European Journal of Trauma and Emergency Surgery (2021) 47:975–990
https://doi.org/10.1007/s00068-020-01522-x

REVIEW ARTICLE

The effect of postoperative respiratory and mobilization interventions on postoperative complications following abdominal surgery: a systematic review and meta-analysis

Dunja Kokotovic[1,2] · Adam Berkfors[1] · Ismail Gögenur[1] · Sarah Ekeloef[1] · Jakob Burcharth[1]

Received: 27 August 2020 / Accepted: 29 September 2020 / Published online: 7 October 2020

Abstract

Purpose Up to 30% of patients undergoing abdominal surgery suffer from postoperative pulmonary complications. The purpose of this systematic review and meta-analyses was to investigate whether postoperative respiratory interventions and mobilization interventions compared with usual care can prevent postoperative complications following abdominal surgery.

Methods The review was conducted in line with PRISMA and GRADE guidelines. MEDLINE, Embase, and PEDRO were searched for randomized controlled trials and observational studies comparing postoperative respiratory interventions and mobilization interventions with usual care in patients undergoing abdominal surgery. Meta-analyses with trial sequential analysis on the outcome pulmonary complications were performed. Review registration: PROSPERO (identifier: CRD42019133629)

Results Pulmonary complications were addressed in 25 studies containing 2068 patients. Twenty-three studies were included in the meta-analyses. Patients predominantly underwent open elective upper abdominal surgery. Postoperative respiratory interventions consisted of expiratory resistance modalities (CPAP, EPAP, BiPAP, NIV), assisted inspiratory flow modalities (IPPB, IPAP), patient-operated ventilation modalities (spirometry, PEP), and structured breathing exercises. Meta-analyses found that ventilation with high expiratory resistance (CPAP, EPAP, BiPAP, NIV) reduced the risk of pulmonary complications with OR 0.42 (95% CI 0.18–0.97, $p = 0.04$, $I^2 = 0\%$) compared with usual care, however, the trial sequential analysis revealed that the required information size was not met. Neither postoperative assisted inspiratory flow therapy, patient-operated ventilation modalities, nor breathing exercises reduced the risk of pulmonary complications.

Conclusion The use of postoperative expiratory resistance modalities (CPAP, EPAP, BiPAP, NIV) after abdominal surgery might prevent pulmonary complications and it seems the preventive abilities were largely driven by postoperative treatment with CPAP.

Keywords Complications · Physiotherapy · Ventilation · CPAP

Introduction

Postoperative complications commonly occur after abdominal surgery and lead to an increase in morbidity, mortality, postoperative hospital stay, and contribute to increased hospital costs [1–4]. Pulmonary complications occur in up to 30% of the patients [5, 6]. Several factors predispose to increased risk of pulmonary complications such as disruptions of the normal breathing activity with shallow rapid breathing, prolonged supine position, impaired mucociliary clearance, postoperative pain, and anesthesia-induced diaphragmatic dysfunction [7].

The prevention of pulmonary complications has been thoroughly investigated and several different respiratory

Results Were Presented As an Oral Presentation At the Danish Surgical Society Meeting October 31 2019.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00068-020-01522-x) contains supplementary material, which is available to authorized users.

✉ Dunja Kokotovic
dunja.kokotovic@hotmail.com

[1] Center for Surgical Science, Department of Surgery, Zealand University Hospital and Copenhagen University, Lykkebækvej 1, 4600 Køge, Denmark

[2] Platanvej 5, 1810 Frederiksberg C, Denmark

interventions (e.g. structured breathing exercises, incentive spirometry, breathing with the assisted inspiratory flow, and different kinds of positive airway pressure breathing) have been suggested as possible preventive solutions [8–13]. Furthermore, several studies have focused on preoperative physiotherapy [9, 14–16]. However, far from all patients have the opportunity to undergo preoperative interventions as a large proportion of patients undergoing abdominal surgery, undergo emergency surgery, which emphasizes the need for clarifying the benefit of strictly performing postoperative care pathways [17].

The purpose of this systematic review and meta-analysis was to investigate whether postoperative interventions directed towards improved respiratory function and compared with usual care can prevent postoperative complications following abdominal surgery with a focus on postoperative pulmonary complications.

Methods

The present systematic review and meta-analysis were planned, conducted, and reported in line with the PRISMA guidelines [18]. Before the study start, a detailed protocol in line with PRISMA-P guidelines [19] describing the review was registered at PROSPERO (identifier: CRD42019133629).

Study eligibility

This study was performed according to the following PICO(S):

The participants (P) of interest were patients (≥ 18 years of age) undergoing intraabdominal gastrointestinal surgery. Patients with preexisting pulmonary/respiratory conditions were also included. The intervention (I) of interest was all postoperative respiratory or mobilization interventions initiated from the end of surgery until hospital discharge. We only included interventions performed after the extubation of the patient. If the patient underwent any instructions about the intervention prior to surgery the study was excluded even though the intervention was only performed postoperatively. The interventions included respiratory interventions with and without adjacent breathing devices such as CPAP (Continuous positive airway pressure), EPAP (Expiratory positive airway pressure), BiPAP (Bilevel positive airway pressure), NIV (Non-invasive ventilation), IPPB (intermittent positive pressure breathing), IPAP (inspiratory positive airway pressure), spirometry, and PEP (positive expiratory pressure), muscle training, or structured breathing exercises. A comparison (C) was made between patients who underwent a respiratory or mobilization intervention postoperatively and patients who were treated with usual care. The primary outcome (O) was postoperative complications including all pulmonary complications (pneumonia, atelectasis, pleural effusion, bronchitis), surgical complications (reoperations, wound infections, reoperations etc.), and medical complications (urinary tract infections, cardiovascular complications, sepsis, etc.). Secondary outcome measures were the length of hospital stay, mortality, and possible side effects to physiotherapeutic interventions. The study types (S) of interest were observational studies (retrospective and prospective) and randomized clinical trials.

Exclusion criteria were patients < 18 years old and patients undergoing non-gastrointestinal surgery. Furthermore, any kind of preoperative instruction of the patient or respiratory or mobilization interventions or initiatives excluded the study. Only English, Danish, Swedish, and Norwegian published literature was included, and data from conference abstracts as well as unpublished data were excluded. No restrictions were made regarding the time of publication.

Search and study selection

A detailed and systematic literature search in MEDLINE, Embase, and PEDRO was conducted on 29 April 2019. The literature search strategy was developed by the first and second author along with a professional medical research librarian and was deliberately made wide to avoid excluding relevant studies. The detailed search strategy from MEDLINE is presented in Table 1. No limits were applied. The search strategy was adapted to Embase and PEDRO. The literature search was supplemented with a hand search of the reference lists of the included studies (snowball-search) [20]. Furthermore, a search for potentially relevant trials at the WHO trial registration website was performed and if a relevant trial was registered as finished, the record of the study was sought out. The potential eligible records were imported to Endnote where duplicates and non-English records were removed. Title and abstract screening were performed independently by authors DK and AB in reference to the eligibility criteria in the online platform Covidence [21]. For papers eligible for inclusion, full-text articles were retrieved and detailed evaluation was performed independently by DK and AB. Disagreements were settled by discussion.

Data collection and data items

The following study data were independently extracted:

Study data: title, author, year, study design, number of participants.

Patient demographics: age, sex, operation type, duration of surgery, BMI (body mass index), American Society of Anesthesiologist classification (ASA), comorbidities, smoking.

Table 1 Search strategy for Pubmed

((((((((((((abdomen/surgery[MeSH Terms]) OR Gastrointestinal Surgical Procedures[MeSH Terms]) OR laparotomy[MeSH Terms]) OR laparoscopy[MeSH Terms]) OR splenectomy[MeSH Terms]) OR "Abdominal surgery") OR "General surgery") OR "Gastrointestinal surgery") OR "Laparotomy") OR "Laparoscopy") OR "Splenectomy")) AND ((((((((((((((((Spirometry/therapeutic use[MeSH Terms]) OR Spirometry/therapy[MeSH Terms]) OR Physical Therapy Modalities[MeSH Terms]) OR Exhalation[MeSH Terms]) OR Physical Fitness[MeSH Terms]) OR Exercise[MeSH Terms]) OR "Physical therapy") OR "Physiotherapy") OR "Pursed-lips breathing") OR "Coughing") OR "Incentive spirometry") OR "Deep breathing") OR "Breathing maneuvers") OR "Breathing Exercises") OR "Positive End Expiratory Pressure") OR "CPAP") OR "Exercise" OR "Spirometry"))) AND ((((((((((((((((Postoperative complications[MeSH Terms]) OR Reoperation[MeSH Terms]) OR Infection[MeSH Terms]) OR Heart disease[MeSH Terms]) OR Mortality[MeSH Terms]) OR Length of stay[MeSH Terms]) OR "Postoperative complications") OR "Reoperation") OR "Heart disease") OR "Infection") OR "respiratory tract disease") OR "Pulmonary complications") OR "Cardiovascular complications") OR "Infectious complications") OR "Length of stay") OR "Mortality") OR respiratory tract diseases[MeSH Terms])

Intervention data: type of respiratory or mobilization intervention, frequency of intervention.

Outcome data: type of postoperative complication, frequency of postoperative complication, length of hospital stay, mortality.

Bias assessment

Randomized controlled trials were evaluated with the Cochrane risk of bias tool [22] and observational studies were evaluated with Cochrane's ROBINS-I tool for non-randomized studies [23].

Data synthesis

All outcomes were narratively summarized. A meta-analysis was conducted on pulmonary complications as a composite outcome including all types of pulmonary complications [24]. Because of the heterogeneity between the interventions, the meta-analysis was stratified on interventions, which were grouped as follows:

- Interventions with high expiratory resistance: CPAP, EPAP, BiPAP, NIV including a subgroup analysis only including CPAP
- Interventions with the isolated assisted inspiratory flow: IPPB, IPAP
- Interventions with patient-operated ventilation devices: Spirometry, PEP
- Interventions based only on structured breathing exercises without the use of any respiratory devices

A posthoc subgroup analysis on CPAP was conducted as CPAP has the highest expiratory resistance and differs from BiPAP and NIV in that both BiPAP and NIV also have a high inspiratory flow. CPAP can be administered at surgical wards without respirators and is thereby easier to apply. A subgroup analysis on upper abdominal surgery was performed, as it was suspected that patients with upper incisions were more challenged breathing postoperatively [25]. Furthermore, a subgroup analysis of open and laparoscopic surgery was performed.

The data-synthesis of the meta-analysis was performed with the review manager (Revman version 5.1, Cochrane Collaboration, 2011). The generic inverse variance method was used, and, furthermore, the random-effects model was applied, as it was not assumed that the outcome variables were identically defined or collected between the studies. Results of meta-analyses were only reported if heterogeneity was not considerable (I^2 more than 75%) and if data on the outcome was sufficient (more than 100 patients and at least 3 trials). The effect measure of the meta-analyses was odds ratio. As the results in the included studies were presented as frequencies, odds ratios were calculated as crude (unadjusted) odds ratios by 2×2 tables. Funnel plots were used to explore the existence of publication bias and small sample size bias [26].

The GRADE approach was used to assess the quality of the body of evidence associated with the outcome of the meta-analysis. The GRADE approach appraises the quality of a body of evidence to assess the certainty in the effect estimates. The quality measures of a body of evidence consider the within-study risk of bias, the inconsistency of the results, indirectness of evidence, imprecision, and reporting bias, and based on that along with the design of the study the quality of the meta-analysis is appointed.

A trial sequential analysis on the outcome of the meta-analysis using TSA software v0.9.5.10 Beta (Copenhagen Trial Unit) was conducted. In the trial sequential analysis, a meta-analytic sample-size calculation [required information size (RIS)] was calculated based on the expected or observed event rate within the control population, the expected clinically relevant relative risk reduction inflicted by the intervention, the chosen type 1 error (alpha-level) and the power (1-beta). In addition, this RIS is adjusted by the observed heterogeneity in the meta-analysis. The heterogeneity-adjusted RIS was calculated for all meta-analyses based on an a priori defined clinically relevant relative risk reduction of 20% for postoperative intervention compared with non-intervention and a control event proportion based on

the pooled event proportion in the control group. This proposed clinically relevant relative risk reduction is in nature arbitrary but is proposed in the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) Handbook [27].

Results

The selection process is illustrated in Fig. 1. The literature search yielded 3306 potentially relevant studies, and, furthermore, one record was identified through the WHO trial registration website. After removing duplicates and studies not in English, Danish, Swedish, and Norwegian, a total of 2678 potentially relevant studies were screened. From these, 105 records were sought out in full-text of which 28 studies were included in the systematic review and 23 studies were included in the meta-analysis (Fig. 1).

A total of 2279 patients (38% male, 62% female) were included. The mean age ranged from 32 to 73 years. The patients predominantly underwent open upper abdominal surgery (1635 patients, 72%), followed by a group of both upper and lower abdominal surgery (239 patients, 11%), laparoscopic bariatric surgery (224 patients, 10%), laparotomy (150 patients, 6%), and colorectal surgery (31 patients, 1%). Only one study including 150 patients reported data on emergency surgery [28]. The rest of the included studies reported data on elective procedures. None of the included studies reported whether patients were already using CPAP/BiPAP for obstructive sleep apnea at home. The designs of the included studies varied with 25 randomized clinical trials, two prospective cohort studies, and one retrospective cohort studies (Table 2). The majority of the studies focused

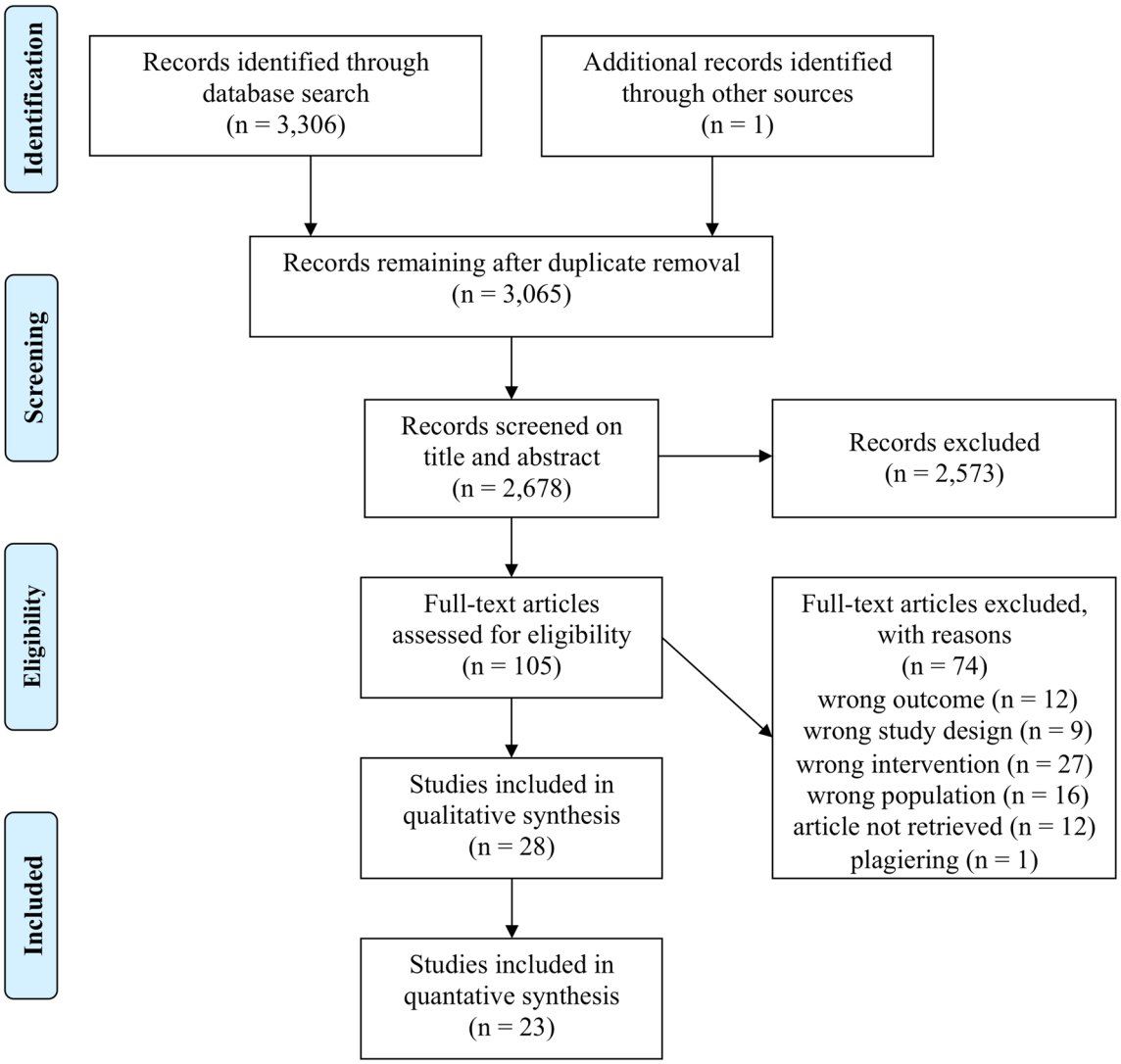

Fig. 1 Flow chart of included studies

Table 2 Overview of included studies

Authors	Year	Design	Surgery	Intervention	Patients	Outcome	Ref
Ahn et al.	2013	RCT	Open/lap/robotic colorectal surgery	Exercise 15 min 2 times/day Usual care	17 14	LOS, surgical complications	[49]
Ali et al.	1984	RCT	Open cholecystectomy	IPPB with NaCl 10 min every 4 h Usual care	15 15	Atelectasis	[29]
Arvidsson et al.	1982	RCT	Open cholecystectomy	Mobilization Mobilization + chest physiotherapy 1 time/day Mobilization + chest physiotherapy + inhalation of salbutamol 1 time/day	45 45 47	Atelectasis, pneumonia, pleura effusion	[30]
Baxter et al.	1969	RCT	Open upper GI (gallbladder, gastric)	IPPB with NaCl 15 min 4 times/day IPPB with isoproterenol 15 min 4 times/day Usual care	50 50 100	Abnormal chest X-ray	[31]
Carlsson et al.	1980	RCT	Open cholecystectomy	CPAP 4 h right after surgery Usual care	13 11	Atelectasis, pneumonia	[32]
Chuter et al.	1990	Prospective cohort	Open cholecystectomy	Incentive spirometry	8	Pneumonia	[33]
Denehy et al.	2001	RCT	Open colorectal, hepaticobilliary	Physiotherapy 10 min 2 times/day Physiotherapy + CPAP for 15 min 4 times/day Physiotherapy + CPAP for 30 min 4 times/day	18 17 15	Atelectasis, pneumonia	[8]
Dohi et al.	1978	RCT	Elective intraabominal	IPPB 15 min 4 times/day Incentive spirometry 5 times/hour for 8 h	30 34	Atelectasis, pneumonia, bronchitis	[34]
Hallbook et al.	1984	RCT	Open cholecystectomy	Mobilization 2 times/day Mobilization + chest physiotherapy 2 times/day Mobilization + chest physiotherapy 2 times/day + salbutamol inhalation 3 times/day	45 45 47	Atelectasis, pneumonia, pleural effusion	[35]
Heisterberg et al.	1979	RCT	Open upper GI (gallbladder, gastric)	Physiotherapy with mobilization + breathing exercises 2 times/hour Blow bottles 10 min every 4 h	49 49	Atelectasis, pneumonia	[36]
Jung et al.	1980	RCT	Open upper GI	IPPB with NaCl 15 min 4 times/day Blow glove 15 min 4 times/day Incentive spirometry 15 min 4 times/day	36 45 45	Atelectasis, pneumonia	[10]
Le et al.	2014	Prospective cohort	Upper and lower GI, open and lap	Walk with volunteers Usual care	15 15	LOS, surgical complications	[50]

Table 2 (continued)

Authors	Year	Design	Surgery	Intervention	Patients	Outcome	Ref
Lederer et al.	1980	RCT	Open upper GI	Incentive spirometry (Triflo device) 10 times/hour Incentive spirometry (Bartlet Edvard device) 10 times/hour Incentive spirometry (Spirocare device) 10 times/hour	27 26 26	Atelectasis, pneumonia	[37]
Lunardi et al.	2015	RCT	Upper GI	Control Deep breathing exercises 50 repetitions once/day Flow incentive spirometry 50 repetitions once/day Volume incentive spirometry 50 repetitions once/day	35 33 35 34	Atelectasis, pneumonia, bronchitis, desaturation > 80%	[38]
Lyager et al.	1979	RCT	Open upper GI (gallbladder, gastric)	Control Incentive spirometry 4 times/hour	51 43	Atelectasis, pneumonia, stasis, pleural effusion	[39]
Mackay et al.	2005	RCT	Upper/lower GI	Mobilization 3 times/day Mobilization + deep breathing exercises 3 times/day	21 29	LOS, lung complications, surgical complications	[11]
Morran et al.	1983	RCT	Open cholecystectomy	Control Chest physiotherapy 15 min/day	51 51	Atelectasis, pneumonia	[40]
O'Connor et al.	1988	RCT	Open cholecystectomy	Routine chest physiotherapy Routine chest physiotherapy + incentive spirometry 3 times/hour	20 20	Lung complications	[41]
Pantel et al.	2017	RCT	Lap bariatric	Incentive spirometry 10 times/hour Control	112 112	Atelectasis, pneumonia	[42]
Possa et al.	2014	Retrospective cohort	Open upper GI	Usual care Standardized physiotherapy with mobilization, incentive spirometry, PEP 2 times/day	133 32	LOS, atelectasis	
Ricksten et al.	1986	RCT	Open upper GI	Mobilization + breathing exercises 2 times/day Mobilization + breathing exercises 2 times/day + CPAP 30 breaths/hour	15 13	Atelectasis	[44]
Rocha et al.	2018	RCT	Open gastric bypass	BIPAP + EPAP 3 times/day Inspiratory load exercise 15 × 6 repetitions 3 times/day	23 22	Atelectasis	[45]
Sanal Bas et al.	2017	RCT	Major abdominal surgery (stomach, liver, pancreas, colon, small intestine)	Control CPAP 4 h right after surgery NIPSV 4 h right after surgery	15 15 15	LOS, atelectasis	[12]

Table 2 (continued)

Authors	Year	Design	Surgery	Intervention	Patients	Outcome	Ref
Schuppisser et al	1980	RCT	Open upper GI	Routine chest physiotherapy IPPB 10 min 3 times/day	9 8	Lung complications	[46]
Schwieger et al	1986	RCT	Open cholecystectomy	Incentive spirometry 5 min/hour 12 times/day Control	20 20	Atelectasis, pneumonia, pleural effusion	[2]
Silva et al.	2013	RCT	Open upper GI	Early mobilization day 1 Early mobilization day 1 + deep breathing exercises 5 times/hour Late mobilization day 3 + deep breathing exercises 5 times/hour	28 28 30	LOS, lung complications	[47]
Sleszynski et al.	1993	RCT	Open cholecystectomy	Incentive spirometry 10 breaths 3 times/day Thorax manipulation 3 times/day	21 21	LOS, atelectasis,	[48]
Tyson et al.	2015	RCT	Laparotomy	Control Deep breathing + incentive spirometry 1 time/hour	75 75	LOS, mortality	[28]

RCT randomized clinical trial, *Lap* laparoscopic, *LOS* length of stay, *IPPB* intermittent positive pressure breathing, *CPAP* continuous positive airway pressure, *PEP* positive expiratory pressure breathing, *BiPAP* Bilevel positive airway pressure, *EPAP* expiratory positive airway pressure, *NIPSV* noninvasive pressure support ventilation

*Patients in this study were stratified on the risk of pulmonary complications into a low risk and a high-risk group based on age > 60 years and ASA > 1, where * = low risk

on respiratory interventions with and without the use of supporting ventilation devices (26 studies). Seven of included studies investigated combined interventions with both mobilization therapy and pulmonary interventions, however, in all of these studies the control group underwent mobilization therapy and the intervention group underwent both mobilization therapy and pulmonary interventions. None of the included studies investigated no intervention vs. mobilization and pulmonary interventions (Table 2). The most commonly reported outcome was pulmonary complications ($n = 25$ studies), followed by length of stay ($n = 8$ studies), surgical complications ($n = 3$ studies), mortality ($n = 2$ studies), and medical complications ($n = 1$). None of the studies reported data on the adverse effects of physiotherapy. Only two studies reported data on intensive care unit length of stay, and no studies reported data on respirator days or reintubation rates. The majority of the studies had a low to unclear risk of bias ($n = 23$), followed by a critical risk of bias ($n = 2$), a high risk of bias ($n = 2$), and moderate risk of bias ($n = 1$) (Tables 3 and 4).

Pulmonary complications

Twenty-five studies with a total of 2068 patients reported on pulmonary complications [2, 8, 10–12, 29–48]. Of these, 23 studies were included in the meta-analyses [2, 8, 10–12, 29–32, 34–36, 38–48]. The intervention was high expiratory resistance (CPAP, EPAP, BiPAP, NIV) in five studies [8, 12, 32, 44, 45], isolated assisted inspiratory flow (IPPB, IPAP) in four studies [10, 29, 31, 46], patient-operated ventilation devices in nine studies [2, 10, 34, 38, 39, 41–43, 48], and structured breathing exercises in seven studies [11, 30, 35, 36, 38, 40, 47].

High expiratory resistance (CPAP, EPAP, BiPAP, NIV)

The studies reporting on high expiratory resistance (CPAP, EPAP, BiPAP, NIV) included a total of 192 patients undergoing open elective upper abdominal surgery ($n = 97$ patients) [32, 44, 45] and either open upper or lower abdominal elective surgery ($n = 95$ patients) [8, 12]. The high expiratory resistance intervention was compared with patients undergoing usual care with mobilization physiotherapy or breathing exercises. The risk of bias for the studies was low/unclear risk ($n = 4$) [12, 32, 44, 45] and high risk ($n = 1$) [8] (Table 3).

The meta-analysis found that ventilation with high expiratory resistance (CPAP, EPAP, BiPAP, NIV) reduced the risk of postoperative pulmonary complications with OR 0.42 (95% CI 0.18–0.97, $p = 0.04$, $I^2 = 0\%$) (Fig. 2). The TSA

Table 3 Risk of bias assessment for the included randomized controlled trials

References	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting
Ahn [49]	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Ali [29]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Arvidsson [30]	Unclear risk	Low risk	Low risk	Low risk	Unclear risk	Unclear risk
Baxter [31]	Unclear risk	Unclear risk	Low risk	Unclear risk	Unclear risk	Unclear risk
Carlsson [32]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Denehy [8]	Unclear risk	Low risk	Low risk	Low risk	High risk	Unclear risk
Dohi [34]	Low risk	Unclear risk	Low risk	Unclear risk	Low risk	Unclear risk
Hallbook [35]	Unclear risk	Low risk	Low risk	Low risk	Low risk	Unclear risk
Heisterberg [36]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Jung [10]	Low risk	Unclear risk	Low risk	Unclear risk	Unclear risk	Unclear risk
Lederer [37]	Unclear risk	Unclear risk	Low risk	Unclear risk	Low risk	Unclear risk
Lunardi [38]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Lyager [39]	Unclear risk	Unclear risk	Low risk	Unclear risk	Low risk	Unclear risk
Mackay [11]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear risk
Morran [40]	Unclear risk	Unclear risk	Low risk	Unclear risk	Unclear risk	Unclear risk
O'Connor [41]	Unclear risk	Unclear risk	Low risk	Unclear risk	Unclear risk	Unclear risk
Pantel [42]	Low risk	Low risk	Low risk	Unclear risk	Low risk	Unclear risk
Ricksten [44]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Rocha [45]	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Sanal Bas [12]	Unclear risk	Unclear risk	Low risk	Low risk	Unclear risk	Unclear risk
Schuppisser [46]	Unclear risk	Unclear risk	Low risk	Unclear risk	Low risk	Unclear risk
Schwieger [2]	Unclear risk	Unclear risk	Low risk	Low risk	Unclear risk	Unclear risk
Silva [47]	Unclear risk	Low risk	Low risk	Low risk	Low risk	Unclear risk
Sleszynski [48]	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Tyson [28]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear risk

Risk of bias assessment tool for randomized controlled trials (RCT): the Cochrane Collaboration's tool for assessing the risk of bias

Table 4 Risk of bias assessment for the included non-randomized controlled trials

	Bias due to confounding	Bias in participant selection	Bias in classification of interventions	Bias due to departures from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported result
Chuter [33]	No information	No information	Low risk	Low risk	Low risk	Low risk	Moderate
Le [50]	Critical risk	Low risk	Low risk	Low risk	Low risk	Low risk	Moderate
Possa [43]	Critical risk	Low risk	Low risk	Low risk	Low risk	Low risk	Moderate

Risk of bias tool for non-randomized trials: ROBINS-I

analysis revealed a RIS of 1,658 patients and the present meta-analysis is, therefore, insufficient to make final conclusions (Fig. 3). The GRADE quality assessment found the level of quality to be moderate as the risk of bias in the individual studies was mostly unclear. A separate subgroup analysis on CPAP including four studies [8, 12, 32, 44] with 132 patients found that CPAP reduced the risk of postoperative pulmonary complications even further with OR 0.34 (95% CI 0.13–0.88, $p = 0.03$, $I^2 = 0\%$) (Fig. 4). The TSA analysis revealed a RIS of 1100 patients (Online Resource 1). The GRADE quality assessment found the level of quality to be moderate as the risk of bias in the individual studies was mostly unclear.

Assisted inspiratory flow only (IPPB, IPAP)

Four studies including 278 patients investigated assisted inspiratory flow only (IPPB, IPAP) [10, 29, 31, 46]. All

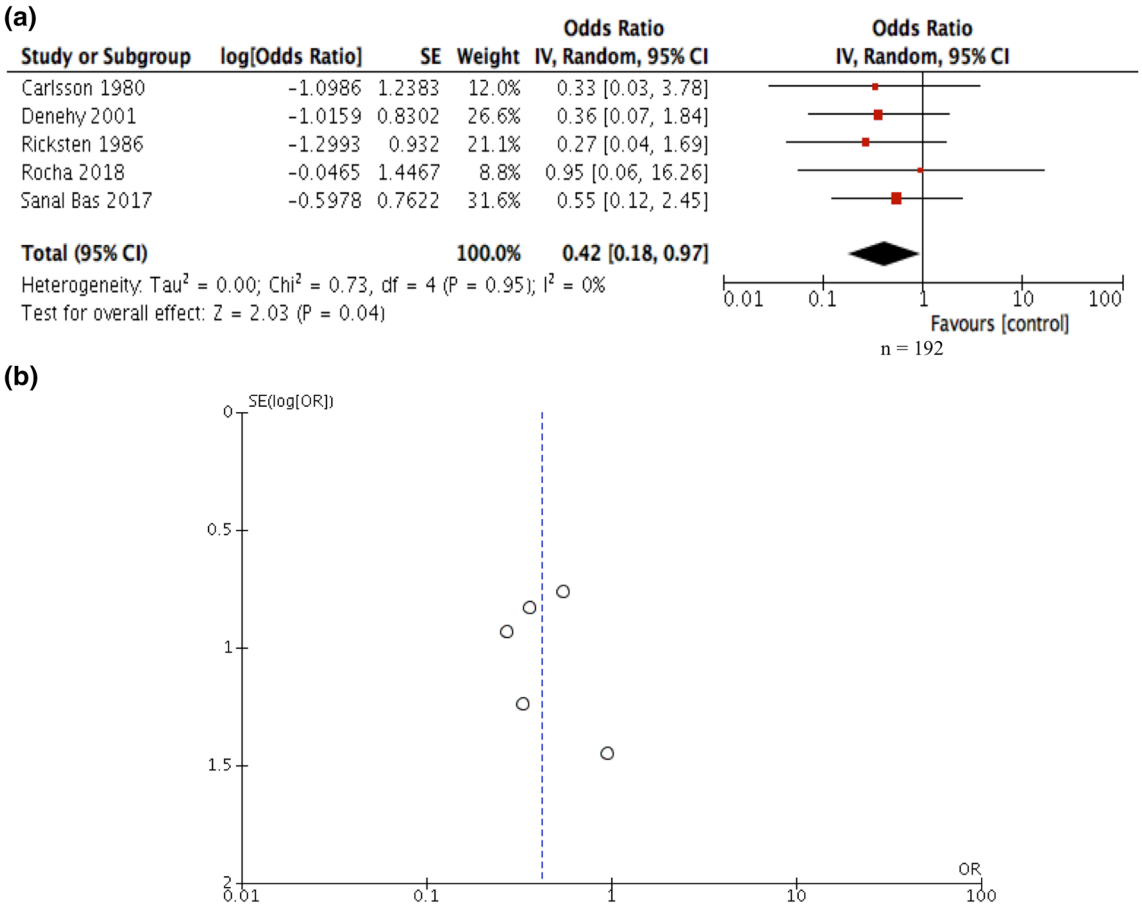

Fig. 2 Meta-analysis of high expiratory resistance (CPAP, EPAP, BiPAP, NIV) vs usual care on pulmonary complications with **a** forest plot and **b** funnel plot

patients underwent elective open upper abdominal surgery. The intervention was compared with patients undergoing usual care or controls undergoing breathing exercises. All of the included studies had low/unclear risk of bias (Table 3). The meta-analysis showed no significant impact of assisted inspiratory flow only (IPPB, IPAP) on the risk of pulmonary complications OR 1.17 (95% CI 0.70–1.96, $p=0.55$, $I^2=0\%$) (Fig. 5). The TSA analysis revealed a RIS of 602 patients (Online Resource 2). The GRADE quality assessment found the level of quality to be moderate as the risk of bias in the individual studies was mostly unclear.

Patient-operated ventilation devices (spirometry, PEP)

Nine studies including 863 patients investigated patient-operated ventilation devices (spirometry, PEP) [2, 10, 34, 38, 39, 41–43, 48]. The majority of the patients underwent elective open upper abdominal surgery ($n=575$ patients) [2, 10, 38, 39, 41, 43, 48], followed by either open upper or lower elective abdominal surgery ($n=64$ patients) [34], and laparoscopic bariatric surgery ($n=22$ patients) [42]. The intervention was compared with patients undergoing usual care or controls. The risk of bias score for the studies was low/unclear risk ($n=7$) [2, 10, 34, 38, 39, 41, 42], high risk ($n=1$) [48], and critical risk ($n=1$) [43] (Table 3 and 4). The meta-analysis showed no significant impact of patient-operated ventilation devices (spirometry, PEP) on the risk of pulmonary complications OR 1.08 (95% CI 0.75–2.10, $p=0.83$, $I^2=56\%$) (Fig. 6). The TSA analysis revealed a RIS of 6831 patients (Online Resource 3). The GRADE quality assessment found the level of quality to be moderate as the risk of bias in the individual studies was mostly unclear and, furthermore, one of the included studies was an observational study [43].

A subgroup analysis on patients who underwent upper abdominal surgery [2, 10, 38, 39, 41, 43, 48] was performed with similar results OR 1.34 (95% CI 0.64–2.67, $p=0.46$, $I^2=44\%$) (Online Resource 4). A subgroup analysis excluding patients undergoing laparoscopic surgery ($n=22$) [42] and including all patients undergoing open surgery ($n=841$) [2, 10, 34, 38, 39, 41, 43, 48] was furthermore performed

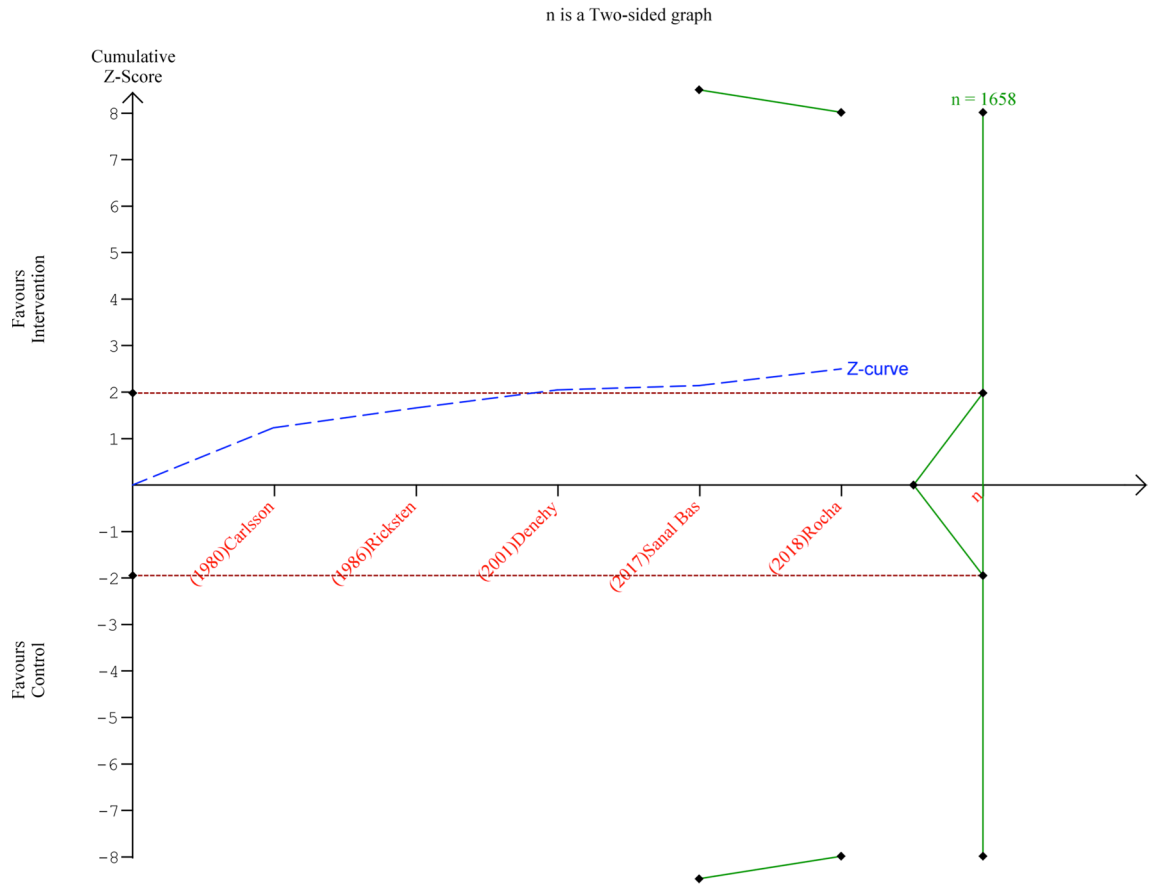

Fig. 3 TSA analysis of required information size for high expiratory resistance (CPAP, EPAP, BiPAP, NIV)

and found similar results with OR 1.00 (95% CI 0.46–2.15, $p = 0.01$, $I^2 = 61\%$) (Online Resource 5).

Respiratory intervention with structured breathing exercises

A total of seven studies including 554 patients reported data on respiratory interventions with structured breathing exercises and without the use of ventilation devices [11, 30, 35, 36, 38, 40, 47]. The patients underwent elective open upper abdominal surgery ($n = 504$ patients) [30, 35, 36, 38, 40, 47] and either open upper or lower elective abdominal surgery ($n = 50$ patients) [11]. The intervention was compared with patients undergoing usual care or controls. The risk of bias score was low/unclear for all the studies (Table 3). The meta-analysis showed no significant impact of respiratory intervention with breathing exercises on the risk of pulmonary complications OR 1.12 (95% CI 0.75–1.65, $p = 0.58$, $I^2 = 5\%$) (Fig. 7). The TSA analysis revealed a RIS of 1647 patients (Online Resource 6). The GRADE quality assessment found the level of quality to be moderate as the risk of bias in the individual studies was mostly unclear.

A subgroup analysis on patients who underwent upper abdominal surgery [30, 35, 36, 38, 40, 47] was conducted with similar results OR 1.13 (95% CI 0.72–1.77, $p = 0.60$, $I^2 = 20\%$) (Online Resource 7).

Surgical complications

A total of three studies including 111 patients reported data on surgical complications [11, 49, 50]. The patients underwent elective colorectal surgery ($n = 31$) [49], and either open upper or lower elective abdominal surgery ($n = 80$) [11, 50]. In two of the studies the intervention was mobilization and exercise, and those studies found that 17% of the patients in the control group and 19% of the patients in the intervention group developed a surgical complication [49, 50]. The final study comparing mobilization only with mobilization and structured breathing exercises reported that 15% of the patients had a surgical complication (wound infection) in the mobilization only group and 0% had a complication in the group with mobilization plus breathing exercises, $p < 0.05$ [11]. The risk of bias in these studies was low/unclear ($n = 2$) [11, 49], and critical ($n = 1$) [50] (Tables 3 and 4).

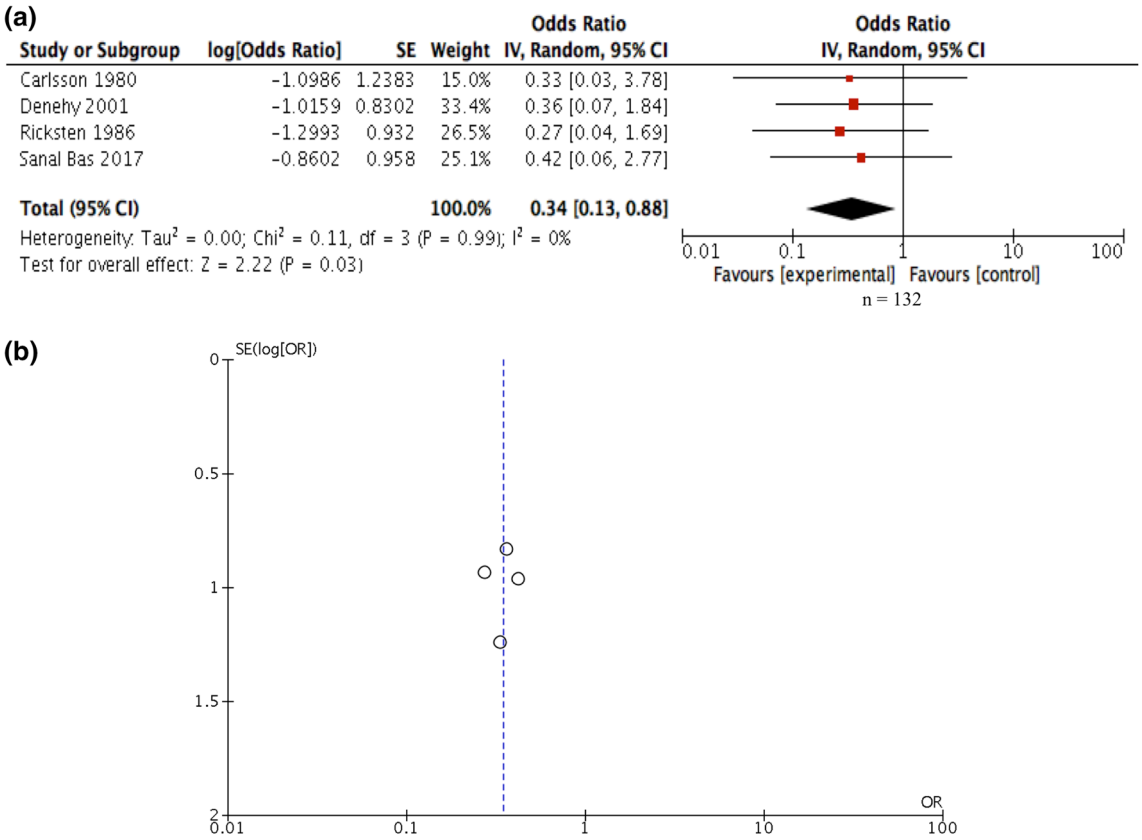

Fig. 4 Meta-analysis of CPAP vs usual care on pulmonary complications with) forest plot and **b** funnel plot

Medical complications

Only one study including 50 patients reported data on postoperative medical complications [11]. The patients in this study underwent either open upper or lower elective abdominal surgery. The study compared mobilization only with mobilization plus structured breathing exercises and reported medical complications such as confusion, atrial fibrillation, cardiac failure, inadequate pain relief, AMI, angina, diarrhea, and vomiting. The study found that 31% of the patients in the mobilization group and 47% of the patients in the mobilization plus breathing exercises group had a medical complication, $p > 0.05$. The risk of bias for this study was unclear (Table 3).

Length of stay

Eight studies including 599 patients reported on length of hospital stay (LOS) [11, 12, 28, 43, 47–50]. The patients in the studies underwent elective colorectal surgery ($n = 31$) [49], either open upper or lower elective abdominal surgery ($n = 125$) [11, 12, 49, 50], elective open upper abdominal surgery ($n = 293$) [43, 47, 48], or emergency laparotomy ($n = 150$) [28]. The intervention of interest was mobilization physiotherapy in two of the studies [49, 50] and different extents of respiratory interventions in the rest of the studies [11, 12, 28, 43, 47, 48]. The studies concerned with mobilization physiotherapy found a mean LOS ranging from 5 to 10 days in the control groups and 5–8 days in the intervention groups [49, 50]. For the studies concerned with respiratory interventions the mean LOS ranged from 4 to 13 days in the control groups and 3–16 days in the intervention groups [11, 12, 28, 43, 47, 48]. The risk of bias of the included studies was low/unclear ($n = 5$) [11, 12, 28, 47, 49], high risk ($n = 1$) [48], and critical risk ($n = 2$) [43, 50] (Tables 3 and 4).

Mortality

Two studies including a total of 200 patients reported data on mortality [11, 28]. The patients underwent elective upper or lower abdominal surgery ($n = 50$) [11] or emergency laparotomy ($n = 150$) [28]. Deep breathing exercises with spirometry were the intervention in one of the studies [28] and deep breathing exercises without spirometry were the intervention in the other study [11]. One study reported zero mortality in the control group and 3% mortality in the intervention group ($p > 0.05$) [11] and the other study reported

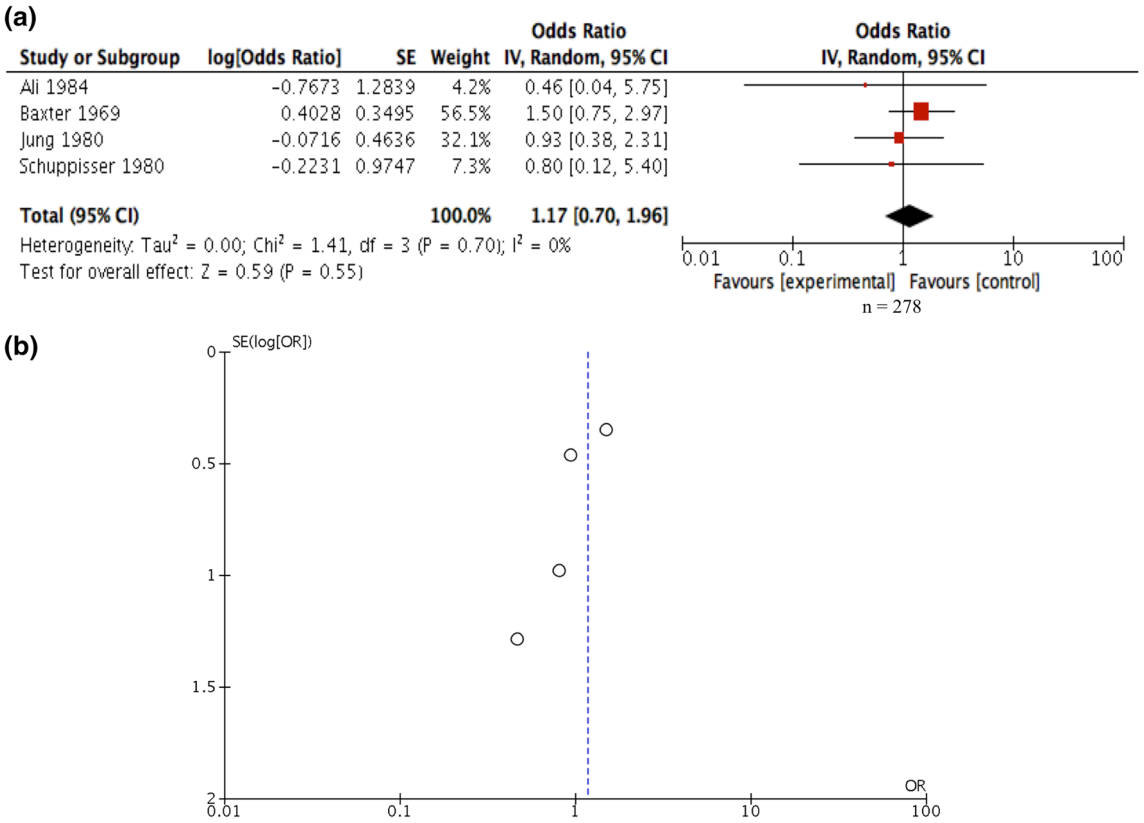

Fig. 5 Meta-analysis of assisted inspiratory flow only (IPPB, IPAP) vs usual care on pulmonary complications with **a** forest plot and **b** funnel plot

10.7% mortality in the control group and 1.3% mortality in the intervention group ($p = 0.02$) [28]. The risk of bias in both studies was low/unclear (Table 3).

Discussion

This review and meta-analysis found that ventilation with high expiratory resistance (CPAP, EPAP, BiPAP, NIV) might reduce the risk of postoperative pulmonary complications and that this risk reduction was largely driven by CPAP. However, the trial sequential analyses revealed that the required information size was insufficient. Postoperative assisted inspiratory flow therapy (IPPB, IPAP), patient-operated ventilation devices (spirometry, PEP), and respiratory intervention with structured breathing exercises did not reduce the risk of postoperative pulmonary complications. No conclusions on the effect of postoperative physiotherapy on postoperative surgical complications could be made from this review as the studies included reported different interventions, had small sample sizes, and varying degrees of bias. Furthermore, no conclusions on the effect of postoperative physiotherapy on the risk of mortality could be made because of limited data.

The ability of CPAP to reduce pulmonary complications is in accordance with previous publications. A meta-analysis from 2008 found that CPAP reduced the risk of postoperative pulmonary complications with a risk ratio of 0.66 favoring CPAP and a number needed to treat of 14.2 patients [51]. This meta-analysis differs from the previous study by only including patients undergoing abdominal gastrointestinal surgery and not vascular surgery and by only including studies where the intervention was applied postoperatively and not preoperatively or intraoperatively. The beneficial effect of CPAP might be explained by the way CPAP affects the lung tissue. The constant pressure over a longer period facilitates alveolar recruitment opening the basal lung sections and increasing functional residual capacity [52, 53]. Furthermore, it has been suggested that cardiac function might be improved with CPAP through reduced left ventricular afterload [54]. These effects cannot be achieved with assisted inspiratory flow therapy, spirometry, PEP, or breathing exercises, which might explain why these modalities did not point towards reducing the incidence of postoperative pulmonary complications. Prior meta-analyses focusing on postoperative spirometry are in accordance with our results as they did

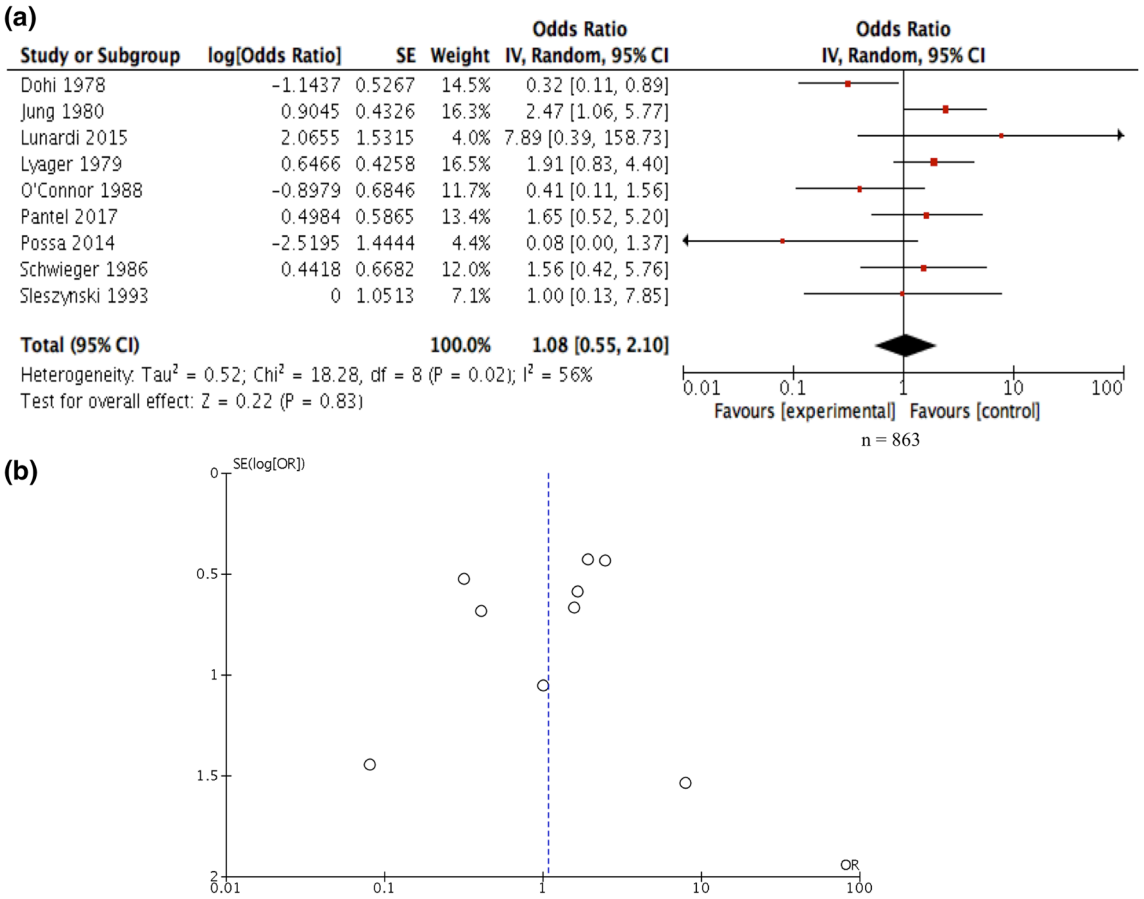

Fig. 6 Meta-analysis of patient operated ventilation devices (spirometry, PEP) vs usual care on pulmonary complications with **a** forest plot and **b** funnel plot

not find an effect of spirometry with respect to prevention of postoperative pulmonary complications [55, 56].

This meta-analysis found a scarcity of published data on postoperative physiotherapy to reduce postoperative surgical complications, medical complications, and mortality why no conclusion in regard to these subjects can be made. Furthermore, all trial sequential analyses revealed that the required information sizes were not met. The length of hospital stay varies from country to country because of cultural aspects and reimbursement, why no final conclusions on the effect of postoperative physiotherapy on LOS were drawn in this study. However, it seems that postoperative physiotherapy has the potential to reduce the postoperative length of hospital stay, which is in accordance with prior investigations in ERAS (Enhanced Recovery After Surgery) settings [57–59]. In the funnel plots for high expiratory resistance and CPAP, we would have expected a greater number of both small positive and negative studies. The lack of small negative studies could implicate some degree of publication bias. However, the funnel plots should be interpreted with caution because of the small number of included studies, which can cause funnel plots to appear asymmetric.

There are several limitations to this study. The review is limited by the included studies, which largely had an unclear risk of bias, however, this limitation is already taken into account in the meta-analysis as the body of evidence is graded in accordance with this. Furthermore, some of the included studies are published more than 30 years ago were both surgeries and the perioperative setups were quite different from today's clinical practice, and some of the breathing modalities investigated in the studies are not used in clinical practice anymore. In this study, a large part of the effect of CPAP is driven by the studies by Carlsson [32] and Ricksten [44] both from the 1980s. Furthermore, some of the drivers of postoperative respiratory complications are pain, opioids, and residual anesthetics. Unfortunately, the majority of the included studies did not report on pain management. We might suspect that older studies were using long-acting anesthetics and no regional or non-opioid pain management. It has previously been shown that epidural analgesia reduces postoperative pulmonary complications [60]. Therefore, the older studies might be difficult to compare with studies using modern perioperative management. This study is strengthened by its concise and transparent methodology. By only

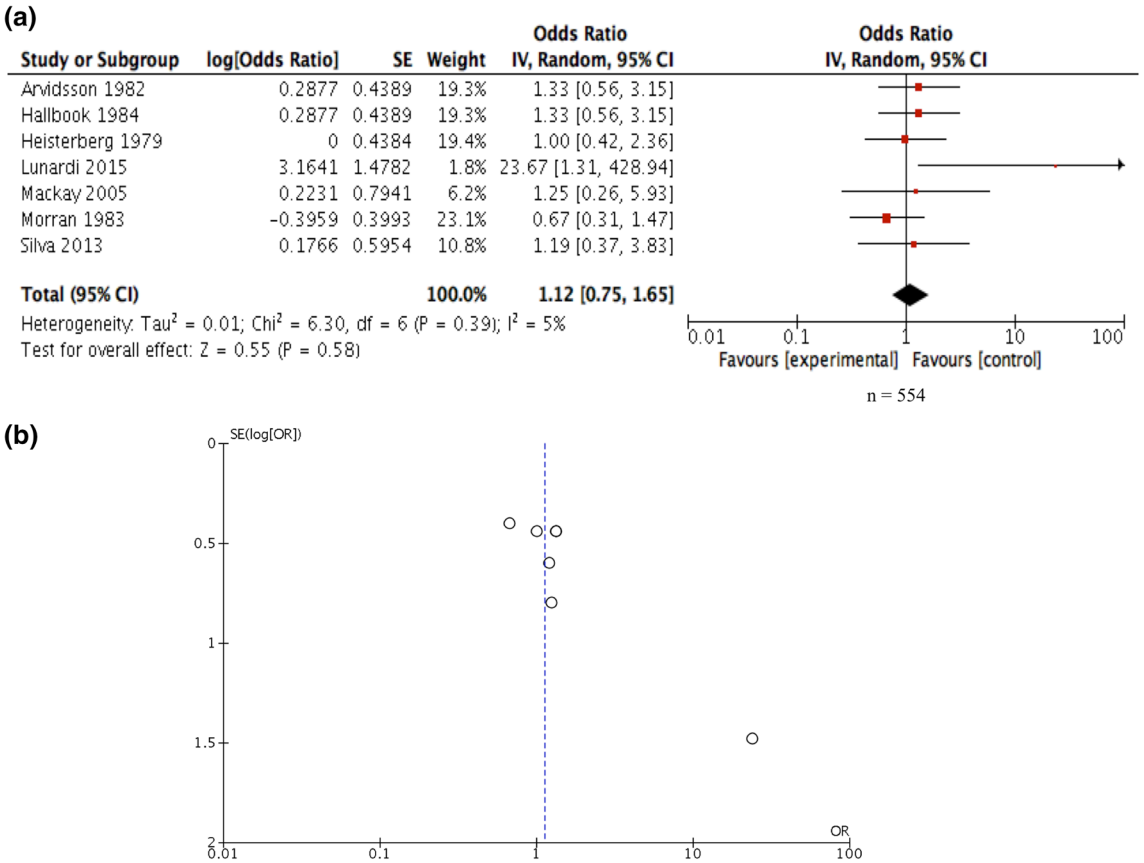

Fig. 7 Meta-analysis of respiratory interventions with breathing exercises vs usual care on pulmonary complications with **a** forest plot and **b** funnel plot

including data on patients undergoing postoperative respiratory and mobilization interventions the findings of this study are applicable in not only elective, but also emergency surgery settings were no preoperative physiotherapy or patient instruction can be planned and executed**.**

This meta-analysis points in favor of CPAP as a postoperative intervention to reduce the risk of postoperative pulmonary complications, however, the TSA analysis found that RIS was not sufficiently met to draw any final conclusions. Compared to other respiratory modalities with high expiratory resistance (EPAP, BiPAP, NIV) CPAP has superior feasibility since it can be administered at surgical wards without respirators. A predictive tool like ARISCAT [61] can help identify the patients at risk for postoperative pulmonary complications and thereby help optimize postoperative care pathways and aim resources.

Conclusions

This meta-analysis indicates that postoperative breathing with high expiratory resistance such as CPAP, EPAP, BiPAP, and NIV might be able to prevent postoperative pulmonary complications and that these preventive abilities are largely driven by ventilation with CPAP. This result should, however, be interpreted with caution, as the trial sequential analyses revealed that the required information size was insufficient.

Funding No funding recieved for this research.

Data availability Data already available as this is a systematic review and meta-analyses.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest All authors declare no conflicts of interest or compering interests.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

1. Lawrence VA, Hilsenbeck SG, Mulrow CD, Dhanda R, Sapp J, Page CP. Incidence and hospital stay for cardiac and pulmonary complications after abdominal surgery. J Gen Intern Med. 1995;10:671–8. https://doi.org/10.1007/bf02602761.
2. Schwieger I, Gamulin Z, Forster A, Meyer P, Gemperle M, Suter PM. Absence of benefit of incentive spirometry in low-risk patients undergoing elective cholecystectomy. A controlled randomized study. Chest. 1986;89:652–6.
3. Dimick JB, Chen SL, Taheri PA, Henderson WG, Khuri SF, Campbell DA Jr. Hospital costs associated with surgical complications: a report from the private-sector National Surgical Quality Improvement Program. J Am Coll Surg. 2004;199:531–7. https://doi.org/10.1016/j.jamcollsurg.2004.05.276.
4. Kazaure HS, Roman SA, Sosa JA. Association of postdischarge complications with reoperation and mortality in general surgery. Arch Surg. 2012;147:1000–7. https://doi.org/10.1001/2013.jamasurg.114.
5. Brooks-Brunn JA. Postoperative atelectasis and pneumonia. Heart Lung. 1995;24(2):94–115.
6. LAS Vegas investigators. Epidemiology, practice of ventilation and outcome for patients at increased risk of postoperative pulmonary complications: LAS VEGAS—an observational study in 29 countries. Eur J Anaesthesiol. 2017;34:492–507. https://doi.org/10.1097/eja.0000000000000646.
7. Warner DO. Preventing postoperative pulmonary complications: the role of the anesthesiologist. Anesthesiology. 2000;92:1467–72.
8. Denehy L, Carroll S, Ntoumenopoulos G, Jenkins S. A randomized controlled trial comparing periodic mask CPAP with physiotherapy after abdominal surgery. Physiother Res Int. 2001;6:236–50.
9. Fagevik Olsen M, Hahn I, Nordgren S, Lonroth H, Lundholm K. Randomized controlled trial of prophylactic chest physiotherapy in major abdominal surgery. Br J Surg. 1997;84:1535–8.
10. Jung R, Wight J, Nusser R, Rosoff L. Comparison of three methods of respiratory care following upper abdominal surgery. Chest. 1980;78:31–5.
11. Mackay MR, Ellis E, Johnston C. Randomised clinical trial of physiotherapy after open abdominal surgery in high risk patients. Aust J Physiother. 2005;51:151–9.
12. Sanal Bas S, Kultufan TS. Comparison of effect of noninvasive pressure techniques on postoperative pulmonary functions in patients undergoing major abdominal surgery. J Crit Intensive Care. 2017;8:71–6.
13. Thomas JA, McIntosh JM. Are incentive spirometry, intermittent positive pressure breathing, and deep breathing exercises effective in the prevention of postoperative pulmonary complications after upper abdominal surgery? A systematic overview and meta-analysis. Phys Ther. 1994;74:3–10. https://doi.org/10.1093/ptj/74.1.3.
14. Hall JC, Tarala R, Harris J, Tapper J, Christiansen K. Incentive spirometry versus routine chest physiotherapy for prevention of pulmonary complications after abdominal surgery. Lancet. 1991;337:953–6. https://doi.org/10.1016/0140-6736(91)91580-n.
15. Celli BR, Rodriguez KS, Snider GL. A controlled trial of intermittent positive pressure breathing, incentive spirometry, and deep breathing exercises in preventing pulmonary complications after abdominal surgery. Am Rev Respir Dis. 1984;130:12–5. https://doi.org/10.1164/arrd.1984.130.1.12.
16. Chumillas S, Ponce JL, Delgado F, Viciano V, Mateu M. Prevention of postoperative pulmonary complications through respiratory rehabilitation: a controlled clinical study. Arch Phys Med Rehabil. 1998;79:5–9.
17. Vester-Andersen M, Lundstrom LH, Møller MH, Waldau T, Rosenberg J, Møller AM. Mortality and postoperative care pathways after emergency gastrointestinal surgery in 2904 patients: a population-based cohort study. Br J Anaesth. 2014;112:860–70. https://doi.org/10.1093/bja/aet487.
18. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535. https://doi.org/10.1136/bmj.b2535.
19. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1. https://doi.org/10.1186/2046-4053-4-1.
20. Greenhalgh T, Peacock R. Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. BMJ. 2005;331:1064–5. https://doi.org/10.1136/bmj.38636.593461.68.
21. https://www.covidence.org. Accessed 14 Mar 2017.
22. Higgins JPT. Cochrane handbook for systematic reviews of interventions. Version 5.1.0. London: The Cochrane Collaboration; 2011.
23. Sterne JAC, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ. 2016. https://doi.org/10.1136/bmj.i4919.
24. Fernandez-Bustamante A, Frendl G, Sprung J, Kor DJ, Subramaniam B, Ruiz RM, et al. Postoperative pulmonary complications, early mortality, and hospital stay following noncardiothoracic surgery: a multicenter study by the perioperative research network investigators. JAMA Surg. 2017;152:157–66. https://doi.org/10.1001/jamasurg.2016.4065.
25. Tusman G, Bohm SH, Warner DO, Sprung J. Atelectasis and perioperative pulmonary complications in high-risk patients. Curr Opin Anaesthesiol. 2012;25:1–10. https://doi.org/10.1097/ACO.0b013e32834dd1eb.
26. Sterne JA, Sutton AJ, Ioannidis JP, Terrin N, Jones DR, Lau J, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. BMJ. 2011;343:d4002. https://doi.org/10.1136/bmj.d4002.
27. Schünemann H BJ, Guyatt G, Oxman A. GRADE handbook for grading quality of evidence and strength of recommendations. guidelinedevelopmentorg/handbook. 2013
28. Tyson AF, Kendig CE, Mabedi C, Cairns BA, Charles AG. The effect of incentive spirometry on postoperative pulmonary function following laparotomy a randomized clinical trial. JAMA Surg. 2015;150:229–36.
29. Ali J, Serrette C, Wood LD, Anthonisen NR. Effect of postoperative intermittent positive pressure breathing on lung function. Chest. 1984;85:192–6.
30. Arvidsson L, Hallbook T, Lindblad B, Lindroth B, Wolff T. Is the physiotherapeutic respirator care as postoperative prevention valuable? Lakartidningen. 1982;79:1480–1.
31. Baxter WD, Levine RS. An evaluation of intermittent positive pressure breathing in the prevention of postoperative pulmonary complications. Arch Surg. 1969;98(6):795–8.
32. Carlsson C, Sonden B, Thylen U. Can postoperative continuous positive airway pressure (CPAP) prevent pulmonary complications after abdominal surgery? Intensive Care Med. 1981;7:225–9.
33. Chuter TA, Weissman C, Mathews DM, Starker PM. Diaphragmatic breathing maneuvers and movement of the diaphragm after cholecystectomy. Chest. 1990;97:1110–4.
34. Dohi S, Gold MI. Comparison of two methods of postoperative respiratory care. Chest. 1978;73:592–5.
35. Hallbook T, Lindblad B, Lindroth B, Wolff T. Prophylaxis against pulmonary complications in patients undergoing gall-bladder surgery. A comparison between early mobilization, physiotherapy with and without bronchodilatation. Ann Chir Gynaecol. 1984;73:55–8.

36. Heisterberg L, Johansen TS, Larsen HW, Holm M, Andersen B. Postoperative pulmonary complications in upper abdominal surgery. A randomized clinical comparison between physiotherapy and blow-bottles. Acta Chir Scand. 1979;145:505–7.
37. Lederer DH, Van de Water JM, Indech RB. Which deep breathing device should the postoperative patient use? Chest. 1980;77:610–3.
38. Lunardi AC, Paisani DM, Silva C, Cano DP, Tanaka C, Carvalho CRF. Comparison of lung expansion techniques on thoracoabdominal mechanics and incidence of pulmonary complications after upper abdominal surgery: a randomized and controlled trial. Chest. 2015;148:1003–100. https://doi.org/10.1378/chest.14-2696.
39. Lyager S, Wernberg M, Rajani N, Boggild-Madsen B, Nielsen L, Nielsen HC, et al. Can postoperative pulmonary conditions be improved by treatment with the Bartlett-Edwards incentive spirometer after upper abdominal surgery? Acta Anaesthesiol Scand. 1979;23:312–9.
40. Morran CG, Finlay IG, Mathieson M, McKay AJ, Wilson N, McArdle CS. Randomized controlled trial of physiotherapy for postoperative pulmonary complications. Br J Anaesth. 1983;55:1113–7.
41. O'Connor M, Tattersall MP, Carter JA. An evaluation of the incentive spirometer to improve lung function after cholecystectomy. Anaesthesia. 1988;43:785–7.
42. Pantel H, Hwang J, Brams D, Schnelldorfer T, Nepomnayshy D. Effect of incentive spirometry on postoperative hypoxemia and pulmonary complications after bariatric surgery: a randomized clinical trial. JAMA Surg. 2017;152:422–8. https://doi.org/10.1001/jamasurg.2016.4981.
43. Possa SS, Amador CB, Costa AM, Sakamoto ET, Kondo CS, Vasconcellos ALM, et al. Implementation of a guideline for physical therapy in the postoperative period of upper abdominal surgery reduces the incidence of atelectasis and length of hospital stay. Rev Port Pneumol. 2014;20:69–77.
44. Ricksten SE, Bengtsson A, Soderberg C, Thorden M, Kvist H. Effects of periodic positive airway pressure by mask on postoperative pulmonary function. Chest. 1986;89:774–81.
45. Rocha M, Souza S, Costa CMD, Merino DFB, Montebelo MIL, Rasera-Junior I, et al. Airway positive pressure vs exercises with inspiratory loading focused on pulmonary and respiratory muscular functions in the postoperative period of bariatric surgery. Arq Bras Cir Dig. 2018;31(2):e1363. https://doi.org/10.1590/0102-672020180001e1363.
46. Schuppisser JP, Brandli O, Meili U. Postoperative intermittent positive pressure breathing versus physiotherapy. Am J Surg. 1980;140:682–6.
47. Silva YR, Li SK, Rickard M. Does the addition of deep breathing exercises to physiotherapy-directed early mobilisation alter patient outcomes following high-risk open upper abdominal surgery? Cluster randomised controlled trial. Physiotherapy. 2013;99:187–93.
48. Sleszynski SL, Kelso AF. Comparison of thoracic manipulation with incentive spirometry in preventing postoperative atelectasis. J Am Osteopat Assoc. 1993;93:834–46.
49. Ahn KY, Hur H, Kim DH, Min J, Jeong DH, Chu SH, et al. The effects of inpatient exercise therapy on the length of hospital stay in stages I–III colon cancer patients: randomized controlled trial. Int J Colorectal Dis. 2013;28:643–51. https://doi.org/10.1007/s00384-013-1665-1.
50. Le H, Khankhanian P, Joshi N, Maa J, Crevensten H. Patients recovering from abdominal surgery who walked with volunteers had improved postoperative recovery profiles during their hospitalization. World J Surg. 2014;38:1961–5. https://doi.org/10.1007/s00268-014-2491-5.
51. Ferreyra GP, Baussano I, Squadrone V, Richiardi L, Marchiaro G, Del Sorbo L, et al. Continuous positive airway pressure for treatment of respiratory complications after abdominal surgery: a systematic review and meta-analysis. Ann Surg. 2008;247:617–26. https://doi.org/10.1097/SLA.0b013e3181675829.
52. Nava S, Hill N. Non-invasive ventilation in acute respiratory failure. Lancet. 2009;374:250–9. https://doi.org/10.1016/s0140-6736(09)60496-7.
53. Pelosi P, Jaber S. Noninvasive respiratory support in the perioperative period. Curr Opin Anaesthesiol. 2010;23:233–8. https://doi.org/10.1097/ACO.0b013e328335daec.
54. Sibbald WJ. Myocardial function in the critically ill: factors influencing left and right ventricular performance in patients with sepsis and trauma. Surg Clin N Am. 1985;65:867–93.
55. Overend TJ, Anderson CM, Lucy SD, Bhatia C, Jonsson BI, Timmermans C. The effect of incentive spirometry on postoperative pulmonary complications: a systematic review. Chest. 2001;120:971–8. https://doi.org/10.1378/chest.120.3.971.
56. Guimaraes MM, El Dib R, Smith AF, Matos D. Incentive spirometry for prevention of postoperative pulmonary complications in upper abdominal surgery. Cochrane Database Syst Rev. 2009. https://doi.org/10.1002/14651858.CD006058.pub2.
57. Liu VX, Rosas E, Hwang J, Cain E, Foss-Durant A, Clopp M, et al. Enhanced recovery after surgery program implementation in 2 surgical populations in an integrated health care delivery system. JAMA Surg. 2017;152:e171032. https://doi.org/10.1001/jamasurg.2017.1032.
58. Spanjersberg WR, Reurings J, Keus F, van Laarhoven CJ. Fast track surgery versus conventional recovery strategies for colorectal surgery. Cochrane Database Syst Rev. 2011. https://doi.org/10.1002/14651858.CD007635.pub2.
59. Greco M, Capretti G, Beretta L, Gemma M, Pecorelli N, Braga M. Enhanced recovery program in colorectal surgery: a meta-analysis of randomized controlled trials. World J Surg. 2014;38:1531–41. https://doi.org/10.1007/s00268-013-2416-8.
60. Pöpping DM, Elia N, Marret E, Remy C, Tramèr MR. Protective effects of epidural analgesia on pulmonary complications after abdominal and thoracic surgery: a meta-analysis. Arch Surg. 2008;143:990–9. https://doi.org/10.1001/archsurg.143.10.990.
61. Canet J, Gallart L, Gomar C, Paluzie G, Valles J, Castillo J, et al. Prediction of postoperative pulmonary complications in a population-based surgical cohort. Anesthesiology. 2010;113:1338–500. https://doi.org/10.1097/ALN.0b013e3181fc6e0a.