and the Chi^2 statistic; as recommended in the Cochrane Handbook for Systematic Reviews of Interventions (25), a P value<0.1 was considered statistically significant. To determine the impact of heterogeneity on the meta-analysis, the I^2 statistic was used, considering an I^2 from 0% to 40% to indicate that heterogeneity might not be important, 30% to 60% moderate heterogeneity, 50% to 90% substantial heterogeneity, and 75% to 100% considerable heterogeneity. In the case of 10 or more studies included in the meta-analysis, publication bias was assessed via visual inspection of funnel plots (26).

All the analyses were performed using Review Manager (RevMan) 5.4.1 software. We planned to perform a narrative synthesis with frequencies if a meta-analysis was not applicable. Meta-analysis was considered only when studies were sufficiently homogeneous in terms of participants, interventions, comparators, outcome definitions, and timing of assessment. For the narrative synthesis, studies were grouped by intervention type (ERCC, MI-E, PEEP–ZEEP, VHI/MHI), comparator, outcome domain (physiological, clinical, safety), and study design. Direction of effect was classified as improvement, no difference, or worsening relative to the comparator based on reported study results. Consistency of findings was assessed qualitatively by comparing the direction and magnitude of effects across studies within each intervention–outcome group.

Particular attention was given to crossover trials. Quantitative pooling was not performed unless paired data were available. In most cases, within-participant correlation coefficients were not reported, and potential carryover effects and unit-of-analysis issues could not be adequately addressed, precluding valid meta-analytic synthesis even for commonly reported outcomes such as sputum weight or volume.

Weighted means and standard deviations were estimated where possible by aggregating the available data or estimating them from medians and interquartile ranges (27).

Analysis of subgroups

We planned to conduct subgroup analyses based on different underlying health conditions (e.g., acute respiratory distress syndrome, thoracic surgery, stroke), if sufficient data were available.

Certainty of evidence assessment

A qualitative assessment of certainty of evidence was conducted on RCTs and crossover trials using GRADE domains (methodological limitations of the studies, indirectness, imprecision, inconsistency, and publication bias), and applied narratively given the absence of quantitative pooling (28). The certainty of evidence across outcomes was summarised in a Summary of Findings table, with detailed domain-level assessments.

Deviation from protocol

During the conduct of the review, the search strategy was expanded to include one additional database beyond those prespecified in the protocol in order to improve study identification. Prespecified outcomes were reorganised for reporting due to substantial heterogeneity in study design, populations, and outcome measurement across included studies. All outcomes analyzed in the review were prespecified in the protocol. For reporting purposes, and due to substantial heterogeneity in outcome definitions and measurement methods, secretion retention/clearance was designated as the primary outcome, because it most directly reflected the physiological target of airway clearance techniques, while the remaining outcomes were grouped into clinically relevant secondary domains (clinical outcomes, safety outcomes, and respiratory complications related to impaired airway clearance). These changes were made to improve clarity and did not alter the underlying review question or eligibility criteria. Two prespecified outcomes (atelectasis and re-intubation) were not reported in the included studies and were therefore not presented as standalone outcomes in the final synthesis. These outcomes remained part of the review framework and were retained during data extraction, but no eligible data were available for synthesis. Finally, a qualitative assessment of the certainty of evidence using GRADE domains (28) was performed post hoc in response to peer reviewers' comments to improve transparency and interpretation of the findings.

Results

Study Selection

The PRISMA flow diagram summarizing the study selection process is reported in **Figure 1**. The literature search identified 12037 records, and after removing duplicates, we screened 7,176 records. We excluded, 7084 records based on title/abstract. We retrieved 92 records for full-text screening and discarded those that did not meet the inclusion criteria. Finally, 33 studies were included, and 13 additional publications were identified via citation searching. The list of the excluded studies and the reasons for exclusion are listed in **Supplementary Table B**.

Study characteristics

The characteristics of the included studies are summarized in **Table 1**. The studies were published between 1998 (29) and 2025 (30) for a total of 1,884 participants. The studies covered the following WHO regions: 14 studies from the Eastern Pacific Region, 3 from the Eastern Mediterranean Region (EMR), 23 from the Region of the Americas, 3 from the European Region, and 3 studies from the South-East Asia Region. The studies covered countries from different income levels: high-income countries (HIC) were represented in 16 studies (11, 29, 31-44), upper-middle income countries in 25 studies (45) (6, 38, 46-67), and lower-middle income countries in 5 studies (30, 68-71) None from low-income countries, according to the 2024 World Bank Classification. Among the eligible studies, 11 were RCTs (6, 29, 30, 39, 48, 52-55, 63, 69), 29 randomized crossover trials (31-36, 38, 40, 43-47, 49-51, 56-58, 60-62, 64-67, 70-72), 3 prospective studies (42, 59, 68), 1 non-randomized controlled trial (37), 1 retrospective study (11), and 1 case series (41). Four of the studies were multicentric (35, 38, 39, 67), while 42 were conducted in a single center.

Population

Sample sizes ranged from 10 to 180; reported mean or median ages ranged from 28 to 73 years, and 56% of participants were male (1,053/1,884). Comorbidities were reported in 16 out of 46 studies, most commonly including COPD, diabetes mellitus, hypertension, and chronic heart disease. Seven studies involved tracheostomized patients (104/1884; 5.5%). Most studies included patients described as clinically stable, generally defined by relatively low ventilatory support requirements (PEEP ≤ 10 cmH_2O, FiO_2 ≤ 0.40) and adequate oxygenation (SpO_2 > 90%). Common exclusions included elevated intracranial pressure, undrained pneumothorax, rib fractures, chest drains, and severe bronchospasm. The included populations were a heterogeneous ICU case mix, predominantly patients with respiratory or neurological/neurosurgical diagnoses, and often also postoperative (abdominal, thoracic, or cardiac surgery) or with sepsis/septic shock.

The main characteristics of patients included in the systematic review are extracted in **Table 2**.

Critical appraisal

Findings from the critical appraisal are summarized in **Supplementary Table C** and **Supplementary Figures 1 and 2**. The single case series and non-randomized controlled trial were assessed as having low risk of bias, as most items on the JBI checklists received positive evaluations. Among the other observational studies, the main methodological limitations were the lack of clear management of confounding factors and missing data. Finally, the risk of bias assessment of the included RCTs indicated a high risk of performance and detection bias due to the absence of blinding of study participants and personnel, which also affected subjective outcome assessment. Unclear risk of selection and other biases was observed due to insufficient information on allocation concealment and on the appropriate management of the crossover study design.

Evidence synthesis

Due to substantial clinical and methodological heterogeneity, meta-analysis was not considered appropriate. Studies differed considerably in intervention protocols, ventilatory settings, co-interventions, comparator groups, outcome definitions, and timing of assessment. Furthermore, many randomized studies used crossover designs but did not report the paired data required for valid quantitative synthesis. As a result, unit-of-analysis considerations and the inability to appropriately account for within-subject correlations and potential carryover effects precluded reliable pooling of results, including for commonly reported outcomes such as secretion weight or volume. Therefore, findings were synthesized narratively (**Figure 2**). Across the selected ACTs, secretion clearance was the most infrequently reported and inconsistently defined. Across the selected ACTs, secretion clearance was the most consistently reported outcome, although assessment methods and timing varied considerably across studies. Respiratory physiological parameters, including respiratory mechanics and gas exchange, were predominantly evaluated immediately after intervention, whereas patient-centred outcomes were infrequently reported and inconsistently defined. Safety outcomes were reported inconsistently across studies. When reported, adverse events mainly included transient haemodynamic, respiratory, or ventilatory changes during or after the intervention. No major adverse events, including barotrauma, accidental extubation, or sustained haemodynamic instability, were reported in the included studies. Definitions of adverse events, monitoring windows, and reporting methods varied across studies.

Overall certainty of evidence, as summarised in the Summary of Findings table (**Table 3**), was low to very low across outcomes (see also **Supplementary Table D**).

<u>Interventions</u>

Most studies (31/46) reported both the invasive MV mode and the clinical setting in which airway clearance interventions were delivered. In the majority of cases, techniques were applied in patients receiving invasive MV, most commonly during pressure support ventilation, and were delivered by physiotherapy staff and/or nursing teams. The distribution of ventilation modes and settings is summarized in **Supplementary Table E**.

ERCC

Ten studies (n=529) (30, 37, 43, 48, 52, 53, 55, 58, 70, 71) examined ERCC alone or combined with suctioning/standard care. Secretion clearance was assessed in several studies, with higher sputum yield reported when ERCC preceded suctioning compared with suctioning alone in some investigations (43, 70, 71), whereas others reported no significant difference. Effects on oxygenation were generally modest and short-term (55, 70). In a multimodal chest physiotherapy protocol including ERCC, the study showed a significant reduction in VAP in the intervention group compared with controls (p=0.01). Duration of MV and ICU LOS did not differ significantly between groups. No serious adverse events directly attributable to ERCC were reported. Key study characteristics are summarized in **Table 4**.

MI-E

Eight studies (11, 36, 40, 41, 51, 54, 64, 72) (n=476) evaluated MI-E, either alone (41) or combined with conventional physiotherapy. Comparator interventions included positioning with suctioning (36, 40, 51, 54, 64), ERCC with suctioning (72) or standard chest physiotherapy (11). Across studies, MI-E was generally associated with increased secretion clearance and short-term improvements in respiratory mechanics, particularly when higher insufflation–exsufflation pressures were applied.

In two studies using pressures of ± 40 cmH_2O, MI-E (alone or combined with manually assisted techniques) resulted in significantly greater secretion yield compared with comparator interventions (both p<0.001) (54, 72). One pressure-level comparison study reported improved static compliance (p=0.005) and reduced airway resistance with higher pressure settings (−50/+50 cmH_2O)(64).

Clinical outcomes were inconsistently reported. One study observed lower VAP incidence or reduced antibiotic use with MI-E compared with conventional chest physiotherapy (11), whereas another reported no significant difference in ventilator-free days (36). Overall, MI-E was well tolerated, with no reports of barotrauma or sustained haemodynamic instability (40, 41). Key study characteristics are summarized in **Table 5**.

PEEP-ZEEP

Seven studies (46, 49, 56, 59, 61, 65, 67) (n=122) evaluated PEEP–ZEEP maneuvers, predominantly in physiologically stable mechanically ventilated patients (**Table 6)**. Most studies focused on exipiratory flow bias and respiratory mechanics rather than patient-centred outcomes.

Studies assessing expiratory flow bias consistently demonstrated increased PEF–PIF gradients during the ZEEP phase, particularly when manual chest compression or volume-controlled ventilation strategies were applied (46, 65). One study reported significantly higher expiratory flow bias indices during volume-controlled ventilation compared with pressure support ventilation (p<0.001) (46). Static compliance improved significantly after the PEEP–ZEEP manoeuvre in one study (p=0.007) (49).

Findings regarding secretion clearance were less consistent. Two studies comparing PEEP–ZEEP with bag squeezing reported no significant differences in sputum weight between groups (56, 61). Hemodynamic variables remained generally stable across studies evaluating safety outcomes (49, 56, 59, 61, 67).

VHI-MHI

Twenty-one randomized crossover trials (n=757) evaluated VHI, MHI, or variants combined with adjuctive maneuvers **(Table 7).** Five trials directly compared VHI and MHI, using secretion clearance as the primary outcome. Results were generally comparable, although one study reported significantly greater secretions removal with VHI (p < 0.001) (31-33, 44, 69).

Compared with suctioning alone, VHI/MHI more consistently increased secretion clearance, with higher sputum weight or volume reported in most studies (35, 47, 60, 62, 63). Improvements in respiratory mechanics were also observed in some investigations, including higher respiratory compliance (35, 38, 47, 50, 62) and increased tidal volume after hyperinflation (47, 62). Among studies comparing MHI with standard care (6, 29, 39) clinical outcomes generally favored MHI across the reported outcome. One study reported significant higher rates of successful weaning ($p < 0.05$) and ICU discharge ($p < 0.01$) in the MHI group (6). Studies evalutating adjunctive manoeuvres in combination with VHI/MHI yielded inconsistent findings, although some suggested that positioning or ERCC may further enhance secretion clearance (34, 63). Two studies comparing ventilator delivery modes reported that volume-controlled strategies more consistently achieved expiratory flow-bias targets than pressure-support ventilation (42, 66).

Discussion

In this systematic review, we synthesised evidence from 46 studies evaluating airway clearance techniques in 1,884 invasively mechanically ventilated adults. The main finding is that selected ACTs may improve short-term physiological measures of airway clearance, particularly secretion weight or volume, but evidence for clinically meaningful outcomes remains limited, heterogeneous, and uncertain. This distinction is important: secretion mobilisation represents a plausible mechanistic target in mechanically ventilated patients with impaired cough and mucociliary clearance, but it should not be interpreted as direct evidence that ACTs reduce ventilator-associated pneumonia, shorten mechanical ventilation, improve weaning success, reduce ICU length of stay, or affect mortality. The available literature was characterised by marked variability in intervention protocols, ventilatory settings, patient populations, timing of assessment, and outcome definitions. Most studies assessed immediate or short-term physiological responses, whereas patient-centred outcomes were either not reported or reported in studies with limited power. These factors limited comparability across studies and precluded robust quantitative synthesis for most outcomes.

Risk-of-bias assessment consistently indicated high or unclear risk across most randomized studies, largely due to lack of blinding, incomplete reporting of allocation and crossover procedures, and potential performance bias. These methodological limitations likely contributed to variability in effect estimates and may have inflated short-term physiological effects, particularly for operator-dependent outcomes such as secretion clearance. Ventilatory mode and ventilator settings appeared particularly relevant. Studies evaluating PEEP–ZEEP and ventilator hyperinflation suggested that volume-controlled strategies may more consistently generate expiratory flow bias compared with pressure-support ventilation. Similarly, inspiratory pressures, inspiratory time, and baseline PEEP varied substantially across studies and may have influenced secretion mobilisation and respiratory mechanics. Although no major adverse events were reported, safety cannot be inferred with confidence because adverse-event reporting was inconsistent, and most studies were not powered to detect uncommon harms. These findings extend previous reviews by providing a clinically oriented synthesis across different modes of ACT delivery and highlighting key sources of heterogeneity affecting comparability (73). ACTs are widely implemented in the respiratory management of critically ill patients. Their physiological rationale is based on the generation of an expiratory flow bias, facilitating mucus transport in conditions characterized by impaired cough effectiveness and altered mucociliary clearance (74, 75). Across the available studies, the most frequently reported effect was increased secretion mobilization, typically quantified by aspirate or sputum weight. Across techniques, shared mechanisms include transient increases in expiratory airflow, modulation of lung volumes, and reduction of mucus adhesion through shear forces.

Peripheral-oriented strategies generally aim to increase lung volume and promote collateral ventilation, whereas proximal-oriented approaches aim to optimize expiratory flow bias (PEF > PIF) (76, 77). However, this distinction should be interpreted cautiously, as mucus transport depends on the interaction between airflow dynamics, regional lung mechanics, and airway geometry (37, 78). Secretion clearance should be interpreted as a surrogate physiological outcome rather than direct evidence of clinical benefit. This kind of outcome is also operator-dependent and particularly vulnerable to performance and detection bias in unblinded studies. Although increased sputum weight or volume is mechanistically relevant, especially in patients with secretion retention or impaired cough, the available evidence does not establish that these short-term effects translate into improved patient-centred outcomes. In particular, effects on ventilator-associated pneumonia, duration of mechanical ventilation, ICU length of stay, weaning success, and mortality remain uncertain because these outcomes were inconsistently reported and generally underpowered. From a clinical perspective, the available evidence suggests that ACTs may be most applicable in mechanically ventilated patients with suspected secretion retention, impaired cough effectiveness, or atelectasis-related respiratory impairment. However, most included studies enrolled relatively clinically stable patients with moderate ventilatory support requirements, limiting extrapolation to patients with severe hypoxaemia or haemodynamic instability. Ventilatory mode, inspiratory settings, baseline PEEP, patient–ventilator interaction, and sedation level may also influence the feasibility and physiological response to these interventions. Therefore, ACTs should be considered adjunctive interventions integrated within a broader respiratory management strategy rather than stand-alone therapies.The current evidence base is characterised by substantial variability across patient populations, intervention protocols, outcome definitions, and timing of assessment, as consistently reported by Battalian et al (79). Geographical variability contributed to differences in ACT application. Ventilator-based strategies (e.g., ventilator hyperinflation, PEEP–ZEEP) predominated in studies from Brazil, whereas manual techniques were more commonly reported in Australia and other regions.

Device-assisted approaches, such as mechanical insufflation–exsufflation, were mainly reported in Japan and parts of Europe.

These observations support the identification of three broad models of ACT delivery, ventilator-based, manual, and device-assisted, reflecting local expertise and resource availability, and potentially limiting comparability across studies.

Among specific techniques, MI-E appears particularly promising in patients at high risk of extubation failure (80, 81). Although recent expert recommendations have suggested asymmetric pressure settings, all studies included in this review used symmetric insufflation–exsufflation pressures, typically ranging from ± 40–50 cmH_2O. This highlights a gap between current recommendations and available clinical evidence.

Consistent with previous literature (9, 82), current evidence supports physiological effects without clear evidence of outcome modification. ACTs should therefore be considered adjunctive interventions within a comprehensive ICU strategy rather than stand-alone therapies expected to directly modify major clinical outcomes. The included studies involved heterogeneous populations with mixed diagnoses and variable illness severity, and interventions were predominantly applied to clinically and haemodynamically stable patients, in line with current consensus recommendations (19). Some commonly reported exclusion criteria, such as rib fractures or the presence of chest drains, may represent relative rather than absolute contraindications to certain airway clearance techniques, depending on clinical context and technique selection, thereby potentially limiting the generalizability of these findings.

ACTs were applied across different ventilatory modes and disease categories, without evidence of disease-specific superiority. Airway anatomy and artificial airway configuration may further influence treatment response. In particular, the presence of a tracheostomy modifies upper airway resistance and expiratory flow dynamics, potentially affecting the generation of expiratory flow bias and the effectiveness of cough-augmenting strategies.

Emerging evidence suggests that airway configuration and ventilatory interface should be considered when selecting and titrating ACTs (83). In the absence of standardized algorithms, ACTs selection remains largely individualized. These interventions may be most appropriate in patients with evidence of secretion retention or impaired airway clearance, particularly when integrated with careful monitoring of ventilatory parameters and patient response.

Differences in operational parameters and treatment dose further limit reproducibility and comparability, with ventilator hyperinflation representing a clear example in which heterogeneous application complicates interpretation of comparative effectiveness.

ACTs are delivered within a multidisciplinary context involving physiotherapists, nurses, and intensivists. Effects on respiratory mechanics were inconsistently reported and appeared dependent on technique intensity, ventilatory settings, and underlying pathophysiology (76). Higher-pressure or volume-oriented strategies were occasionally associated with transient improvements in compliance, whereas lower-intensity interventions generally produced minimal or short-lived effects. These context-dependent responses may explain both the variability observed across studies and the limited translation of short-term physiological improvements into clinically relevant outcomes. In clinical practice, treatment effectiveness is assessed through multimodal evaluation that integrates ventilator parameters, respiratory patterns, patient–ventilator interactions, and secretion characteristics. Within this framework, compliance should be interpreted as an integrative physiological marker rather than an isolated indicator of treatment success (84).

Although physiotherapists and nurses perform ACTs, the safety and effectiveness of these interventions are strongly influenced by ventilatory settings and sedation strategies managed by intensivists. Among the evaluated techniques, ventilator hyperinflation was the most extensively studied. It demonstrated clearance of secretions and short-term physiological effects comparable to those of manual hyperinflation while maintaining PEEP and circuit integrity (32). Mechanical insufflation–exsufflation and PEEP–ZEEP manoeuvres were investigated in smaller and more selected populations, without evidence of superiority.

In summary, current evidence suggests that selected ACTs may facilitate short-term secretion mobilisation and produce transient physiological effects in carefully monitored, clinically stable mechanically ventilated ICU patients. However, these findings largely concern surrogate outcomes, and the certainty of evidence (assessed using GRADE domains) for clinically relevant outcomes remains low or very low. No consistent safety signal emerged, but adverse events were not uniformly defined or systematically collected across studies. The impact of ACTs on ventilator-associated pneumonia, duration of mechanical ventilation, ICU length of stay, weaning success, and mortality therefore remains uncertain.

(85). Future trials should distinguish physiological efficacy from clinical effectiveness, use standardised intervention protocols, and be adequately powered for patient-centred outcomes.

Clinical implications

ACTs should be considered part of multimodal respiratory management in invasively ventilated patients with retained secretions, primarily targeting short-term physiological optimisation rather than major clinical outcomes. Their use should be guided by clear clinical indications, appropriate patient selection, and integration with ventilatory and sedation strategies. Close collaboration among intensivists, physiotherapists, and nurses is essential to ensure safe application and consistency with lung-protective ventilation principles.

Implications for future research

Future studies should adopt standardized outcome definitions and include clinically relevant endpoints such as ventilator-associated pneumonia, duration of mechanical ventilation, and ICU LOS. Adequately powered randomized trials are needed to evaluate both individual ACTs and combinations of techniques within structured respiratory care pathways, and to identify patient subgroups most likely to benefit from targeted airway clearance interventions.

Limitations and strengths

This review has some limitations. The restriction to English-language publications may have introduced a potential language bias and limited the generalisability of the findings to non-English-speaking settings. The predominance of crossover designs with short washout periods further complicates interpretation, particularly for outcomes with potential carryover effects. These design characteristics also limited the feasibility of quantitative synthesis. Several studies were at high or unclear risk of bias, further limiting certainty in the observed effects. In addition, many studies focused primarily on surrogate physiological endpoints and were underpowered to detect differences in clinically meaningful outcomes. Inconsistent reporting of illness severity, comorbidities, and tracheostomy status further limits comparability across studies. Finally, heterogeneity in outcome definitions and reporting required refinement of the outcome framework during the review process, and some prespecified outcomes (e.g., atelectasis and re-intubation) were either not reported or had limited applicability to the final review population.

This review also has important strengths. It provides a comprehensive synthesis of the available evidence on airway clearance techniques in invasively ventilated adults, integrating data across different techniques and ventilatory settings. The systematic approach allows a structured appraisal of both physiological and clinical outcomes and highlights the current gaps in evidence regarding clinically meaningful endpoints.

Conclusion

In invasively ventilated adult ICU patients, selected ACTs may improve short-term secretion mobilisation, but the evidence remains heterogeneous largely based on surrogate physiological outcomes, and of low or very low certaintly. There is currently insufficient evidence to support a consistent effect on patient-centred clinical outcomes. ACTs should therefore be integrated within individualised multidisciplinary respiratory care rather than considered stand-alone interventions expected to improve ICU outcomes. Further well-designed studies are needed to define optimal techniques, ventilatory settings, timing, and patient selection.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analysed during this study are included in this published article and its supplementary information files.

Competing interest

The authors declare that they have no competing interests.

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Author Contributions

Veronica Rossi: Writing – original draft, Project administration, Investigation, Data curation, Conceptualization. Martina Callera: Investigation, Writing – original draft. Girolama Trombetta: Investigation, Writing – original draft. Raffaella Bellini: Data curation, Conceptualization. Filippo Binda: Data curation, Conceptualization. Matteo Johann Del Furia: Review, and editing, approved the final version of the manuscript. Emilia Privitera: Data curation, Conceptualization. Claudio Cordani: Writing – original draft, Methodology, Formal analysis. Alessandro Palleschi: Writing – review and editing, Supervision. Giacomo Grasselli: Writing – review and editing, Supervision.

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References

1. Torrini F, Gendreau S, Morel J, Carteaux G, Thille AW, Antonelli M, et al. Prediction of extubation outcome in critically ill patients: a systematic review and meta-analysis. Crit Care. 2021;25(1):391.

2. Jelic S, Cunningham JA, Factor P. Clinical review: airway hygiene in the intensive care unit. Crit Care. 2008;12(2):209.

3. Boles JM, Bion J, Connors A, Herridge M, Marsh B, Melot C, et al. Weaning from mechanical ventilation. Eur Respir J. 2007;29(5):1033–56.

4. Thille AW, Boissier F, Muller M, Levrat A, Bourdin G, Rosselli S, et al. Role of ICU-acquired weakness on extubation outcome among patients at high risk of reintubation. Crit Care. 2020;24(1):86.

5. Chen YH, Yeh MC, Hu HC, Lee CS, Li LF, Chen NH, et al. Effects of Lung Expansion Therapy on Lung Function in Patients with Prolonged Mechanical Ventilation. Can Respir J. 2016;2016:5624315.

6. Berti JS, Tonon E, Ronchi CF, Berti HW, Stefano LM, Gut AL, et al. Manual hyperinflation combined with expiratory rib cage compression for reduction of length of ICU stay in critically ill patients on mechanical ventilation. J Bras Pneumol. 2012;38(4):477–86.

7. Lippi L, de Sire A, D'Abrosca F, Polla B, Marotta N, Castello LM, et al. Efficacy of Physiotherapy Interventions on Weaning in Mechanically Ventilated Critically Ill Patients: A Systematic Review and Meta-Analysis. Front Med (Lausanne). 2022;9:889218.

8. Trudzinski FC, Neetz B, Bornitz F, Muller M, Weis A, Kronsteiner D, et al. Risk Factors for Prolonged Mechanical Ventilation and Weaning Failure: A Systematic Review. Respiration. 2022;101(10):959–69.

9. Volpe MS, Guimaraes FS, Morais CC. Airway Clearance Techniques for Mechanically Ventilated Patients: Insights for Optimization. Respir Care. 2020;65(8):1174–88.

10. Zhang J, Wang X, Xie J, Shen L, Mo G, Xie L. Effects of THE PEEP-ZEEP Maneuver in Adults Receiving Mechanical Ventilation: A Systematic Review with Meta-Analysis. Heart Lung. 2024;63:159–66.

11. Kuroiwa R, Tateishi Y, Oshima T, Inagaki T, Furukawa S, Takemura R, et al. Mechanical Insufflation-exsufflation for the Prevention of Ventilator-associated Pneumonia in Intensive Care Units: A Retrospective Cohort Study. Indian J Crit Care Med. 2021;25(1):62–6.

12. Lockstone J, Love A, Chian K, Garnham K, Brumby S, Parry SM. Benefits and risks of ventilator hyperinflation in mechanically ventilated intensive care patients: A systematic review and meta-analysis. Aust Crit Care. 2023;36(6):1150–8.

13. Ntoumenopoulos G, Hammond N, Watts NR, Thompson K, Hanlon G, Paratz JD, et al. Secretion clearance strategies in Australian and New Zealand Intensive Care Units. Aust Crit Care. 2018;31(4):191–6.

14. Rose L, Adhikari NK, Poon J, Leasa D, McKim DA, Group CA. Cough Augmentation Techniques in the Critically Ill: A Canadian National Survey. Respir Care. 2016;61(10):1360–8.

15. Stilma W, van der Hoeven SM, Scholte Op Reimer WJM, Schultz MJ, Rose L, Paulus F. Airway Care Interventions for Invasively Ventilated Critically Ill Adults-A Dutch National Survey. J Clin Med. 2021;10(15).

16. Valer BB, Bonczynski GS, Scheffer KD, Ibrahim Forgiarini SG, Eibel B, Lisboa Cordeiro AL, et al. Ventilator versus manual hyperinflation in adults receiving mechanical ventilation: A systematic review. Physiother Res Int. 2022;27(2):e1936.

17. Martinez BP, Lobo LL, de Queiroz RS, Saquetto MB, Junior LAF, Correia HF, et al. Effects of ventilator hyperinflation on pulmonary function and secretion clearance in adults receiving mechanical ventilation: A systematic review with meta-analysis. Heart Lung. 2022;56:8–23.

18. Anderson A, Alexanders J, Sinani C, Hayes S, Fogarty M. Effects of ventilator vs manual hyperinflation in adults receiving mechanical ventilation: a systematic review of randomised clinical trials. Physiotherapy. 2015;101(2):103–10.

19. Esmeijer AA, Nasa P, Ntoumenopoulos G, Battaglini D, Juneja D, Ball L, et al. Consensus Statements on Airway Clearance Interventions in Intubated Critically Ill Patients-Protocol for a Delphi Study. Life (Basel). 2025;15(8).

20. Higgins J, Thomas J, Chandler J, Cumpston M, Li T, Page M, et al. Cochrane Handbook for Systematic Reviews of Interventions version 6.5 (updated August 2024): Cochrane; 2024.

21. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210.

22. Higgins J, Altman D, Sterne J. Chapter 8: Assessing risk of bias in included studies. In: Higgins J, Churchill R, J C, al. e, editors. Cochrane Handbook for Systematic Reviews of Interventions version 520 (updated June 2017): Cochrane; 2017.

23. Munn Z, Stone JC, Aromataris E, Klugar M, Sears K, Leonardi-Bee J, et al. Assessing the risk of bias of quantitative analytical studies: introducing the vision for critical appraisal within JBI systematic reviews. JBI Evid Synth. 2023;21(3):467–71.

24. Munn Z, Barker TH, Moola S, Tufanaru C, Stern C, McArthur A, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evid Synth. 2020;18(10):2127–33.

25. HJAD DJ. Chapter 10: Analysing data and undertaking meta-analyses. In: Higgins J, Thomas J, Chandler J, al. e, editors. Cochrane Handbook for Systematic Reviews of Interventions version 652024.

26. Sterne JA, Sutton AJ, Ioannidis JP, Terrin N, Jones DR, Lau J, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. BMJ. 2011;343:d4002.

27. Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol. 2014;14:135.

28. Murad MH, Mustafa RA, Schunemann HJ, Sultan S, Santesso N. Rating the certainty in evidence in the absence of a single estimate of effect. Evid Based Med. 2017;22(3):85–7.

29. Ntoumenopoulos G, Gild A, Cooper DJ. The effect of manual lung hyperinflation and postural drainage on pulmonary complications in mechanically ventilated trauma patients. Anaesth Intensive Care. 1998;26(5):492–6.

30. Thenmozhi P, Dineshkumar P, Bhuvaneswari G, Minolin TM, Tamilselvi S. Thoracic squeezing on airway secretion and respiratory parameters in mechanically ventilated patients: An interventional study. J Educ Health Promot. 2025;14:69.

31. Savian C, Paratz J, Davies A. Comparison of the effectiveness of manual and ventilator hyperinflation at different levels of positive end-expiratory pressure in artificially ventilated and intubated intensive care patients. Heart Lung. 2006;35(5):334–41.

32. Dennis D, Jacob W, Budgeon C. Ventilator versus manual hyperinflation in clearing sputum in ventilated intensive care unit patients. Anaesth Intensive Care. 2012;40(1):142–9.

33. Berney S, Denehy L. A comparison of the effects of manual and ventilator hyperinflation on static lung compliance and sputum production in intubated and ventilated intensive care patients. Physiother Res Int. 2002;7(2):100–8.

34. Berney S, Denehy L, Pretto J. Head-down tilt and manual hyperinflation enhance sputum clearance in patients who are intubated and ventilated. Aust J Physiother. 2004;50(1):9–14.

35. Hodgson C, Denehy L, Ntoumenopoulos G, Santamaria J, Carroll S. An investigation of the early effects of manual lung hyperinflation in critically ill patients. Anaesth Intensive Care. 2000;28(3):255–61.

36. Kubota S, Hashimoto H, Yoshikawa Y, Hiwatashi K, Ono T, Mochizuki M, et al. Effects of mechanical insufflation-exsufflation on ventilator-free days in intensive care unit subjects with sputum retention; a randomized clinical trial. PLoS One. 2024;19(5):e0302239.

37. Ntoumenopoulos G, Presneill JJ, McElholum M, Cade JF. Chest physiotherapy for the prevention of ventilator-associated pneumonia. Intensive Care Med. 2002;28(7):850–6.

38. Choi JS, Jones AY. Effects of manual hyperinflation and suctioning in respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia. Aust J Physiother. 2005;51(1):25–30.

39. Maa SH, Hung TJ, Hsu KH, Hsieh YI, Wang KY, Wang CH, et al. Manual hyperinflation improves alveolar recruitment in difficult-to-wean patients. Chest. 2005;128(4):2714–21.

40. Sanchez-Garcia M, Alvarez-Gonzalez M, Domingo-Marin S, Pino-Ramirez AD, Martinez-Sagasti F, Gonzalez-Arenas P, et al. Comparison of Mechanical Insufflation-Exsufflation and Hypertonic Saline and Hyaluronic Acid With Conventional Open Catheter Suctioning in Intubated Patients. Respir Care. 2024;69(5):575–85.

41. Sanchez-Garcia M, Santos P, Rodriguez-Trigo G, Martinez-Sagasti F, Farina-Gonzalez T, Del Pino-Ramirez A, et al. Preliminary experience on the safety and tolerability of mechanical "insufflation-exsufflation" in subjects with artificial airway. Intensive Care Med Exp. 2018;6(1):8.

42. Thomas P, Paratz J. Ventilator hyperinflation - what settings generate an expiratory flow rate bias? Physiotherapy. 2023;119:44–53.

43. Unoki T, Kawasaki Y, Mizutani T, Fujino Y, Yanagisawa Y, Ishimatsu S, et al. Effects of expiratory rib-cage compression on oxygenation, ventilation, and airway-secretion removal in patients receiving mechanical ventilation. Respir Care. 2005;50(11):1430–7.

44. Jacob W, Dennis D, Jacques A, Marsh L, Woods P, Hebden-Todd T. Ventilator hyperinflation determined by peak airway pressure delivered: A randomized crossover trial. Nurs Crit Care. 2021;26(1):14–9.

45. Genc A, Akan M, Ali G. The effects of manual hyperinflation with or without rib-cage compression in mechanically ventilated patients. Italian Journal of Physiotherapy. 2011;1(2).

46. Amaral BLR, de Figueiredo AB, Lorena DM, Oliveira ACO, Carvalho NC, Volpe MS. Effects of ventilation mode and manual chest compression on flow bias during the positive end- and zero end-expiratory pressure manoeuvre in mechanically ventilated patients: a randomised crossover trial. Physiotherapy. 2020;106:145–53.

47. Assmann CB, Vieira PJ, Kutchak F, Rieder Mde M, Forgiarini SG, Forgiarini Junior LA. Lung hyperinflation by mechanical ventilation versus isolated tracheal aspiration in the bronchial hygiene of patients undergoing mechanical ventilation. Rev Bras Ter Intensiva. 2016;28(1):27–32.

48. Biarzi KF, Severo SB, Baptistella AR. Immediate and long-term effects of manual chest compression and decompression maneuver on patients

receiving invasive mechanical ventilation. Physiother Res Int. 2022;27(4):e1962.

49. Cardozo C, Rosa J, Zambiazi R, Palmeiro R, Guerreiro M, Di Naso F. Effects of PEEP-ZEEP technique on hemodynamics and ventilatory mechanics of neurological patients undergoing invasive mechanical ventilation. ASSOBRAFIR Ciência. 2018;9(3):25–34.

50. Chicayban LM. Acute effects of ventilator hyperinflation with increased inspiratory time on respiratory mechanics: randomized crossover clinical trial. Rev Bras Ter Intensiva. 2019;31(3):289–95.

51. Coutinho WM, Vieira PJC, Kutchak FM, Dias AS, Rieder MM, Forgiarini LA, Jr. Comparison of Mechanical Insufflation-Exsufflation and Endotracheal Suctioning in Mechanically Ventilated Patients: Effects on Respiratory Mechanics, Hemodynamics, and Volume of Secretions. Indian J Crit Care Med. 2018;22(7):485–90.

52. da Silva K, Oliveira CC, Cabral LF, Malaguti C, Jose A. Pulmonary expansion manoeuvres compared to usual care on ventilatory mechanics, oxygenation, length of mechanical ventilation and hospital stay, extubation, atelectasis, and mortality of patients in mechanical ventilation: A randomized clinical trial. PLoS One. 2023;18(12):e0295775.

53. Naue Wda S, da Silva AC, Guntzel AM, Condessa RL, de Oliveira RP, Rios Vieira SR. Increasing pressure support does not enhance secretion clearance if applied during manual chest wall vibration in intubated patients: a randomised trial. J Physiother. 2011;57(1):21–6.

54. Ferreira de Camillis ML, Savi A, Goulart Rosa R, Figueiredo M, Wickert R, Borges LGA, et al. Effects of Mechanical Insufflation-Exsufflation on Airway Mucus Clearance Among Mechanically Ventilated ICU Subjects. Respir Care. 2018;63(12):1471–7.

55. Avena Kde M, Duarte AC, Cravo SL, Sologuren MJ, Gastaldi AC. [Effects of manually assisted coughing on respiratory mechanics in patients requiring full ventilatory support]. J Bras Pneumol. 2008;34(6):380–6.

56. de Oliveira TF, Peringer VS, Forgiarini Junior LA, Eibel B. PEEP-ZEEP Compared with Bag Squeezing and Chest Compression in Mechanically Ventilated Cardiac Patients: Randomized Crossover Clinical Trial. Int J Environ Res Public Health. 2023;20(4).

57. Dias CM, Siqueira TM, Faccio TR, Gontijo LC, Salge JA, Volpe MS. Bronchial hygiene technique with manual hyperinflation and thoracic compression: effectiveness and safety. Rev Bras Ter Intensiva. 2011;23(2):190–8.

58. Guimaraes FS, Lopes AJ, Constantino SS, Lima JC, Canuto P, de Menezes SL. Expiratory rib cage Compression in mechanically ventilated subjects: a randomized crossover trial [corrected]. Respir Care. 2014;59(5):678–85.

59. Herbst-Rodrigues MV, Carvalho VO, Auler JO, Jr., Feltrim MI. PEEP-ZEEP technique: cardiorespiratory repercussions in mechanically ventilated patients submitted to a coronary artery bypass graft surgery. J Cardiothorac Surg. 2011;6:108.

60. Lemes DA, Zin WA, Guimaraes FS. Hyperinflation using pressure support ventilation improves secretion clearance and respiratory mechanics in ventilated patients with pulmonary infection: a randomised crossover trial. Aust J Physiother. 2009;55(4):249–54.

61. Lobo DM, Cavalcante LA, Mont'Alverne DG. Applicability of bag squeezing and zeep maneuvers in mechanically ventilated patients. Rev Bras Ter Intensiva. 2010;22(2):186–91.

62. Naue Wda S, Forgiarini Junior LA, Dias AS, Vieira SR. Chest compression with a higher level of pressure support ventilation: effects on secretion removal, hemodynamics, and respiratory mechanics in patients on mechanical ventilation. J Bras Pneumol. 2014;40(1):55–60.

63. Naue WDS, Herve BB, Vieira FN, Deponti GN, Martins LF, Dias AS, et al. Comparison of bronchial hygiene techniques in mechanically ventilated patients: a randomized clinical trial. Rev Bras Ter Intensiva. 2019;31(1):39–46.

64. Nunes LC, Rizzetti DA, Neves D, Vieira FN, Kutchak FM, Wiggers GA, et al. Mechanical insufflation/exsufflation improves respiratory mechanics in critical care: Randomized crossover trial. Respir Physiol Neurobiol. 2019;266:115–20.

65. Oliveira ACO, Lorena DM, Gomes LC, Amaral BLR, Volpe MS. Effects of manual chest compression on expiratory flow bias during the positive end-expiratory pressure-zero end-expiratory pressure maneuver in patients on mechanical ventilation. J Bras Pneumol. 2019;45(3):e20180058.

66. Ribeiro BS, Lopes AJ, Menezes SLS, Guimaraes FS. Selecting the best ventilator hyperinflation technique based on physiologic markers: A randomized controlled crossover study. Heart Lung. 2019;48(1):39–45.

67. Santos FR, Schneider Junior LC, Forgiarini Junior LA, Veronezi J. Effects of manual rib-cage compression versus PEEP-ZEEP maneuver on respiratory system compliance and oxygenation in patients receiving mechanical ventilation. Rev Bras Ter Intensiva. 2009;21(2):155–61.

68. Pattanshetty RB, Gaude GS. Effect of multimodality chest physiotherapy in prevention of ventilator-associated pneumonia: A randomized clinical trial. Indian J Crit Care Med. 2010;14(2):70–6.

69. Ahmed F, Shafeeq AM, Moiz JA, Geelani MA. Comparison of effects of manual versus ventilator hyperinflation on respiratory compliance and arterial blood gases in patients undergoing mitral valve replacement. Heart Lung. 2010;39(5):437–43.

70. Kohan M, Rezaei-Adaryani M, Najaf-Yarandi A, Hoseini F, Mohammad-Taheri N. Effects of expiratory ribcage compression before endotracheal suctioning on arterial blood gases in patients receiving mechanical ventilation. Nurs Crit Care. 2014;19(5):255–61.

71. Yousefnia-Darzi F, Hasavari F, Khaleghdoost T, Kazemnezhad-Leyli E, Khalili M. Effects of thoracic squeezing on airway secretion removal in mechanically ventilated patients. Iran J Nurs Midwifery Res. 2016;21(3):337–42.

72. Martinez-Alejos R, Marti JD, Li Bassi G, Gonzalez-Anton D, Pilar-Diaz X, Reginault T, et al. Effects of Mechanical Insufflation-Exsufflation on Sputum Volume in Mechanically Ventilated Critically Ill Subjects. Respir Care. 2021;66(9):1371–9.

73. Cork G, Wade C, Gordon A, Vaughan-France A, Palmer A, Walker K, et al. Airway clearance techniques for the intubated adult: a scoping review. Journal of the Association of Chartered Physiotherapists in Respiratory Care 2022;54(3).

74. Shannon H, Stiger R, Gregson RK, Stocks J, Main E. Effect of chest wall vibration timing on peak expiratory fl ow and inspiratory pressure in a mechanically ventilated lung model. Physiotherapy. 2010;96(4):344–9.

75. Hill DB, Button B, Rubinstein M, Boucher RC. Physiology and pathophysiology of human airway mucus. Physiol Rev. 2022;102(4):1757–836.

76. Volpe MS, Adams AB, Amato MB, Marini JJ. Ventilation patterns influence airway secretion movement. Respir Care. 2008;53(10):1287–94.

77. Li Bassi G, Saucedo L, Marti JD, Rigol M, Esperatti M, Luque N, et al. Effects of duty cycle and positive end-expiratory pressure on mucus clearance during mechanical ventilation*. Crit Care Med. 2012;40(3):895–902.

78. Marti JD, Li Bassi G, Rigol M, Saucedo L, Ranzani OT, Esperatti M, et al. Effects of manual rib cage compressions on expiratory flow and mucus clearance during mechanical ventilation. Crit Care Med. 2013;41(3):850–6.

79. Battalian T, Escudero Romero R, Barzaga Molina A. Characteristics and temporality of the ventilatory techniques in the management of acute respiratory distress syndrome: A scoping review. J Crit Care Med (Targu Mures). 2025;11(2):122–31.

80. Rose L, Adhikari NK, Leasa D, Fergusson DA, McKim D. Cough augmentation techniques for extubation or weaning critically ill patients from mechanical ventilation. Cochrane Database Syst Rev. 2017;1(1):CD011833.

81. Goncalves MR, Honrado T, Winck JC, Paiva JA. Effects of mechanical insufflation-exsufflation in preventing respiratory failure after extubation: a randomized controlled trial. Crit Care. 2012;16(2):R48.

82. Battaglini D, Robba C, Caiffa S, Ball L, Brunetti I, Loconte M, et al. Chest physiotherapy: An important adjuvant in critically ill mechanically ventilated patients with COVID-19. Respir Physiol Neurobiol. 2020;282:103529.

83. Rossi V, Binda F, Cordani C, Marelli F, Tammaro S, Colombo S, et al. Impact of tracheostomy on ICU stay in adult patients with ARDS: A systematic review. Intensive Crit Care Nurs. 2025;89:104076.

84. Gattinoni L, Tonetti T, Quintel M. Regional physiology of ARDS. Crit Care. 2017;21(Suppl 3):312.

85. Stiller K. Physiotherapy in intensive care: an updated systematic review. Chest. 2013;144(3):825–47.

Table 1. Characteristics of the included studies.

Study	Study design	Country	Sample size	Age (years)	Sex (male) (%)	Airway clearance technique	Main outcome
Ahmed (2010)	RCT	India	30	28.4 (7.4)	12 (40%)	MHI	PaO2/FiO2, Cdyn
Amaral (2020)	RXT	Brazil	19	61 (34-64)	13(68%)	PEEP-ZEEP	PEF/PIF
Assmann (2016)	RXT	Brazil	50	44.7 (21.6)	31 (62%)	VHI	Weighing the sputum Cdyn Vte PIP
Berney (2002)	RXT	Australia	30	45.2 (16-86)	17 (57%)	MHI	Weighing the sputum Cst
Berney (2004)	RXT	Australia	20	51.3 (23-82)	18 (90%)	MHI + positioning	Weighing the sputum
Berti (2012)	RCT	Brazil	35	56.6 (15.6)	13 (37%)	MHI	ICU LOS Weaning
Biarzi (2022)	RCT	Brazil	105	62.3 (17.8)	73 (70%)	ERCC	Vt
Cardozo (2018)	RXT	Brazil	10	48.8 (23.5)	6 (60%)	PEEP-ZEEP	HR, MAP, SpO_2, PPeak, Pplat, Cst
Chicayban (2019)	RXT	Brazil	38	59.4 (15.3)	18 (47%)	VHI	Cst Vt
Choi (2005)	RXT	Cina	15	60 (16.8)	8 (53%)	MHI	PIP, VT, Pplat, Cst,

Coutinho (2018)	RXT	Brazil	43	51.4 (21.2)	30 (70%)	MI-E	Weighing the sputum
da Silva (2023)	RCT	Brazil	51	67.2 (14.9)	27 (53%)	ERCC	Cst
da Silva Naue (2011)	RCT	Brazil	66	64.5 (17.1)	28 (42%)	ERCC	Weighing the sputum
de Camillis (2018)	RCT	Brazil	180	72.7 (16.9)	92(51%)	MI-E	Weighing the sputum
De Miranda Avena (2008)	RCT	Brazil	16	56.6 (15.2)	12 (75%)	ERCC	PIP, Pplat, Rst, Cdyn, Cst
De Oliveira (2023)	RXT	Brazil	36	70.3 (10.6)	21 (58%)	PEEP-ZEEP	Weighing the sputum, VT, PPeak, Pplat, DP, Cst, Cdyn
Dennis (2012)	RXT	Australia	46	57 (18.9)	33 (72%)	MHI + chest wall vibration	Weighing the sputum
Dias (2011)	RXT	Brazil	20	56 (24)	11 (55%)	MHI + ERCC	HR, MAP, SpO2, VT, Pplat, Cst, Weighing the sputum
Genc (2011)	RXT	Turkey	22	59.9 (17.7)	16 (73%)	MHI + ERCC + positioning	Cst, VT, Weighing the sputum, PaO2/FiO2
Guimarães (2014)	RXT	Brazil	20	65 (13)	9 (45%)	ERCC	Weighing the sputum
Herbst-Rodrigues (2011)	Prospective	Brazil	15	60 (9)	11 (73%)	PEEP-ZEEP	HR, MAP
Hodgson (2000)	RXT	Australia	18	64.5	13 (72%)	MHI + sidelying	Cst, Weighing the sputum
Jacob (2021)	RXT	Australia	48	55 (17.3)	29 (60%)	MHI + chest wall vibration	Weighing the sputum
Kohan (2014)	RXT	Iran	70	51.3 (15.8)	35 (50%)	ERCC	PO2/FiO2, PaCO2, SpO2
Kubota (2024)	RXT	Japan	48	73 (58–86)	39 (81%)	MI-E	Number of ventilator-free days on day 28
Kuroiwa (2021)	Retrospective	Japan	30	56 (10–87)	21 (70%)	MI-E	Incidence of VAP
Lemes (2009)	RXT	Brazil	30	61 (16)	19 (63%)	VHI	Weighing the sputum
Lobo (2010)	RXT	Brazil	20	63 (20)	6 (30%)	PEEP-ZEEP	Feasibility of technique
Maa (2005)	RCT	Taiwan	23	NR	17 (74%)	MHI	Chest radiography Vt

							f/Vt, PaO2/FiO2 Airway secretions
Martinez (2021)	RXT	France	26	61.1 (19.2)	8 (31%)	ERCC + MI-E	Weighing the sputum
Naue (2014)	RXT	Brazil	34	64.2 (14.6)	19 (56%)	VHI + ERCC	Weighing the sputum Vte Cdyn
Naue (2019)	RCT	Brazil	93	64.1 (12.6)	41 (44%)	VHI	Weighing the sputum, MV days, mortality, Reintubation within 48h
Ntoumenopoulos (1998)	RCT	Australia	46	40.12 (18.4)	NR	MHI +postural drainage	Incidence of nosocomial pneumonia PaO2/FiO2
Ntoumenopoulos (2002)	NCT	Australia	60	65.1 (14.5)	34 (57%)	ERCC	Prevalence of VAP
Nunes (2019)	RXT	Brazil	16	57.6 (19.1)	6 (37.5)	MI-E	Airway resistance, PPeak, Pplat, Cst
Oliveira (2019)	RXT	Brazil	10	63 (14)	6 (60%)	PEEP-ZEEP	PEF/PIF, PEF-PIF
Pattanshetty (2010)	Prospective	India	101	49.8 (19.1)	77 (76%)	MHI + chest wall vibration	VAP, Mortality, weaning, MV duration, ICU LOS
Ribeiro (2019)	RXT	Brazil	30	61.5 (19.8)	12 (40%)	VHI in six ventilatory modes	Expiratory flow bias Adverse events Cst, Rrs
Sánchez-García (2024)	RXT	Spain	30	62.9 (15.4)	20 (67%)	MI-E	Adverse events
Sánchez-García (2018)	Case series	Spain	13	62.6 (20)	7 (54%)	MI-E	Safety and tolerability of MI-E
Santos (2009)	RXT	Brazil	12	54.9 (19.3)	6 (50%)	PEEP-ZEEP	PEEP, iPEEP controlled pressure (CP), SpO2, VT, PPeak, Pplat
Savian (2006)	RXT	Australia	14	62.3 (23-83)	9 (64%)	MHI	Weighing the sputum, PEFR, Cst, VCO2, Vt
Thenmozhi (2025)	RCT	India	60	NR	35 (58.3%)	ERCC	Weighing the sputum
Thomas (2023)	Prospective	Australia	24	60.5 (48–68.5)	17 (71%)	Low vs High PEEP: comparison in VCV, PCV, PSV	PIFR/PEFR PEFR-PIFR

Unoki (2005)	RXT	Japan	31	56.7 (17.6)	24 (87%)	ERCC	Weighing the sputum
Yousefnia-Darzi (2016)	RXT	Iran	50	NR	NR	ERCC	Weighing the sputum

Note: Data are expressed as mean (SD); □□ median (IQR) or count and percentage (%); (*) mean (range).

Abbreviations: RCT=randomized controlled trials, RXT=randomized crossover trials, NCT=non-randomized controlled trial, MHI-VHI = manual hyperinflation and ventilator hyperinflation, PEEP-ZEEP = Positive End-Expiratory Pressure – Zero End-Expiratory, ERCC = Expiratory rib-cage compression, MI-E= Mechanical insufflation–exsufflation, MAC= manual assisted coughing, PIFR/PEFR = peak inspiratory flow rate and peak expiratory flow rates, PEF/PIF= peak expiratory flow/peak inspiratory flow (PIF) ratio, PaO2/FiO2= Vt= tidal volume, Ppeak= Peak pressure, Pplat =plateau pressure, PIP=Peak inspiratory pressure, Raw =airway resistance, VAP=ventilator-associated pneumonia, Cst= Static Compliance, Cdyn= Dynamic Compliance; Rrs= Respiratory System Resistance.

Table 2. Characteristics of the participants enrolled in the included studies.

Study	Type of participants	Interventions/ Comparison	Sample size	Score		Comorbidities		MV (days)	Baseline				
				SAPS II	APACHE II	Charlson Comorbidities Index	COPD		PCO2	PEF L/min	PaO2/FiO2	Vt	Cdyn (mL/cmH2O)
Ahmed (2010)	Cardiothoracic surgery	MHI	15	NR	NR	NR	NR	NR	34 (1.8)	NR	509 (67.3)	NR	35.1 (8.7)
		VHI	15	NR	NR	NR	NR	NR	34.9 (4.0)	NR	467 (56.1)	NR	33.2 (7.4)
Amaral (2020)	Mix population	PEEP-ZEEP +MCC	19	NR	NR	NR	0	11 (2 - 16)	NR	41.1 (12.5)	NR	458 (101)	NR
		PEEP-ZEEP											
Assmann (2016)	Traumatic brain injury/Others	VHI	50	NR	NR	NR	NR	NR	NR	NR	NR	448 (105)	30 (11.5)
		suctioning		NR	NR	NR	NR	NR	NR	NR	NR	498 (62)	31.4 (6.5)
Berney (2002)	Trauma/ medical	MHI	20	NR	13.9 (3.6)	NR	0	NR	NR	NR	289.2 (97.3)	NR	46.2 (41.5 – 50.9)
		VHI											44.9 (40.5 - 49.3)

Berney (2004)	Mix population	MHI+ tilt + SL	20	NR	NR	NR	NR	NR	NR	NR	NR	NR	47.5 (13.9)
		MHI+ SL		NR	NR	NR	NR	NR	NR	NR	NR	NR	41.9 (9.5)
Berti (2012)	Mix population	MHI+ ERCC + percussion	16	NR	15.8 (4.3)	NR	NR	NR	NR	NR	NR	NR	NR
		suctioning	19	NR	17.2 (7.5)	NR	NR	NR	NR	NR	NR	NR	NR
Biarzi (2022)	Mix population	ERCC	105	NR	24.3 (7.5)	NR	23 (%)	3.6 (2.9)	NR	NR	NR	540 (114.4)	39 (10.3)
Cardozo (2018)	Neurological injury	PEEP-ZEEP	10	NR	NR	NR	NR	3.6 (3.3)	NR	44.8 (17.7)	NR	399 (66)	20.7 (6.2)
		MCC		NR	NR	NR	NR		NR		NR		20.6 (5.7)
Chicayban (2019)	Mix population	VHI	38	NR	11	NR	6 (16 %)	NR	NR	32.0 (16.0)	301.9 (112.7)	NR	46.2 (14.8)
		suctioning						NR	NR	32.9 (15.8)		NR	46.8 (12.8)
Choi (2005)	Mix population	MHI+ suction	15	NR	NR	NR	NR	NR	NR	NR	NR	NR	35.2 (4.9)
		suction											36.0 (4.9)
Coutinho (2018)	Traumatic brain injury	MI-E	43	NR	NR	NR	NR	9.8 (15)	NR	NR	NR	525.2 (97.9)	38 (11)
		suctioning											
da Silva (2023)	Mix population	ERCC	25	NR	NR	NR	NR	11 (6.5 - 23)	45.6 (9.6)	NR	NR	388 (0.7)	NR
		Control group	26	NR	NR	NR	NR	12 (7.5 - 20.3)	48.9 (11.4)	NR	NR	385 (0.8)	NR
da Silva Naue (2011)	Mix population	ERCC	34	NR	26 (7)	NR	7 (21 %)	8 (5)	NR	NR	NR	465 (88)	32 (9)
		Control group	32		23 (7)	NR	5 (16 %)	8 (6)	NR	NR	NR	522 (119)	36 (11)
de Camillis (2018)	Medical/ surgical population	MI-E	90	52.9 (13.3)	NR	2.5 (1.9)	14 (15.5%)	NR	NR	NR	NR	NR	NR
		Suctioning + compression	90	54.3 (15.1)	NR	2.8 (2.4)	14 (15.5%)	NR	NR	NR	NR	NR	NR

		and vibration											
De Miranda Avena (2008)	Surgical patients	ERCC	16	NR	NR	NR	NR	NR	NR	NR	NR	NR	20.4 (4.0)
De Oliveira (2023)	Mix population	PEEP - ZEEP + MCC	29	NR	NR	NR	NR	5.3 (3.1)	NR	NR	NR	410.7 (11.7)	30.3 (3.6)
		bag squeezing + MCC	27		NR	NR	NR		NR	NR	NR	425.2 (11.9)	26.9 (1.9)
Dennis (2012)	Mix population	MHI + Chest wall vibration	46	NR	18.5 (5 - 42)	NR	NR	4 (1-13)	37.4 (6.4)	NR	273 (85.4)	587 (85.4)	61.3 (32.1)
		VHI + Chest wall vibration							37.9 (6.2)		268 (6.2)	551 (125)	39.3 (28.4)
Dias (2011)	Mix population	MHI +ERCC	20	NR	NR	NR	NR	6.5 (4 - 15.3)	NR	NR	NR	NR	NR
		suction											
Genc (2011)	Medical/ Surgical	MHI + ERCC	22	NR	NR	NR	NR	NR	NR	NR	NR	504 (449 - 540)	44.2 (36.5 - 52.4)
		MHI + positioning											46.8 (40.8 - 62.5)
Guimarães (2014)	Pulmonary infection	ERCC + VHI	20	NR	19 (7)	NR	NR	11.2 (4.5)	NR	45.0 (16.4)	322 (74)	NR	34 (10)
		Control group											
Herbst-Rodrigues (2011)	Cardiothoracic surgery	PEEP-ZEEP +ERCC	15	NR	NR	NR	0	NR	NR	NR	NR	NR	46 (11)
Hodgson (2000)	Mix population	MHI + SL	18	NR	NR	NR	NR	NR	45.1 (1.7)	NR	215.8 (14.8)	585.5	36.5 (3.7)
		SL		NR	NR	NR	NR	NR	44.8 (1.6)	NR	214.9 (16.5)		38.3 (3.3)
Jacob (2021)	Mix population	MHI + chest wall vibration	48	NR	NR	NR	NR	NR	36.5 (35.1 - 37.9)	NR	307.7 (283.5 - 331.9)	544.4 (516 - 572.4)	55.7 (48 - 63.4)
		VHI+ chest wall vibration							37.1 (35.7 - 38.5)		296.2 (272 - 320)	533.2 (505.2 - 56	55.6 (47.9 - 63.3)

												1.1)	
Kohan (2014)	Mix population	Suctioning with ERCC Suctioning without ERCC	70	NR	NR	NR	NR	NR	38.9 (5.4)	NR	NR	198 (39)	NR
Kubota (2024)	Mix population	MI-E	27	NR	19 (14 - 27)	NR	NR	6 (3 - 9)	NR	NR	< 200	NR	NR
		suctioning	21	NR	16 (13 - 23)	NR	NR	8 (4 - 14)	NR	NR	< 200	NR	NR
Kuroiwa (2021)	Medical/Surgical/Trauma	MI-E	11	NR	23.3 (8.4)	NR	NR	15 (7 – 180)	NR	NR	198 (80 – 517)	NR	NR
		CPT	19	NR	29.9 (9)	NR	NR	15 (8 – 108)	NR	NR	185 (47 – 503)	NR	NR
Lemes (2009)	Mix population	VHI SL SL	30	NR	13.7 (6.2)	NR	NR	NR	NR	NR	322 (105)	557 (88.5 - 750)	NR
Lobo (2010)	Mix population	PEEP-ZEEP + MCC (VB)	20	NR	NR	NR	9 (45 %)	35 (48)	NR	NR	NR	NR	NR
		Bag squeezing + MCC (VB)		NR	NR	NR			NR	NR	NR	NR	NR
Maa (2005)	Mix population	MHI+ percussion + positioning	10	NR	NR	NR	4 (40 %)	NR	NR	NR	222 (93.9)	196.3 (80.9)	NR
		Percussion + positioning	13	NR	NR	NR	2 (15 %)	NR	NR	NR	228.6 (131.8)	228.6 (131.8)	NR
Martinez (2021)	Mix population	ERCC + MI-E/ERCC	26	NR	21.1 (19.6)	NR	NR	NR	36 (5.3)	NR	243.9 (53)	NR	NR
Naue (2014)	Mix population	ERCC + PS	34	NR	25.5 (6.6)	NR	7 (20.6%)	8.2 (4.9)	NR	NR	465 (88)	NR	31.9 (9.2)
		suctioning		NR		NR			NR	NR	478 (147)	NR	34 (10.3)
Naue (2019)	Mix population	HMV+ VB group	32	NR	23.9 (6.6)	NR	10.8 %	5 (1 - 16)	NR	NR	NR	490 (450 - 580)	36 (27 - 46)

		HMV	32	NR	24.9 (8.6)	NR	9.4 %	4.5 (2 - 30)	NR	NR	NR	555 (483 - 664)	36 (31 - 54)
		VB group	29	NR	24.1 (7.1)	NR	10.3 %	6 (2 - 38)	NR	NR	NR	512 (467 - 613)	34 (29 - 44)
Ntoumenopoulos (1998)	Mix population	MHI	22	NR	12.3 (3.8)	NR	NR	6.1 (5.4)	NR	NR	253.2 (119.2)	NR	NR
		Control group	24	NR	14.1 (7.4)	NR	NR	5.2 (3.5)	NR	NR	317.9 (117.8)	NR	NR
Ntoumenopoulos (2002)	Mix population	CPT	24	NR	20.7 (6.9)	NR	NR	NR	NR	NR	NR	NR	NR
		Sham treatment	36	NR	18.8 (5.4)								
Nunes (2019)	Sepsis/Septic shock/other	MI-E different pressures	16	42.3 (21.6 %)	NR	NR	4 (25 %)	NR	NR	43.3 (9)	279 (80)	473.1	NR
		suctioning											
Oliveira (2019)	Cardiopulmonary arrest/Others	MCC +PEEP - ZEEP	10	NR	NR	NR	NR	16 (7)	NR	79.5 (12.7)	NR	556 (167)	NR
		PEEP-ZEEP		NR	NR	NR	NR		NR	72.2 (12.9)	NR		NR
Pattanshetty (2010)	Mix population	MHI + positioning + vibration	50	NR	NR	NR	NR	8.7 (5.6)	NR	NR	NR	NR	NR
		MHI	51	NR	NR	NR	NR	8.5 (5.2)	NR	NR	NR	NR	NR
Ribeiro (2019)	Mix population	VHI different setting	30	NR	24.6 (7.2)	NR	NR	9.3 (9.4)	NR	NR	377 (104)	490 (91)	46.3 (16.7)
Sánchez-García (2018)	Medical/Postop	MI-E	12	NR	23.3 (7.4)	NR	1 (8.3 %)	11.5 (6.2 - 25.8)	37.5 (12.6)	NR	239.8 (96.8)	524.1 (106.6)	17.7 (9.5)
Sánchez-García (2024)	Mix population	MI-E	30	NR	23.3 (9.0)	NR	13 (43.3%)	19 (10.3 - 37.5)	42.2 (6.8)	NR	244 (111)	490.5 (436 - 532)	33.7 (26.8 - 42.6)

		MI-E + HS-HA	30	NR	21.2 (6.7)	NR	12 (40 %)	19 (8.7 - 40)	42.8 (6.8)	NR	253 (67)	500 (471 - 601)	35.7 (26.7 - 45.9)
		Suctioning	30	NR	22.6 (8.1)	NR	13 (43.3%)	18.5 (2.2 - 36)	43.4 (8.1)	NR	264.4 (111.0)	503 (415 - 575)	37.9 (23.4 - 50)
		Suctioning + HS-HA	30	NR	22.2 (7.2)	NR	17 (56.7%)	21 (11.5 - 42)	40.2 (7.1)	NR	236.7 (126)	549 (484 - 630)	35.4 (26.7 - 50.1)
Santos (2009)	Acue respiratory failure	PEEP-ZEEP	12	NR	NR	NR	NR	6 (2-13)	NR	NR	NR	561 (336 - 661)	35 (19 - 46)
		MRC										547 (380 - 705)	39.5 (20 - 47)
Savian (2006)	Mix population	MHI	14	NR	17.5 (6 - 30)	NR	NR	NR	NR	27.8 (8.2)	NR	NR	NR
		VHI								34.3 (6.6)			
Thenmozhi (2025)	Respiratory / cardiac disease	ERCC	30	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Control group	30	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Thomas (2023)	Mix population	VHI Low PEEP	12	NR	52 (48 - 100)	NR	NR	8 (5-12)	NR	NR	243 (212 - 363)	NR	49 (41-55)
		VHI High PEEP	12	NR	62 (48 - 95)			9 (3-11)	NR	NR	219 (163 - 252)	NR	52 (35-58)
Unoki (2005)	Mix population	ERCC Suctioning	31	59.4 (10.7)	NR	NR	NR	19 (28)	39.3 (6.4)	NR	298.8 (80.1)	NR	39 (12.6)
Yousefnia-Darzi (2016)	Mix population	ERCC	50	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		suctioning		NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: Data are expressed as mean (±1 SD), median (IQR), or count and percentage (%); (*) information retrieved from the author.

Abbreviations: APACHE II = Acute Physiology and Chronic Health Evaluation II; SAPS II. Simplified Acute Physiology Score II; Charlson index. Charlson Comorbidity Index; COPD. chronic obstructive pulmonary disease; MV. mechanical ventilation; ICU. intensive care unit; PCO2 (PaCO2). partial pressure of carbon dioxide; PEF. peak expiratory flow; PaO2/FiO2. arterial oxygen partial pressure to inspired oxygen fraction ratio; Vt. tidal volume; Cdyn. dynamic compliance of the respiratory system; MHI. manual hyperinflation; VHI. ventilator hyperinflation; PEEP. positive end-expiratory pressure; ZEEP. zero end-expiratory pressure; MCC. manual chest compression; ERCC. expiratory rib cage compression; MI-E. mechanical insufflation-exsufflation; CPT. chest physiotherapy; PS. Pressure support; SL. side-lying; HS-HA. hypertonic saline-hyaluronic acid; HMV. hyperinflation maneuver; VB. vibrocompression; MRC. manual rib cage compression; NR. not reported.

Table 3. Summary of findings table based on narrative synthesis.

Outcome	**Effect**	**Number of participants (studies)**	**Certainty of evidence**
Secretion celarance	Several studies reported greater short-term secretion clearance after the intervention	960 (5 RCTs; 17 crossover trials)	VERY LOW†*‡ ⊕OOO
Oxygenation	Some studies reported short-term improvements in PaO_2/FiO_2 after the intervention, whereas others found no clear differences	223 (3 RCTs; 5 crossover trials)	VERY LOW†*‡ ⊕OOO
Respiratory mechanics	Most studies showed small improvements immediatly	804 (3 RCTs; 19 crossover trials)	VERY LOW†*‡ ⊕OOO

	after the intervention		
Ventilator-associated pneumonia	Airway cleareance techniques may reduce the incidence of ventilator-associated pneumonia	147 (2 RCTs)	LOW†‡ ⊕⊕OO
Duration of mechanical ventilaltion	No consistent reduction in mechanical ventilation duration was observed	288 (3 RCTs; 1 crossover trials)	VERY LOW†*‡ ⊕OOO
ICU lenght of stay	Some studies shorter ICU lenght of stay in intervention group and others reporting similar or longer staty	397 (4 RCTs; 2 crossover trials)	VERY LOW†*‡ ⊕OOO
Mortality	One study reported a large reduction in ICU mortality during the intervention, whereas the orther found no difference	194 (2 RCTs)	VERY LOW†*‡ ⊕OOO
Adverse events	No major adverse events were reported	453 (1 RCTs; 6 crossover trials)	VERY LOW†*‡ ⊕OOO

A single pooled effect estimate was not available for the outcomes, and only a narrative synthesis of the evidence was provided.

Symbols used to describe certainty in evidence in evidence profiles: high certainty ⊕⊕⊕⊕, moderate certainty ⊕⊕⊕O, low certainty ⊕⊕OO, and very low certainty ⊕OOO.

†Serious risk of bias across studies mainly because of unclear or inadequate blinding, sequence generation, and allocation concealment.

*Serious concerns about indirectness due to high heterogeneity of the populations studied in terms of population, intervention, comparison, outcome measures and setting.

‡Serious imprecision and inconsistency were considered together as there were small effects, or'no effects' reported in studies.

Table 4. Characteristics of studies on Expiratory Rib Cage Compression.

Study	Intervention/dosing	Description of the control group	Narrative synthesis
Biarzi (2022)	30° in the bed PCV: PC above the PEEP of 14 cm H2O, PEEP of 5 cm H2O, RR of 15 rpm, and inspiratory time of 1.1 s.	No control group	Inspiratory and expiratory tidal volumes and dynamic compliance increased during the manoeuvre but returned to baseline after 10 min.
da Silva (2023)	Chest compression–decompression manoeuvre and chest block manoeuvre, each applied for 5 min twice daily.	Usual care	No significant differences were observed in static compliance compared with the control group.
da Silva Naue (2011)	ERCC with chest vibrations applied for 5 min to each hemithorax. Inspiratory pressure support increased by 10 cmH_2O during the manoeuvre.	Standard ventilatory management	No significant difference in sputum wet weight between groups.
De Miranda Avena (2008)	ERCC applied 10 times with three respiratory cycles between compressions. Hyperoxygenation performed before suctioning.	No control group	Airway resistance decreased after ERCC and suctioning, while airway pressures and compliance remained unchanged.

Guimarães (2014)	Bilateral ERCC applied for 5 min every 2 breaths during expiration. Hyperinflation manoeuvre performed after suctioning for 10 min with pressure support of 35 cmH_2O.	Normal ventilation + hyperinflation manoeuvre	ERCC significantly increased sputum wet weight compared with the control condition.
Kohan (2014)	ERCC applied for 5 min during VCM with rib-cage compression every two breaths.	Suctioning alone	PaO2/FiO2: at 25 min ERCC 204.16 ± 40.58 vs control 200.13 ± 39.46.
Ntomenopulus (2005)	Four sets of six cycles of expiratory chest wall vibrations followed by suctioning, performed twice daily.	Sham physiotherapy	The intervention significantly reduced the prevalence of ventilator-associated pneumonia (OR 0.14, 95% CI 0.03–0.56)
Thenmozhi (2025)	ERCC applied 10 times per session (5 per side), repeated four times. Hyperoxygenation for 1 min before and after suctioning.	Routine care	ERCC significantly increased airway secretion removal immediately and 15 min after suctioning compared with routine care.
Unoki (2005)	ERCC performed for 5 min during volume-controlled ventilation with rib-cage compression every 2 breaths. No hyperoxygenation before suctioning.	Suctioning alone	ERCC did not significantly modify sputum weight or gas exchange parameters (PaO_2/FiO_2 and $PaCO_2$) compared with suctioning alone.
Yousefnia-Darzi (2016)	ERCC applied 10 times with three respiratory cycles between compressions. Patients received 100% oxygen before and after suctioning.	Suctioning alone	ERCC significantly increased sputum secretion removal compared with suctioning alone.

Abbreviations: VCM=Volume-Controlled Mechanical ventilation; ERCC = Expiratory Rib Cage Compression; PaO_2/FiO_2 = Ratio of arterial oxygen partial pressure to inspired oxygen fraction; $PaCO_2$ = Arterial partial pressure of carbon dioxide; SaO_2 = Arterial oxygen saturation; VAP = ventilator-associated pneumonia ; Cst = Static pulmonary compliance; Cdyn = Dynamic pulmonary compliance; Vt = Tidal volume; iVt = Inspiratory tidal volume; eVt = Expiratory tidal volume; PIP= Peak inspiratory pressure; Pplat = Plateau pressure; Rpul = Pulmonary resistance; Rsr = Respiratory system resistance.

Table 5. Characteristics of studies on mechanical insufflation–exsufflation

Study	Intervention/dosing	Description of control group	Narrative synthesis
Coutinho (2018)	MI-E (Automatic mode +40/−40 cmH_2O via EOT) T insp 3sec, T esp 3sec, no Pause Hyperoxygenation ($FiO_2$100%) was performed for 1 min before applying each technique and a 20 s interval was allowed between repetitions.	Endotracheal suctioning	MI-E did not significantly modify dynamic compliance or pulmonary vascular resistance compared with suctioning. Hemodynamic parameters and oxygen saturation remained stable, indicating good safety of the technique.
de Camillis (2018)	MI-E +chest physiotherapy. 3 sets of 10 cycles; Ti 2 s, Te 3 s, pause 2 s; pressures +40/−40 cmH_2O (EOT).	CPT	The combination of MI-E with chest physiotherapy increased secretion removal compared with chest physiotherapy alone and was associated with improvements in static lung compliance. No differences were observed in airway resistance or work of breathing, and no adverse hemodynamic or ventilatory events were reported.
Kubota (2024)	MI-E (+40/−40 cmH_2O); 10 cycles via EOT.	Endotracheal suctioning	Ventilator-free days by day 28: no difference between the MI-E and control groups (21 days, IQR, 13–24 vs 18 days, IQR, 0–23) MV (days) was 6 (IQR, 3-9) days in the MI-E and 8 (IQR, 6-15) in the control group. 28-day mortality rate was no significantly different between the two group. Tracheostomy rate among surviving subjects did not significantly difference. No new cases of hemodynamic instability or arrhythmia. No adverse events in MI-E group (barotrauma, oxygen desaturation, pnx, mucus plugging)
Kuroiwa (2021)	MI-E (Automatic mode +15 to −40 cmH_2O) via EOT or tracheostomy; 5–10 cycles.	CPT	Incidence of VAP: significantly different between the CPT and MI-E groups (84.2% [16/19] vs 26.4% [3/11]). Antibiotic exposure: the duration of antibiotic use days/MV was significantly lower in the MI-E group than in the CPT group.

Martinez (2021)	MI-E + ERCC. Automatic mode +40/−40 cmH_2O; Ti 2 s, Te 3 s, pause 1 s; 4 series of 5 cycles.	ERCC alone	The addition of MI-E to ERCC significantly increased secretion clearance compared with ERCC alone. Respiratory compliance improved in both groups but to a greater extent in the combined MI-E intervention.
Nunes (2019)	The protocols were: a) 30S – MI-E with I/E pressures of −30/+30 cmH_2O followed by endotracheal suctioning; b) 50S – MI-E with I/E pressures of −50/+50 cmH_2O followed by endotracheal suctioning; and c) isolated endotracheal suctioning.	Different settings	Higher MI-E pressures (−50/+50 cmH_2O) were associated with greater secretion clearance and improvements in lung compliance, whereas lower pressures showed limited physiological effects. Airway resistance decreased significantly only with the higher pressure protocol.
Sánchez-García (2018)	MI-E (50/−45 cmH_2O) via EOT or tracheostomy; 2 cycles.	No control group	MI-E was well tolerated, with no clinically relevant adverse events or need for treatment escalation. Hemodynamic and respiratory stability was maintained throughout the intervention.
Sánchez-García (2024)	a) MI-E (+50/-50 cmH_2O) b) MI-E (+50/-50 cmH_2O) +HS-HA	1)Suctioning 2)Suctioning after HS-HA	MI-E was not associated with significant changes in respiratory or hemodynamic parameters compared with suctioning strategies. The incidence of adverse events 30/120 (25%) was similar across groups and no radiological complications were observed. Follow up chest radiographs did not show complications Hemodynamic and respiratory parameters: no significant differences at baseline, or at the 5-minute and 60-minute evaluations across the four groups. MI-E avoids pain and agitation.

Abbreviations: MI-E = mechanical insufflation–exsufflation; CPT= Chest physiotherapy; MV= mechanical ventilation; VAP=Ventilator-associated pneumonia; EOT= Endotracheal tube; HS-HA= Hypertonic saline with hyaluronic acid; ERCC=expiratory rib chest compression.

Table 6. Characteristics of studies on Positive End-Expiratory - Zero End-Expiratory Pressure.

Study	Intervention/dosing	Description of the control group	Narrative synthesis
Amaral (2020)	PEEP-ZEEP in VCV PEEP-ZEEP in PCV PEEP increased to 15 cmH_2O for 5 respiratory cycles, followed by rapid reduction to 0 cmH_2O (ZEEP). PIP target 30–35 cmH_2O (max 40 cmH_2O), Ti 1.5 s. Total 10 cycles	MCC	Expiratory flow bias increased in VCV compared with PCV. PEF–PIF difference and PEF/PIF ratio were significantly higher in VCV, both with and without MCC.
Cardozo (2018)	Supine position, head elevated 30°. PEEP increased to 15 cmH_2O for 5 cycles, then reduced to 0 cmH_2O. Maneuver duration 10 min.	MCC	Static and dynamic compliance improved after the maneuver. No significant changes in SBP, DBP, SpO_2 or airway resistance.
de Oliveira (2023)	PEEP-ZEEP + MCC Patients in supine position, head elevated 30°. PEEP increased to 15 cmH_2O for 5 cycles, then reduced to 0 $cmH_2O$with MCC. Maneuver repeated for 10 min with 2-cycle rest intervals. Different ventilatory mode (PCV, VCV, PSV, IPPV) Maneuver repeated for 10 min with 2-cycle rest intervals.	Bag-squeezing + MCC	Small increases in MAP, DBP and RR in both groups. PIP decreased and dynamic compliance improved after intervention. No difference in aspirated secretion weight.

dos Santos (2009)	PEEP increased to 15 cmH_2O, then reduced to 0 cmH_2O, repeated cycles for 10 min.	MCC	No significant changes in Vt, compliance or SpO_2 between techniques.
Herbst-Rodrigues (2011)	PEEP increased to 15 cmH_2O for 5 cycles, followed by reduction to 0 cmH_2O, combined with MCC.	No CG	No significant changes in MAP, HR or SpO_2
Lobo (2010)	PEEP–ZEEP maneuver combined with manual hyperinflation and vibrocompression in dorsal decubitus.	Bag-squeezing + MCC (vibrocompressio)	No significant changes in hemodynamic variables or secretion volume.
Oliveira (2019)	PEEP–ZEEP maneuver in volume assist-control ventilation. PEEP increased to 15 cmH_2O for 5 cycles, then reduced to 0 cmH_2O. PIP 30–35 cmH_2O, Ti 1–1.5 s. Two maneuvers per step (10 cycles).	PEEP-ZEEP vs PEEP-ZEEP + MCC performed by RT1, RT2, RT3	PEF/PIF ratio significantly increased during ZEEP and further increased when MCC was applied. Similar results regardless of therapist.

Note: *Data are expressed as mean (±1 SD) or count and percentage (%); (*) information retrieved from the author.*

Abbreviations: MCC = Manual Chest Compression; PEEP = Positive End-Expiratory Pressure; ZEEP = Zero End-Expiratory Pressure; VCV = Volume-Controlled Ventilation; PCV = Pressure-Controlled mode Ventilation; PIP = Peak Inspiratory Pressure; Ti = inspiratory Time; PEF = Peak Expiratory Flow; PIF = Peak Inspiratory Flow; RT1 = first respiratory therapist; RT2 = second respiratory therapist; RT3 = third respiratory therapist; VACV = Volume Assist-Control Ventilation; PSV = Pressure Support Ventilation; IPPV = Intermittent Positive Pressure Ventilation; CG = Control Group; IG = Intervention Group; Cdyn = dynamic pulmonary Compliance; MAP = Mean Arterial Pressure; HR = Heart Rate; SpO_2 = peripheral Oxygen Saturation; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; Cst = static pulmonary Compliance; Rrs = Respiratory system resistance; Vt = tidal Volume; RR = Respiratory Rate.

Table 7. Characteristics of studies on manual hyperinflation and ventilator hyperinflation.

Study	Intervention/dosing	Description of the control group	Narrative synthesis
Ahmed (2020)	MHI	VHI	PaO_2/FiO_2 improved after MHI at 1 and 20 min. PaO_2/FiO_2 increased after VHI only at 1 min; Cdyn increased after VHI at 1 min.
Assman (2016)	VHI + suctioning	Suctioning	Sputum wet weight increased with VHI compared with control (6.4 g vs 3.9 g). Cdyn improved to a greater extent with VHI (Δ −2.9 vs −1.3 cmH_2O). Vte increased following VHI (Δ −54.1 vs −0.7 mL). Peak inspiratory pressure decreased after VHI (Δ 2.5 vs 0.2 cmH_2O).
Berney (2002)	MHI + suctioning	VHI + suctioning	No difference in sputum wet weight between MHI and VHI. Cst increased with both MHI (+11.5% immediate) and VHI (+11.6% at 30 min).
Berney (2004)	MHI + Head-down tilt position 35°–45° + suctioning	MHI + Flat side-lying position + suctioning	PEFR increased in the intervention group. Sputum wet weight increased after treatment in both groups, with a greater increase in the intervention group.
Berti (2012)	MHI + ERCC + percussion in syde-lying	Standard care (positioning, suctioning, brief manual ventilation)	Successful weaning rates were higher in the MHI group compared with standard care (37.5%vs15.9%). ICU discharge rates were also higher in the MHI group (31% vs 0%).
Chycaiban (2019)	VHI + suctioning	Positioning + suctioning	Cst increased after VHI. Vt markedly increased with VHI (+118%), with a further increase after inspiratory time adjustment (+145%).
Choi (2005)	MHI + suctioning	Suctioning	Cst increased after MHI (22%). Raw decreased at 30 min (21%).
Dennis (2012)	MHI + chest wall vibration + suctioning	VHI + chest wall + vibration + suctioning	Sputum wet weight: no difference MHI vs VHI.
Dias (2011)	MHI + ERCC + positioning + suctioning	Suctioning	No difference in sputum wet weight between groups (5.95 g vs 6.60 g). No differences were observed in Vt, plateau pressure, or Cst.

Genc (2011)	MHI + ERCC + positioning + suctioning	MHI + positioning + suctioning	Cst and Vt increased in both groups (transiently at 5 minutes for Vt), with no between-group differences. No differences were observed in gas exchange (PaO_2/FiO_2, $PaCO_2$) or sputum wet weight between groups.
Hodgson (2000)	MHI + side-lying + suctioning	Side-lying positioning + suctioning	Cst and sputum wet weight increased following MHI, with greater secretion clearance compared with control (5.5 g vs 3.5 g).
Jacob (2021)	MHI + chest wall vibration+ suctioning	VHI + chest wall vibration+ suctioning	VHI resulted in greater sputum clearance compared with MHI (2.84 g vs 1.50 g).
Lemes (2009)	VHI + suctioning	Side-lying position + suctioning	VHI increased sputum clearance compared with sidelying alone (mean difference 1.3 mL, 95% CI 0.5–2.2)
Maa (2005)	MHI + suctioning	Standard care (positioning, percussion, suctioning)	MHI was associated with greater radiographic improvement (OR 16.56) and increased Vt. A trend toward improvement was observed in f/VT and PaO_2/FiO_2, with no difference in airway secretions.
Naue (2014)	Increasing PS + ERCC + suctioning	Suctioning	Increasing PS + ERCC significantly increased sputum clearance, Vte, and Cdyn compared with control
Naue (2019)	Between- and within-intervention comparisons of VHI, vibrocompression, and combined VHI + vibrocompression	Suctioning	Combined VHI and vibrocompression resulted in greater sputum clearance compared with aspiration alone (0.7 g vs 0.2 g), with no overall differences between techniques. No differences were observed in duration of mechanical ventilation or mortality; lower reintubation rates within 48 hours were reported with vibrocompression-based approaches.
Ntomenopulus (1998)	MHI + postural drainage + suctioning	Standard care (positioning, suctioning, musculoskeletal physiotherapy)	A trend toward higher VAP incidence was observed in the control group, particularly in patients with greater severity (APACHE II >15) or prolonged mechanical ventilation (>7days). No differences were found in gas exchange, duration of MV, ICU length of stay, or ICU mortality.
Pattanshetty (2010)	MHI + suctioning + chest wall vibration	MHI + suctioning	Intervention group showed a greater reduction in CPIS score

	+ positioning + suctioning		(−3.4 vs −1.9), lower mortality (24% vs 49%), and higher successful weaning rates (62% vs 31.4%) compared with control. No differences were observed in duration of mechanical ventilation or ICU length of stay.
Ribeiro (2019)	VHI in six ventilatory modes: VC-CMV20, VC-CMV50, PC-CMV1, PC-CMV3, PSV10, PSV25.		Expiratory flow bias and lung expansion were achieved in all VHI modes; overall effectiveness increased in VC-CMV20, PSV 10, and PSV 25.
Savian (2006)	VHI + suctioning	MHI + suctioning	Cst increased after VHI only at 30 min +5.5 mL/cmH_2O. PEFR increased MHI 34.3 ± 6.6 L/min vs VHI 27.8 ± 8.2 L/min. VCO_2 increased MHI Δ+48 mL/min (during), +66 mL/min (post), Vt increased VHI +105 mL.
Thomas 2022	VHI with low vs high PEEP: comparison in VCV, PCV, PSV		VCV-based VHI protocols achieved expiratory flow-bias criteria more consistently than PCV or PSV (PIFR/PEFR ≤ 0.9; PEFR–PIFR ≥ 33 L/min; PEFR ≥ 40 L/min)

Note: *Data are expressed as mean (□1 SD) or count and percentage (%); (*) information retrieved from the author.*

Abbreviations: MHI = manual hyperinflation; VHI = ventilator hyperinflation; PaO_2/FiO_2 = arterial oxygen partial pressure to inspired oxygen fraction ratio; Cdyn = dynamic pulmonary compliance; Vte = expiratory tidal volume; Cst = static pulmonary compliance; Vt = tidal volume; Raw = airway resistance; $PaCO_2$ = arterial carbon dioxide partial pressure; PS = pressure support; CPIS = Clinical Pulmonary Infection Score; OR = odds ratio; f/Vt = rapid shallow breathing index; APACHE II = Acute Physiology and Chronic Health Evaluation II; MV = mechanical ventilation; ICU = intensive care unit; VAP = ventilator-associated pneumonia; VCV = Volume-Controlled Ventilation; PCV = Pressure-Controlled Ventilation; PSV = Pressure Support Ventilation; PEEP = Positive End-Expiratory Pressure; PEFR = Peak Expiratory Flow Rate; PIFR = Peak Inspiratory Flow Rate; VCO_2 = carbon dioxide production.

Figure 1. PRISMA flow diagram.

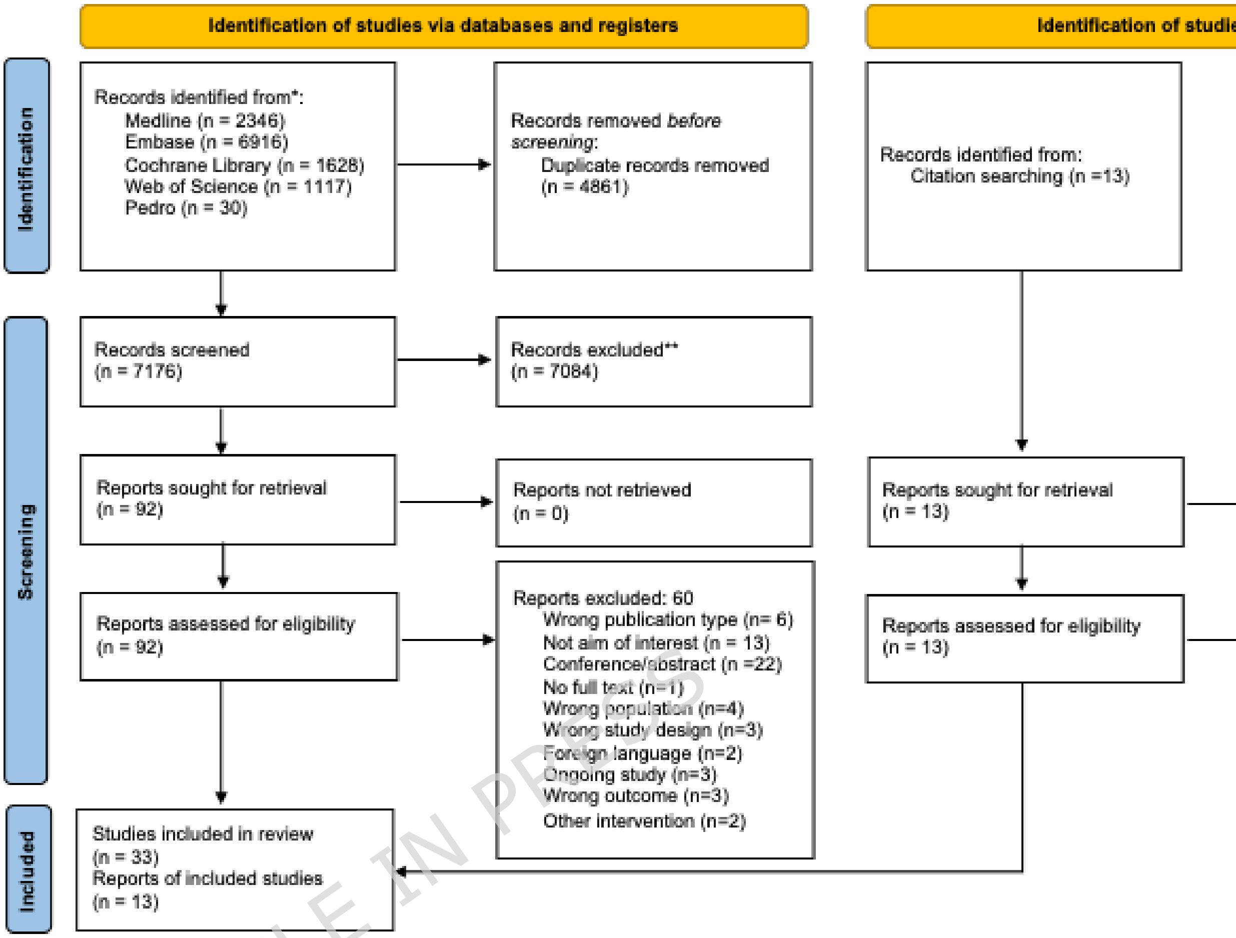
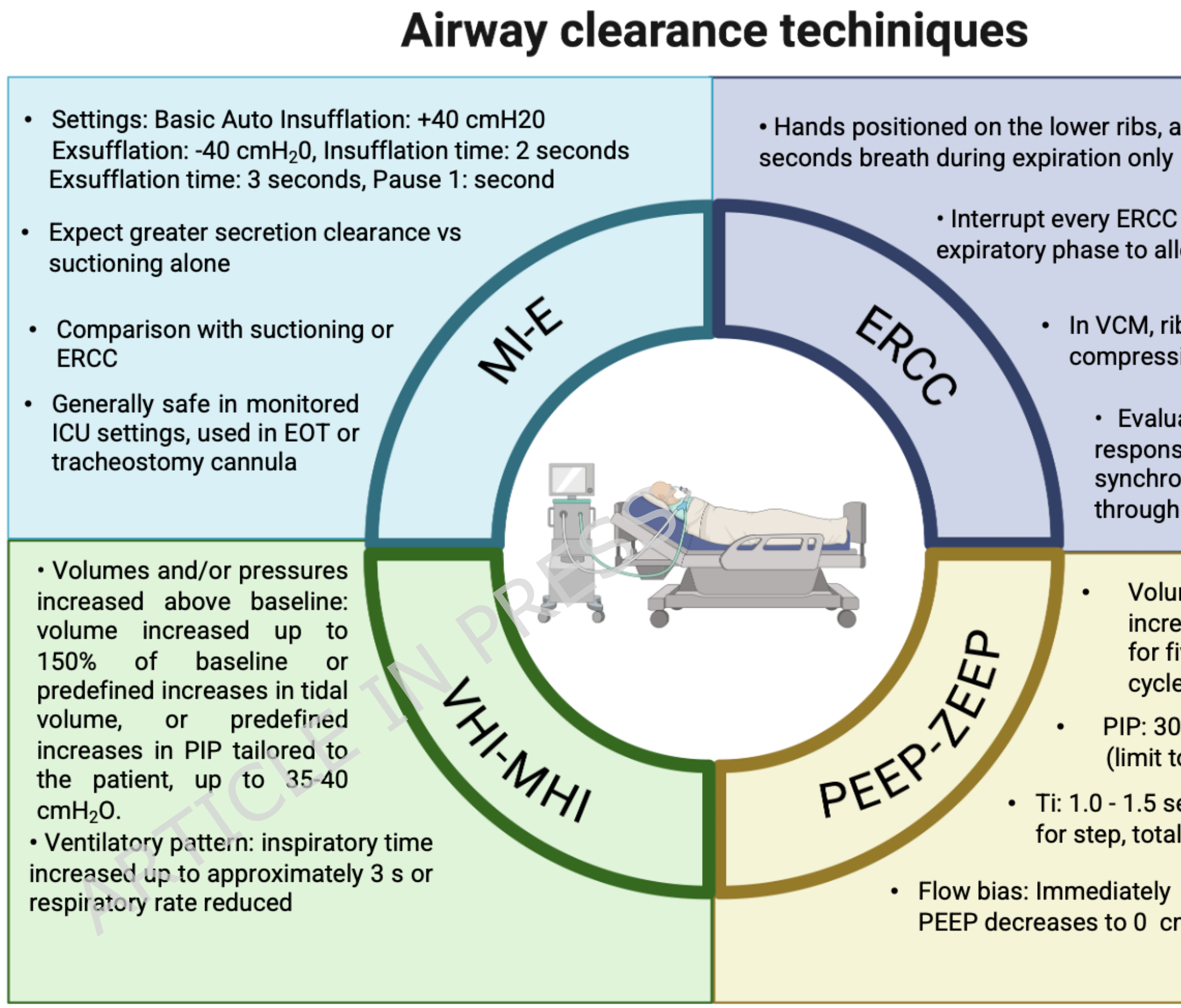


Figure 2. Graphical summary of the main findings from the different airway clearance techniques.


Airway clearance techiniques
MI-E
ERCC
VHI-MHI
PEEP-ZEEP
Settings: Basic Auto Insufflation: +40 cmH20 Exsufflation: -40 cmH20, Insufflation time: 2 seconds Exsufflation time: 3 seconds, Pause 1: second
Expect greater secretion clearance vs suctioning alone
Comparison with suctioning or ERCC
Generally safe in monitored ICU settings, used in EOT or tracheostomy cannula
Hands positioned on the lower ribs,
seconds breath during expiration only
Interrupt every ERCC
expiratory phase to
In VCM,
Volumes and/or pressures increased above baseline: volume increased up to 150% of baseline or predefined increases in tidal volume, or predefined increases in PIP tailored to the patient, up to 35-40 cmH2O.
Ventilatory pattern: inspiratory time increased up to approximately 3 s or respiratory rate reduced
PIP: 30
Ti: 1.0 - 1.5
for step, total
Flow bias: Immediately
PEEP decreases to 0