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Review Article

Prehabilitation Interventions for Cardiac Surgery to Prevent Postoperative Pulmonary Complications: Systematic Review and Meta-Analysis

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Abstract

Background: Postoperative pulmonary complications (PPCs) are associated with a higher risk of morbidity and mortality in patients undergoing cardiac surgery. We aimed to investigate the effect of preoperative interventions on PPCs and length of intensive care unit and hospital stay in patients undergoing cardiac surgery.

Methods: A systematic review and meta-analysis was conducted on randomized or quasi-randomized trials by searching PubMed, Medline, ISI Web of Science, Science Direct, Physiotherapy Evidence Database (PEDro), and the Cochrane Library for all available years until December 2023. Our primary outcomes were PPCs including atelectasis and Pneumonia and secondary outcomes were length of intensive care unit and hospital stay.

Results: Twenty-one included trials provide data on 2895 participants. The preoperative intervention of inspiratory muscle training (IMT) significantly reduced the PPCs including atelectasis (OR: 0.49, 95%CI: 0.28, 0.86) and Pneumonia (OR: 0.41, 95%CI: 0.25, 0.67) in cardiac patients compared with the control group. Preoperative exercise training intervention is significantly associated with a lower risk (OR: 0.15, 95%CI: 0.06, 0.38) of composite PPCs (i.e. atelectasis and Pneumonia) in the intervention group. Preoperative IMT significantly reduced the postoperative hospital stay by -1.57 days (95% CI: -2.33, -0.81) in the intervention group. Preoperative exercise training significantly decreased the postoperative intensive care unit stay by -2.22 hours (95% CI: -3.05, -1.38) and hospital stay by -1.82 days (95% CI: -3.38, -0.27) in the intervention group.

Conclusion: Preoperative intervention of IMT and exercise training significantly reduce PPCs and hospital stay in patients undergoing cardiac surgery.

Keywords: Cardiac surgery; Exercise training; Health education; Inspiratory muscle training

Introduction

Cardiovascular disease (CVD) is a predominant cause of death, responsible for 18.6 million global deaths in 2019 (1). It causes more than four million annual deaths in Europe and a half million annual deaths in the United States (2). It is projected that CVD will exceed 23 million deaths worldwide in 2030 (3). Globally, more than 230 million surgical procedures are performed each year and the number will continue to rise in developed countries due to the aging population and growing demand for invasive procedures in developing countries (4, 5). Cardiac surgery is the most common and expensive surgical procedure in the world. In the United States, the total number of cardiac surgeries increased by 484% over the last three decades (1979 to 2005) and coronary heart diseases cost 156.4 billion USD in 2008 (6).

Postoperative pulmonary complications including atelectasis, pneumonia, bronchitis, and other respiratory problems are the leading cause of morbidity and mortality in patients undergoing cardiac surgery (7). The prevalence of postoperative pulmonary complications varies from 20% to 95% in cardiac patients and increases the healthcare expenditure, length of hospital and intensive care unit (ICU) stay (6). Preoperative interventions such as inspiratory muscle training (IMT), exercise training, and health education are associated with preventing and reducing postoperative pulmonary complications-related morbidity and mortality among cardiac patients. These preoperative interventions are aimed to optimize the physiological function of cardiorespiratory and musculoskeletal systems to mitigate the effects of general anesthesia (2, 8, 9).

Several previous systematic reviews have investigated the impact of preoperative intervention on various clinical outcomes among different population groups (i.e. cancer and cardiac (10), cardiac and abdominal surgery (7), and cardiothoracic or upper abdominal surgery (11). However, limited systematic reviews observed the impact of various preoperative interventions on postoperative pulmonary complications in cardiac patients (2, 6, 12). We aimed to conduct a systemic review and meta-analysis to investigate the effect of different preoperative interventions (i.e. inspiratory muscle training, exercise, and health education) on postoperative pulmonary complications and length of hospital and intensive care unit stay in patients undergoing cardiac surgery.

Methods

Identification and selection of studies

This systematic review and meta-analysis sought to identify and select randomized or quasi-randomized trials of preoperative intervention in patients undergoing cardiac surgery by searching the electronic databases of PubMed, Medline, ISI Web of Science, Science Direct, Physiotherapy Evidence Database (PEDro), and the Cochrane Library for all available years until December 2023. The combined search terms related to population were cardiac, open heart, coronary, coronary artery bypass graft, percutaneous coronary intervention, myocardial revascularization, and transcatheter aortic valve replacement with terms for the preoperative intervention such as inspiratory muscle training, exercise, health education, and mobilization, and the outcomes including postoperative pulmonary complications, length of hospital, and intensive care unit stay. Two authors (N and CD) independently assessed and screened eligible studies according to the inclusion criteria and authors were contacted where appropriate for clarification or for more information and data.

Study population, preoperative interventions, and outcomes

The number of participants in the intervention and control group was extracted for each trial of various cardiac surgeries conducted in different countries. The preoperative interventions such as inspiratory muscle training, exercise, and health education and outcomes including postoperative pulmonary complications (i.e. atelectasis and Pneumonia), length of hospital and intensive care unit stay were extracted for each trial wherever available.

Inclusion and exclusion criteria

We included randomized or quasi-randomized trials comparing the effect of preoperative interventions (i.e. inspiratory muscle training, exercise, and health education) with no-preoperative intervention on postoperative pulmonary complications (i.e. atelectasis and Pneumonia) and length of hospital and intensive care unit stay in patients undergoing cardiac surgery. We included adults aged ≥18 years awaiting cardiac surgery and all those cardiac surgeries that involve the heart such as coronary artery bypass graft, percutaneous coronary intervention, myocardial revascularization, and transcatheter aortic valve replacement. Full-text, abstract, and peer-reviewed English articles were included. Studies were excluded if they investigated the effect of preoperative interventions on combined population groups such as cardiac and abdominal surgery and cardiothoracic or upper abdominal surgery.

Assessment of study quality and characteristics

The data were extracted according to the PRISMA statement (13) (Fig. 1) and the PEDro scale was used to assess the quality of included studies (14). The PEDro scale is considered a reliable tool for the evaluating risk bias of randomized controlled trials in systematic reviews.

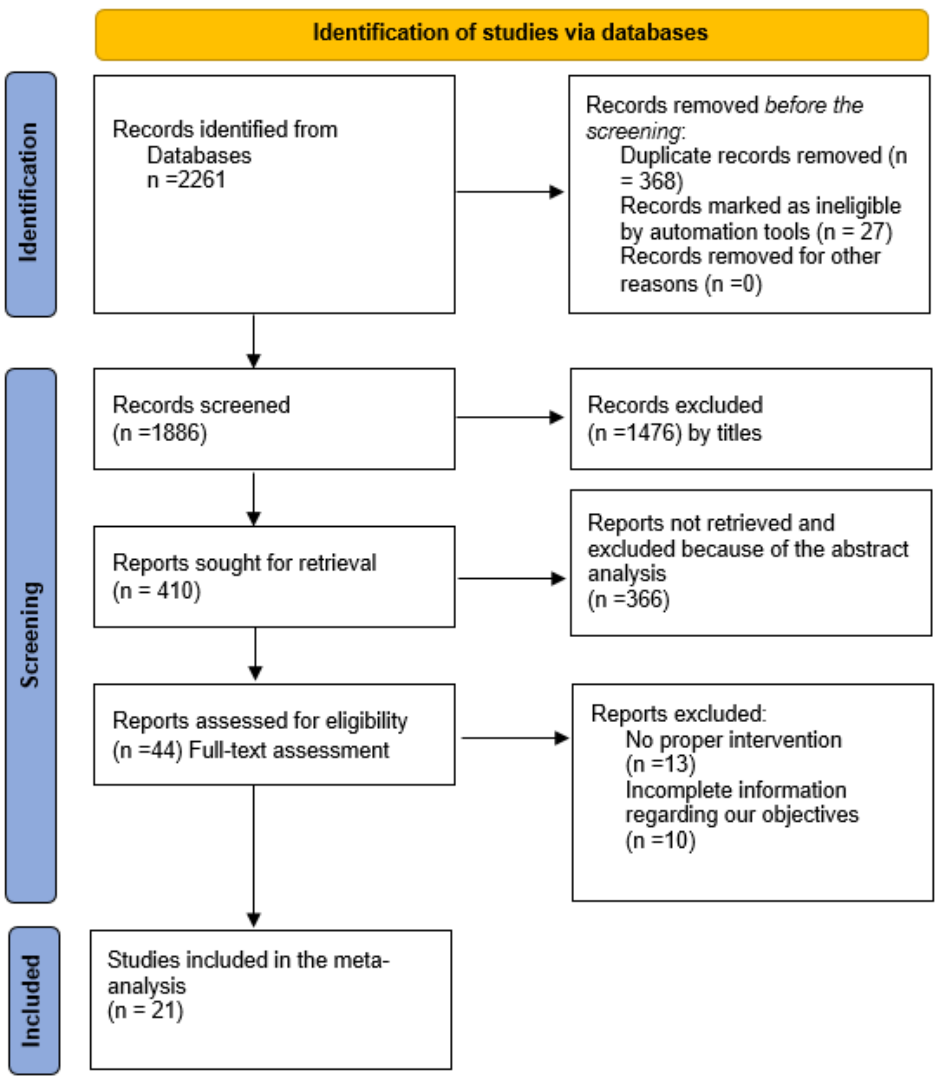

Fig. 1: PRISMA flow diagram for systematic review and meta-analysis

The score of the PEDro scale ranges between 0 to 10 (15). In the current systematic and meta-analysis review, the PEDro score was used to evaluate the methodological quality of each trial except Carvalho et al. trial (16) due to the lack of a full-text manuscript. Based on the PEDro score, the methodological quality of a trial is considered excellent (9 to 10 score), good (6 to 8 score), fair (4 to 5 score), and poor (<4 score) (17). Two authors (N and CD) independently evaluated the PEDro score for each trial.

Data analysis

The present meta-analysis was conducted using Revman 5.4 version software (Revman 2023). The preoperative interventions were inspiratory muscle training, exercise, and health education. The primary outcomes were atelectasis and Pneumonia and the secondary outcomes were length of hospital stay (days) and intensive care unit stay (hours). The pooled estimate of the preoperative intervention effect was reported using odds ratio (OR) with a 95% confidence interval (CI) for dichotomous outcomes (i.e. primary outcome) and the pooled mean difference with a 95% CI for continuous outcomes (i.e. secondary outcomes). Based on the heterogeneity level, a random effect model (I^2>50%) and a fixed effect model (I^2<50%) were selected in our analysis.

Results

General characteristics of the included studies

Twenty-one studies were included in the current meta-analysis which provides data on 2895 participants including the intervention group (n= 1467) and control group (n= 1428). The sample size of the individual study ranged from 26 to 406 participants. Three different preoperative interventions were used in various studies such as exercise (n= 5) (18-22), health education (n= 6) (23-28), and inspiratory muscle training (IMT) (n= 10) (16, 29-37) to investigate its effect on participants undergoing cardiac surgery. Eighteen studies investigated the effect of preoperative interventions on participants undergoing coronary artery bypass graft (CABG) surgery (n= 2613) (16, 19-22, 24-30, 32-37), and the rest of three studies investigated participants undergoing percutaneous coronary intervention (PCI) (n= 104) (23), transcatheter aortic valve replacement (TAVR) (n= 108) (18), and myocardial revascularization (MR) (n= 70) (31) (Table 1).

Quality of the included studies

According to the PEDro score, the methodological quality of the twenty trials ranges from 5 to 8 except for one trial (16). For seven trials, the PEDro score is from 7 to 8, and for thirteen trials ranges from 5 to 6. All twenty trials used random allocation and nine trials used concealed allocation. Moreover, assessors were blinded in eight trials (Table 2).

Primary outcomes

Eight trials (16, 29, 30, 33-37) investigated the effect of preoperative IMT on PPCs including atelectasis and Pneumonia. Meta-analysis results from the five trials (16, 29, 34-36) showed a significantly lower risk of atelectasis in the intervention group (OR: 0.49, 95%CI: 0.28, 0.86) as presented in Fig. 2 and data from the seven trials (16, 29, 30, 33-35, 37) indicated a significantly lower risk of Pneumonia in the intervention group (OR: 0.41, 95%CI: 0.25, 0.67) as presented in Fig. 3. The effect of exercise on composite PPCs (i.e. atelectasis and Pneumonia) was assessed in three trials (18, 20, 21). The findings show that exercise significantly lowered the risk of composite PPCs in the intervention group (OR: 0.15, 95%CI: 0.06, 0.38) as presented in Fig. 4.

Table 1: General characteristics of included 21 studies (N = 2895)

Study	*Study type*	*Country*	*Sample size (n)*	*Partici-pants I:C (n)*	*Sur-gery type*	*Intervention type*	*Outcomes*
Zhuo (23)	RCT	China	104	52:52	PCI	Health education	LOS
Weber (18)	RCT	Germany	108	58:50	TAVR	Exercise	Pneumonia, LOS
Chen (29)	RCT	China	197	98:99	CABG	IMT	Atelectasis, Pneumonia, LOS
Valkenet (30)	RCT	Netherlands	235	119:116	CABG	IMT	Pneumonia, LOS
Moises (31)	RCT	Brazil	70	35:35	MR	IMT	LOS
Guo (24)	RCT	China	135	68:67	CABG	Health education	LOS
Carvalho (16)	RCT	Brazil	32	16:16	CABG	IMT	Atelectasis, Pneumonia, LOS
SAVCI (32)	RCT	Turkey	43	22:21	CABG	IMT	LOS
Rosenfeldt (19)	RCT	Australia	117	60:57	CABG	Exercise	LOS
Ferreira (33)	RCT	Brazil	30	15:15	CABG	IMT	Pneumonia
Arthur (20)	RCT	Brazil	56	29:27	CABG	Exercise	Atelectasis, Pneumonia, LOS
Goodman (25)	RCT	UK	181	91:90	CABG	Health education	LOS
Deyirmenjian (26)	RCT	Lebanon	110	57:53	CABG	Health education	LOS
Hulzebos (A) (34)	RCT	Netherlands	276	139:137	CABG	IMT	Atelectasis, Pneumonia, LOS
Hulzebos (B) (35)	RCT	Netherlands	26	14:12	CABG	IMT	Atelectasis, Pneumonia, LOS
Watson (27)	RCT	Canada	406	202:204	CABG	Health education	LOS
Shuldham (28)	RCT	UK	314	162:152	CABG	Health education	LOS
Arthur (21)	RCT	Canada	246	123:123	CABG	Exercise	Atelectasis, LOS
Rajendran (36)	RCT	India	45	25:20	CABG	IMT	Atelectasis, LOS
Weiner (37)	RCT	Israel	84	42:42	CABG	IMT	Pneumonia
Stiller (22)	RCT	Australia	80	40:40	CABG	Exercise	LOS

Note: RCT (randomized control trials), PCI (percutaneous coronary intervention), I (intervention), C (control), TAVR (transcatheter aortic valve replacement) CABG (coronary artery bypass graft) IMT (inspiratory muscle training), MR (myocardial revascularization), LOS (length of stay means both ICU and hospital)

Table 2: PEDro scale and total scores for included trials (n = 20)

Study	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Total score*
Zhuo (23)	√	√	√	×	×	√	√	√	√	√	8/10
Weber (18)	√	√	×	×	×	×	√	√	√	√	6/10
Chen (29)	√	√	√	×	×	√	√	√	√	√	8/10
Valkenet (30)	√	×	×	√	×	×	√	√	√	√	6/10
Moises (31)	√	√	√	×	×	×	√	√	√	√	7/10
Guo (24)	√	√	√	×	×	√	√	√	√	√	8/10
SAVCI (32)	√	×	√	×	×	×	√	√	√	√	6/10
Rosenfeldt (19)	√	√	√	×	×	×	√	×	√	√	6/10
Ferreira (33)	√	×	√	×	×	×	√	×	√	√	5/10
Arthur (20)	√	×	×	×	×	√	√	√	√	√	6/10
Goodman (25)	√	×	√	×	×	×	√	√	√	√	6/10
Deyirmenjian (26)	√	×	√	×	×	√	√	×	√	√	6/10
Hulzebos (A) (34)	√	√	√	×	×	√	√	√	√	√	8/10
Hulzebos (B) (35)	√	×	√	×	×	√	√	√	√	√	7/10
Watson (27)	√	×	√	×	×	×	√	√	√	√	6/10
Shuldham (28)	√	√	×	√	×	√	√	√	√	√	8/10
Arthur (21)	√	√	√	×	×	×	√	×	√	√	6/10
Rajendran (36)	√	×	√	×	×	×	√	√	√	√	6/10
Weiner (37)	√	×	√	√	×	×	×	×	√	√	5/10
Stiller (22)	√	×	√	×	×	×	√	√	√	√	6/10

Note: √= yes criteria satisfied, ×= no criteria not satisfied**,** 1 = random allocation, 2 = concealed allocation, 3 = groups similar at baseline, 4 = participant blinding, 5 = therapist blinding, 6 = assessor blinding, 7 = < 15% dropouts, 8 = intention-to-treat analysis, 9 = between-group comparisons, 10 = point estimates and variability reported

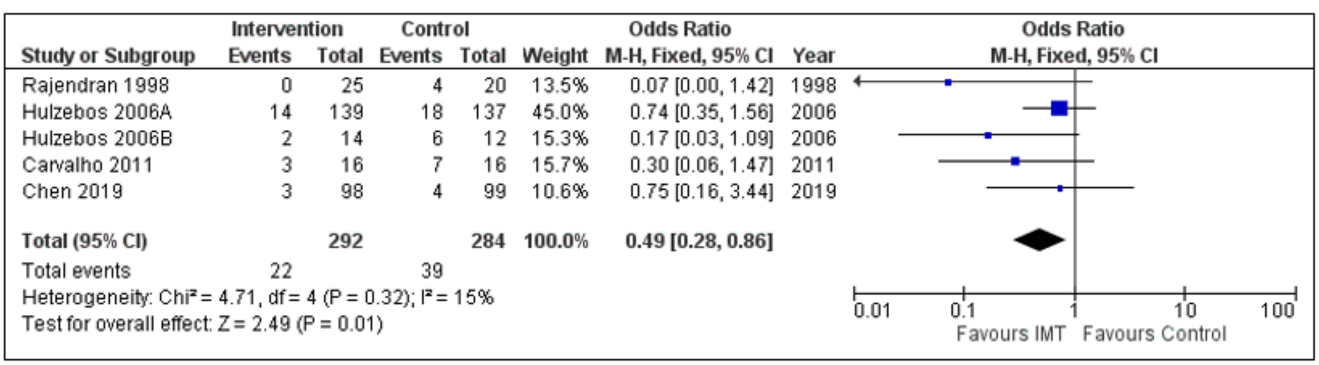

Fig. 2: Forest plot of the effect of inspiratory muscle training (IMT) on postoperative atelectasis

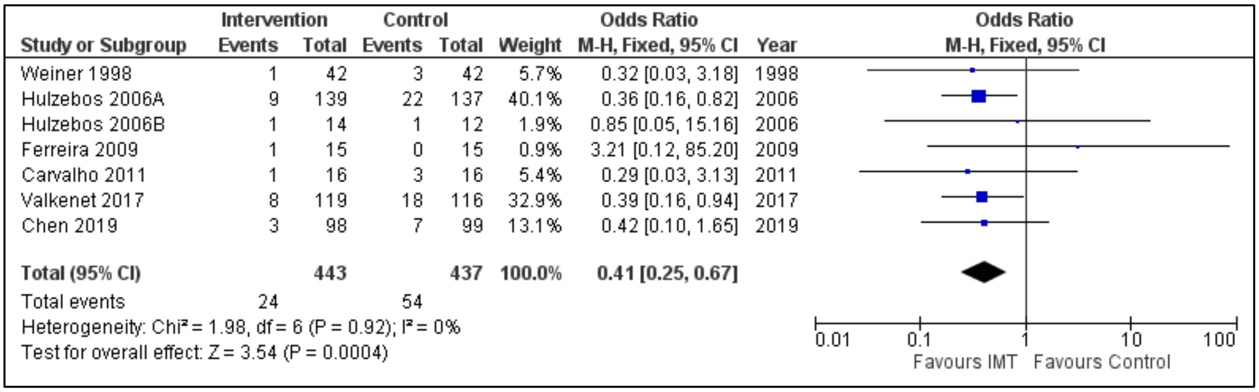

Fig. 3: Forest plot of the effect of IMT on postoperative Pneumonia

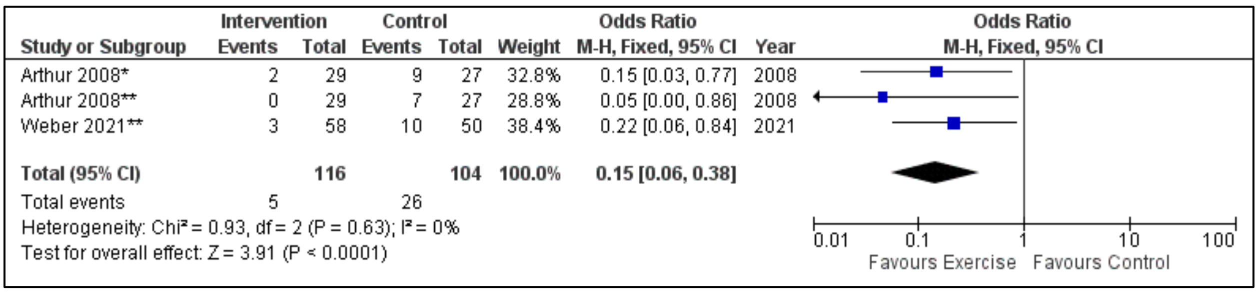

Fig. 4: Forest plot of the effect of exercise on postoperative composite pulmonary complications (i.e. atelectasis* and Pneumonia**)

Secondary outcomes

Based on data from three trials, preoperative IMT non-significantly reduced the ICU length of stay by 0.39 hours (95% CI: -0.60, 1.38) as presented in Fig. 5. However, data from eight trials showed that preoperative IMT significantly reduced the hospital length of stay by -1.57 days (95% CI: -2.33, -0.81) as presented in Fig. 6. Moreover, preoperative exercise significantly decreased the ICU length of stay in three trials by -2.22 hours (95% CI: -3.05, -1.38) as presented in Fig. 7 and the hospital length of stay in five trials by -1.82 days (95% CI: -3.38, -0.27) as presented in Fig. 8. On the other hand, preoperative health education non-significantly reduced the hospital length of stay by 0.48 days (95% CI: -0.17, 1.12) as presented in Fig. 9.

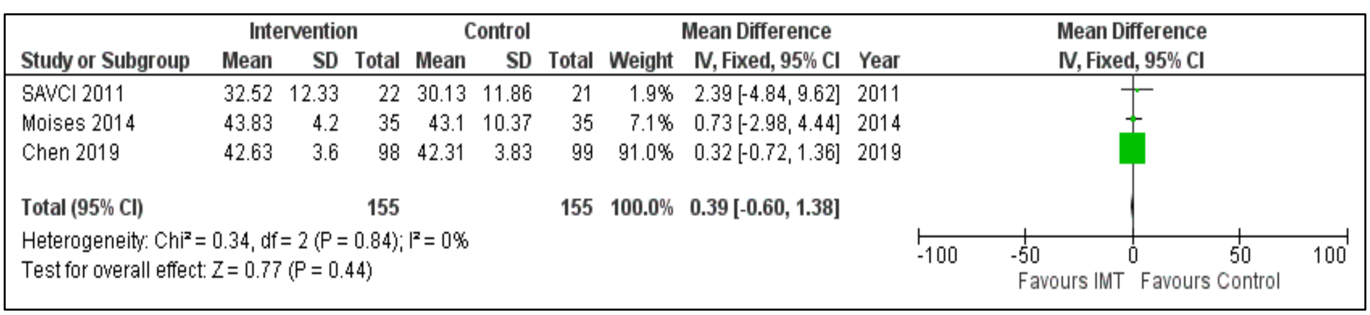

Fig. 5: Forest plot of the effect of IMT on postoperative ICU stay (hours)

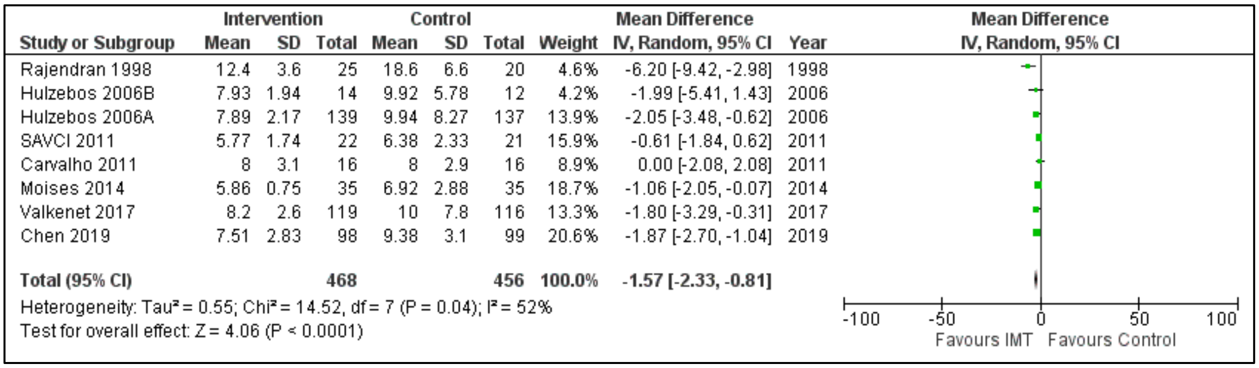

Fig. 6: Forest plot of the effect of IMT on postoperative length of hospital stay (days)

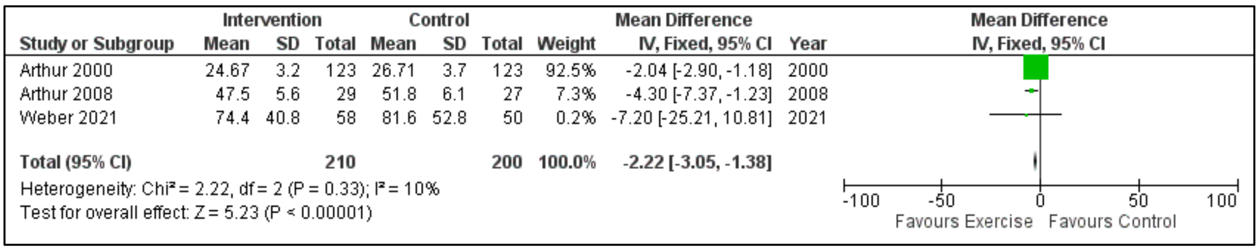

Fig. 7: Forest plot of the effect of exercise on postoperative ICU stay (hours)

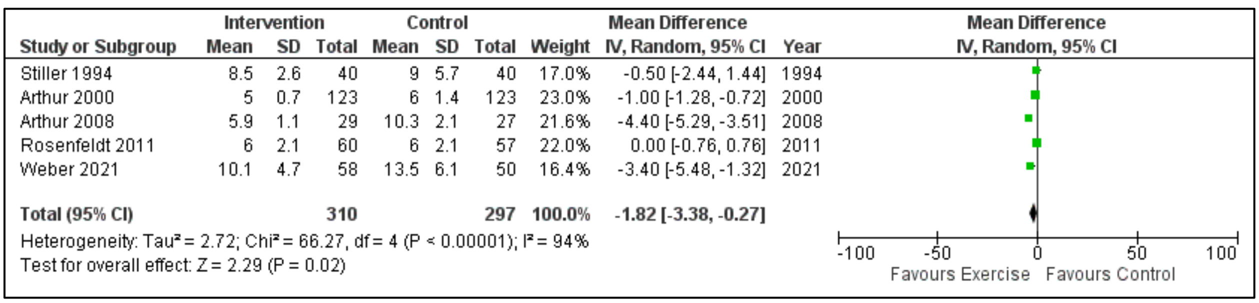

Fig. 8: Forest plot of the effect of exercise on postoperative length of hospital stay (days)

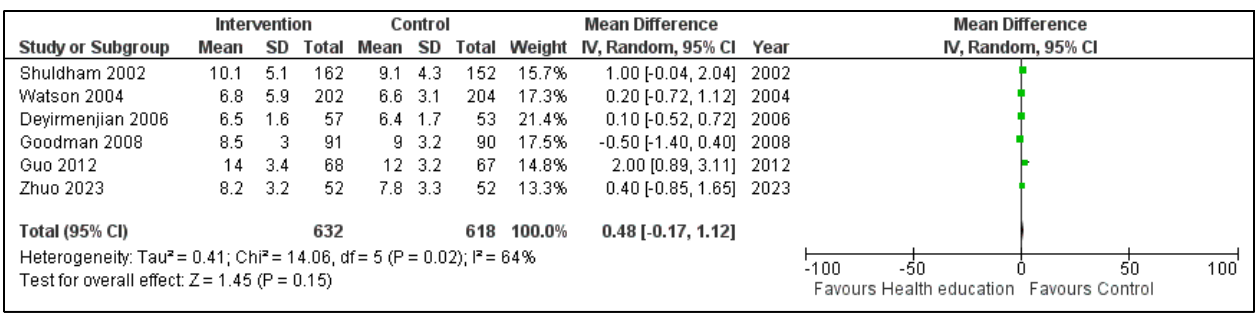

Fig. 9: Forest plot of the effect of health education on postoperative length of hospital stay (days)

Discussion

The current systematic review and meta-analysis investigates the effect of various preoperative interventions (i.e. inspiratory muscle training, exercise, and health education) on postoperative pulmonary complications (PPCs) (i.e. atelectasis and Pneumonia) and length of hospital and intensive care unit stay in patients undergoing different cardiac surgery. We selected and pooled the data from 21 trials, of these eighteen studies investigated the effect of preoperative interventions on participants undergoing coronary artery bypass graft (CABG) surgery, and the rest of three studies investigated participants undergoing percutaneous coronary intervention (PCI), transcatheter aortic valve replacement (TAVR), and myocardial revascularization (MR).

The findings indicate that preoperative inspiratory muscle training (IMT) and exercise significantly reduced PPCs in cardiac patients. However, the included trials in the present systematic review and meta-analysis failed to report the effect of preoperative intervention of health education on PPCs. Moreover, preoperative intervention of IMT and exercise significantly shorten the postoperative length of hospital stay (days) in cardiac patients. Preoperative intervention of exercise is also associated with a significant reduction in postoperative length of intensive care unit (ICU) stay (hours). On the other hand, preoperative intervention of IMT and health education had no significant effect on postoperative ICU and hospital stay, respectively.

We found that preoperative IMT intervention significantly reduced the odds of postoperative atelectasis, Pneumonia, and mean length of hospital stay in cardiac patients compared with the control group. IMT has been considered a significant prehabilitation intervention that increases the strength and endurance of inspiratory muscles (38). IMT includes inspiratory resistive flow loading, inspiratory threshold pressure loading, and isocapnic/normocapnic hyperpnoea, which may expedite postoperative recovery and reduce the incidence of pulmonary complications (11, 39). Our findings are comparable with the previous reports (2, 6, 11, 12). However, this study showed lower odds of postoperative atelectasis and Pneumonia in cardiac patients compared with the previous reports (2, 6, 11, 12). It could be due to limited included trials (2, 6, 12) and different population groups (i.e. cardiothoracic or upper abdominal surgery) (11).

Preoperative IMT intervention reduces the risk of PPCs which untimely decreases the length of hospital stay in patients undergoing cardiac surgery (40). We observed that preoperative IMT intervention significantly shortened the postoperative length of hospital stay (by a mean of 1.5 days) in cardiac patients. Previous studies also observed a significant reduction in the length of hospital stay (by a mean of 3.2 days) (6) and (by a mean of 1.6 days) (11) in patients undergoing cardiac and cardiothoracic surgery. It suggests that shortening the length of hospital stay by preoperative IMT intervention could be of considerable significance to the public healthcare system as well as for cardiac patients to reduce the extra financial cost of hospital stay.

Exercises including breathing and coughing exercises, physiotherapy exercises, and physical conditioning improve cardiorespiratory function, which may reduce the risk of PPCs in both low and high-risk cardiac patients (6, 22). Our findings show that preoperative exercise significantly decreases the risk of PPCs such as atelectasis and pneumonia in patients undergoing cardiac surgery. In addition, preoperative exercise was associated with a significant reduction in postoperative ICU stay (by a mean of 2.2 hours) and hospital stay (by a mean of 1.8 days) in cardiac patients. A previously published systematic review meta-analysis evaluated the effect of preoperative exercise training on postoperative pulmonary complications in patients undergoing major surgery (i.e. cardiac, lung, abdominal, and esophageal). They observed a significant reduction in the risk of PPCs and mean length of hospital stay in all major and cardiac surgery (10) which is in accordance with our results.

To obtain the benefits of preoperative exercise, various trials used different kinds of preoperative exercises. For example, Herdy et al. (20) carried out exercise training such as progressive exercise, spirometer training, and intermittent positive pressure breathing in patients undergoing CABG Surgery. Weber et al. (18) used ambulatory physiotherapy exercises (i.e. composite of physiotherapy and IMT) on a daily basis for a minimum of two weeks and a minimum of 30 minutes of walking in patients undergoing TAVR surgery. Rosenfeldt et al. (19) conducted physical exercise (i.e. 60-minute exercise sessions per week) for two weeks including gentle stretching, cycling on a stationary bicycle (15 minutes), and walking on a treadmill (10-15 minutes) in patients undergoing cardiac surgery. It indicates that clinicians should conduct preoperative exercise according to the patient's condition (i.e. low and high-risk) and type of surgery to prevent postoperative pulmonary complications in cardiac patients.

It is essential to prepare cardiac patients both physically and psychologically before their surgery to obtain postoperative desired clinical outcomes (24). It has been found that cardiac-related interventions (i.e. surgery and PCI) develop pre-operative anxiety and depression in cardiac patients which are associated with increased risk of cardiovascular morbidity and mortality (23, 41). Preoperative health education has been associated with a significant reduction in pre-operative anxiety and depression in patients undergoing surgery (24). However, we failed to include anxiety and depression as postoperative outcomes in our analysis. Moreover, we found that preoperative health education had no significant effect on the reduction of postoperative hospital stay in cardiac patients. Previous two trials also reported no significant reduction in postoperative hospital stay in patients undergoing percutaneous coronary intervention and cardiac surgery (23, 24). The non-significant effect of preoperative health education intervention on postoperative hospital stay could be affected by the socioeconomic status, health care service, disease severity, and age of the cardiac patients (23, 24, 42).

Our study had several limitations. First, not all the included trials were related to cardiac patients and our findings can be generalized to other patient groups. Second, 9 of the 21 included trials are subjected to small-study effect bias due to a small sample size (<100 patients) (43). Third, we did not include postoperative all-cause mortality and pneumothorax in our analysis. Fourth, the preoperative exercise interventions were highly heterogeneous which are consisting of breathing and coughing exercises, physiotherapy exercises, and physical conditioning.

Conclusion

The current study supports the preoperative intervention of inspiratory muscle training and exercise to reduce postoperative pulmonary complications and hospital stay in patients undergoing cardiac surgery. Inspiratory muscle training and exercise significantly reduced postoperative pulmonary complications including atelectasis and pneumonia in cardiac patients. Moreover, preoperative intervention of inspiratory muscle training and exercise significantly shortened the postoperative length of hospital stay in cardiac patients. The preoperative intervention of exercise is also associated with a significant reduction in postoperative length of intensive care unit stay. These findings may be helpful to provide references to clinicians to reduce postoperative pulmonary complications and hospital stay by prehabilitation interventions particularly inspiratory muscle training and exercise in cardiac patients.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare no conflict of interest.

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