Perioperative respiratory muscle training improves respiratory muscle strength and physical activity of patients receiving lung surgery: A meta-analysis

Yang MX et al. RMT in patients receiving lung surgery

Meng-Xuan Yang, Jiao Wang, Xiu Zhang, Ze-Ruxin Luo, Peng-Ming Yu

Abstract

BACKGROUND
The clinical role of perioperative respiratory muscle training (RMT), including inspiratory muscle training (IMT) and expiratory muscle training (EMT) in patients undergoing pulmonary surgery remains unclear up to now.

AIM
To evaluate whether perioperative RMT is effective in improving postoperative outcomes such as the respiratory muscle strength and physical activity level of patients receiving lung surgery.

METHODS
The PubMed, EMBASE (via OVID), Web of Science, Cochrane Library and Physiotherapy Evidence Database (PEDro) were systematically searched to obtain eligible randomized controlled trials (RCTs). Primary outcome was postoperative respiratory muscle strength expressed as the maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP). Secondary outcomes were physical activity,
exercise capacity, including the 6-min walking distance and peak oxygen consumption during the cardio-pulmonary exercise test, pulmonary function and the quality of life.

RESULTS
Seven studies involving 240 participants were included in this systematic review and meta-analysis. Among them, four studies focused on IMT and the other three studies focused on RMT, one of which included IMT, EMT and also combined RMT (IMT-EMT-RMT). Three studies applied the intervention postoperative, one study preoperative and the other three studies included both pre- and postoperative training. For primary outcomes, the pooled results indicated that perioperative RMT improved the postoperative MIP (mean = 8.13 cmH2O, 95%CI: 1.31 to 14.95, P = 0.02) and tended to increase MEP (mean = 13.51 cmH2O, 95%CI: -4.47 to 31.48, P = 0.14). For secondary outcomes, perioperative RMT enhanced postoperative physical activity significantly (P = 0.006) and a trend of improved postoperative pulmonary function was observed.

CONCLUSION
Perioperative RMT enhanced postoperative respiratory muscle strength and physical activity level of patients receiving lung surgery. However, RCTs with large samples are needed to evaluate effects of perioperative RMT on postoperative outcomes in patients undergoing lung surgery.

Key Words: Respiratory muscle training; Respiratory muscle strength; Physical activity; Lung surgery; Systematic review and meta-analysis

Core Tip: Our study indicated that perioperative respiratory muscle training (RMT) improved the postoperative maximal inspiratory pressure \( (P = 0.02) \) and tended to increase maximal expiratory pressure \( (P = 0.14) \). For secondary outcomes, perioperative RMT enhanced postoperative physical activity significantly \( (P = 0.006) \) and a trend of improved postoperative pulmonary function was observed. Perioperative RMT enhanced postoperative respiratory muscle strength and physical activity level of patients receiving lung surgery.
INTRODUCTION

Respiratory muscle strength, representing as maximal inspiratory pressure (MIP) and maximal expiratory (MEP), and physical activity level decreased inevitably after thoracic surgery due to pain and ineffective coughing\(^{[1,2]}\). These will adversely affect postoperative recovery and quality of life\(^{[3,4]}\). The function of respiratory muscles is directly impaired by the surgical incision in the chest wall. Meanwhile, the total chest compliance is reduced due to the injured respiratory muscles after thoracic surgery, especially after lung surgery\(^{[4]}\). The impairment of respiratory muscle strength after pulmonary resection leads to an adverse effect on the expectoration of sputum\(^{[4,5]}\).

With the great advance of the enhanced recovery after surgery concept, a number of physiotherapy methods have been widely introduced and applied in clinical practice in order to remove secretions from the lungs and decrease respiratory work load following thoracic surgery. These methods include airway clearance techniques, active cycle of breathing, incentive spirometry, breathing exercises, early mobilization and also respiratory muscle training (RMT). RMT includes both inspiratory muscle training (IMT) and expiratory muscle training (EMT)\(^{[6-8]}\). IMT increases inspiratory muscle strength, relieve inspiratory muscle tension, improve diaphragm function and contributes to lung expansion, thereby helping to maintain the airtway patency\(^{[9,10]}\). Meanwhile, it could also inhibit sympathetic nerve function, improve vagus nerve activity and reduce peripheral vascular resistance\(^{[9,10]}\). EMT help create high expiratory flows to remove airway secretions and increases the overall effectiveness of participants’ voluntary cough, which effectively reduces the incidence of pulmonary complications\(^{[11,12]}\). For most of patients receiving lung surgery, including patients who receive the segmentectomy, lobectomy or pneumonectomy with video-assisted thoracic surgery (VATS) or open thoracotomy, the RMT is applicable. However, in some conditions such as combining the tracheotomy, recurrent paralysis, myasthenia gravis or unstable coronary artery disease, the RMT is prohibited. Up to now, a large number of studies have investigated the clinical effects of perioperative RMT in patients undergoing major surgery. Mans et al\(^{[13]}\) analyzed eight relevant studies involving 295
participants undergoing upper abdominal or cardiothoracic surgery. They demonstrated that preoperative IMT could substantially improve MIP (mean = 15 cmH\textsubscript{2}O, 95%CI: 9 to 21 cmH\textsubscript{2}O, \(P < 0.001\)) and reduce PPCs [relative risk (RR) = 0.48, 95%CI: 0.26 to 0.89, \(P = 0.02\)]. However, large differences exist between lung surgery and other types of surgery, including the effect on respiratory muscle function, level of physical activity and risk for PPCs\textsuperscript{[13-15]}.

Therefore, we conducted this systematic review and meta-analysis to further investigate the effect of perioperative RMT on postoperative outcomes, especially the respiratory muscle strength and physical activity, in patients following lung surgery, which also helps strengthen the understanding of the value of RMT before and after lung surgery.

**MATERIALS AND METHODS**

We performed this systematic review and meta-analysis according to the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines \textsuperscript{[16]}. Meanwhile, it has been registered with PROSPERO (ID: CRD42020214940).

**Literature search**

The electronic databases of PubMed, EMBASE (via OVID), Web of Science, Cochrane Library and PEDro were systematically searched from inception to March 24, 2021. The following MeSH terms were used for literature search: “respiratory muscle training”, “inspiratory muscle training”, “expiratory muscle training”, “lung resection”, “pulmonary resection”, “lung surgery”, “lobectomy”, “segmentectomy”, “wedge resection”, “pneumonectomy”, “video-assisted thoracoscopic surgery”, “video-assisted thoracic surgery” and “VATS”. The specific search strategy was: (respiratory muscle training OR inspiratory muscle training OR expiratory muscle training) AND (lung resection OR pulmonary resection OR lung surgery OR pulmonary surgery OR lobectomy OR segmentectomy OR wedge resection OR pneumonectomy OR video-
assisted thoracic surgery OR video-assisted thoracoscopic surgery OR VATS). The reference lists of included studies were also reviewed for eligibility.

Inclusion criteria and exclusion criteria
The following inclusion criteria were applied: (1) randomized controlled trials (RCT) investigating the effects of perioperative RMT, compared with sham RMT or no RMT; (2) participants were adults; (3) articles were published in English; and (4) at least one of the following outcomes was reported.

The exclusion criteria of this study were as follows: (1) meeting abstracts, letters, reviews, non-human trials, protocols, case reports; (2) other perioperative interventions were combined; and (3) training programs were poorly designed and the clinical parameters and training doses of patients were not reported.

Primary outcome was the postoperative respiratory muscle strength representing as the MIP and MEP and.

Secondary outcomes were the physical activity, exercise capacity including the 6-min walking distance (6MWD) and peak oxygen consumption (VO₂peak) during the cardio-pulmonary exercise test (CPET), pulmonary function such as the forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC), and the quality of life representing as the intensity of pain and dyspnoea.

Two authors (YP and YM) screened the records for availability independently. At first, the titles and abstracts were reviewed. Then, the full-texts were further assessed to determine the eligibility when the information in the titles or abstracts was potentially related or insufficient and the availability of relevant data was verified. Any discrepancy was solved by team discussion.

Data extraction
The following data were extracted: author, publication year, country, sample size, type of surgery, specific intervention strategy including the initial training pressure, training time, frequency and duration of training program, treatment strategy of control group,
information necessary to calculate the PEDro scale score, primary outcomes and secondary outcomes.

All patients in the included studies received usual care after surgery. Usual care consists of different breathing exercises aiming pulmonary re-expansion and bronchial clearance, early ambulation and mobilization.

**Methodological quality assessment**

The methodological quality of included studies was assessed by two independent investigators (MY and JW) using the PEDro. The high quality was defined as a PEDro score of 6 or higher, the fair quality was defined as a PEDro score of 4 or 5 and a score of 3 or lower indicated poor quality.[17,18]

**Statistical analysis**

All statistical analysis was performed by RevMan version. The heterogeneity between included studies was quantified by the $I^2$ statistic and Q test. If significant heterogeneity was observed, representing as $I^2 > 50\%$ or $P < 0.10$, the random-effect model was used; otherwise, the fixed-effect model was used.[19,20]. Continuous data were analyzed as the changes from baseline values at one of the following time points: at admission, before the intervention or operation to final values at one of the following time points: at discharge, after the intervention or an interval after the surgery. For continuous variables, the mean differences (MDs) with standard deviations (SDs) were extracted to calculate the MDs and corresponding 95% CIs between the intervention and control group. The data that were reported as the means and range values were converted to means and SDs using the formula reported by Hozo et al.[21]. A $P$ value < 0.05 was considered statistically significant.

**RESULTS**

**Literature retrieval and selection**
The PRISMA statement flowchart displayed the process of literature search, records selection and reasons for exclusion (Figure 1). At first, 1266 records were searched and 309 duplicated records were removed. After screening the titles and abstracts, 895 irrelevant publications were excluded. Then 62 potentially related publications were screened for eligibility 42 publications were excluded due to the study design. Among remaining 20 publications, 12 records were excluded on the basis of the study not meeting the inclusion criteria and 1 record was excluded because of duplicated data after reviewing the full texts. Finally, only seven articles were included in this meta-analysis after reviewing the full texts of the remaining 20 studies[22-28].

**Basic characteristics of included studies**

The included seven trials reported data on 240 participants with the sample size ranged from 26 to 68. It should be noted that Brocki et al[23,24] described different outcomes of the same group of patients in two articles. Three studies explored the clinical effect of IMT[22-24], and the other four trials evaluated the clinical effect of RMT, including the IMT and EMT, in patients undergoing lung surgery[25-28]. One study focused on preoperative RMT[26], three studies focused on the postoperative RMT[25-27] and the other three studies contained both pre and postoperative RMT[22-25]. Detailed information is presented in Table 1.

**Quality of included trials**

The average score of included RCTs in the PEDro scale was 6.43, ranging from 5 to 7, which indicates high quality (Table 2).

**Primary outcomes**

A total of five trials assessed the effect of RMT on the postoperative MIP in 197 participants[22,23,25,27,28]. The pooled results indicated that perioperative RMT improved the postoperative MIP significantly (mean = 8.13 cmH₂O, 95%CI: 1.31 to 14.95, \( P = 0.02 \); \( I^2 = 66\% \), \( P_{\text{heterogeneity}} = 0.02 \) (Figure 2). Furthermore, perioperative RMT tended to
increase the postoperative MEP (mean = 13.51 cmH₂O, 95% CI: -4.47 to 31.48, \( P = 0.14; I^2 = 91\%\), \( P_{\text{heterogeneity}} < 0.001\)) after combining four relevant studies including involving 171 patients (Figure 3)\(^{[23,25,27,28]}\), although statistical significant differences were not reached.

Subsequently, a subgroup analysis was conducted by stratifying intervention time and training method. For MIP, the results indicated that postoperative RMT significantly increased postoperative MIP (mean = 12.33 cmH₂O, 95% CI: 3.55 to 21.11 cmH₂O, \( P = 0.006; I^2=0.0\%\), \( P_{\text{heterogeneity}} = 0.67\)) and only IMT substantially improved postoperative MIP (mean = 9.53 cmH₂O, 95% CI: 3.98 to 15.08 cmH₂O, \( P < 0.001; I^2 = 44\%\), \( P_{\text{heterogeneity}} = 0.13\)). Furthermore, postoperative MEP was improved by preoperative RMT (mean = 27 cmH₂O, 95% CI: 18.67 to 35.33 cmH₂O, \( P < 0.001\)) and IMT-EMT-RMT (mean = 20.72 cmH₂O, 95% CI: 8.60 to 32.84 cmH₂O, \( P < 0.001; I^2 = 60\%\), \( P_{\text{heterogeneity}} = 0.08\)) showed better effect than IMT (mean = -3.49 cmH₂O, 95% CI: -10.57 to 3.60 cmH₂O, \( P = 0.33; I^2 = 0\%\), \( P_{\text{heterogeneity}} = 0.65\)) or EMT (mean = 1.70 cmH₂O, 95% CI: -14.67 to 18.07 cmH₂O, \( P = 0.84\)) (Table 3).

**Secondary outcomes**

Brocki et al\(^{[21]}\) evaluated the effect of IMT on postoperative self-reported physical activity (Physical Activity Scale 2.1 questionnaire\(^{[29]}\)) and their results revealed that patients receiving two weeks of postoperative IMT had higher physical activity level than those who received usual care only (sedentary 6% vs 22%, moderate activity 38% vs 12%, low activity 56% vs 66%, respectively; \( P = 0.006\)). Furthermore, results of the study conducted by Kendall et al\(^{[27]}\) also indicated that perioperative RMT could improve sedentary physical activity (\( P = 0.009\)) and total physical activity (\( P = 0.035\)). (Table 4) Three trials assessed the effect of RMT on 6MWD\(^{[23,25,27]}\) and the pooled results manifested that postoperative 6MWD of patients who received RMT did not increase compared to those who received usual care (mean = 9.96 m, 95% CI: -34.61 to 54.54, \( P = 0.66; I^2 = 63\%\), \( P_{\text{heterogeneity}} = 0.06\)) (Figure 4). Besides, two studies reported the effect of RMT on \( VO_{2\text{peak}} \) during the CPET\(^{[26,28]}\) and pooled results indicated that RMT did not
improve VO₂peak (mean = 2.44 mL/min/kg, 95% CI: -2.36 to 7.24, \( P = 0.32 \), \( I^2 = 96\% \), 
\( P_{\text{heterogeneity}} < 0.001 \)).

Regarding the pulmonary function, four trials investigated the effect of RMT on the 
postoperative FEV1 and FVC\cite{22,23,27,28}. According to the pooled results of our meta-
analysis, none of these indexes were increased significantly by the RMT. However, 
there was a trend that RMT could improve the postoperative FEV1 (mean = 0.06 L, 
95% CI: -0.07 to 0.19, \( P = 0.39 \), \( I^2 = 13\% \), \( P_{\text{heterogeneity}} = 0.32 \)) (Figure 5) and FVC (mean = 
0.29, 95% CI: -0.05 to 0.64, \( P = 0.10 \), \( I^2 = 0\% \), \( P_{\text{heterogeneity}} = 0.96 \)) (Table 4).

Postoperative RMT did not improve the symptoms of pain (visual analog scale (VAS) 
(mean = 0.67, 95% CI: -0.99 to 2.32, \( P = 0.43 \), \( I^2 = 61\% \), \( P_{\text{heterogeneity}}=0.11 \)) and dyspnoea 
(VAS) (mean = -0.16, 95% CI: -0.58 to 0.25, \( P = 0.44 \), \( I^2 = 0\% \), \( P_{\text{heterogeneity}} = 0.61 \))\cite{25,27}. 
Besides, no significant improvement on quality of life (European Organization for 
Research and Treatment of Cancer, EORTC QLQ-C30 questionnaire) was observed\cite{26}. 
(Table 4)

**DISCUSSION**

To the best of our knowledge, this is the first to comprehensively identify the clinical 
role of perioperative RMT in patients receiving lung surgery in the form of a meta-
analysis after reviewing several relevant studies. To some extent, this is the highest-
quality study with the GRADE A to assess the clinical value of RMT in patients 
undergoing pulmonary resection. Our results demonstrated that perioperative RMT 
Improved respiratory muscle strength and physical activity of patients undergoing lung 
resection. Furthermore, perioperative RMT might also improve the pulmonary function 
representing as the FEV1 and FVC. However, the exercise capacity and quality of life 
were not significantly improved by RMT due to the limitations of small sample size 
and heterogeneity between included studies, more RCTs with high quality are still 
needed to verify our finding.

The pooled results indicate that additional perioperative RMT increases the MIP (\( P = 
0.02 \)) of patients receiving lung surgery significantly compared with usual perioperative
care alone such as the breathing exercises, chest physiotherapy. For patients receiving
major surgery, postoperative reductions in MIP are regarded as the result of altered
respiratory mechanics and pain and may be a contributor of PPCs[30-32]. Besides,
increased MIP would assist postoperative lung expansion especially in patients who
receive lung surgery which, in turn, contributes to the generation of forceful expiratory
manoeuvres for secretion clearance[33]. The meta-analysis conducted by Mans et al[13]
manifested that preoperative IMT could not only increase MIP (mean = 15 cmH2O,
95%CI: 9 to 21, P < 0.001) but also reduce PPCs (RR = 0.48, 95%CI: 0.26-0.89, P = 0.02) in
patients receiving cardiothoracic or upper abdominal surgery, which is consistent with
our results and above inferences. Although the pooled results for the effect of
perioperative RMT on MEP did not reach the statistical difference, an obvious trend
that perioperative RMT may improve MEP was also observed (mean = 13.51 cmH2O,
95%CI: -4.47 to 31.48, P = 0.14). Furthermore, two of included studies reported positive
findings that the MEP was increased significantly with the mean changes of 25.20
cmH2O and 27 cmH2O after the postoperative RMT and preoperative RMT,
respectively[25,28]. Thus, the authors deem that perioperative RMT may also increase
MEP of patients undergoing pulmonary resection.

A postoperative decline of physical activity level is commonly observed in patients
undergoing major surgery because of acute pain or (and) temporary decrease of
cardiopulmonary function, which may result in adverse postoperative recovery. Brocki
et al[24] verified that perioperative IMT was effective to prevent the postoperative
decline of physical activity level in high-risk patients following pulmonary resection,
which is consistent with the results shown in the research performed by Kendall et al[27].

The 6MWD is widely applied to evaluate the effect of rehabilitation therapy in clinics.
The pooled results based on three included trials indicated nonsignificant effect of
perioperative RMT on 6MWD in patients receiving lung surgery (P = 0.66). However,
6MWD is often used to assess the exercise endurance and cardiopulmonary function of
patients with cardiopulmonary diseases; and actually, improving daily physical activity
level is more important for short-term recovery after surgery than increasing exercise
endurance, which means physical activity level assessed by sufficient data may be a 
more meaningful index in evaluating effects of perioperative rehabilitation treatment 
than single 6MWD. Meanwhile, in the trial conducted by Kendall *et al.*[^27], IMT plus EMT 
was significantly effective in preventing the decline of 6MWD postoperatively, 
although the other two studies reported negative results[^23,25,27]. Thus, more trials 
investigating the effect of perioperative RMT on 6MWD are still needed.

With the great advances of RMT technologies in recent years, RMT has been widely 
applied in various types of surgeries including the lung surgery during the 
perioperative period. RMT is believed to play an essential role in postoperative 
recovery for patients who receiving pulmonary resection since the lung works as a 
respiratory organ. However, the clinical value of RMT in lung surgery has not been well 
recognized, especially in our country. Furthermore, there are many fields worth 
investigating about the effect of RMT in patients undergoing pulmonary resection. For 
example, the parameters of initial training pressure, training time, sessions and 
duration time for different groups of patients should be different. Brocki *et al.*[^23] and 
Laurent *et al.*[^38] defined 30% of MIP as the initial training pressure for preoperative RMT 
and Weiner *et al.*[^22], Brocki *et al.*[^24], and Taşkin *et al.*[^25] defined 15% of MIP as the initial 
training pressure for postoperative RMT. However, Weiner *et al.*[^22] defined 15% of MIP 
as the initial training pressure and Messaggi-Sartor *et al.*[^26] and Kendall *et al.*[^27] defined 
30% and 25% of MIP as the initial training pressure for postoperative RMT, 
respectively. Besides, RMT consists of IMT and EMT, it is necessary to compare the 
differences between the effects of IMT, EMT and IMT-EMT-RMT in different outcomes 
like Kendall *et al.*[^27]. According to the information provided by their trial, IMT alone 
showed a similar effect on MIP as IMT-EMT-RMT, nevertheless IMT-EMT-RMT was 
more effective to enhance 6-MWD than IMT or EMT alone. Furthermore, the 
comparison between the effects of preoperative, postoperative and pre plus 
postoperative RMT is also important, especially in different groups of patients. It is 
believed that pre plus postoperative RMT is more significant in high-risk patients than
in patients with good physical and more effective in enhancing recovery after lung surgery than pre or postoperative RMT alone.

**Strength and weakness**

This systematic review and meta-analysis manifested the effects of perioperative RMT on most of postoperative outcomes except for PPCs by combining seven relevant RCTs. This is the first study to comprehensively review clinical value of perioperative RMT in patients undergoing lung surgery, which may provide us some novel suggestions for clinical application of RMT. Besides, we also showed current evidence on the clinical effect of RMT and proposed some valuable directions worth further investigating, which might contribute to the development of RMT in lung surgery.

There are several limitations in this study. First, the sample sizes are relatively small and we were unable to control for some important pretreatment parameters which could affect the outcomes, like the pretreatment pulmonary function indexes. Second, the parameters of RMT are not the same in each included study, such as the initial training pressure ranging from 15% to 30% of MIP and training time ranging from 15 min to 60 min per day. It was too hard to establish a general perioperative RMT protocol in this meta-analysis. Third, although we conducted subgroup analysis stratified by the period (pre or postoperative) and type of RMT (IMT, EMT or IMT + EMT), the results did not well verify the conclusion of our study due to the limited included trials. Four, we contacted all the corresponding authors for original data we needed; however, no response was received. Five, only articles published in English were included in this meta-analysis.

**CONCLUSION**

In conclusion, this systematic review and meta-analysis demonstrated that perioperative RMT could enhance the postoperative respiratory muscle strength and physical activity in patients undergoing lung resection. However, more trials with high
quality are still needed to verify the effects of perioperative RMT on postoperative outcomes in patients receiving lung surgery.

ARTICLE HIGHLIGHTS

Research background
The clinical values of perioperative respiratory muscle training (RMT), including inspiratory muscle training and expiratory muscle training in patients receiving lung surgery are not clear now.

Research motivation
To evaluate whether perioperative RMT is effective in improving postoperative outcomes such as the respiratory muscle strength and physical activity level in patients receiving lung surgery.

Research objectives
To further identify the clinical role of perioperative RMT in patients undergoing pulmonary surgery.

Research methods
Several databases were systematically searched to obtain eligible randomized controlled trials (RCTs). Primary outcome was postoperative respiratory muscle strength expressed as the maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP). Secondary outcomes were physical activity, exercise capacity, including the 6-min walking distance and peak oxygen consumption during the cardiopulmonary exercise test, pulmonary function and the quality of life.

Research results
For primary outcomes, the pooled results indicated that perioperative RMT improved the postoperative MIP (mean = 8.13 cmH2O, \( P = 0.02 \)) and tended to increase MEP
(mean = 13.51 cmH₂O, \( P = 0.14 \)). For secondary outcomes, perioperative RMT enhanced postoperative physical activity significantly \( (P = 0.006) \) and a trend of improved postoperative pulmonary function was observed.

**Research conclusions**

Perioperative RMT enhanced postoperative respiratory muscle strength and physical activity level of patients receiving lung surgery.

**Research perspectives**

However, RCTs with large samples are needed to evaluate effects of perioperative RMT on postoperative outcomes in patients undergoing lung surgery.
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