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The effect of respiratory training on lung function in intensive care unit patients: A systematic review and meta-analysis

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Abstract

Background

Mechanically ventilated patients in the intensive care unit (ICU) usually develop respiratory muscle wasting atrophy, causing pulmonary dysfunction. The benefits of respiratory muscle training (RMT) on pulmonary function recovery have been demonstrated, but whether it is effective in patients following mechanical ventilation in the ICU has not been proven. This study aimed to evaluate the effectiveness of RMT on lung function and mechanical ventilation duration in ICU patients, addressing the lack of comprehensive evidence on its benefits for mechanically ventilated individuals.

Methods

This systematic review and meta-analysis was conducted on the databases from PubMed, Cochrane Library, Web of Science, and Embase. The search period was extended to 30th April 2025. Studies included ICU patients receiving RMT, and outcomes such as maximum inspiratory pressure (MIP), forced vital capacity (FVC), and mechanical ventilation duration were analyzed using RevMan software. Heterogeneity was assessed using I^2 statistics.

Results

18 randomized controlled trials (RCTs) were included for analysis. RMT significantly improved MIP (SMD: 0.88, 95% CI: 0.53-1.24) and FVC (SMD: 0.32, 95% CI: 0.07–0.58) and reduced mechanical ventilation duration by 0.88 days (95% CI: -1.10 to -0.66).

Conclusions

Respiratory muscle training enhances lung function and shortens mechanical ventilation duration in ICU patients, supporting its early implementation as a

rehabilitation strategy.

Keywords: Intensive care unit, Mechanical ventilation, Lung function, Respiratory muscles, Exercise

Introduction

The majority of patients admitted to the intensive care unit (ICU) require mechanical ventilation, and invasive ventilatory support promotes normal alveolar ventilation and effective gas exchange, treats underlying disease, and reverses respiratory failure (1). However, in conjunction with prolonged controlled ventilation, respiratory muscle disuse also weakens muscle function (2) and decreases diaphragm strength in a manner that is logarithmically proportional to the duration of mechanical ventilation (MV) (3) as well as to the use of sedation and muscle blockers (4). Weaning from mechanical ventilation presents significant clinical and economic challenges. Earlier weaning benefits patients financially. Failure to wean leads to prolonged ventilation, which poses substantial risks to patients by increasing the likelihood of respiratory muscle weakness, hospital-acquired infections, and airway injury (5).

Although early mobilization addresses limb weakness, respiratory muscle weakness is even more prevalent in ICU patients. For instance, Dres et al. reported that diaphragmatic dysfunction affects up to 63% of medical ICU patients at the time of liberation from MV, compared to 34% with limb muscle weakness(5). ICU survivors ventilated for 7 days or longer exhibit a decrease in inspiratory muscle strength and endurance (6, 7). Prolonged MV also adversely affects consciousness, cognition, psychological state, healthcare costs, and long-term quality of life (8-10). Therefore, respiratory muscle rehabilitation is a critical, yet sometimes overlooked, component of recovery for patients undergoing long-term invasive ventilation (11).

The diaphragm is the primary muscle of inspiration, and its dysfunction is nearly universal in mechanically ventilated patients (12). A previous study used a lighter sedation regimen as a way to keep the patient's diaphragm activated during mechanical ventilation, but it still failed to prevent the onset of ventilator-induced diaphragmatic dysfunction (13). Emerging evidence suggests that targeted exercise of the respiratory muscles, particularly the diaphragm, can shorten MV duration, improve respiratory function, and accelerate overall recovery (14, 15).

Rehabilitation interventions to facilitate weaning include conventional physiotherapy, inspiratory muscle training (IMT), expiratory muscle training, and early mobilization.

Inspiratory muscle training is one of the more widely used rehabilitation tools internationally and can be delivered using various devices, including threshold loaders, electronic resistive devices, and pressure-based trainers (16). A previous systematic review indicated that inspiratory muscle training shortens extubation time but does not reduce mechanical ventilation duration, and the included studies exclusively focused on inspiratory muscle training (17). More recently, Vorona et al. confirmed that IMT improves respiratory muscle strength in critically ill adults, though it did not assess other lung function parameters comprehensively (18). The most recent systematic review suggests IMT may reduce the risk of reintubation and shorten IMV weaning time, while also increasing MIP measurements (19, 20). However, clinical practice indicates that both inspiratory and expiratory muscles are affected during prolonged MV. Optimal respiratory rehabilitation should theoretically engage both muscle groups, yet few syntheses have analyzed the effect of comprehensive respiratory muscle training on objective lung function measures in ICU patients.

While recent reviews have focused on IMT and MV duration, fewer have systematically evaluated the impact of diverse respiratory training techniques—including expiratory and integrative methods—on objective lung function measures such as forced vital capacity (FVC). This meta-analysis therefore aimed to evaluate the effectiveness of various respiratory muscle training techniques on lung function and MV duration in mechanically ventilated ICU patients, compared to conventional care. We focused on maximum inspiratory pressure (MIP) as a direct measure of respiratory muscle strength, forced vital capacity (FVC) as an indicator of lung volume, and MV duration as a critical clinical outcome reflecting weaning progress and resource utilization.

Methods

This systematic review was registered (PROSPERO registration number: CRD42024599044) and is reported according to the PRISMA guidelines(see the appendix for the full report) (21).

Search strategy

This systematic review was conducted on the databases from PubMed, Web of Science, EMBASE, and Cochrane Library from inception to 30th April 2025. For specific search strategies, please refer to Table S1. Keywords were retrieved using PubMed filters and screened using Medical Subject Headings (MeSH). The search terms were subsequently adapted for use in other electronic databases. Included study references and clinical trial registries were hand-searched. There was no publication date, age, or setting restrictions; however, only articles published in English were included.

Eligibility criteria

The inclusion criteria for this review were as follows: a) Participants were adults (≥18 years) receiving invasive mechanical ventilation in an ICU for over 48 hours. b) Clear diagnosis of outcomes: Respiratory dysfunction leading to mechanical ventilation for more than 48 hours. c) Study design: A randomized controlled study. d) The right intervention: The experimental group underwent respiratory muscle strength training, including active respiratory training devices and adjunctive modalities such as neuromuscular electrical stimulation or chest physiotherapy. The comparators in the RCT were conventional physical therapy, usual care, or a sham for mechanically ventilated patients. Exclusion criteria: a) The full text was unavailable; b) Repeat publication; c) Unpublished reports and gray literature.

Study selection and data collection process

The search strategy was developed in consultation with a medical librarian specializing in systematic reviews. The literature search was initially conducted by two researchers (HJY and MH) in August 2024 and finally updated in April 2025 (HH and MH). Two authors (HJY and HH) independently performed an initial screening of the retrieved study titles and abstracts. The full texts were reviewed as necessary. Carefully review the inclusion and exclusion criteria to determine which eligible articles can be included in this study. In the event of a dispute, we will have a third person (MH) review the matter. Two researchers thoroughly extracted key information from the eligible studies included in this review. Variables considered for extraction were first author, year of publication, basic patient profile, sample size, interventions and outcome indicators. The quality of the included studies was then independently assessed using the Cochrane Collaboration's risk of bias tool(22). Studies providing point estimates of outcome measures and measures of variability (such as mean and standard deviation) were included in the analysis. Discrepancies were identified and resolved through discussion with a third review author. For the missing data in the article, we first read the full article again carefully, and if we did not find any relevant reports, we contacted the author of this article to obtain detailed data.

Data synthesis and analysis

We used Review Manager 5.3 software to conduct data review and perform meta-analysis. We estimated the differences between the control and intervention groups. Continuous variables were analyzed using standardized mean differences (SMD). Each effect size was presented with a 95% confidence interval (CI). Heterogeneity among studies was assessed using the I^2 test: $I^2 \leq 50\%$ indicated homogeneity, warranting a fixed-effect model; $I^2 > 50\%$ indicated heterogeneity, necessitating a random-effects model (23). $I^2 < 35\%$ indicates low heterogeneity, $35\% \leq I^2 < 75\%$ indicates moderate heterogeneity, and $I^2 \geq 75\%$ indicates high heterogeneity. Subgroup analyses were conducted to assess sources of heterogeneity. Funnel plots were constructed for visual assessment of potential publication bias for the primary outcomes (MIP, FVC, and MV duration).

Results

Study identification

The flowchart illustrating the literature search and study selection is presented in Fig.1. A total of 1049 studies were retrieved from these databases, of which 269 duplicate studies were preliminarily excluded. After screening titles and abstracts, an additional 698 articles were excluded. Were further excluded after full-text review because the treatment modality was not met in 45 studies, other inclusion criteria were not met in 17 articles, and outcome indicators were not reported in 2 articles. After full-text screening, 18 studies met the inclusion criteria.

Study characteristics

The characteristics and the number of participants in all included studies are presented in Table 1. These 18 studies were published between 1998 and 2024. Finally, five different interventions provided sufficient data for the meta-analysis. Rehabilitation interventions include IMT(n=12) (24-35), functional electrical stimulation(n=2), one in each limb and abdomen (36, 37), supported arm exercise(n=1) (38), Liuzijue exercise(n=1) (39) and comprehensive pulmonary rehabilitation refers to a combination of multiple therapies, including electrical stimulation and physical exercise training(n=2) (40, 41). Fourteen of the studies had maximum inspiratory pressure as an outcome measure, six assessed FVC, and six assessed Duration of mechanical ventilation.

Risk of bias assessment

The risk of bias of the included RCTs is shown in Fig.2. We read in detail the study design of the included article and we defined it as a randomized controlled study as long as they had an elaboration of the method of randomization or a statement of randomization in the experimental design. If the article had a statement of non-double blinding or there was an explanation of non-blinding in the experimental procedure we defined it as a non-double blinded study, otherwise all were considered to have reached the level of double blinding. A low risk of bias in the generation of a random sequence was evident in 16 studies (88.89%). A suitable method of allocation concealment was used in 16 studies (88.89%). Although this was a set of clinical trials, our study had a high level of participant blinding assurance for both trials. In addition, the 18 studies we included were at low risk for outcome assessment blinding, incomplete data, selective reporting bias, and other potentially risky outcome evaluations.

Primary outcome measures

Not all studies chose the same primary outcome assessment. The following outcomes were assessed: inspiratory muscle strength, forced vital capacity and duration of mechanical ventilation. In 14 of the included studies, inspiratory muscle force was measured as maximum inspiratory pressure in cmH_2O (24-29, 31-35, 37-39). In addition, six studies measured the change in FVC (30, 32, 37, 39-41) and duration of mechanical ventilation (24-26, 29, 31, 34) in patients before and after the intervention. In addition to these studies, a small number of studies used peak inspiratory flow rate, peak expiratory flow, maximum expiratory pressure, and modified Borg scale as an assessment of treatment efficacy.

Inspiratory muscle strength

These 14 studies provided data on a total of 762 participants, 384 in the control group and 368 in the intervention group. As we can see in Fig.3, inspiratory muscle training significantly improved maximum inspiratory pressure in the experimental compared with the control group, with a mean difference of 0.88 cmH_2O (I^2=79%, 95% CI 0.53 to 1.24).

Forced vital capacity

Six of the included studies reported FVC, and these six studies provided data on a total of 257 participants, 105 in the control group and 152 in the intervention group. Respiratory muscle training significantly improved FVC by a mean difference of 0.32 breaths/l (I^2=0%, 95% CI 0.07 to 0.58). See Fig.4 for a detailed forest plot.

Duration of mechanical ventilation

Six of the included studies reported the duration of mechanical ventilation, and these six studies provided data on a total of 347 participants, 178 in the control group and 169 in the intervention group. On average, the respiratory muscle training group had a shorter time to wean by 0.88 days, indicating a significant improvement in the voluntary respiratory function of the patients in the intervention group (I^2=15%, 95% CI -1.10 to -0.66). See Fig.5 for a detailed forest plot.

Subgroup analyses

To explore the effects of different respiratory muscle training techniques on maximum inspiratory pressure, in a post hoc subgroup analysis, studies in which participants performed respiratory muscle training with an IMT device were analyzed separately from studies in which other respiratory muscle training modalities were used. Unless an IMT device is used for the intervention, it is uniformly categorized into the other technology group. Study subgroups of patients in the intervention group with either an IMT device or other respiratory training approaches showed significant improvements in MIP (Fig.6).

Publication Bias

Visual inspection of funnel plots for maximum inspiratory pressure (MIP; Supplementary Fig. S1), forced vital capacity (FVC; Supplementary Fig. S2), and mechanical ventilation duration (Supplementary Fig. S3) revealed generally symmetrical distributions of studies around the pooled effect estimate, indicating a low risk of publication bias. Minor asymmetries observed in the MIP plot may be attributed to clinical heterogeneity or the limited number of smaller studies reporting negative results.

Discussion

Our meta-analysis, incorporating 18 RCTs, demonstrates that RMT significantly improves MIP and FVC, while shortening the duration of mechanical ventilation in ICU patients. These findings reinforce the role of targeted respiratory rehabilitation as a valuable adjunct to standard ICU care, particularly for facilitating weaning.

With the development and improvement of medical technology, there has been a significant increase in clinical trials investigating the efficacy of respiratory muscle training on mechanically ventilated patients in the ICU. Compared to earlier systematic reviews (e.g., Elkins & Dentice), our analysis benefits from a larger number of trials, more diverse intervention modalities, and a broader set of outcome measures(18, 42). While Vorona et al. established the efficacy of IMT for improving respiratory strength, and recent 2025 reviews have further quantified its impact on weaning parameters, our review uniquely synthesizes data across multiple RMT techniques (IMT, functional electrical stimulation, supported arm exercise, Liuzijue, comprehensive rehab) and includes the under-reported outcome of FVC(18, 19). The consistency of positive effects across different techniques strengthens the general argument for integrating some form of respiratory-specific exercise into ICU rehabilitation protocols.

Fourteen of the 18 studies included in this review reported changes in maximum inspiratory pressure before and after training, and meta-analysis showed that respiratory training significantly improved maximum inspiratory pressure (24-29, 31-34, 37-39). Unfortunately, one study had incomplete data because the MIP values for the control group before and after the intervention were not published in the article (40). Three studies did not detect MIP values, possibly due to limitations of their equipment or unfamiliarity with the technique (30, 36, 41).

The significant improvement in MIP observed herein can be attributed to the reversal of ventilator-induced diaphragmatic dysfunction. Prolonged mechanical ventilation leads to disuse atrophy, oxidative stress, and proteolysis in the diaphragm(43, 44). RMT, particularly IMT, acts as a form of overload exercise for the inspiratory muscles. By imposing a threshold or resistive load, it enhances neural drive, improves neuromuscular efficiency and motor unit recruitment, and may stimulate muscle protein synthesis while reducing catabolic pathways(45). The increase in MIP thus reflects not merely greater strength, but restored neuromuscular integrity and physiological reserve—key factors that reduce the work of breathing and delay fatigue during weaning trials(46, 47).

Pulmonary function tests include spirometry and ventilatory function tests. Pulmonary function tests are helpful in the diagnosis and treatment of various lung diseases, of which the most commonly used is spirometry (48). Although our results showed that respiratory muscle exercise significantly elevated FVC in patients, only seven studies in this review measured FVC, and one of them was missing post-intervention FVC values (38). Of course, some of the studies used other lung function indices, such as peak inspiratory flow rate, peak expiratory flow rate, and maximum expiratory pressure. There were also a majority of studies that did not report objective data on lung volumes. This likely reflects the inherent challenges of performing volitional spirometry in critically ill, often debilitated or cognitively impaired patients (49). Even small gains in lung volume may contribute to improved secretion clearance and alveolar recruitment, supporting the weaning process(50). The reduction in MV duration by nearly a full day is clinically meaningful, as it translates to decreased exposure to ventilator-associated risks and potentially lower ICU costs.

Reduced respiratory muscle workload in mechanically ventilated patients leads to respiratory muscle atrophy, and the duration of mechanical ventilation significantly impacts the patient's recovery process (51). It can be argued that the average effect of inspiratory muscle training on weaning success has clinical value (52). Although only six studies in this review reported the duration of mechanical ventilation, the results suggest that performing respiratory muscle training can significantly shorten the MV time of patients. Of course, more experimental data are needed to further demonstrate that there is a significant effect of performing this training and that this effect has clinical value. In addition, some studies have also responded to the effect of training by looking at the patient's time in the ICU or the overall length of hospitalization, but care needs to be taken to assess the patient's economic status, as the time, effort, and money spent in the ICU have a significant impact on the outcome of the patient's duration (53).

The included studies differed in various aspects, and different respiratory muscle training techniques may have led to statistical heterogeneity among the findings (54). Therefore, this review conducted a subgroup analysis of technical factors that may influence the effectiveness of respiratory muscle exercise. Our subgroup analysis indicated that most RMT techniques improved MIP. However, the study by McCaughey et al. found that abdominal FES did not significantly improve MIP(37). This negative result invites a nuanced interpretation. Abdominal FES aims to augment expiratory force and cough efficacy. Its lack of effect on MIP is perhaps unsurprising but also highlights patient-specific factors that may limit its utility. Critically ill patients often present with fluid overload, elevated intra-abdominal pressure, or significant edema, which could dampen the mechanical transmission of electrical stimuli and attenuate muscle contraction. This suggests that abdominal FES might be less effective in patients with severe abdominal distension. Future research should stratify participants by intra-abdominal pressure or volume status to identify which patient phenotypes might benefit most from this modality.

Study strengths and limitations

A key strength of this review is its inclusion of diverse respiratory training techniques beyond IMT alone, providing a broader perspective on ICU respiratory rehabilitation.

We also reported on the less commonly synthesized outcome of FVC. However, several limitations must be acknowledged. First, significant clinical and methodological heterogeneity was present across studies, including variations in patient populations (e.g., post-operative, COPD, COVID-19), intervention protocols (type, intensity, duration of RMT), and ICU settings. While we employed random-effects models and conducted subgroup analyses, this heterogeneity necessitates cautious interpretation of the pooled effect estimates. Second, the need to convert data reported as median and interquartile range to mean and standard deviation in some instances may have introduced measurement error and affected precision. Third, the exclusion of non-English studies and potential publication bias may limit the comprehensiveness of our findings. Finally, the reporting of adverse events related to RMT was sparse in the included trials, an important gap for future research to address safety profiles.

Conclusions and Future Directions

In conclusion, this meta-analysis supports the use of respiratory muscle training as an effective intervention to improve respiratory strength (MIP), lung volumes (FVC), and accelerate liberation from mechanical ventilation in ICU patients. The benefits appear consistent across several training modalities, offering clinicians flexibility in application. To strengthen the evidence base, future RCTs should prioritize: (1) larger, multi-center designs with adequate sample sizes; (2) standardized reporting of RMT protocols (including intensity, frequency, and progression); (3) inclusion of patient-centered outcomes such as weaning success rates, ICU/hospital length of stay, and long-term functional recovery; and (4) systematic assessment and reporting of intervention safety and tolerability. Such studies will help refine clinical guidelines and establish the most efficient and effective respiratory rehabilitation strategies for critically ill patients.

Abbreviations

ICU intensive care unit

RCTs randomized controlled trials

RMT respiratory muscle training

MIP maximum inspiratory pressure

FVC forced vital capacity

MV mechanical ventilation

IMT inspiratory muscle training

SMD standardized mean difference

CI confidence interval

Author contributions

HY, HH, WD, LW, MH and LY substantially contributed to the study concept and design. Literature searches were performed by HY, HH and MH; statistical analyses were conducted by HY and WD. LW, MH, and LY contributed significantly to the analysis and interpretation of the data. Patient perspective insight was provided and written by LY. All authors contributed to manuscript drafting, critically revised the work, and agreed with the presented findings. All authors are responsible for the overall content as guarantors. All authors approved the version of the article to be published.

Clinical trial number

Not applicable.

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Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Table 1. Characteristics of included studies

Author (year)	Participants	Ages (years)	Sample size (con/exp)	Gender (men/women)	Intervention	Primary outcomes
Stefano Nava (1998)	Patients with acute respiratory failure	65.5±6.9	80 (20/60)	51/29	Comprehensive rehabilitation program	FVC; FEV1
Fadia Ahmed Abdelkader Reshia (2023)	Patients who received MV for 48 hours	38.1±6.9	70 (35/35)	42/28	Comprehensive rehabilitation program	FVC; FEV1
Olcay Akar (2015)	Intubated chronic obstructive pulmonary disease patients were monitored for a minimum of 24 hours on mechanical ventilation.	69.0±14.9	20 (10/10)	9/11	Functional electrical stimulation	Heart rate; Muscle strength
Euan J. McCaughey (2019)	Patients who dependent on MV	58.8±13.2	20 (10/10)	8/12	Functional electrical stimulation	MIP; FVC; FEV1
Roberto Porta (2005)	Patients who received MV for 48 to 96 hours	71.0±5.7	66 (34/32)	45/21	Supported arm exercise	MIP; FVC; FEV1
ZHANG Qiao-li (2023)	Patients had undergone cardiovascular surgery in the Cardiothoracic ICU	55.9±13.0	80 (40/40）	50/30	Liuzijue exercise	MIP; FVC; FEV1
Samária Ali	Patients who	82.5±5.3	41 (20/21)	19/22	IMT	MIP; Duration of

Cader (2010)	received MV for 48 hours					mechanical ventilation
Samária Ali Cader (2012)	Patients who received MV for 48 hours in a controlled mode	81.5±5	28 (14/14)	13/15	IMT	MIP; Duration of mechanical ventilation
Mohammed S. Elbouhy (2014)	Patients were diagnosed with an acute exacerbation of chronic obstructive pulmonary disease with acute respiratory failure requiring mechanical ventilation support.	62.7±10.5	40 (20/20)	33/7	IMT	MIP; Duration of mechanical ventilation
Bernie M Bissett (2016)	Patients who received MV for 7 days	59.0±14.4	70 (36/34)	45/25	IMT	MIP
Rodrigo Marques Tonella (2017)	Patients who received MV	53.2±5.1	19 (8/11)	15/4	IMT	MIP; Rapid shallow breathing index
L.M. Sandoval Moreno (2019)	Patients who received MV for 48 hours	61.5±20.3	126 (64/62)	71/55	IMT	MIP; Duration of mechanical ventilation
Bruno da Silva Guimarães (2020)	Patients who received MV	66.1±16.2	101 (53/48)	49/52	IMT	MIP; Duration of mechanical ventilation
Ahmed M. Abodonya (2021)	COVID-19 patients who received MV	48.1±8.8	42 (21/21)	33/9	IMT	FVC; FEV1

Marine Van Hollebeke (2022)	Patients who received MV	57.6±15.1	41 (19/22)	22/19	IMT	MIP; FVC
Bernie M. Bissett (2023)	Patients who received MV for 7 days	60.0±16.0	70 (37/33)	41/29	IMT	MIP
Reyhan Kaygusuz Benli (2024)	Patients who received MV for 48 hours	63.5±12.6	20 (10/10)	16/4	IMT	MIP
Farnoosh Khodabandelo o (2023)	Patients who received MV	65.0±14.5	79 (39/40)	41/38	IMT	MIP; Duration of mechanical ventilation

MV: mechanical ventilation; IMT: inspiratory muscle training; FVC: forced vital capacity; FEV1: forced expiratory volume in one second; MIP: maximum inspiratory pressure.

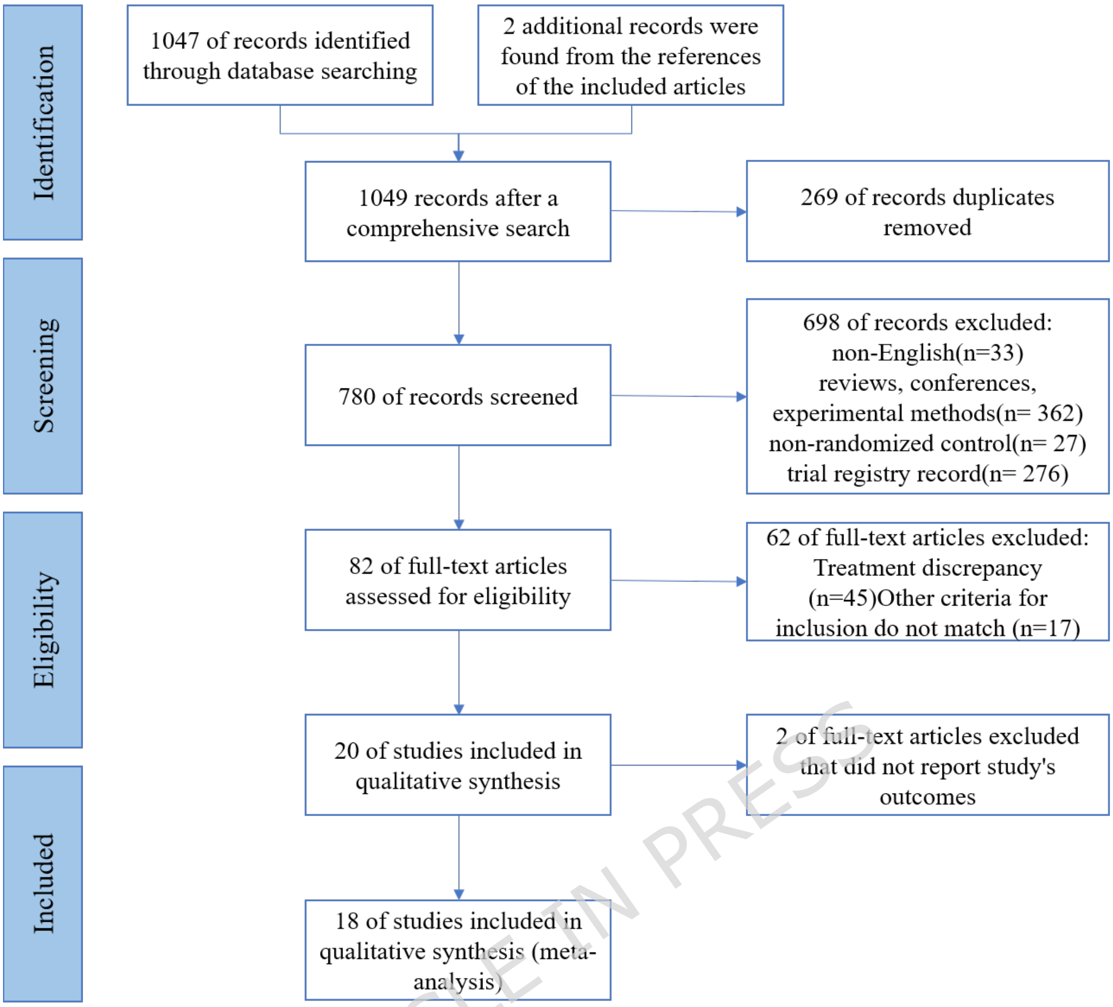

Fig.1. PRISMA flowchart of the study selection process.

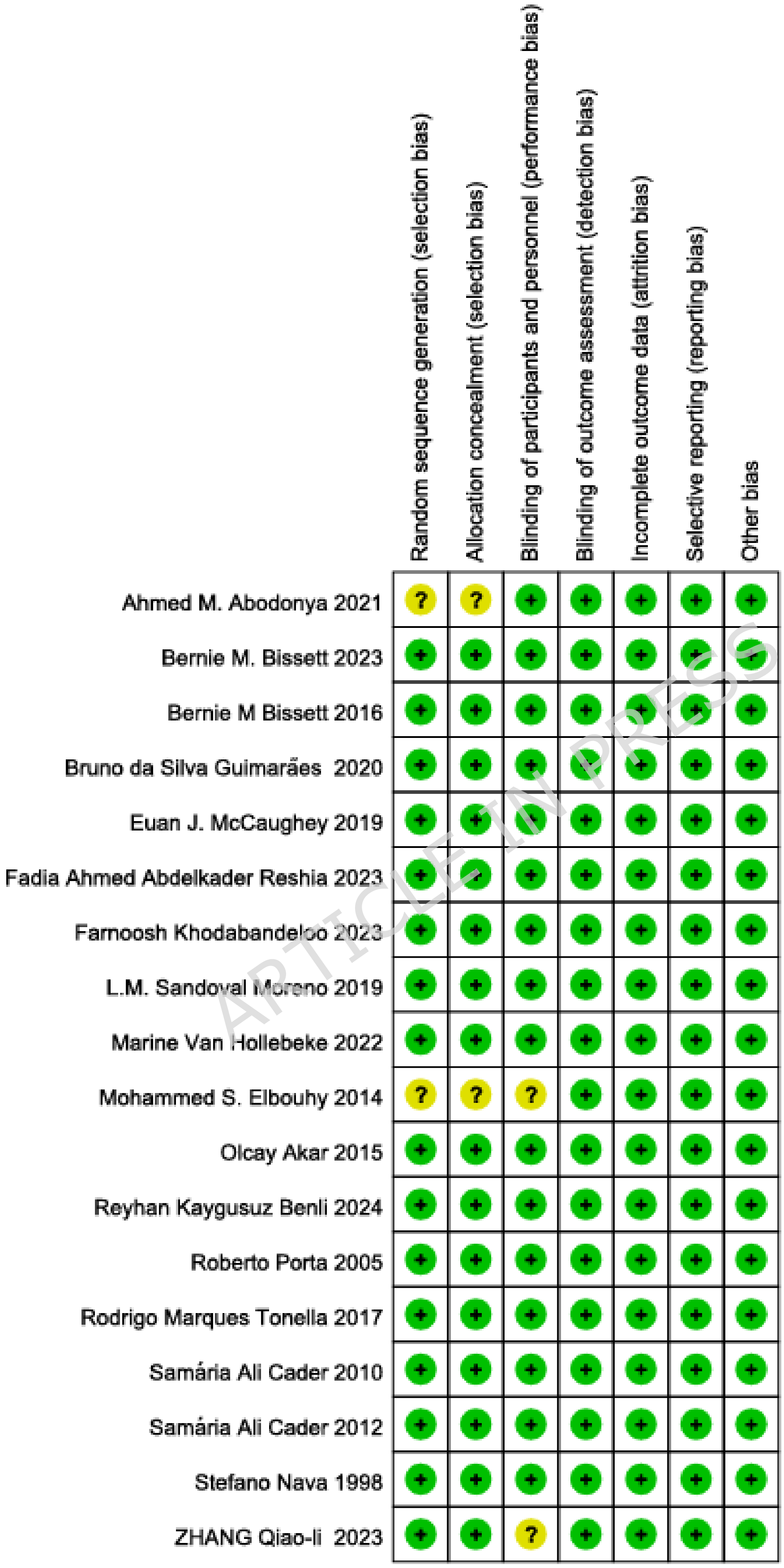

Fig.2. Results of risk of bias assessment for included studies.

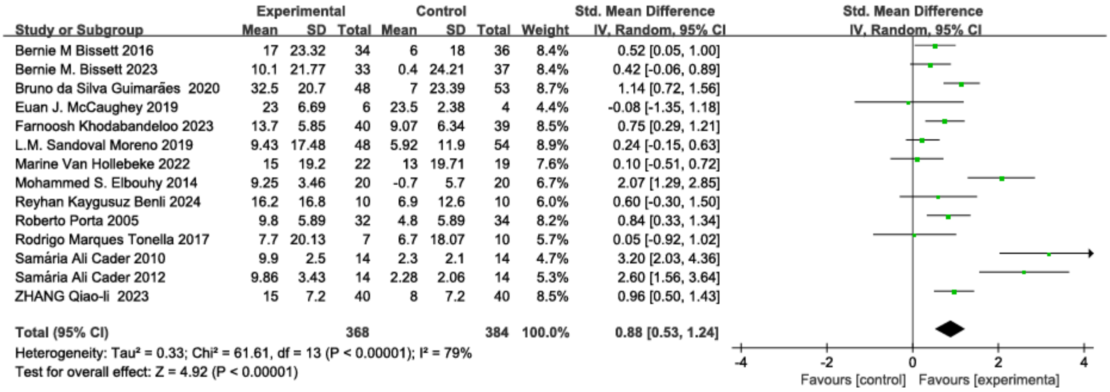

Fig.3. Forest plot showing the effects of respiratory training on maximum inspiratory pressure.

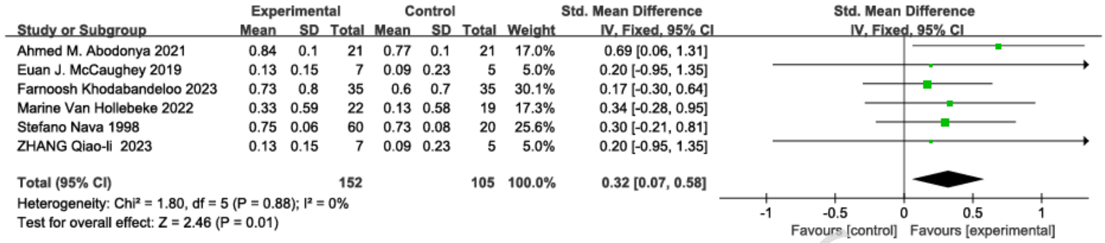

Fig.4. Forest plot showing the effects of respiratory training on forced vital capacity.

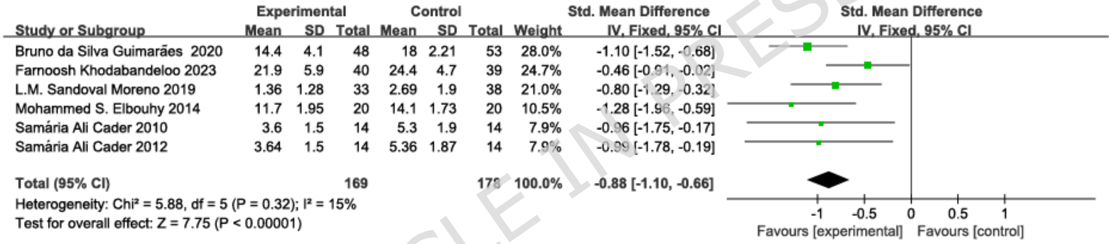

Fig.5. Forest plot showing the effects of respiratory training on the duration of mechanical ventilation.

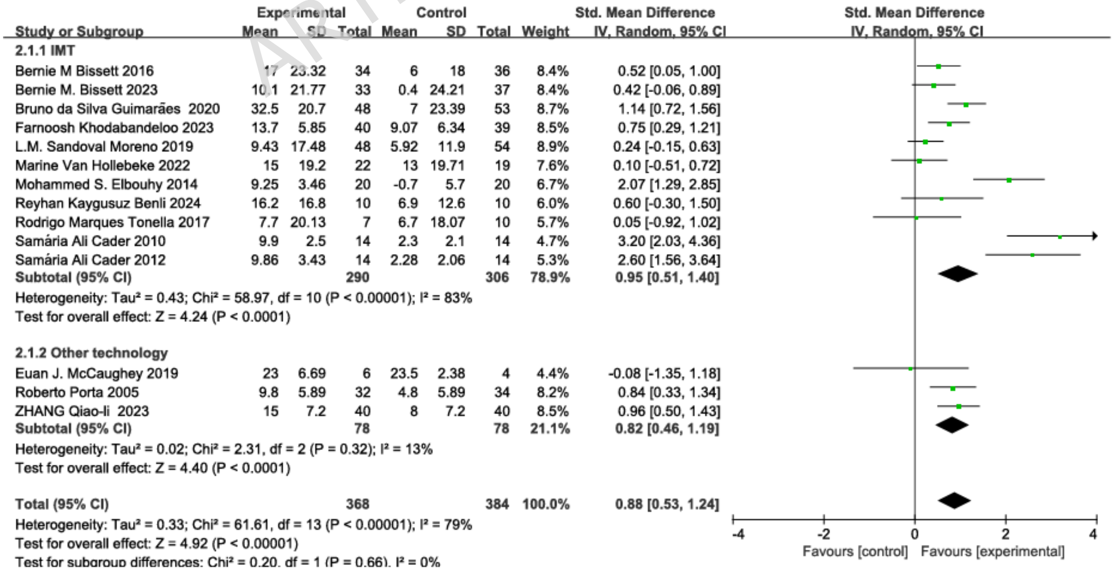

Fig.6. Forest plot showing the effects of different respiratory muscle training modalities on maximum inspiratory pressure.