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META-ANALYSIS

Effects of respiratory muscle training on post-stroke rehabilitation: A systematic review and meta-analysis

Yong-Tao Liu, Xiao-Xin Liu, Yi-Qing Liu, Lei Zhang, Lin-Jing Zhang, Jian-Hua Wang, Yan Shi, Qing-Fan Xie

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Yong-Tao Liu, Lin-Jing Zhang, Jian-Hua Wang, Yan Shi, Qing-Fan Xie, Department of Rehabilitation, Xingtai People's Hospital, Xingtai 054001, Hebei Province, China

Xiao-Xin Liu, Ophthalmologist Clinic, Xingtai People's Hospital, Xingtai 054001, Hebei Province, China

Yi-Qing Liu, Department of Cardiology, Xingtai People's Hospital, Xingtai 054001, Hebei Province, China

Lei Zhang, Department of Ultrasound, Xingtai People's Hospital, Xingtai 054001, Hebei Province, China

Corresponding author: Qing-Fan Xie, MBBS, Doctor, Department of Rehabilitation, Xingtai People's Hospital, No. 818 Xiangdu North Road, Xingtai 054001, Hebei Province, China. jqf190525@126.com

Abstract

BACKGROUND
Stroke often results in significant respiratory dysfunction in patients. Respiratory muscle training (RMT) has been proposed as a rehabilitative intervention to address these challenges, but its effectiveness compared to routine training remains debated. This systematic review and meta-analysis aim to evaluate the effects of RMT on exercise tolerance, muscle strength, and pulmonary function in post-stroke patients.

AIM
To systematically assess the efficacy of RMT in improving exercise tolerance, respiratory muscle strength, and pulmonary function in patients recovering from a stroke, and to evaluate whether RMT offers a significant advantage over routine training modalities in enhancing these critical health outcomes in the post-stroke population.

METHODS
Following the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines, a comprehensive search across PubMed, Embase, Web of Science, and the Cochrane Library was conducted on October 19, 2023, without temporal restrictions. Studies were selected based on the predefined inclusion and exclusion criteria focusing on various forms of RMT, control groups, and outcome measures [including forced expiratory volume in the first second (FEV1), forced

vital capacity (FVC), maximal voluntary ventilation (MVV), peak expiratory flow (PEF), maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and 6-min walking test (6MWT)]. Only randomized controlled trials (RCTs) were included. Data extraction and quality assessment were conducted independently by two reviewers using the Cochrane Collaboration's risk of bias tool. Statistical analyses, including those using the fixed-effect and random-effects models, sensitivity analysis, and publication bias assessment, were performed using Review Manager software.

RESULTS

A total of 15 RCTs were included. Results indicated significant improvements in MIP (12.51 cmH_2O increase), MEP (6.24 cmH_2O increase), and various pulmonary function parameters (including FEV1, FVC, MVV, and PEF). A substantial increase in 6MWT distance (22.26 meters) was also noted. However, the heterogeneity among studies was variable, and no significant publication bias was detected.

CONCLUSION

RMT significantly enhances walking ability, respiratory muscle strength (MIP and MEP), and key pulmonary function parameters (FEV1, FVC, MVV, and PEF) in post-stroke patients. These findings support the incorporation of RMT into post-stroke rehabilitative protocols.

Key Words: Respiratory muscle training; Stroke rehabilitation; Pulmonary function; Exercise tolerance; Meta-analysis

Core Tip: Our research aimed to contribute to the ongoing discourse regarding the efficacy of respiratory muscle training (RMT) in enhancing rehabilitation outcomes for post-stroke patients. By systematically analyzing data from 15 randomized controlled trials, our meta-analysis provided compelling evidence that RMT significantly improves respiratory muscle strength, pulmonary function, and walking ability in this patient population. These findings hold considerable potential to impact clinical practices and stroke rehabilitation protocols.

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INTRODUCTION

Cerebrovascular accidents, commonly referred to as strokes, are a major cause of disability worldwide. Characterized by an abrupt loss of cerebral function secondary to either an infarction or hemorrhage, strokes lead to localized neurological deficits that significantly impact patients' quality of life[1]. Among the myriad complications following a stroke, the impairment of respiratory muscles is a critical but often underappreciated consequence. This impairment manifests as respiratory muscle weakness, altered respiratory rhythms, and decreased lung volumes and flow rates, which can severely limit a patient's functional capacity and quality of life[2,3]. Moreover, the post-stroke period is marked not only by peripheral muscle dysfunction but also by respiratory complications. Impairments such as weakened respiratory muscles, limited thoracic expansion, and dysfunctional postural trunk control are common. These complications not only diminish the overall muscle strength but also notably restrict exercise capacity and the ability to perform daily activities, exacerbating the physical and psychological burden on post-stroke patients[4,5].

Given these respiratory challenges faced by post-stroke patients, the utilization of respiratory muscle training (RMT) as a rehabilitative intervention appears plausible and warranted. The rationale for incorporating RMT is grounded in the observed decline in respiratory muscle strength in this patient population[6,7]. However, the literature presents a complex and somewhat contradictory picture of the effectiveness of RMT in post-stroke rehabilitation. Previous reviews have yielded mixed findings regarding the efficacy of RMT in post-stroke patients. Xiao *et al*[8], in their analysis, highlighted the lack of robust evidence supporting the benefits of inspiratory muscle exercise following a stroke. In the context of neurological disorders more broadly, Pollock *et al*[9] reported that while RMT might improve inspiratory muscle strength, its effects on expiratory muscle strength are less clear, and the overall clinical significance remains uncertain. Further complicating the narrative, Kulnik *et al*[10] observed that respiratory muscle activity and cough flow naturally improve over time post-stroke, without any additional benefits conferred by targeted inspiratory or expiratory muscle training.

These inconsistent findings, coupled with limitations in study design such as small sample sizes, variable study quality, and the inclusion of patients with stroke-related comorbidities, underscore the need for an updated and comprehensive systematic review and meta-analysis. Our study aimed to fill this gap by meticulously evaluating the available randomized controlled trials (RCTs) that investigate the effects of RMT on exercise tolerance, respiratory muscle strength, and pulmonary function in post-stroke patients. By synthesizing and critically appraising the current evidence, this review intended to clarify the role of RMT in enhancing the respiratory function and overall rehabilitation outcomes in this vulnerable population.

MATERIALS AND METHODS

Search strategy

To ensure the comprehensive acquisition of pertinent literature for our meta-analysis, a systematic search strategy was employed, adhering strictly to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines. On October 19, 2023, an extensive search was conducted across four major electronic databases: PubMed, Embase, Web of Science, and the Cochrane Library. This search was executed without imposing any temporal constraints to maximize the inclusivity of relevant studies. The search terms utilized included "respiratory muscle training," "respiratory function," "lung function," and "stroke." These terms were strategically chosen to align with the PICO (patient, intervention, comparison, outcome) framework, thereby ensuring a broad yet focused retrieval of studies relevant to our analysis. Furthermore, no restrictions were placed on the language of the publications. Additionally, the reference lists of all identified articles were manually scrutinized to uncover any additional studies that might contribute valuable data to our meta-analysis. This meticulous search strategy was designed to assemble a comprehensive body of evidence, facilitating a robust and thorough analysis of the effects of RMT in stroke patients.

Inclusion criteria and exclusion criteria

The inclusion criteria were: (1) Intervention: Various forms of RMT were considered, including inspiratory muscle training (IMT), expiratory muscle training (EMT), or a combination thereof; (2) Control group: Studies included must have had a control group that either did not receive any respiratory training or underwent sham RMT without resistance; (3) Outcomes: The primary outcome variables were related to pulmonary function, encompassing forced expiratory volume in the first second (FEV1), forced vital capacity (FVC), maximal voluntary ventilation (MVV), and peak expiratory flow (PEF). Additionally, parameters indicating respiratory muscle weakness, such as maximal expiratory pressure (MEP) and maximal inspiratory pressure (MIP), were considered, along with functional capacity measures, including the 6-min walking test (6MWT); and (4) Study design: Only RCTs were included to ensure the reliability and validity of the results.

The exclusion criteria were: (1) Outcome reporting: Studies that did not report the specified outcome variables were not considered; (2) Study design: Non-RCTs were excluded to maintain the integrity of the study design; and (3) Data availability: Studies with insufficient data available for analysis were also excluded.

Data extraction

For our meta-analysis, two independent evaluators conducted the literature screening and data extraction process, with each evaluator working separately and then cross-checking their results for consistency. In cases of any discrepancies, the evaluators engaged in discussions to resolve these issues and, if necessary, consulted a third-party reviewer for an objective resolution. The data extracted included key information such as the first author's name and the publication year, the country of origin of the study, the period of data collection, and detailed characteristics of the study sample, including the size, mean age, and gender distribution. Additionally, specific details about the inclusion and exclusion criteria of each study were recorded, along with the principal outcomes. In situations where the published reports lacked necessary data, we reached out to the original study investigators *via* email to request any unpublished data, ensuring a comprehensive and accurate dataset for our analysis. This rigorous and methodical approach to data extraction was vital for ensuring the reliability and integrity of our meta-analysis.

Quality assessment

In our meta-analysis, the evaluation of study quality was conducted using the Cochrane Collaboration's risk of bias tool. This assessment was carried out independently by two reviewers, who scrutinized various domains of potential bias within the included studies. These domains encompassed the generation of random sequences, the concealment of allocation processes, the blinding of study participants and personnel, the completeness of outcome data, the presence of selective reporting, and the identification of any other possible sources of bias. For each domain, the risk of bias was categorized as low, unclear, or high. In instances where the two reviewers had differing opinions on the risk of bias in any domain, they engaged in a detailed discussion to reach a consensus. If a consensus could not be reached through discussion alone, the issue was escalated to a third reviewer for an additional opinion and resolution. This rigorous quality assessment process was integral to ensuring the validity and reliability of our meta-analysis findings.

Statistical analysis

In our meta-analysis, the statistical analysis focused on assessing the heterogeneity between the included studies. This assessment was performed using chi-square statistics, and the degree of heterogeneity was quantified by the I^2 value. When the I^2 value was found to be less than 50% and the corresponding P-value was 0.10 or higher, it was interpreted as an absence of significant heterogeneity among the studies. Under these conditions, a fixed-effect model was employed to calculate the combined effect size. Conversely, in cases where the I^2 value reached or exceeded 50%, or the corresponding P-value fell below 0.10, this indicated the presence of significant heterogeneity. In such scenarios, the random-effects

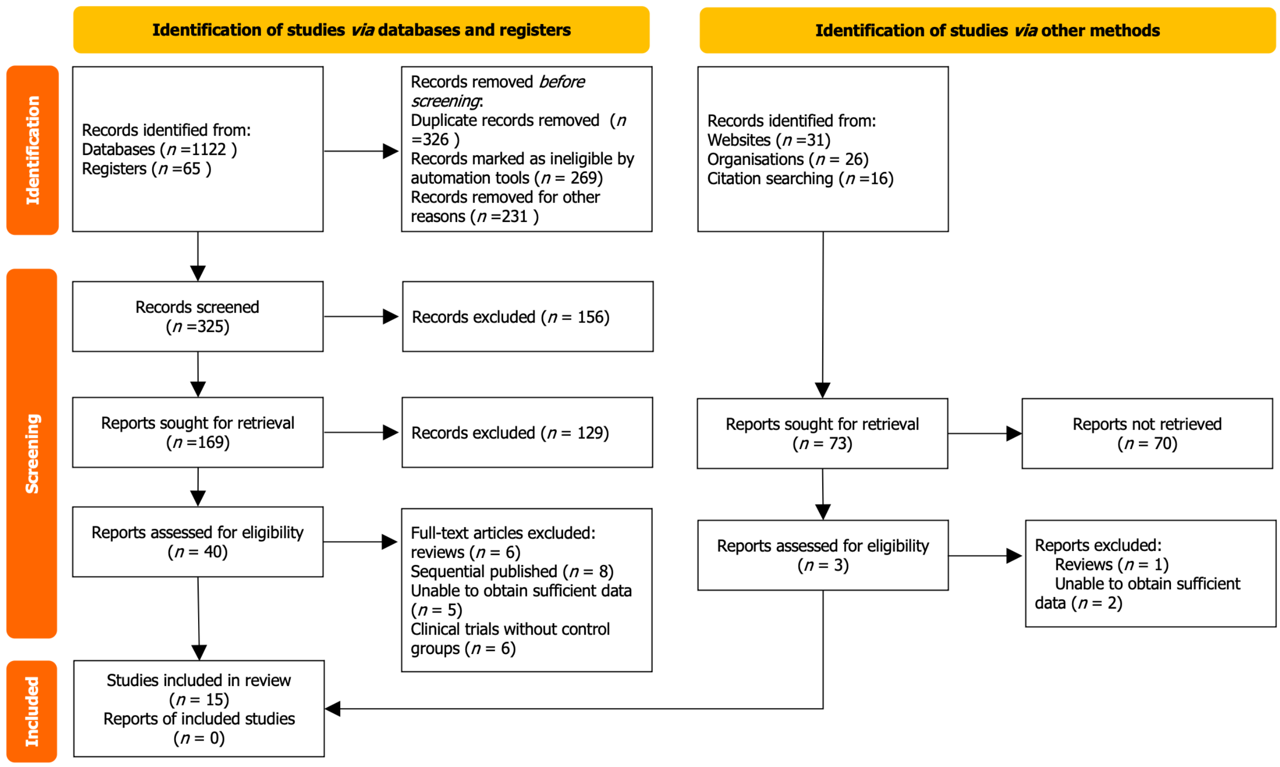

Figure 1 Flowchart depicting process of article selection for meta-analysis, illustrating stages of screening, eligibility assessment, and final inclusion.

model was utilized to compute the combined effect size. This model takes into account the variation between studies, offering a more nuanced understanding of the data in the presence of heterogeneity. To ensure the robustness of our findings, a sensitivity analysis was conducted. This analysis aims to identify and address potential sources of heterogeneity. It involves a sequential omission process, where each study is removed one at a time from the meta-analysis, followed by a recalculation of the overall effect size. This procedure is instrumental in determining the influence of individual studies on the cumulative effect size and in verifying the stability of the results. Additionally, the potential for publication bias was explored by analyzing the symmetry of the funnel plot. A symmetric distribution of data points around the apex of the funnel plot would indicate a lower risk of results being skewed by publication bias. For a more quantitative assessment of publication bias, Egger's linear regression test was applied. All statistical tests conducted in this meta-analysis were two-sided, with a *P*-value threshold of less than 0.05 set for statistical significance. The data analyses were performed using Review Manager software (version 5.3; Cochrane Collaboration, Copenhagen, Denmark).

RESULTS

Search results and study selection

In the inception stage of this systematic review and meta-analysis, an exhaustive search across various electronic databases culled an initial set of 1260 articles of potential relevance. To refine this dataset, an algorithm was employed to remove duplicate entries, thus ensuring that each unique study was represented only once. A meticulous evaluation of titles and abstracts ensued, based on the rigorously defined inclusion and exclusion criteria. These criteria covered an array of variables, including the study methodology, demographic characteristics of the study population, clinical outcomes measured, and the overall quality of research methods. Post this preliminary filtering, a subset of 43 articles was identified for more in-depth scrutiny. Multiple investigators independently conducted a thorough examination of each article's full text to ensure an unbiased, comprehensive assessment. During this phase, 28 articles were excluded for specific reasons, enumerated as follows: Review articles (*n* = 7), sequentially published works (*n* = 8), insufficient data for analysis (*n* = 7), and clinical trials lacking control groups (*n* = 6). As a result, a total of 15 articles were deemed to meet all stringent requirements as delineated in our research protocol, thus qualifying for inclusion in the final meta-analysis[11-25] (Figure 1).

Study characteristics

The meta-analysis encompassed a diverse range of studies that investigated the effects of RMT on patients who had suffered from strokes. A total of 15 studies were included, each varying in their approach to RMT and control interventions. The studies were conducted between 2008 and 2022, reflecting a comprehensive overview of recent research in this field. The experimental interventions across these studies primarily involved different forms of RMT,

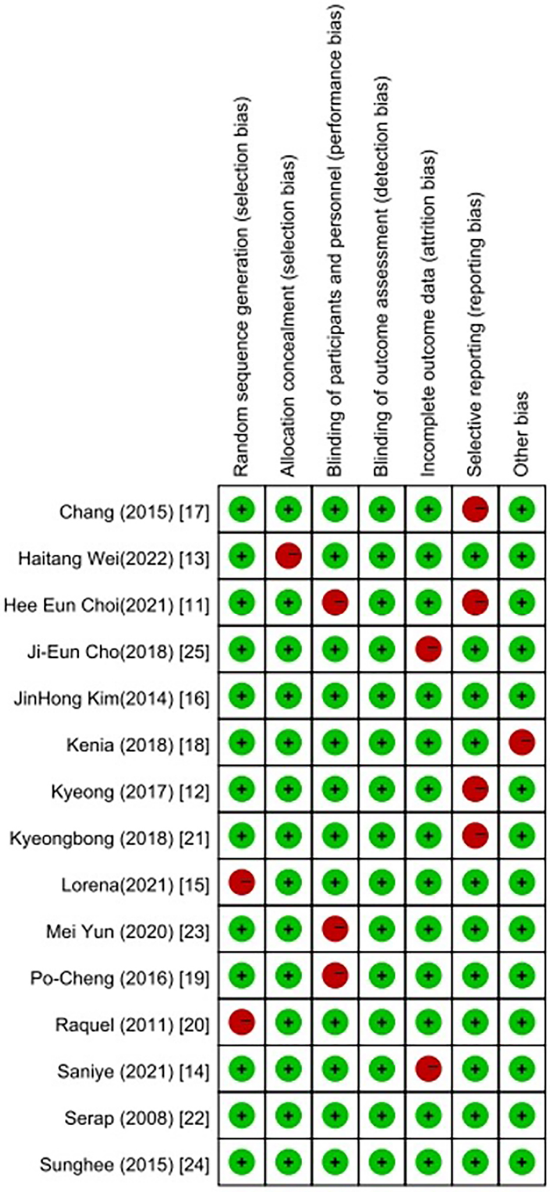

Figure 2 Graphical representation of quality assessment for included studies, based on the Cochrane Collaboration's risk of bias tool. The color-coding indicates the level of risk: Red for high risk, yellow for unclear risk, and green for low risk.

such as IMT and EMT, with training regimens ranging from daily sessions to weekly protocols over periods of 4 to 12 wk. Control groups in these studies typically received either standard rehabilitation without RMT, sham RMT, or conventional physical and occupational therapies. Key outcome measures evaluated across these studies included pulmonary function parameters like FVC, FEV1, PEF, and the FEV1/FVC ratio. Respiratory muscle strength was commonly assessed through MIP and MEP. However, exercise tolerance, measured through tests like the 6MWT, was less frequently assessed and was not applicable in some studies (Table 1).

Results of quality assessment

In the meta-analysis, the risk of bias was meticulously evaluated across several domains in the included studies. This assessment revealed that a significant portion of the studies, precisely seven, exhibited a low risk of bias in all evaluated categories. This finding indicates a commendable level of methodological rigor and reliability in these studies, suggesting that their findings are likely to be robust and credible. On the other hand, a notable concern was observed in the domain of blinding of participants and personnel. Approximately 20% of the studies were identified as having a high risk of bias in this area. This suggests a potential for performance bias, which could have influenced the outcomes and interpretations of these studies, thereby impacting the overall reliability of their results. Additionally, in 26% of the RCTs included in the meta-analysis, there was a high risk of selective reporting bias. This type of bias arises when certain outcomes are selectively reported or omitted, which can lead to a skewed understanding of the study's results. The presence of such bias raises concerns about the completeness and objectivity of the reported findings in these trials. This varied spectrum of bias risks among the included studies, as depicted in Figure 2, underscores the need for cautious interpretation of the overall results of the meta-analysis. It highlights the importance of considering the potential impact of methodological

Table 1 Characteristics of studies included in the meta-analysis

Ref.	Intervention (experimental group)	Intervention (control group)	Pulmonary function	Respiratory muscle strength	Exercise tolerance
Kim *et al*[17] (2015)	Received routine therapy and RMT using incentive respiratory spirometer for 15 min a day, five times a week for 6 wk	All of the subjects received routine therapy for stroke rehabilitation for 1 h, five times a week for 6 wk	FVC, FEV1	NA	NA
Wei *et al*[13] (2022)	The experimental group received a Breathe-Link trainer based on regular training, with rehabilitation training for 12 wk as the time node	One group was set as the control group and received routine breathing training	FVC, FEV1, FEV1/FVC	NA	NA
Choi *et al* [11] (2021)	The RMT program was conducted daily 5 times/wk for 1 mo. Each exercise session lasted 30 min	The standard rehabilitation (SR) group (patients who did not undergo RMT)	MVV, FVC, FEV1, PEF	MIP, MEP	NA
Cho *et al*[25] (2018)	The experimental group underwent inspiratory muscle training with resistance adjusted to 30% of maximal inspiratory pressure, 90 breaths a day, 5 times a week for 6 wk	Both groups received regular physical therapy for the same amount of time	NA	MIP	6MWT
Kim *et al*[16] (2014)	The exercise group performed the same exercise regimen as the control group, as well as an additional respiratory muscle training regimen using a respiratory exercise device for 20 min	The control group received basic exercise treatments for 30 min, followed by an automated full-body workout for 20 min	FVC, FEV1, FEV1/FVC, PEF	NA	6MWT
Parreiras de Menezes *et al*[18] (2018)	The experimental group received 40-min high-intensity home-based respiratory muscle training, 7 d per week, for 8 wk, progressed weekly	The control group received a sham intervention of similar dose	NA	MIP, MEP	6WMT
Lee *et al*[21] (2018)	Both forced expiratory/inspiratory muscle training were repeated 10-15 times, 5 set for 20 min in a session and a resting time of 30-60 s between each set	All patients received conventional physical and occupational therapy conducted for 30 min, 2 times a day, and 6 times per week, but no RMT or TSE	PEF, FEV1, VC	MIP, MEP	NA
Jung *et al* [12] (2017)	Patients in the experimental group received inspiratory muscle training for 30 min (six sets of 5-min) and traditional physical therapy once a day, 5 d a week, for 4 wk	The control group received aerobic exercise for 30 min and traditional physical therapy for 30 min a day, 5 d a week, for 4 wk	FVC, FEV1	NA	10MWT, 6MWT
Vaz *et al*[15] (2021)	The experimental group (EG) (n = 23) underwent IMT for 30 min/d, five times/wk over 6 wk	The control group (CG) (n = 27) performed sham IMT	NA	MIP, MEP	6MWT
Liaw *et al* [23] (2020)	Expiration training pressure commenced from 15% to 75% of threshold load of an individual's MEP for 5 sets of 5 repetitions, 1 to 2 times per day, 5 d a week for 6 wk; 1 to 2 min of rest was allowed between each set	Usual rehabilitation program	FVC, FEV1, FEV1/FVC, MMEF	MIP, MEP	NA
Chen *et al* [19] (2016)	Patients in the IMT group received an additional IMT program beginning with an intensity of 30% maximal inspiratory pressure (MIP), then increased by 2 cmH_2O each week for 30 min daily for at least 5 d a week for 10 wk	Participated in a conventional stroke rehabilitation program	FVC, FEV1, FEV1/FVC	MIP, MEP	NA
Britto *et al* [20] (2011)	Interventions were based on home-based training, with resistance adjusted biweekly to 30% of MIP for the experimental group	The control group underwent the same protocol without the threshold resistance valve. Both groups received home training 30 min a day 5 times a week for 8 wk	NA	MIP	NA
Aydoğan Arslan *et al* [14] (2021)	The patient was asked to work-out 15 min in 2 sessions (30 min per day), 7 d a week. IMT was performed 5 d a week in 1 session with the help of a physiotherapist	Received routine breathing training	FVC, FEV1, PEF, FEV1/FVC	MIP, MEP	6MWT
Sutbeyaz *et al*[22] (2008)	The subjects started breathing at a load of 40% of the maximum inspiratory pressure (PImax). Exercise intensity was gradually increased, 5%–10% each session, to 60% of PImax as tolerated. All patients trained daily for two sessions of 15 min each, six times a week for 6 wk	Both the training groups and the control group participated in a conventional stroke rehabilitation programme, 5 d a week for 6 wk	FEV1, FVC, VC, PEF, MVV	MIP, MEP	NA
Joo *et al*[24] (2015)	The GBE group participated in a GBE program for 25 min a day, 3 d a week, during a 5-wk period	Both groups participated in a conventional stroke rehabilitation program	FVC, FEV1, FEV1/FVC, MVV	NA	NA

NA: Not available; FVC: Forced vital capacity; FEV1: Forced expiratory volume in the first second; FEV1/FVC: Ratio of forced expiratory volume in the first second to forced vital capacity; PEF: Peak expiratory flow; MIP: Maximal inspiratory pressure; MEP: Maximal expiratory pressure; MWT: Minute walk test.

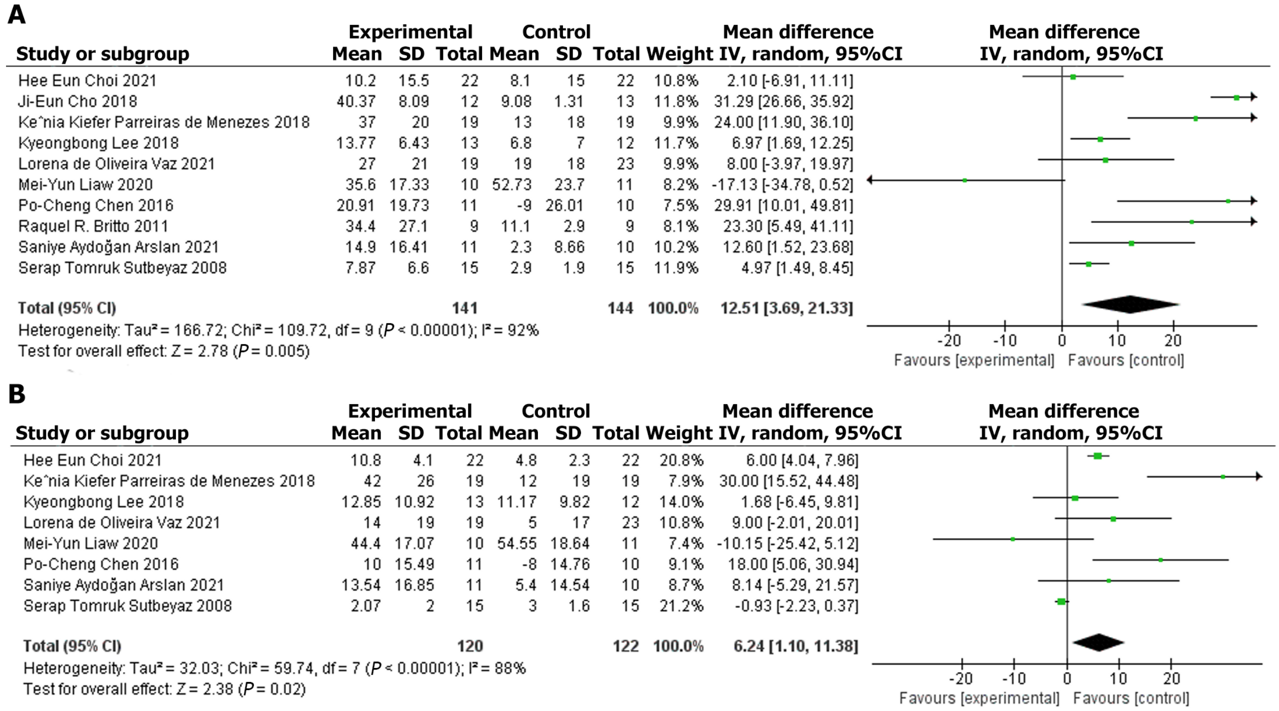

Figure 3 Graphs showing impact of respiratory muscle training on (A) maximal inspiratory pressure and (B) maximal expiratory pressure, indicating changes in inspiratory and expiratory muscle strength.

weaknesses in the included studies on the meta-analysis's conclusions.

Effects of RMT on maximal inspiratory pressure and maximal expiratory pressure

In this meta-analysis, the effects of RMT on both inspiratory and expiratory muscle strengths were examined through an assessment of MIP in ten studies and MEP in eight studies. Due to the heterogeneity among these studies, a random-effects model was applied for both analyses. The findings revealed significant improvements in respiratory muscle strength following the training. Specifically, MIP showed a considerable increase of 12.51 cmH_2O (95% confidence interval [CI]: 3.69 to 21.33, P = 0.005) with a high heterogeneity (I^2 = 92%), as shown in Figure 3A. In parallel, MEP also demonstrated notable enhancement, registering an improvement of 6.24 cmH_2O (95%CI: 1.10 to 11.38, P = 0.02), accompanied by significant heterogeneity (I^2 = 88%) as depicted in Figure 3B. These results collectively highlight the effectiveness of RMT in substantially enhancing both inspiratory and expiratory muscle strengths.

Impact of RMT on pulmonary function tests

This meta-analysis evaluated the effect of RMT on various pulmonary function test parameters, employing standardized mean difference (SMD) for analysis due to the use of different units in the included studies. Eleven studies were analyzed for FEV1 as an outcome. The meta-analysis revealed a significant enhancement in FEV1 among participants who underwent RMT, with an SMD of 1.11 (95%CI: 0.17 to 2.05, P = 0.02). The heterogeneity across these studies was high (I^2 = 92%), as illustrated in Figure 4A. In assessing FVC, ten studies were included. The findings indicated a notable improvement in FVC for those in the RMT group, with an SMD of 1.58 (95%CI: 0.51 to 2.66, P = 0.004). This outcome also exhibited substantial heterogeneity (I^2 = 93%), as shown in Figure 4B. The ratio of FEV1 to FVC was evaluated in six studies. The analysis showed a non-significant difference in this ratio among RMT participants compared to controls, with an SMD of 1.57 (95%CI: -0.10 to 3.25, P = 0.07) and a very high level of heterogeneity (I^2 = 95%), presented in Figure 4C. MVV was assessed in three studies. The results demonstrated a significant improvement in MVV in the RMT group, evidenced by an SMD of 1.13 (95%CI: 0.19 to 2.06, P = 0.02). The heterogeneity was moderately high (I^2 = 80%), as depicted in Figure 4D. Lastly, PEF was examined in five studies. The meta-analysis indicated a significant improvement in PEF for those undergoing RMT, with an SMD of 0.52 (95%CI: 0.18 to 0.86, P = 0.003). Notably, these studies showed low heterogeneity (I^2 = 6%), as seen in Figure 4E.

In summary, this meta-analysis underscores the positive impact of RMT on various aspects of pulmonary function, particularly in the improvements observed in FEV1, FVC, MVV, and PEF, while the effect on FEV1/FVC ratio was not significant. The varying levels of heterogeneity across these results suggest the influence of diverse methodologies and

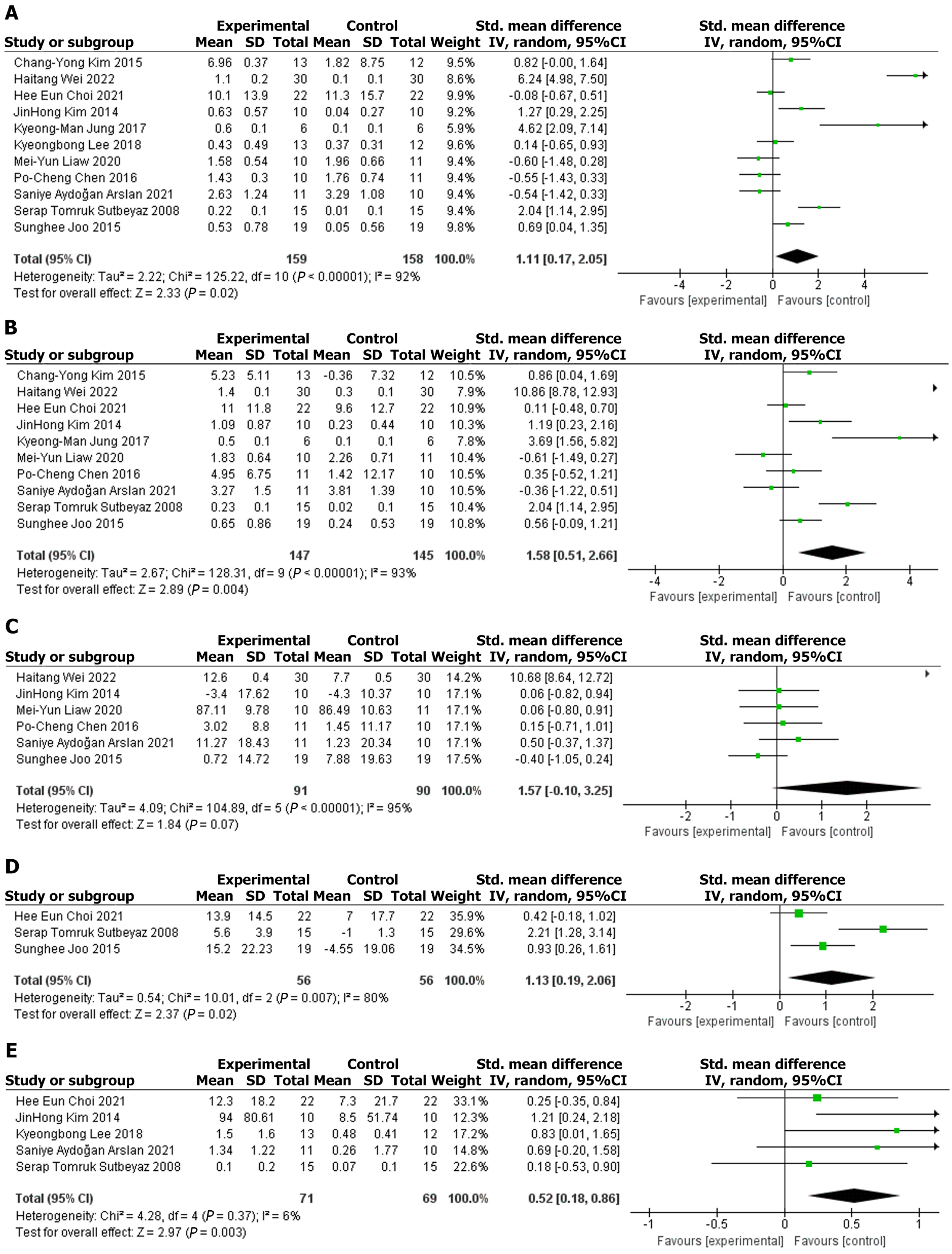

Figure 4 Series of charts illustrating effects of respiratory muscle training on various pulmonary function test outcomes. A: Forced expiratory volume in the first second (FEV1); B: Forced vital capacity (FVC); C: FEV1/FVC ratio; D: Maximal voluntary ventilation; E: Peak expiratory flow.

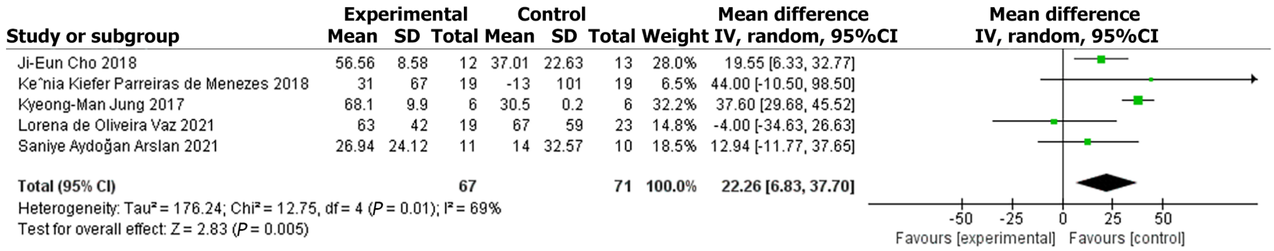

Figure 5 Graph demonstrating influence of respiratory muscle training on exercise tolerance, measured by improvements in the 6-min walk test.

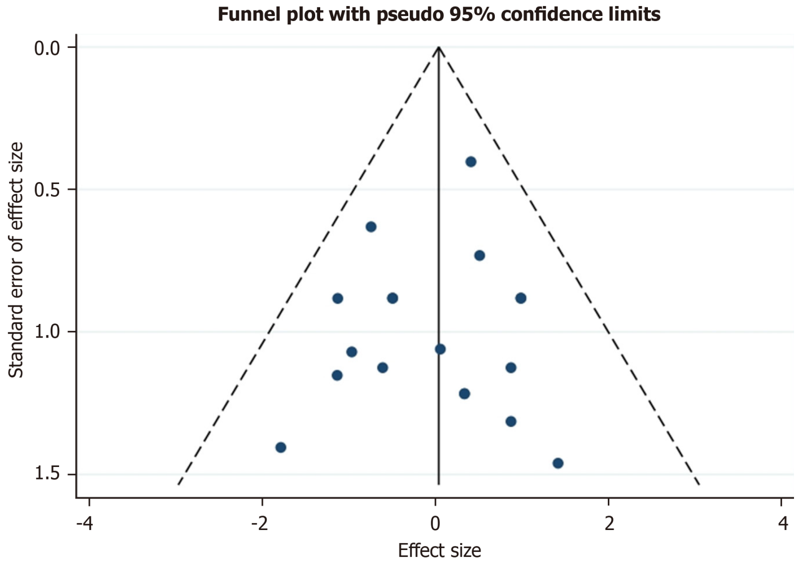

Figure 6 Funnel plot analyzing publication bias across all studies included in the meta-analysis, visually assessing the symmetry of data distribution.

participant characteristics in the included studies.

Improvement in exercise tolerance due to RMT

This segment of the meta-analysis focused on evaluating the effect of RMT on exercise tolerance, particularly measured by the 6MWT. The assessment was based on data extracted from five studies. The meta-analytical results revealed a significant enhancement in exercise tolerance among participants who underwent RMT. Specifically, the improvement in 6MWT distance was quantified as 22.26 meters (95%CI: 6.83 to 37.70, P = 0.005). This positive outcome denotes a substantial increase in the functional exercise capacity of these individuals. The heterogeneity among the studies was moderate, indicated by an I^2 value of 69%, as depicted in Figure 5.

Publication bias

Publication bias in this meta-analysis was rigorously evaluated using funnel plots and Egger's linear regression test. The funnel plots, displaying symmetry (Figure 6), suggested no significant publication bias among the included studies. Complementing this, Egger's test across various variables revealed no significant bias (P > 0.05 for all), affirming the robustness and reliability of our meta-analysis findings.

DISCUSSION

Stroke incidence is on an upward trajectory, increasingly becoming a leading cause of disability. A significant concern in stroke patients is the prevalent respiratory dysfunction, characterized by markedly reduced respiratory muscle strength. It has been observed that a substantial majority of these patients display impaired respiratory muscle function, with 89.0% showing weakened inspiratory muscles and 82.6% exhibiting compromised expiratory muscles[26]. Additionally, stroke patients who remain bedridden for extended periods, especially those requiring long-term mechanical ventilation, are at a heightened risk of developing respiratory muscle wasting and atrophy[27]. This decline in respiratory muscle strength is a critical issue, as it leads to several adverse outcomes. These include impaired pulmonary ventilation, diminished capacity for coughing, an increased likelihood of pulmonary complications, and a reduction in cardiopulmonary endurance. Furthermore, it adversely affects trunk balance and control, key factors in the rehabilitation process for stroke survivors[28,29].

In addressing these respiratory challenges, RMT plays a pivotal role. Typically, this training involves using a respiratory trainer to engage patients in repetitive pressurized breathing exercises. Such training has been shown to effectively enhance respiratory function in stroke patients, not only helping to prevent pulmonary complications but also improving trunk stability and cardiopulmonary endurance[30]. However, there is some debate in the scientific community regarding the efficacy of RMT, with certain studies suggesting that its effects may not significantly differ from those of standard routine training. This controversy underscores the need for a comprehensive systematic review and meta-analysis to elucidate the true impact of RMT in the rehabilitation of stroke patients.

Our meta-analysis robustly supports the use of RMT for improving respiratory muscle strength in stroke patients, a group commonly experiencing significant respiratory dysfunction. This is particularly relevant given that stroke patients often have respiratory muscle strength less than half that of healthy adults, with high incidences of impaired inspiratory and expiratory muscles. Our findings showed substantial improvements in MIP by 47% and MEP by 28%. These enhancements are crucial in the context of stroke rehabilitation, as reduced respiratory muscle strength is known to lead to impaired pulmonary ventilation, decreased coughing capacity, and increased risk of pulmonary complications. Furthermore, our analysis indicates significant improvements in pulmonary function tests, including FEV1, FVC, PEF, and MVV. These results are in line with previous systematic reviews and meta-analyses[31], emphasizing the effectiveness of RMT in improving lung volumes and flows. This improvement is particularly important given the abdominal and diaphragmatic dysfunction observed in stroke patients, which contributes to weakened respiratory muscles and constrictive ventilatory patterns[32,33].

The enhancement in exercise tolerance, as observed in the 6MWT, underscores the importance of respiratory muscle strength in stroke patients[34]. Diminished exercise tolerance in stroke patients is often attributed to respiratory impairments, such as reduced lung volumes and weakened respiratory muscles. Our findings suggest that RMT significantly ameliorates these issues, leading to improved exercise tolerance and, consequently, better ability to perform daily tasks. The load applied during RMT is a critical factor for effectiveness. Our analysis revealed that loads ranging from 15% to 75% of MEP and 30% to 60% of MIP were used, with higher loads often linked to better functional outcomes [35]. Additionally, the baseline respiratory muscle strength plays a pivotal role in the efficacy of RMT. In ten of the included trials, baseline strength was reported to be less than the anticipated MIP of 60 cmH2O, significantly below the 80 cmH2O threshold for clinically significant weakness[36]. This aligns with findings from Montemezzo *et al*[37], which suggest that patients with poorer baseline inspiratory muscles experienced more significant improvements post-training.

Our study, while comprehensive, has limitations that should be acknowledged. Meta-analyses inherently come with heterogeneity, and our study was no exception. Not all included studies provided uniform variables, leading to the exclusion of certain variables like BBS and MAS scores from our analysis. The predominance of studies involving patients with post-stroke respiratory muscle weakness (MIP < 50 cmH_2O) might have skewed the results. Variations in RMT characteristics and the inclusion/exclusion criteria of the studies were also present. However, subgroup analysis could differentiate the benefits of IMT alone from combined IMT and EMT exercises. Finally, the overall sample size, despite a large number of included studies, was relatively small.

CONCLUSION

The meta-analysis results affirm the substantial impact of RMT in post-stroke rehabilitation. It significantly boosts walking ability in stroke patients, enhances both inspiratory and expiratory muscle strength, and improves crucial pulmonary function parameters, including FEV1, FVC, MVV, and PEF.

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FOOTNOTES

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