Expiratory pause in patients undergoing mechanical ventilation: a systematic review with meta-analysis

Pausa expiratória em pacientes sob ventilação mecânica: revisão sistemática com meta-análise

Pausa espiratoria en pacientes con ventilación mecánica: una revisión sistemática con metaanálisis

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REVISA

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RESUMO

Objetivo: avaliar a eficácia e a segurança da aspiração traqueal em sistema fechado associada à pausa expiratória em pacientes sob ventilação mecânica invasiva. Métodos: revisão sistemática com meta-análise. Foram incluídos ensaios clínicos randomizados, sem restrições de idioma, período de publicação ou faixa etária da amostra. Buscou-se na Medical Literature Analysis and Retrieval System Online, Cumulative Index to Nursing and Allied Health Literature, Scopus, Literatura Latino-Americana e do Caribe em Ciências da Saúde, Web of Science, Cochrane Library e Excerpta Medica dataBASE e o Banco Digital de Teses e Dissertações. Os desfechos analisados incluíram volume de secreção aspirada, estabilidade hemodinâmica, parâmetros de oxigenação e mecânica ventilatória. Avaliou-se o risco de viés pela ferramenta RoB 2. Resultados: três estudos foram incluídos, os quais demonstraram aumento estatisticamente significativo no volume de secreção removido com a técnica associada à pausa, sem comprometimento da estabilidade hemodinâmica. A avaliação de risco de viés indicou "alguma preocupação" em todos os estudos, especialmente em relação à randomização e relato seletivo. No modelo de efeitos aleatórios, a técnica com pausa aumentou o peso seco aspirado em 1,48 g (IC95% 0,17 a 2,79; k = 3). Conclusão: a aspiração traqueal em sistema fechado associada à pausa expiratória mostrou-se mais eficaz na remoção de secreções quando comparada à técnica convencional, com perfil de segurança adequado.

Descritores: Aspiração Traqueal; Pausa Expiratória; Ventilação Mecânica; Revisão Sistemática.

ABSTRACT

Objective: to evaluate the efficacy and safety of closed-system tracheal suctioning combined with an expiratory pause in patients undergoing invasive mechanical ventilation. Methods: a systematic review with meta-analysis. Randomized clinical trials were included, with no restrictions regarding language, publication period, or sample age group. Searches were conducted in the Medical Literature Analysis and Retrieval System Online, Cumulative Index to Nursing and Allied Health Literature, Scopus, Latin American and Caribbean Health Sciences Literature, Web of Science, Cochrane Library, Excerpta Medica dataBASE, and the Digital Library of Theses and Dissertations. Analyzed outcomes included the volume of aspirated secretions, hemodynamic stability, oxygenation parameters, and ventilatory mechanics. Risk of bias was assessed using the RoB 2 tool. Results: three studies were included, demonstrating a statistically significant increase in the volume of secretions removed using the technique combined with a pause, without compromising hemodynamic stability. Risk of bias assessment indicated "some concerns" in all studies, particularly regarding randomization and selective reporting. In the random-effects model, the technique with a pause increased the aspirated dry weight by 1.48 g (95% CI: 0.17 to 2.79; k = 3). Conclusion: closed-system tracheal suctioning combined with an expiratory pause proved more effective at removing secretions compared to the conventional technique, with an adequate safety profile.

Descriptors: Tracheal Suctioning; Expiratory Pause; Mechanical Ventilation; Systematic Review.

RESUMEN

Objetivo: evaluar la eficacia y seguridad de la aspiración traqueal de sistema cerrado asociada con pausa espiratoria en pacientes sometidos a ventilación mecánica invasiva. Métodos: revisión sistemática con metaanálisis. Se incluyeron ensayos clínicos aleatorizados, sin restricciones de idioma, período de publicación o rango de edad de la muestra. Las búsquedas incluyeron el Sistema de Análisis y Recuperación de Literatura Médica en Línea, el Índice Acumulativo de Literatura de Enfermería y Ciencias de la Salud Afines, Scopus, Literatura Latinoamericana y Caribeña en Ciencias de la Salud, Web of Science, la Biblioteca Cochrane, la base de datos Excerpta Medica y el Banco Digital de Tesis y Disertaciones. Los resultados analizados incluyeron el volumen de secreción aspirada, la estabilidad hemodinámica, los parámetros de oxigenación y la mecánica ventilatoria. El riesgo de sesgo se evaluó utilizando la herramienta RoB 2. Resultados: se incluyeron tres estudios, que demostraron un aumento estadísticamente significativo en el volumen de secreción extraído con la técnica asociada con la pausa, sin comprometer la estabilidad hemodinámica. La evaluación del riesgo de sesgo indicó "cierta preocupación" en todos los estudios, especialmente con respecto a la aleatorización y la notificación selectiva**. En el** modelo de efectos aleatorios, la técnica con pausa aumentó el peso seco aspirado en 1,48 g (IC del 95%: 0,17 a 2,79; k = 3). Conclusión: la aspiración traqueal en sistema cerrado con pausa espiratoria demostró ser más eficaz para eliminar secreciones en comparación con la técnica convencional, con un perfil de seguridad adecuado.

Descriptores: Aspiración Traqueal; Pausa Espiratoria; Ventilación Mecánica; Revisión Sistemática.

REVISÃO

Introdução

Invasive mechanical ventilation (IMV) is a strategy widely employed in intensive care units (ICUs) for patients with acute respiratory failure, with the primary objective of ensuring adequate gas exchange, reducing the work of breathing, and maintaining alveolar oxygenation and ventilation. However, despite its unquestionable benefits, IMV is associated with a range of potentially serious complications, such as ventilator-associated pneumonia (VAP), barotrauma, and ventilator-induced lung injury, all of which may significantly compromise the patient's clinical outcome[1].

The literature indicates that prolonged IMV duration is one of the main risk factors for nosocomial infections, with a direct association between the length of endotracheal intubation and the incidence of VAP. From this perspective, implementing strategies that not only optimize ventilation but also minimize the deleterious effects of invasive ventilatory support is essential. Among these strategies, maintaining the patency of the artificial airway through tracheal suctioning is an essential routine procedure, although it is not without risks[2,3].

The presence of thick secretions, especially in patients with pre-existing respiratory diseases or severe systemic inflammatory conditions, is exacerbated by impaired mucociliary clearance, the use of sedatives, reduced cough reflex, and the presence of the endotracheal tube itself. This imbalance between mucus production and clearance promotes airway obstruction, impairs alveolar ventilation, and predisposes patients to distal pulmonary collapse[3,4].

Although tracheal suctioning is effective in removing these secretions, it may trigger adverse events such as oxygen desaturation, hypoxemia, tracheobronchial mucosal injury, vagally mediated bradycardia, and, paradoxically, an increased risk of infection, particularly when performed using an open suction system. In this context, closed endotracheal suctioning is recommended for patients receiving positive end-expiratory pressure (PEEP) greater than 10 cmH_2O, as well as for patients infected with viral or multidrug-resistant microorganisms, in whom complete isolation of the artificial airway is required to prevent pathogen dissemination within the hospital environment[5].

The closed endotracheal suction system using the Trach-Care device has emerged as a promising method for preventing hypoxemia. It is capable of adequately preserving blood oxygenation in patients with varying degrees of respiratory dysfunction, both with and without PEEP. Furthermore, this system may reduce cross-contamination between patients and contamination of the respiratory tract by environmental microorganisms, provided that the suction catheter is replaced every seven days and irrigated with saline solution after each suction procedure[5–7].

More recently, the combination of closed-system suctioning with the expiratory pause maneuver has been proposed as a potentially more effective technique. The expiratory pause consists of temporarily interrupting the ventilatory cycle at the end of expiration, when inspiratory flow is absent and alveolar pressure remains stable. This condition creates a favorable pressure gradient between the ventilatory system and the negative pressure generated by the suction catheter, promoting improved mucus displacement toward the upper airway while preventing inappropriate ventilator triggering that may interfere with suction effectiveness[8].

From a physiological standpoint, secretion mobilization depends on multiple factors, including the relationship between inspiratory and expiratory flows, the viscoelastic properties of mucus, gas flow intensity, and the adopted ventilatory pattern.

Studies indicate that expiratory flow should exceed inspiratory flow by at least 10% to facilitate proximal secretion transport. The absence of inspiratory flow during the expiratory pause and the greater negative pressure generated within the system suggest a more favorable environment for effective tracheobronchial secretion removal[9].

However, despite promising physiological evidence, clinical studies investigating tracheal suctioning combined with expiratory pause remain scarce, methodologically heterogeneous, and often present conflicting results. Variations in expiratory pause duration, suction parameters, patients' clinical conditions, and outcome assessment methods hinder the establishment of standardized clinical recommendations.

Therefore, this systematic review aims to evaluate the efficacy and safety of closed-system tracheal suctioning associated with the expiratory pause maneuver in patients undergoing invasive mechanical ventilation. By doing so, it seeks to strengthen evidence-based clinical practice, optimize patient care, and reduce risks in critically ill individuals receiving intensive care.

Methodology

Study Design

This systematic review was conducted according to the methodological recommendations of the Joanna Briggs Institute (JBI) Evidence Synthesis Groups[10]. The review was carried out between July and September 2025 and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement[11]. The protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42025111639[12].

Search Strategy

The review question and search strategy were developed using the PEO framework (P – Population or Patients; E – Exposure; O – Outcomes)[11], where P comprised adult and pediatric patients receiving IMV in the ICU; E referred to closed-system tracheal suctioning associated with the expiratory pause maneuver; and O included the efficacy of the technique (amount of aspirated secretions, hemodynamic stability, oxygenation [SpO_2/PaO_2], changes in ventilatory mechanics, and adverse effects). Based on this framework, the following research question was formulated: What are the efficacy and safety of closed-system tracheal suctioning associated with the expiratory pause maneuver?

Randomized controlled trials (RCTs), without language or publication date restrictions and involving participants of any age group, were included. Other study designs, as well as in vitro studies, letters to the editor, editorials, studies without access to the full text despite attempts to contact the authors, and studies that did not clearly describe the suctioning protocol combined with the expiratory pause maneuver were excluded. Duplicate studies were counted only once.

Search Process and Eligibility Criteria

The literature search was conducted in the Medical Literature Analysis and Retrieval System Online (MEDLINE) via PubMed, the Cumulative Index to Nursing and Allied Health Literature (CINAHL) via EBSCO, Scopus, the Latin American and

Caribbean Health Sciences Literature (LILACS), Web of Science, the Cochrane Library, Excerpta Medica Database (Embase), and the Brazilian Digital Library of Theses and Dissertations (BDTD). The inclusion of the latter database aimed to identify randomized clinical trials that had not yet been published in peer-reviewed journals. Subscription-based databases were accessed through the CAPES Journal Portal.

The search strategy combined controlled vocabulary from the Health Sciences Descriptors (DeCS) and the Medical Subject Headings (MeSH), along with alternative terms and keywords, as presented in Table 1.

Table 1. Search strategies used to identify eligible publications. Porto Alegre, Rio Grande do Sul, Brazil, 2026.

Database	Search Strategy
Medline	Search: ("Respiration, Artificial"[mesh terms] OR "Artificial Respiration"[tw] OR "Artificial Respirations"[tw] OR "Mechanical Ventilations"[tw] OR "Mechanical Ventilation"[tw]) AND ("Suction"[mesh terms]OR "Suctions"[tw] OR "Mechanical Aspiration"[tw] OR "Suction Drainage"[tw] OR "Suction Drainages"[tw]) Search: ("Suction"[MeSH Terms] OR "Suctions"[All Fields] OR "Mechanical Aspiration"[All Fields] OR "Suction Drainage"[All Fields] OR "Suction Drainages"[All Fields] OR "Aspirated secretions"[All Fields] OR "tracheal aspiration"[All Fields]) AND ("Expiratory Pause"[All Fields]) "Expiratory Pause"[All Fields]
Embase	('artificial ventilation'/exp OR 'artificial ventilation') AND 'endotracheal intubation':ab,ti AND 'suction':ab,ti 'Expiratory pause'
Web of Science, LILACS, Scopus e CINAHL	("Artificial Respiration" OR "Artificial Respirations" OR "Mechanical Ventilations" OR "Mechanical Ventilation") AND ("intubation, Intratracheal" OR "Intratracheal Intubation" OR "Intratracheal Intubations" OR "Endotracheal Intubation" OR "Endotracheal Intubations") AND ("Suction" OR "Suctions" OR "Mechanical Aspiration" OR "Mechanical Aspirations" OR "Suction Drainage" OR "Suction Drainages") ("Suction" OR "Suctions" OR "Mechanical Aspiration" OR "Mechanical Aspirations" OR "Suction Drainage" OR "Suction Drainages") AND ("Expiratory pause") "Expiratory Pause"
BDTD	"Expiratory pause"

Source: Research data, 2025.

Study Selection

The studies retrieved from the databases were exported to EndNote® Online for duplicate detection and removal and subsequently imported into Rayyan®, developed by the Qatar Computing Research Institute (QCRI), to ensure blinded assessment throughout the screening process.

The literature search was independently conducted by two reviewers. Data extraction was performed by initially screening the titles and abstracts of the selected studies, followed by a full-text reading and analysis of the eligible articles. Any disagreements between reviewers were resolved by consensus.

For study characterization, a data extraction form developed by the authors was used. The form included information on the authors, title, journal, publication year, study design, as well as relevant data related to the research topic, including study objectives, sample characteristics, and main findings.

Statistical Analysis

All statistical analyses were conducted using R (R Foundation for Statistical Computing). The meta-analysis was performed using the meta package, employing a random-effects model to estimate the pooled effect size, heterogeneity statistics, and forest plots. The pooled effect estimate was calculated using the DerSimonian–Laird (DL) estimator for τ^2, with 95% confidence intervals (CIs) obtained using the normal approximation method. Statistical heterogeneity was assessed using I^2 and τ^2, and confidence intervals for τ^2 were estimated using the Jackson method under the DL estimator.

Considering the small number of included studies (k = 3), an additional analysis was performed using the Hartung–Knapp–Sidik–Jonkman (HKSJ) adjustment, with τ^2 estimated by Restricted Maximum Likelihood (REML), a method commonly recommended for meta-analyses including a limited number of studies. A prediction interval for a future study was also calculated. Given the small sample size, the t-distribution with df = k − 1 was used to obtain a more conservative estimate.

For studies that did not report the within-subject correlation between paired measurements, the standard deviation of the paired differences (SDd) was calculated assuming an a priori correlation coefficient of r = 0.5. Sensitivity analyses were conducted by varying the assumed correlation coefficient (r = 0.00, 0.25, 0.50, and 0.75) to evaluate the robustness of the pooled estimates. The influence of each individual study was assessed through leave-one-out analysis. Forest plots displaying the individual study effects, pooled effect estimate, and prediction interval were generated.

Risk of Bias Assessment and Certainty of Evidence

The risk of bias was assessed using the Risk of Bias 2 (RoB 2) tool, considering the following domains: (1) bias arising from the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in outcome measurement; and (5) bias in the selection of the reported results[13].
The certainty of the evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach[14].

Results

Search and Study Selection

A total of 188 records were identified in MEDLINE, 161 in Embase, 37 in Web of Science, 12 in LILACS, 94 in Scopus, 15 in CINAHL, and 9 in the Brazilian Digital Library of Theses and Dissertations (BDTD), resulting in 516 records overall. Following the screening and eligibility assessment, three studies were included in the final sample. The study selection process is presented in Figure 1. Additionally, three national clinical trial records were identified in the Cochrane Library.

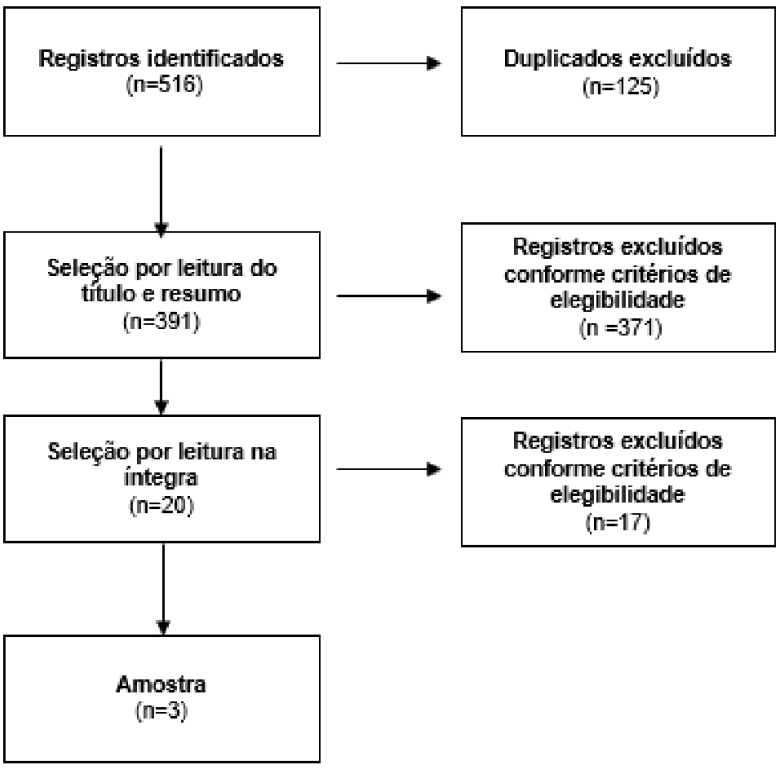

Figure 1. Flowchart of the study selection process. Porto Alegre, Rio Grande do Sul, Brazil, 2026.

General Characteristics, Risk of Bias, and Certainty of the Evidence

The final sample comprised three randomized controlled trials (RCTs) with a crossover design, all employing a closed endotracheal suction system. The intervention

differed according to the duration of the expiratory pause, whereas the control group underwent tracheal suctioning without an expiratory pause. All studies demonstrated a statistically significant difference in the amount of aspirated secretions in favor of the intervention (Table 2).

Regarding the risk of bias, as assessed using the Risk of Bias 2 (RoB 2) tool, all three RCTs (100%) were judged as having "some concerns" regarding the randomization process, low risk of bias due to deviations from the intended interventions, completeness of outcome data, and outcome measurement, and "some concerns" regarding the selection of the reported results. Consequently, the overall risk of bias for all included studies was rated as "some concerns," primarily due to the incomplete description of the randomization process and the absence of prospective protocol registration.

Table 2 – Characteristics and main findings of the included studies. Porto Alegre, Rio Grande do Sul, Brazil, 2026.

N	Authors	Objective	Sample	Expiratory Pause	Outcomes	Main Findings
1	Peiter APD[15] 2024	To evaluate the volume of aspirated secretions, respiratory mechanics, and hemodynamic parameters during closed-system suctioning associated with an expiratory pause compared with conventional suctioning in infants.	10 infants with a median age of 2 months	5s	Secretion volume, respiratory mechanics, heart rate, and SpO_2	Increased volume of aspirated secretions, increased driving pressure and inspiratory airway resistance (ResINS), with no hemodynamic changes.
2	Pinheiro DRR et al. [16] 2022	To compare the effects of applying an expiratory pause during closed-system suctioning by quantifying the volume of aspirated bronchial secretions and evaluating hemodynamic and ventilatory responses in mechanically ventilated ICU patients.	24 adults with a mean age of 45.5 years.	15s	Secretion volume, tidal volume (VT), heart rate, and mean arterial pressure (MAP).	Increased volume of aspirated secretions, reduced heart rate, and increased tidal volume.. ↑ VAC
3	Martins et al. [9] 2019	To compare the volume of aspirated secretions, respiratory mechanics, and hemodynamic parameters in intubated patients	31 adults with a mean age of	10s	Secretion volume, respiratory mechanics, and hemodynamic parameters.	Increased volume of aspirated secretions, with no significant changes in respiratory

		undergoing conventional closed-system endotracheal suctioning (control group) versus closed-system tracheal suctioning associated with an expiratory pause (intervention group).	61.1 years.			mechanics or hemodynamic parameters.

The certainty of the evidence, assessed using the **GRADE** approach, was rated as **moderate** for the outcomes **"amount of aspirated secretions"** and **"hemodynamic stability,"** and **low** for ventilatory and oxygenation parameters because of the variability among study results and the limited sample sizes.

Meta-analysis of the Primary Outcome

The quantitative outcome was the **dry weight of aspirated secretions (g)**, comparing suctioning **with** versus **without** an expiratory pause. As the within-subject correlations for paired measurements were not reported, a correlation coefficient of **r = 0.5** was assumed to calculate the standard deviation of the paired differences. Sensitivity analyses using different correlation coefficients are presented below.

Individual Study Effects

The mean differences (**MD = "with expiratory pause" − "without expiratory pause"**) and their corresponding **95% confidence intervals (95% CI)** were as follows:

- **Study 1:** MD = **0.31 g** (95% CI: **0.12 to 0.51**);
- **Study 2:** MD = **3.70 g** (95% CI: **2.62 to 4.78**);
- **Study 3:** MD = **0.82 g** (95% CI: **0.29 to 1.35**)

Pooled Effect and Heterogeneity

Using the **DerSimonian–Laird random-effects model**, tracheal suctioning associated with an expiratory pause increased the dry weight of aspirated secretions by **1.48 g** (95% CI: **0.17 to 2.79**; **k = 3**).

Very high statistical heterogeneity was observed (**I^2 = 94.8%; τ^2 = 1.22; Q = 38.23; p < 0.0001**).

The **prediction interval (PI)** for a future study, calculated using the **t-distribution** with **df = 2**, ranged from **−4.08 to 7.04 g**. For comparison, the prediction interval obtained using the normal approximation ranged from **−1.06 to 4.01 g**.

The corresponding **forest plot** is presented in **Figure 2**, where **MD > 0 favors suctioning with an expiratory pause**.

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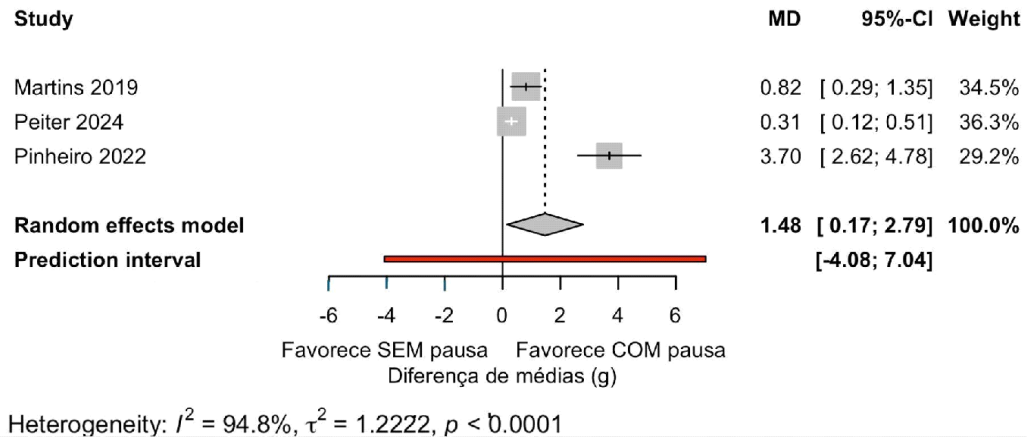

Source: Research data, 2025. Random-effects model (DerSimonian–Laird). Horizontal bars represent the **95% confidence intervals (95% CIs)** of the individual studies; the diamond represents the pooled effect estimate. The dashed line indicates the **prediction interval** (t-distribution, df = 2). **MD**, mean difference.

Figure 2. Forest plot of the mean difference (g) in the dry weight of aspirated secretions comparing tracheal suctioning **with** versus **without** an expiratory pause in crossover studies. Porto Alegre, Rio Grande do Sul, Brazil, 2026.

Sensitivity Analyses

- HKSJ Adjustment: After applying the **Hartung–Knapp–Sidik–Jonkman (HKSJ)** adjustment, the direction of the pooled effect remained unchanged; however, the confidence intervals widened and included the null effect: **DL + HKSJ:** MD = **1.48 g** (95% CI: **−2.92 to 5.87**); **REML + HKSJ:** MD = **1.55 g** (95% CI: **−2.93 to 6.03**).

When the assumed within-subject correlation coefficient (**r**) varied from **0.00 to 0.75**, the pooled mean difference showed minimal variation (**1.45–1.47 g**), whereas statistical heterogeneity remained consistently high (**I^2 = 92–96%**). Using the **DerSimonian–Laird (DL)** estimator, the **95% confidence intervals remained entirely above zero** across all scenarios. In contrast, when the **Hartung–Knapp–Sidik–Jonkman**

(HKSJ) adjustment was applied, the **95% confidence intervals included the null value**, indicating greater uncertainty in the pooled effect estimate (Table 1).

Table 1 - Sensitivity analysis according to the assumed within-subject correlation coefficient (**r**) in the paired meta-analysis of the dry weight of aspirated secretions. Porto Alegre, Rio Grande do Sul, Brazil, 2026.

r	MD pooled	IC95%	I^2
0,00	1,45	[0,01; 2,90]	91,9%
0,25	1,47	[0,07; 2,86]	93,3%
0,50	1,48	[0,17; 2,79]	94,8%
0,75	1,47	[0,34; 2,61]	96,2%

Leave-one-out analysis: when article N2 was removed, the pooled effect decreased to 0.50 g (95% CI 0.02 to 0.98) and I^2 to 67.5%. When publications N3 or N1 were omitted, the effects were 1.96 g (95% CI −1.36 to 5.28; I^2 = 97.2%) and 2.22 g (95% CI −0.60 to 5.04; I^2 = 95.4%), respectively (Table 2).

Table 2- Leave-one-out analysis (influence by study) in the meta-analysis of aspirated dry weight. Porto Alegre, RS, Brazil, 2026.

Omitido	MD pooled	IC95%	I^2
Martins, 2019[15]	1,96	[−1,36; 5,28]	97,2%
Peiter, 2024[13]	2,22	[−0,60; 5,04]	95,4%
Pinheiro, 2022[14]	0,50	[0,02; 0,98]	67,5%

Results and Discussion

This study identified consistent evidence that closed-system tracheal suctioning associated with an expiratory pause is more effective in removing secretions than conventional closed-system tracheal suctioning without an expiratory pause, while demonstrating clinical safety in both pediatric and adult populations. Despite the heterogeneity in expiratory pause duration among the included studies, the findings reinforce the potential of this technique as an adjunctive intervention in tracheal suctioning protocols in intensive care units.

Study N1[15] demonstrated an increase in driving pressure and inspiratory airway resistance in infants during the application of a 5-second expiratory pause, highlighting possible transient changes in respiratory mechanics in this specific population. Although these alterations were not associated with immediate adverse clinical effects, they emphasize the need for careful monitoring and further investigations to ensure the safety of the procedure in more vulnerable patients.

Study N2[16] reported that a 15-second expiratory pause was associated with the greatest volume of aspirated secretions while also improving tidal volume and producing a transient reduction in heart rate. These findings suggest a beneficial physiological effect, possibly related to the optimization of the alveolar pressure gradient during the expiratory pause. Martins et al.[9], using a 10-second expiratory pause, also demonstrated

enhanced secretion removal without negative effects on respiratory mechanics or hemodynamic parameters, further supporting the safety of the technique.

The physiological rationale underlying the use of the expiratory pause during tracheal suctioning can be explained by the stabilization of alveolar pressure and the absence of inspiratory flow, creating favorable conditions for secretion displacement toward the suction catheter. However, differences among the studies regarding pause duration, outcome assessment criteria, measurement instruments, and patient characteristics limit the generalizability of the findings and hinder the standardization of the procedure.

The risk of bias of the studies included in this systematic review was assessed using the **Cochrane Risk of Bias 2 (RoB 2)** tool[14]. All studies were classified as presenting **"some concerns"** regarding the overall risk of bias, mainly because of insufficient information on randomization methods, allocation concealment, and prospective protocol registration. Conversely, the domains related to adherence to the intervention, completeness of outcome data, and outcome measurement were considered to have a **low risk of bias**, as the evaluated outcomes were objective, measured using standardized methods, and no losses to follow-up were reported.

All three included studies were randomized controlled trials, providing a high initial level of methodological quality. However, according to the **GRADE** assessment[13], all studies presented **"some concerns"** regarding the risk of bias, primarily because of the lack of detailed reporting of the randomization process and the absence of prospective protocol registration[16]. The certainty of the evidence was rated as **moderate** for the outcomes **"volume of aspirated secretions"** and **"hemodynamic stability,"** and **low** for ventilatory and oxygenation parameters because of the variability of the findings and the limited sample sizes.

The technique incorporating an expiratory pause increased the dry weight of aspirated secretions by **1.48 g** (95% CI: **0.17 to 2.79**; **k = 3**), demonstrating its effectiveness in increasing the amount of aspirated secretions as assessed by the pooled mean difference (MD). These findings suggest that, although the results are promising, additional studies with greater methodological rigor are required to increase confidence in the estimated effect and support the implementation of this technique in clinical practice.

The pooled effect indicates that tracheal suctioning associated with an expiratory pause results, on average, in greater secretion removal than conventional suctioning. This finding supports the hypothesis that the temporary interruption of expiratory flow facilitates more efficient mobilization of mucus accumulated in the lower airways, promoting the displacement of bronchial secretions toward the endotracheal tube and consequently increasing the amount of aspirated material[17–19].

Nevertheless, the very high heterogeneity (**I^2 = 94.8%**) suggests substantial differences among the included studies regarding methodology, patient populations, and clinical conditions, thereby limiting the precision of the pooled estimate. This variability may be related to factors such as the duration of the expiratory pause (5, 10, or 15 seconds), the type of mechanical ventilator used, ventilatory pressure settings, patients' secretion characteristics, and the control of hemodynamic variables during the procedure[20–22].

The wide prediction interval (**−4.08 to 7.04 g**) indicates that, although the average effect across studies favors the intervention, future studies may report smaller, null, or even negative effects depending on the clinical context and methodological rigor. Therefore, the findings presented in the forest plot should be interpreted cautiously, acknowledging that tracheal suctioning with an expiratory pause appears to be effective

under specific conditions, but its widespread implementation still requires greater protocol standardization and confirmation through additional high-quality studies with representative samples[23,24].

Sensitivity analyses demonstrated that the direction of the pooled effect remained unchanged after applying the **Hartung–Knapp–Sidik–Jonkman (HKSJ)** adjustment for both the **DerSimonian–Laird (DL)** and **Restricted Maximum Likelihood (REML)** models. However, confidence intervals became wider and included the null value, indicating greater statistical uncertainty. The pooled estimates remained similar to those of the primary analysis (**DL + HKSJ = 1.48 g; 95% CI: −2.92 to 5.87** and **REML + HKSJ = 1.55 g; 95% CI: −2.93 to 6.03**), demonstrating consistency in the direction of the effect despite reduced precision.

When the assumed within-subject correlation coefficient (**r**) varied from **0.00 to 0.75**, the pooled mean difference showed only minimal variation (**1.45–1.47 g**), reinforcing the stability of the estimated effect. Nevertheless, heterogeneity remained consistently high (**I^2 ranging from 92% to 96%**), suggesting that methodological and clinical differences among the included studies substantially contributed to the observed variability. These findings indicate that, although the estimated treatment effect is robust to changes in statistical assumptions, the high heterogeneity reduces the overall certainty of the evidence.

In the leave-one-out analysis, excluding **Study N2** reduced the pooled effect to **0.50 g** (95% CI: **0.02 to 0.98**) and decreased heterogeneity to **I^2 = 67.5%**. The study by **Pinheiro et al.** therefore exerted considerable influence on the meta-analysis, as both the magnitude of the pooled effect and statistical heterogeneity were substantially reduced after its exclusion. In contrast, omitting **Study N3** or **Study N1** resulted in pooled effects of **1.96 g** (95% CI: **−1.36 to 5.28**; **I^2 = 97.2%**) and **2.22 g** (95% CI: **−0.60 to 5.04**; **I^2 = 95.4%**), respectively. These findings indicate that, even after excluding the studies by **Martins et al. (2019)** or **Peiter (2024)**, the pooled effect remained relatively stable, although heterogeneity persisted at very high levels (95–97%). Therefore, neither of these studies substantially contributed to reducing the between-study heterogeneity.

Overall, these findings reinforce the physiological potential of the expiratory pause as a strategy to optimize bronchial secretion clearance in mechanically ventilated patients without compromising patient safety, while also emphasizing the need for additional randomized clinical trials to clarify the magnitude and consistency of its effects[8,17,18].

Another important finding was the absence of significant adverse events associated with the technique, which supports its potential incorporation into routine clinical practice. Nevertheless, caution and continuous monitoring are recommended, particularly in pediatric populations and in patients with more fragile respiratory mechanics.

A limitation of this systematic review is the inclusion of only three eligible studies, highlighting the scarcity of available evidence on this topic and the need for further research. Nevertheless, the available findings suggest that closed-system tracheal suctioning associated with an expiratory pause is a promising strategy for optimizing bronchial hygiene in patients receiving invasive mechanical ventilation, potentially reducing the risk of complications related to secretion retention. Future studies involving larger sample sizes, standardized protocols, and more comprehensive evaluations of hemodynamic and respiratory outcomes are essential to establish robust evidence-based clinical guidelines.

Conclusion

This systematic review demonstrated that closed-system tracheal suctioning associated with an expiratory pause is more effective in removing secretions from mechanically ventilated patients without compromising hemodynamic or respiratory stability in both pediatric and adult populations. Despite the limited number of studies and the methodological heterogeneity observed, the findings indicate the safety and clinical benefit of the technique, suggesting its broad and versatile clinical applicability.

Further clinical trials with larger samples and standardized expiratory pause durations are recommended to better establish guidelines for clinical use.

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