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Continuous positive airway pressure (CPAP) during the postoperative period for prevention of postoperative morbidity and mortality following major abdominal surgery (Review)

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[Intervention Review]

Continuous positive airway pressure (CPAP) during the postoperative period for prevention of postoperative morbidity and mortality following major abdominal surgery

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ABSTRACT

Background

Major abdominal surgery can be associated with a number of serious complications that may impair patient recovery. In particular, postoperative pulmonary complications (PPCs), including respiratory complications such as atelectasis and pneumonia, are a major contributor to postoperative morbidity and may even contribute to increased mortality. Continuous positive airway pressure (CPAP) is a type of therapy that uses a high-pressure gas source to deliver constant positive pressure to the airways throughout both inspiration and expiration. This approach is expected to prevent some pulmonary complications, thus reducing mortality.

Objectives

To determine whether any difference can be found in the rate of mortality and adverse events following major abdominal surgery in patients treated postoperatively with CPAP versus standard care, which may include traditional oxygen delivery systems, physiotherapy and incentive spirometry.

Search methods

We searched the Cochrane Central Register of Controlled Trials (CENTRAL) 2013, Issue 9; Ovid MEDLINE (1966 to 15 September 2013); EMBASE (1988 to 15 September 2013); Web of Science (to September 2013) and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (to September 2013).

Selection criteria

We included all randomized controlled trials (RCTs) in which CPAP was compared with standard care for prevention of postoperative mortality and adverse events following major abdominal surgery. We included all adults (adults as defined by individual studies) of both sexes. The intervention of CPAP was applied during the postoperative period. We excluded studies in which participants had received PEEP during surgery.

Data collection and analysis

Two review authors independently selected studies that met the selection criteria from all studies identified by the search strategy. Two review authors extracted the data and assessed risk of bias separately, using a data extraction form. Data entry into RevMan was performed

by one review author and was checked by another for accuracy. We performed a limited meta-analysis and constructed a summary of findings table.

Main results

We selected 10 studies for inclusion in the review from 5236 studies identified in the search. These 10 studies included a total of 709 participants. Risk of bias for the included studies was assessed as high in six studies and as unclear in four studies.

Two RCTs reported all-cause mortality. Among 413 participants, there was no clear evidence of a difference in mortality between CPAP and control groups, and considerable heterogeneity between trials was noted (risk ratio (RR) 1.28, 95% confidence interval (CI) 0.35 to 4.66; I^2 = 75%).

Six studies reported demonstrable atelectasis in the study population. A reduction in atelectasis was observed in the CPAP group, although heterogeneity between studies was substantial (RR 0.62, 95% CI 0.45 to 0.86; I^2 = 61%). Pneumonia was reported in five studies, including 563 participants; CPAP reduced the rate of pneumonia, and no important heterogeneity was noted (RR 0.43, 95% CI 0.21 to 0.84; I^2 = 0%). The number of participants identified as having serious hypoxia was reported in two studies, with no clear difference between CPAP and control groups, given imprecise results and substantial heterogeneity between trials (RR 0.48, 95% CI 0.22 to 1.02; I^2 = 67%). A reduced rate of reintubation was reported in the CPAP group compared with the control group in two studies, and no important heterogeneity was identified (RR 0.14, 95% CI 0.03 to 0.58; I^2 = 0%). Admission into the intensive care unit (ICU) for invasive ventilation and supportive care was reduced in the CPAP group, but this finding did not reach statistical significance (RR 0.45, 95% CI 0.18 to 1.14; I^2 = 0).

Secondary outcomes such as length of hospital stay and adverse effects were only minimally reported.

A summary of findings table was constructed using the GRADE (Grades of Recommendation, Assessment, Development and Evaluation) principle. The quality of evidence was determined to be very low.

Authors' conclusions

Very low-quality evidence from this review suggests that CPAP initiated during the postoperative period might reduce postoperative atelectasis, pneumonia and reintubation, but its effects on mortality, hypoxia or invasive ventilation are uncertain. Evidence is not sufficiently strong to confirm the benefits or harms of CPAP during the postoperative period in those undergoing major abdominal surgery. Most of the included studies did not report on adverse effects attributed to CPAP.

New, high-quality research is much needed to evaluate the use of CPAP in preventing mortality and morbidity following major abdominal surgery. With increasing availability of CPAP to our surgical patients and its potential to improve outcomes (possibly in conjunction with intraoperative lung protective ventilation strategies), unanswered questions regarding its efficacy and safety need to be addressed. Any future study must report on the adverse effects of CPAP.

PLAIN LANGUAGE SUMMARY

Is continuous positive airway pressure (CPAP) during the postoperative period useful?

Review question

Does continuous positive airway pressure during the postoperative period help reduce death and major lung complications after major abdominal surgery?

Background

General anaesthesia can lead to reduced lung volumes and collapse of the alveoli as well as to reversible, patchy collapse of areas of lung (atelectasis) and subsequent low oxygenation. These problems are worse in those patients undergoing upper abdominal surgery, in those who have predisposing factors such as obesity and chronic lung disease and in smokers. Continuous positive airway pressure (CPAP) is a type of therapy that uses a high-pressure gas source to deliver constant pressure to the airways throughout both inspiration and expiration in spontaneously breathing people; oxygen is added in appropriate amounts. CPAP uses a variety of masks, which are placed over the nose or mouth. The aim of this technique is to improve the oxygenation of patients while preventing common postoperative complications in vulnerable people, especially smokers and the obese.

This review was conducted to determine whether any difference can be found in death and major chest complications following major abdominal operations between patients treated with CPAP and those given standard care (oxygen by mask and physiotherapy).

Study characteristics

We searched the literature until 15 September 2013. We included all adults who underwent elective major abdominal surgery. We included only studies in which the intervention was started postoperatively.

We employed the standard methods of the Cochrane Anaesthesia Review Group for data collection and analysis. A total of 709 participants were included in the 10 selected trials. Considerable differences between studies were noted in the populations studied, duration of treatment and supportive care provided.

Key results

Two controlled trials (413 participants) reported deaths; no clear evidence showed a difference between CPAP and control groups. Six trials (249 participants) reported on atelectasis, which was reduced in the CPAP group. Pneumonia was reported in five trials (563 participants), and the rate of pneumonia was reduced in the CPAP group. The need for further respiratory support with artificial ventilation (reintubation) was reported in two studies, which favoured CPAP. No clear evidence revealed a difference between CPAP and control groups in rates of admission to intensive care units, nor were severely low oxygen levels reported.

Few studies reported on length of hospital stay and harm due to CPAP.

Quality of evidence

Substantial variability was seen in trial characteristics (heterogeneity), and risk of bias was high in six of the 10 studies. The included studies were small, and some were at least 20 years old; currently, computed tomography (CT) scans are used more often than chest x-rays and clinical examination alone for diagnosis. The summary of findings (GRADE) suggests that the strength of evidence supporting the use of CPAP was ‘very low.’ This means that recommendations based on currently available evidence from randomized controlled trials investigating use of CPAP during the postoperative period are not definitive.

SUMMARY OF FINDINGS

Summary of findings for the main comparison.

CPAP during postoperative period for participants having major abdominal surgery

Patient or population: patients having major abdominal surgery

Settings: major abdominal surgery

Intervention: CPAP during postoperative period as intervention

Comparison: usual postoperative care as control

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Control	CPAP during postoperative period				
Reported mortality As reported in the trials Follow-up: up to 5-7 days	**Study population**		**RR 1.28** (0.35 to 4.66)	413 (2 studies)	⊕⊝⊝⊝ **very low** [a,b,c]	Data contain only mortality figures reported in the studies
	14 per 1000	**18 per 1000** (5 to 65)				
	Moderate					
	14 per 1000	**18 per 1000** (5 to 63)				
Atelectasis As reported in the trials Follow-up: up to 1-10 days	**Study population**		**RR 0.62** (0.45 to 0.86)	249 (6 studies)	⊕⊝⊝⊝ **very low** [d,e,f]	Data include only the numbers identified in included studies
	441 per 1000	**240 per 1000** (148 to 371)				
	Moderate					
	402 per 1000	**212 per 1000** (129 to 335)				

Pneumonia As reported in the included trials Follow-up: up to 5-7 days	**Study population**		**RR 0.43** (0.21 to 0.84)	563 (5 studies)	⊕⊝⊝⊝ **very low** g,h,i	Data include only documented cases in included studies
	81 per 1000	**32 per 1000** (16 to 67)				
	Moderate					
	59 per 1000	**23 per 1000** (11 to 49)				

*The basis for the **assumed risk** (e.g. median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio.

GRADE Working Group grades of evidence.
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[a]Risk of bias for the 2 included studies (Bohner 2002; Squadrone 2005) assessed as unclear.
[b]Heterogeneity is considerable in the methods of intervention and controls in the 2 studies (Bohner 2002; Squadrone 2005).
[c]Even though the 2 studies (Bohner 2002; Squadrone 2005) included around 400 participants, the rate of (mortality) is very low.
[d]Four of the 6 studies in this analysis (Carlsson 1981; Christensen 1991; Lindner 1987; Lotz 1984; Ricksten 1986: Stock 1985) are marked as high risk of bias, and Stock 1985, Carlsson 1981 and Christensen 1991 are marked as unclear risk of bias.
[e]Heterogeneity between the 6 studies included in this analysis is considerable; intervention groups and control groups were somewhat different; duration of intervention and period of observations were also different in these studies.
[f]Numbers of participants and event rates in included trials were low in the included trials.
[g]Three of the selected studies (Bohner 2002; Christensen 1991; Squadrone 2005) were assessed as unclear risk of bias and two of the studies (Lindner 1987; Stock 1985) were assessed as high risk of bias.
[h]In the included trials, differences in control and intervention groups, methods of assessing outcomes (pneumonia) and time when outcomes were assessed were inconsistent, resulting in important clinical heterogeneity.
[i]The 5 included studies have varying numbers of participants and low rates of pneumonia. This leads to serious imprecision.

BACKGROUND

Description of the condition

Major abdominal surgery, which is defined as abdominal surgery requiring laparotomy, can be associated with several serious complications that may impair patient recovery. In particular, postoperative pulmonary complications (PPCs) are a major contributor to postoperative morbidity (Warner 2000). Studies investigating the incidence of PPCs following abdominal surgery have suffered from the use of varying definitions of the term. Thus the documented incidence among patients varies between 9% and 40% (Arozullah 2000). Mortality following all types of inpatient surgery ranges from 0.4% to 1.5% (Haynes 2009). However, a large study conducted to evaluate mortality and morbidity in patients undergoing higher-risk elective and emergency abdominal and vascular surgery reported mortality rates of 3.5% to 6.9% (Ghaferi 2009).

Atelectasis can be defined as reversible loss of aerated lung (Duggan 2007). Atelectasis may be the result of alveolar collapse from surfactant impairment, gas resorption or lung compression. Atelectasis is no longer considered a benign entity. It can result in reduced lung compliance, increased pulmonary vascular resistance and gas exchange abnormalities. Atelectasis is considered an important postoperative pulmonary complication that increases the risk of postoperative pneumonia and acute respiratory failure. Acute respiratory failure may result in endotracheal intubation, lengthened hospital stay and increased morbidity and mortality (Pelosi 2010). In a prospective cohort study of a broad range of surgical procedures, the 30-day mortality rate was increased from 1% to 27% in the presence of postoperative respiratory failure (Arozullah 2000).

It has long been recognized that general anaesthesia can impair respiratory function, leading to hypoxaemia (Nunn 1962). Anaesthetic agents can impair central respiratory regulation as well as the function and co-ordination of respiratory muscles (Warner 2000). The overall effect of this is reduced functional residual capacity, predisposing to atelectasis. It is now recognized that atelectasis occurs in dependent lung regions among most patients under general anaesthesia (Duggan 2005). These changes can persist for several days postoperatively (Lindberg 1992). Mechanisms of atelectasis formation include compression of lung tissue, absorption of alveolar air and impairment of surfactant function (Duggan 2005).

During the postoperative period, contributors to pulmonary dysfunction include residual anaesthetic effects, surgical trauma and pain (Warner 2000). Also important in the development of PPCs are patient risk factors such as age, smoking, pre-existing respiratory disease, functional status and obesity (Arozullah 2000; Arunotai 2010).

Another potential cause of postoperative hypoxia is upper airway obstruction causing apnoea. It is recognized that obstructive sleep apnoea syndrome (OSAS) is a common and frequently undiagnosed condition. The incidence of OSAS among patients presenting for surgery is estimated to be between 1% and 9%, and most of these are undiagnosed cases (Kaw 2006). Symptoms of OSAS can be exacerbated during the postoperative period, predisposing to PPCs and adverse outcomes (Kaw 2006).

A previous Cochrane review found no evidence to support the use of incentive spirometry (a mechanical device that can increase lung volume by encouraging deep inspiration) for prevention of PPCs following upper abdominal surgery (Guimaraes 2009).

Description of the intervention

Continuous positive airway pressure (CPAP) is a form of non-invasive respiratory support (NRS). It uses a high-pressure gas source to deliver constant positive pressure to the airways throughout both inspiration and expiration (Weksler 1991). CPAP can deliver positive pressure to the airways in various ways and may involve one of a variety of masks (nasal, oral, oronasal, full face) or a helmet that covers the whole head (Pelosi 2010).

CPAP therapy in the immediate postoperative period requires staff who are well trained in its use. Traditionally, this treatment has been provided in a specialized environment (e.g. a high-dependency unit), but it can be used on surgical wards in some hospitals. When CPAP is instituted, pressures of 7 to 10 cm H_2O appear well tolerated with few adverse effects. CPAP is often instituted intermittently, for example, for 60 to 90 minutes at two- to three-hourly intervals. Pressures greater than 20 cm H_2O are generally avoided following abdominal surgery to reduce the presence of air in the digestive tract (Pelosi 2010).

NRS such as CPAP is now used increasingly to prevent postoperative respiratory complications such as atelectasis after major abdominal surgery. However, several potential contraindications to its use have been identified. These include inability to fit a mask, unco-operative patients, medical instability and inability of patients to protect their airway (Nava 2009). Poor compliance with CPAP therapy is recognized in patients given long-term treatment, 46% to 83% of whom are non-adherent with treatment (Weaver 2008). Whether this will be an issue in the acute setting remains unclear. Potential reasons for non-compliance include noise from the machine, discomfort caused by the mask, claustrophobia, skin trauma and nasal congestion.

How the intervention might work

CPAP may improve respiratory function postoperatively by increasing functional residual capacity, improving alveolar recruitment and reducing the work of breathing (Nava 2009; Pelosi 2010). Consequences of atelectasis such as pneumonia and acute respiratory failure may subsequently be prevented. Additionally, CPAP may help treat the symptoms of unrecognized OSAS, thus preventing hypoxia.

Cardiac function may improve through reduced left ventricular afterload (Sibbald 1985) and improved oxygenation.

Why it is important to do this review

Major abdominal surgery is frequently associated with postoperative complications. CPAP may help reduce the occurrence of postoperative complications while improving patient outcomes. Currently, no consensus has been reached on the role of prophylactic CPAP following major abdominal surgery.

OBJECTIVES

To determine whether any difference can be found in the rate of mortality and adverse events following major abdominal surgery

in patients treated postoperatively with CPAP versus standard care, which may include traditional oxygen delivery systems, physiotherapy and incentive spirometry.

METHODS

Criteria for considering studies for this review

Types of studies

We included all randomized controlled trials (RCTs) in which CPAP was compared with standard care for prevention of postoperative mortality and morbidity following major abdominal surgery.

Types of participants

We included all adults (adults as defined by individual studies) of both sexes who underwent elective or emergency major abdominal surgery.

We did not exclude patients with co-morbidities such as obesity, respiratory disease and a history of smoking.

We excluded patients who received bilevel positive airway pressure (BiPAP) and those treated with CPAP perioperatively, because the review was confined to postoperative use of CPAP.

Types of interventions

The intervention of CPAP was applied during the postoperative period. The control group was made up of those who received standard postoperative care, which may have included traditional oxygen delivery systems, physiotherapy and incentive spirometry.

Types of outcome measures

Primary outcomes

1. All-cause mortality.
2. Major respiratory complications as defined in individual studies (significant atelectasis, pneumonia, significant hypoxia, tracheal reintubation, intensive care unit (ICU) admission).

We have accepted 'atelectasis' as defined by the authors of the individual studies and have explored obvious differences between varying definitions used in different studies, which were recorded as sources of clinical heterogeneity. However, if considerable heterogeneity existed between various studies, we did not proceed to meta-analysis but presented the available data.

Secondary outcomes

1. Length of stay in hospital.
2. Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia).
3. Other postoperative complications (wound infection, anastomotic leak, renal failure).
4. Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury).

Search methods for identification of studies

Electronic searches

We searched the Cochrane Central Register of Controlled Trials (CENTRAL) 2013, Issue 9; Ovid MEDLINE (1966 to September 2013); EMBASE (1988 to September 2013); Web of Science (to September 2013); and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (to September 2013). The search strategies are given in Appendix 1 (MEDLINE), Appendix 2 (EMBASE), Appendix 3 (CENTRAL), Appendix 4 (Web of Science) and Appendix 5 (CINAHL).

Searching other resources

We also searched reference lists and bibliographical data from all retrieved articles as well as reviews for any additional, relevant material. We endeavoured to contact the relevant authors and known experts in this area to ask for further information on published studies or for unpublished data. We tried to identify unpublished studies or ongoing studies from relevant clinical trial registries. We did not restrict our selection of studies on the basis of language or country of study.

We searched for ongoing trials through the following websites.

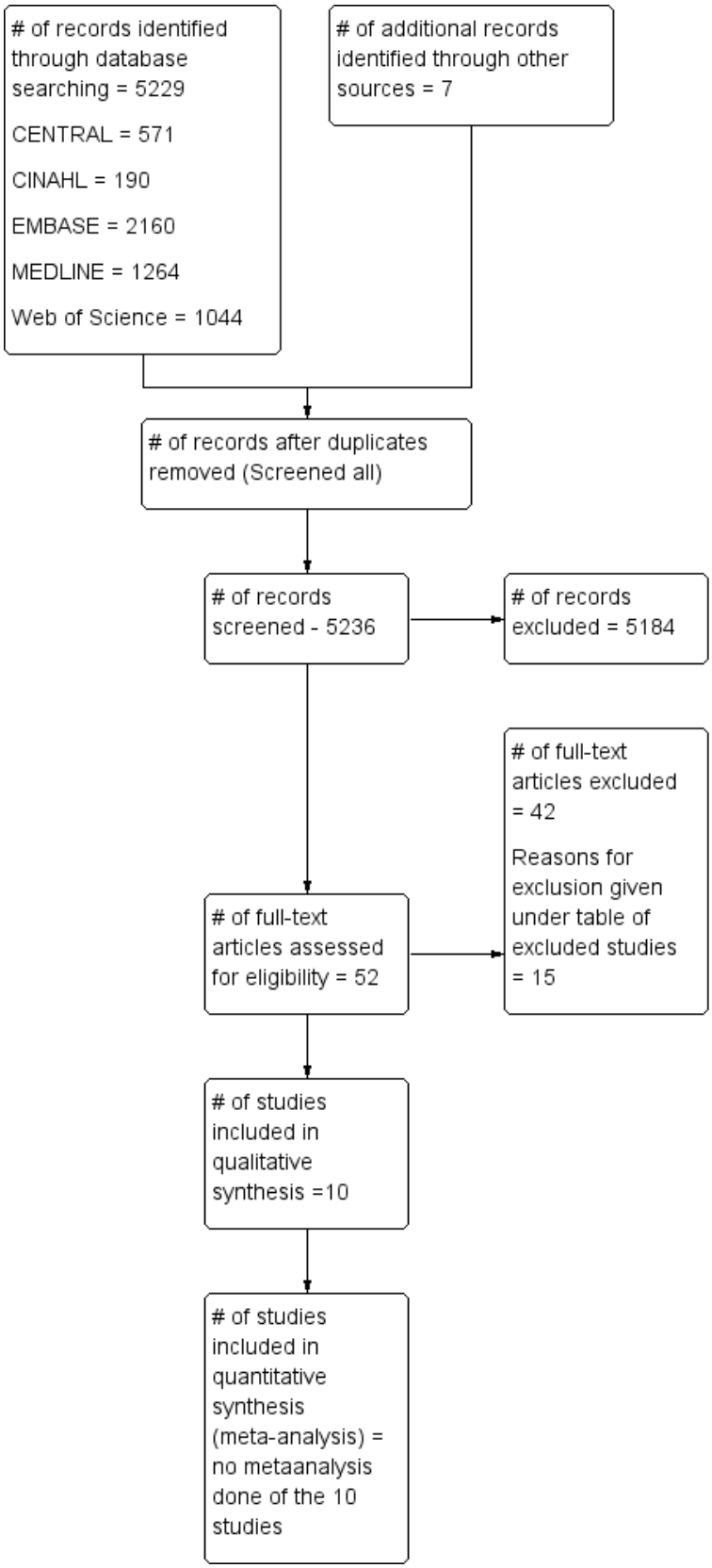
1. www.controlled-trials.com
2. http://clinicaltrials.gov/ct2/search

Data collection and analysis

Selection of studies

We evaluated all 5236 studies identified by the search methods for appropriateness of inclusion (see Figure 1). We first examined abstracts or summaries of publications. We obtained full publications for studies that required further assessment. Two review authors (CI, TC) evaluated these studies for appropriateness of inclusion without prior consideration of the results. Studies in languages other than English were selected, and translation by foreign language experts was required for some. Consensus on the final selection was reached; if necessary, another review author (MZ) helped to make the final selection.

Figure 1. Study flow diagram.



Data extraction and management

Two review authors (MZ, SFM) independently extracted data using a suitable data extraction form (Appendix 6). Special focus was placed on study design, methods of analysis and relevant study results. Information regarding study methodological quality included method of randomization, concealment of allocation, blinding (masking) used, frequency and handling of withdrawals and completion of an intention-to-treat (ITT) analysis. We resolved disagreements through discussion and in consultation with another review author (CI). We attempted to contact the authors of all included trials to obtain additional details on study methodology and missing data as required.

All data were entered and double-checked by MZ and SFM.

Assessment of risk of bias in included studies

The measures recommended by the Cochrane Anaesthesia Review Group (CARG) were used to assess risk of bias and included the following.

Adequate randomization and concealment of allocation (allocation bias)

Allocation bias: This was assessed as low risk of bias, high risk of bias or unclear risk of bias, as below.

Generation of the allocation sequence: This was considered adequate if a computer-generated randomization sequence or a random number table was used.

Adequate concealment of allocation: Allocation was performed through a central office; an on-site computer system with allocation was kept in a locked computer file or numbered and sealed opaque envelopes were used.

Inadequate concealment of allocation: alternation using date of birth, an open list of random numbers or day of the week.

Unclear concealment of allocation: Study did not report any concealment approach or stated that concealment was not used.

Blinding or masking (performance bias)

Information about blinding was sought in the trial reports. However, blinding may not be possible, as differences in the two techniques are very evident.

Completeness of follow-up (attrition bias)

Information regarding loss of participants from a study after allocation was noted (e.g. withdrawal, dropout, protocol deviation).

Adequacy of follow-up (detection bias)

This was determined from the following:

Outcomes clearly defined in the text.

Appropriate timing of outcome measures in the text.

Reporting bias (selective reporting)

Information was sought regarding the availability of a study protocol with prespecified outcomes reported in a prespecified way.

Based on the above criteria, the risk of bias was assessed by the review authors (CI, TC) as below; the two review authors resolved disagreements regarding the assessment by discussion and by reaching consensus, if necessary with the help of another review author (MZ).

Low risk of bias: All criteria were adequately met.

High risk of bias: One or more criteria were not met.

Unclear risk of bias: Insufficient information was available to permit assessment of "low" or "high" risk.

Risk of bias table

We generated a risk of bias (ROB) table as recommended by the Cochrane Anaesthesia Review Group (CARG) and as per recommendations in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). The ROB is given in Figure 2 and Figure 3.

Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

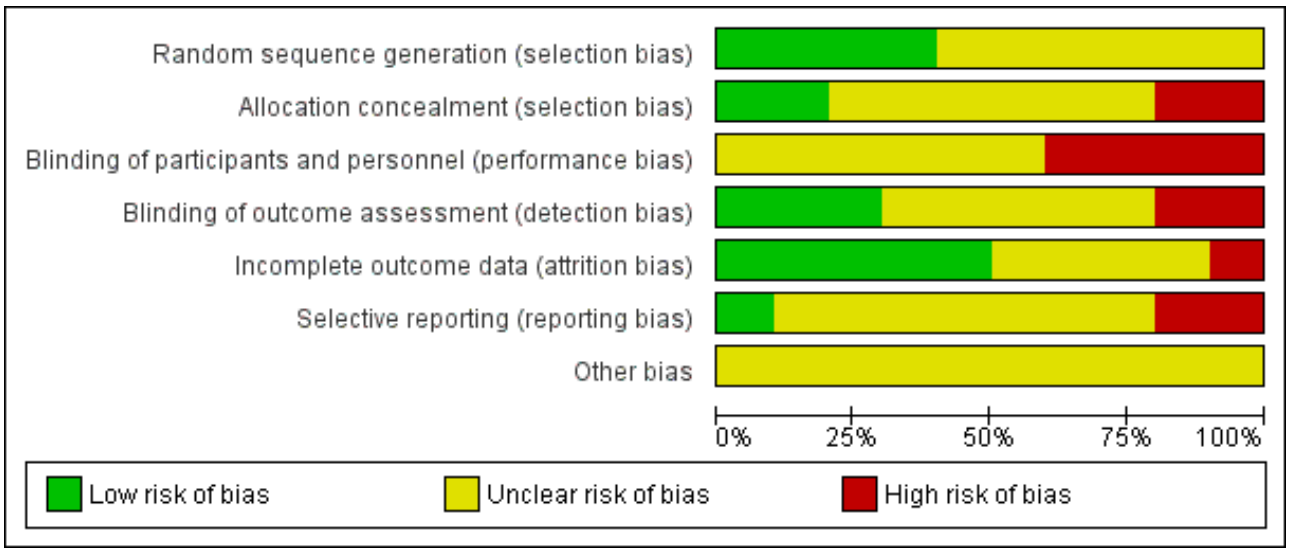
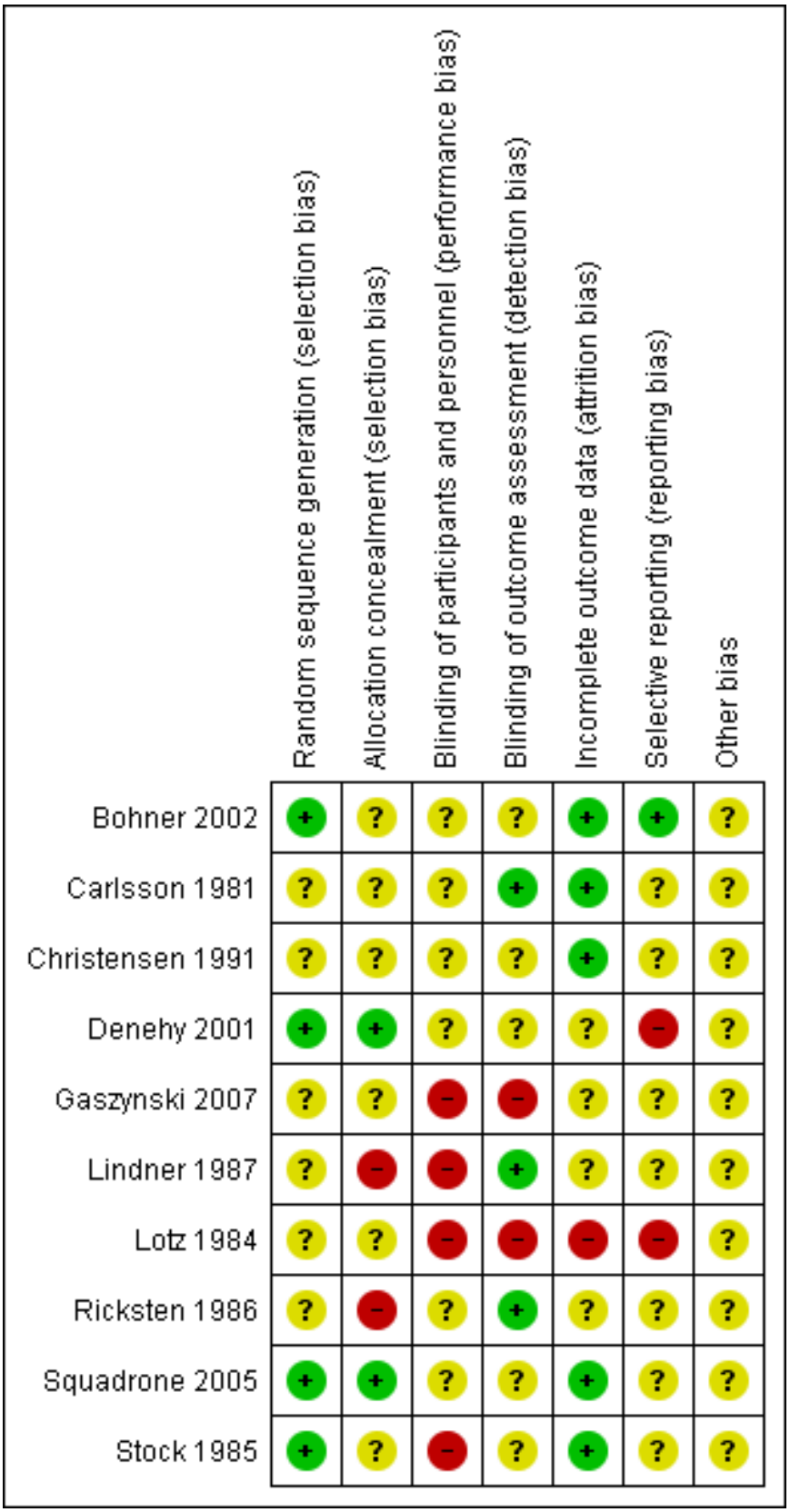


Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



Measures of treatment effect

We summarized treatment effects using risk ratio (RR) for dichotomous outcomes. We had no continuous outcomes to incorporate in this review because of inconsistent and limited reporting of length of hospital stay, but we would have used mean difference (MD) for this purpose.

Unit of analysis issues

In the unlikely event that cluster-randomized trials or cross-over trials were identified, we planned to make sure that they were analysed correctly before they were included in meta-analyses. It may have been possible to get corrected estimates from what was presented.

Dealing with missing data

We attempted to contact investigators using email as the means to inquire about missing data or to ask for further information on the methodological quality of the studies. Unfortunately, a number of the studies selected were many years old; hence this was mostly unsuccessful.

Assessment of heterogeneity

Clinical heterogeneity was judged by the review authors (CI, MZ, SFM, TC) and the results noted in the review. If significant clinical heterogeneity existed, pooling of data was to be avoided; data from individual studies would have been presented in a tabular format.

We tested for statistical heterogeneity using visual inspection of the forest plot and the I^2 statistic (Higgins 2011). We used the following thresholds as a guide to interpretation of the I^2 statistic.

0% to 40%: might not be important.
30% to 60%: may represent moderate heterogeneity.
50% to 90%: may represent substantial heterogeneity.
75% to 100%: show considerable heterogeneity.

Assessment of reporting biases

We would have looked for publication bias by using a funnel plot, plotting the size of the treatment effect for the outcome against trial precision (one/standard error), if at least 10 studies were identified in an individual meta-analysis (Egger 1997). In this case, we would have used a formal statistical test for funnel plot asymmetry. If asymmetry existed, we would have explored and presented the reasons for this, such as publication bias or studies with poor methodology.

Data synthesis

We used Review Manager (RevMan 5.2) to perform quantitative analysis. A fixed-effect model meta-analysis was used for synthesis of all data.

Subgroup analysis and investigation of heterogeneity

If it were possible, we would have carried out subgroup analyses for the following.

1. Bariatric surgery.
2. Pre-existing respiratory disease.
3. Elective versus emergency surgery.
4. Age.
5. Continuous versus intermittent CPAP.
6. Obstructive sleep apnoea syndrome.

If important heterogeneity was not explained by the subgroups above, we examined studies for other factors that may help to explain the heterogeneity.

Sensitivity analysis

Sensitivity analysis would have been performed for studies with low risk of bias versus the others, and for those with adequate allocation concealment versus the others.

Summary of findings table

We summarized the evidence in the Summary of findings for the main comparison, as recommended by CARG, using the programme GRADEpro (GRADEpro 2008). The GRADE (Grades of Recommendation, Assessment, Development and Evaluation) approach appraises the quality of a body of evidence on the basis of the extent to which one can be confident that an estimate of effect or association reflects the item being assessed. The quality of a body of evidence considers within-study risk of bias (methodological quality), directness of the evidence, heterogeneity of the data, precision of effect estimates and risk of publication bias.

We had planned to use the GRADEPro system to assess the quality of the body of evidence associated with specific outcomes, as below.

1. All-cause mortality.
2. Major respiratory complications as defined in individual studies (significant atelectasis, pneumonia, significant hypoxia, tracheal reintubation, ICU admission).
3. Length of stay in hospital.
4. Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia).
5. Other postoperative complications (wound infection, anastomotic leak, renal failure).
6. Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury).

As we had limited data, we used the following outcomes to construct the SOF table (Summary of findings for the main comparison).

1. Reported mortality.
2. Atelectasis.
3. Pneumonia.

RESULTS

Description of studies

Details of studies can be found in Characteristics of included studies, Characteristics of excluded studies and Characteristics of studies awaiting classification.

Results of the search

We searched the literature until September 2013. We searched MEDLINE, EMBASE, CENTRAL, CINAHL and Web of Science; the search details are given in Appendix 1; Appendix 2; Appendix

3; Appendix 4; and Appendix 5. The studies identified and subsequently selected are shown in Figure 1.

We searched reference lists and bibliographical data from all retrieved articles and reviews to look for additional, relevant material. We sought information from authors of unpublished studies and contacted recognized experts on this topic about any unpublished data. Unfortunately, many of the studies were old (over 20 years old); hence we were unable to reliably contact the study authors.

Our final selection yielded 10 studies for inclusion in the review (from 5229 identified articles); this occurred for multiple reasons, including use of broad search criteria and duplication in multiple databases.

Included studies

We selected 10 studies for the analysis (see Characteristics of included studies). However, these studies were found to have substantial clinical heterogeneity (Table 1) in the form of different operations, different nature and details of intervention, differences in control groups and differences in the duration of the study and in reporting. Reported outcomes were varied and infrequent (Table 2).

Excluded studies

We had to exclude many studies at the final selection process (see Characteristics of excluded studies). Reasons for this included interventions that were outside our selection criteria and lack of randomization. As we planned to select studies that used CPAP only during the postoperative period, we did not select studies in which positive end-expiratory pressure (PEEP) was used intraoperatively, followed by CPAP in the postoperative period.

We identified two studies that are awaiting final reporting (Characteristics of ongoing studies), and we have been unable to get one publication translated to this point (Characteristics of studies awaiting classification). We hope to address this in our next update of this review.

Risk of bias in included studies

The most disappointing part of the review was that our assessment determined that most of the selected studies (six out of 10) were at high risk of bias, and in the remaining studies the risk of bias was unclear (Table 3). The main reason for this could be that most of the selected studies were old, and methodological quality and reporting in those studies were inadequate or insufficient. Many of the studies were at least 20 years old; therefore, we were unsuccessful in contacting most of the study authors to obtain further details (Denehy 2001; Squadrone 2005; Stock 1985; see Table 3).

Allocation

Randomization was adequate in four trials (Bohner 2002; Denehy 2001; Squadrone 2005; Stock 1985) but was not reported in detail in the other studies.

Allocation concealment was described in only three studies (Denehy 2001; Squadrone 2005; Stock 1985), and these details are lacking in the other publications.

Blinding

Blinding to the radiologist was reported in three studies (Carlsson 1981; Denehy 2001; Ricksten 1986) but not in the other studies. No other evidence suggested blinding during the conduct of the trials.

Incomplete outcome data

Data reporting seems to be complete in four studies (Carlsson 1981; Christensen 1991; Lindner 1987; Stock 1985);information obtained from the other studies does not give evidence of any issues related to incomplete outcome reporting but does not confirm that the reporting is complete.

Selective reporting

Reporting bias could be identified in only one study (Stock 1985).

Other potential sources of bias

None of the studies revealed any other possible biases, but one study (Stock 1985) gave a clear indication of no further biases.

Effects of interventions

See: **Summary of findings for the main comparison**

As was previously mentioned, substantial heterogeneity exists between studies for some outcomes, and the methodological quality of the included studies was poor. We therefore were somewhat hesitant to perform meta-analyses of the data; however, we did completedata analysis and prepared tables for the different outcomes of interest. We have provided a narrative description of the main outcomes, which are summarized in Table 2.

Primary outcomes

1. All-cause mortality

Two included RCTs (Bohner 2002; Squadrone 2005) reported the main primary outcome of interest: all-cause mortality. Seven postoperative deaths were reported among 413 participants: three of 209 (0.73%) participants in the control group, and four of 204 (0.97%) in the CPAP group. No clear evidence of a difference in mortality was found between CPAP and control groups, and considerable heterogeneity was noted between available trials (Analysis 1.1; RR 1.28, 95% confidence interval (CI) 0.35 to 4.66; I^2 = 75%).

2. Major respiratory complications as defined in individual studies (significant atelectasis, pneumonia, significant hypoxia, tracheal reintubation, ICU admission)

We have reported the data given in the selected publications and have used the criteria listed in those publications (Table 2).

Atelectasis: Six studies including 249 participants reported demonstrable atelectasis (Carlsson 1981; Christensen 1991; Lindner 1987; Lotz 1984; Ricksten 1986; Stock 1985). Atelectasis was a common finding, with 39 of 131 (29.8%) participants in the CPAP group and 52 of 118 (44.1%) in the control group diagnosed on days one to five postoperatively. A reduction in atelectasis in the CPAP group reached statistical significance, although clinical heterogeneity between studies was substantial (Analysis 2.1; RR 0.62, 95% CI 0.45 to 0.86; I^2 = 61%).

Pneumonia was reported in five studies with 563 participants (Bohner 2002; Christensen 1991; Lindner 1987; Squadrone 2005; Stock 1985). This was seen in 12 participants in the CPAP group (4.3%) and 23 participants (8.1%) in the control group. Reduction of pneumonia in the CPAP group was statistically significant, with no important statistical heterogeneity observed between studies (Analysis 2.2; RR 0.43, 95% CI 0.21 to 0.84; I^2 = 0%).

Significant hypoxia: The number of participants identified as having **severe hypoxia** was reported in two studies with a total of 255 participants (Bohner 2002; Christensen 1991). The CPAP group reported 11 of 133 (8.3%) and the control group 19 of 122 (15.6%), with no statistically significant advantage for CPAP and substantial heterogeneity between trials (Analysis 2.3; RR 0.48, 95% CI 0.22 to 1.02; I^2 = 67%).

Tracheal reintubation was reported in two studies with a total of 411 participants (Bohner 2002; Squadrone 2005). A statistically significant reduction was seen in postoperative reintubation of participants in the CPAP group versus the control group, and no important heterogeneity was noted between these studies (Analysis 2.4; RR 0.14, 95% CI 0.03 to 0.58; I^2 = 0%).

ICU admission for invasive ventilation and supportive care was reported in one study (Bohner 2002), which included a total of 204 participants. Reported rates of intubation were reasonably high, with six of 99 (6.1%) in the CPAP group and 14 of 105 (13.3%) in the control group admitted to the ICU (RR 0.45, 95% CI 0.18 to 1.14; I^2 = 0%). This study reported a total of 20 postoperative ICU admissions, the reasons for which are not clearly documented.

Secondary outcomes

1. Length of hospital stay: Four studies (Bohner 2002; Christensen 1991; Denehy 2001; Squadrone 2005) including 497 participants reported on length of hospital stay (see Table 2). We were reluctant to formally analyse these data because of the multiplicity of reasons presented for discharge from the hospital.

2. Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): Only one study reported cardiac complications of any kind. Bohner 2002 described cardiac arrest in two of 105 participants in the control group and in one of 99 participants in the CPAP group. None of our predetermined outcomes (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia) were reported.

3. Other postoperative complications (wound infection, anastomotic leak, renal failure): Three studies (Bohner 2002; Christensen 1991; Squadrone 2005) reported instances of renal failure, anastomotic leak and/or infection during the postoperative period (Table 2).

4. Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): One RCT (Bohner 2002) reported the incidence of nasal ulcers, which were noted in four of 99 participants receiving nasal CPAP and in no participants in the control group (0/105) (Table 2).

DISCUSSION

Summary of main results

We conducted a limited meta-analysis of available outcome data from the 10 selected studies (see the table of data and analysis and Summary of findings for the main comparison).

No clear evidence of a difference in postoperative mortality was found between CPAP and control groups in the two studies that reported this outcome (Bohner 2002; Squadrone 2005), and clinical heterogeneity between these studies was substantial. The rate of mortality following major abdominal surgery in these RCTs was consistent with previously documented rates (Haynes 2009). No deaths were reported in either group in one study (Gaszynski 2007), possibly because both of these studies involved younger participants undergoing bariatric surgery. All three deaths in the control group were reported by Squadrone 2005 among participants undergoing elective major abdominal surgery;no details were given as to the cause of death. All four postoperative deaths in the CPAP group were reported by Bohner 2002 among participants undergoing vascular surgery by midline laparotomy. Two participants died of surgical complications: one from cardiac failure and another from septic shock of unknown source. It may be that the small number of included studies was not sufficiently powered to determine a difference in mortality —a relatively uncommon outcome—between CPAP and control groups.

We identified major respiratory complications as they were defined and reported in the individual studies.

Atelectasis was common on days two to five postoperatively, and this outcome was reduced in the CPAP groups compared with the control groups (Analysis 2.1). However, the methodological quality of these earlier trials was poor, and heterogeneity between trials was substantial. The presence of atelectasis has been shown to impair lung compliance, increase pulmonary vascular resistance, impair oxygenation and predispose to lung injury (Duggan 2005); it has been cited as an important factor in the development of postoperative respiratory complications and as a clinical entity in itself, requiring targeted postoperative treatment to prevent hypoxia (Pelosi 2010; Tusman 2012); therefore, this finding is encouraging. However, all of the included studies were small and at least 20 years old, and CT scanning has evolved in recent times as a more accurate diagnostic tool than chest x-ray or clinical evaluation (Brismar 1985; Lindberg 1992). Therefore, our finding must be interpreted with caution.

It is thought that atelectasis is a precursor to the development of pneumonia, and although this seems likely clinically, no direct causal association between the presence of atelectasis and the development of pneumonia itself has been confirmed to date (Tusman 2012). Fewer participants developed postoperative pneumonia in the CPAP groups compared with the control groups. Evidence of this in the meta-analysis is significant (Analysis 2.2). Similarly, some evidence of a reduction in severe hypoxia was seen in the CPAP groups compared with the control groups, but the two included studies reporting severe hypoxia during the postoperative period were assessed as having an unclear risk of bias (Table 3), and substantial heterogeneity between them was noted.

A reduction in postoperative admission to the ICU in the CPAP groups versus the control groups was noted in one study, although this finding did not reach statistical significance. In the Bohner 2002 study, a total of 20 postoperative ICU readmissions were reported. The causes were not specifically reported, although the study authors commented that their cohort of participants were elderly with significant co-morbidities, and that admission was due primarily to cardiac and pulmonary complications. The possibility of a reduction in ICU admissions among patients receiving postoperative CPAP is encouraging; however, our analysis cannot confirm this as fact.

We found a statistically significant reduction in postoperative reintubation in the CPAP groups versus the control groups. Two studies (Bohner 2002; Squadrone 2005) including 411 participants evaluated this outcome. Documentation as to whether the reintubations were due to respiratory complications was incomplete, but nonetheless, the use of CPAP may have prevented this significant clinical event in some participants. Although no important heterogeneity was observed between these studies, this result again must be interpreted with caution, as the risk of bias in these trials is unclear.

Reporting of cardiovascular complications was minimal, with one study reporting cardiac arrest in three participants undergoing elective vascular surgery via a midline laparotomy (Bohner 2002), and analysis of the data was not possible.

Length of hospital stay was reported in some studies, but we were unable to analyse these data. Available data have been reported in Table 2. The modern practice of 'fast track surgery' will make it impossible to combine data from previous years with those of recent years (Olsen 2011).

Bohner 2002 was the sole study to describe any adverse effects of the use of CPAP, but data were insufficient for analysis. Of note, pulmonary aspiration, a recognized and serious complication of CPAP use that is associated with considerable morbidity and mortality, was not reported in any of the included RCTs.

Overall completeness and applicability of evidence

Only 10 eligible studies were included in this review; this number was insufficient to allow firm conclusions to be drawn regarding our primary outcome measures. We identified major respiratory complications as they were defined and reported in the individual studies; however, this lead to clinical heterogeneity between the included studies. Despite this fact, we were able to analyse data for all primary outcome measures, although only a few eligible trials were available. A paucity of secondary outcomes measured was noted; some were not reported at all in any of the selected trials.

We were unable to perform subgroup analysis because of the inadequate number of studies identified. Therefore, we were unable to evaluate whether observed differences in the CPAP groups versus the control groups were more representative of certain patient groups, such as those with underlying respiratory disease or undergoing emergency surgery. We did not complete a sensitivity analysis to examine outcomes in any studies at low risk of bias, as all studies were at high or unclear risk. We were unable to contact some study authors to obtain further information, as many of the studies were at least 20 years old, and contact details were scarce.

Quality of the evidence

Unfortunately, the overall quality of evidence available for this review was disappointing, and several trials were more than 20 years old with poor methodological quality. Four trials had an unclear risk of bias, and the remaining trials were classified as high risk. A lot of information required to assess the risk of bias was unclear or was not stated. Most commonly, allocation concealment and blinding of participants and personnel were not adequately addressed. All trials were RCTs, but in only three trials was the method of allocation clearly described (Denehy 2001; Squadrone 2005; Stock 1985). It is impossible to blind all personnel to the use of CPAP against standard care, as the difference is very evident, but consistent blinding of some participants and observers such as radiologists was not achieved.

We constructed the summary of findings (SOF) table in accordance with the GRADE principle (see Summary of findings for the main comparison). Even though the meta-analysis suggests an advantage of CPAP over control measures, the SOF tables show that the quality of evidence is 'very low' for the reported outcomes of mortality, atelectasis and pneumonia. Reasons for this include the methodological quality of selected studies (high risk of bias of the included studies) and inconsistency and imprecision of reporting (caused most often by clinical heterogeneity among selected studies).

Potential biases in the review process

The review protocol was thorough and included a comprehensive search strategy using multiple sources, independent screening of trials for inclusion and independent data extraction. Risk of bias of individual studies was assessed using measures recommended by the Cochrane Anaesthesia Review Group (CARG). We analysed pooled data for the primary outcome measures, despite the presence of substantial heterogeneity between studies for some outcomes, which may introduce bias into this review. As such, we have been cautious in interpreting these results.

The GRADE method of construction of SOF tables may have been influenced by interpretation of the review authors. Only three of the six predefined outcome measures were included for evaluation in the SOF tables because of insufficient data; we acknowledge that this could be a source of bias in the review. We plan to expand the table in the next review update to include the remaining outcomes.

Agreements and disagreements with other studies or reviews

Only one previous systematic review has explored this topic; it was published in 2008 (Ferreyra 2008). Differences between the 2008 review and the current review include the exclusion of emergency and vascular surgery and differing definitions of pulmonary complications. Ferreyra 2008 concluded that CPAP significantly reduces the risk of postoperative pulmonary complications, namely, atelectasis and pneumonia. The current review also found a significant reduction in atelectasis and pneumonia. We used the GRADE method to construct SOF tables in this review; these pointed to the strength of evidence as 'very low.' The previous review (Ferreyra 2008) suggested that evidence supports the use of CPAP in patients undergoing abdominal surgery. We are unable to make such a recommendation because the quality of evidence as indicated from the SOF table was 'very low.' Also note that our review is confined to studies in which CPAP was initiated after major

abdominal surgery and does not include studies in which CPAP is initiated during the intraoperative period and is continued into the postoperative phase.

AUTHORS' CONCLUSIONS

Implications for practice

Very low-quality evidence from this systematic review suggests that CPAP initiated during the postoperative period after major abdominal surgery might reduce postoperative atelectasis, pneumonia and reintubation, but its effects on mortality, hypoxia and invasive ventilation are uncertain. Evidence is not sufficiently strong to permit conclusions on the benefits or harms of CPAP during the postoperative period in reducing mortality and morbidity following major abdominal surgery. Summary of findings data obtained from the GRADE analysis reveal that the strength of evidence supporting the use of CPAP during the postoperative period is very low. None of the studies assessed provided reasons to be cautious about using CPAP during the postoperative period, mainly because most of these studies did not report on adverse effects attributed to CPAP.

Implications for research

New, high-quality research is much needed to definitively evaluate the use of CPAP in preventing mortality and morbidity following major abdominal surgery. A targeted approach investigating the use of CPAP in patients at higher risk for postoperative respiratory complications would be of value. A focus on well-defined, pertinent outcomes, including adverse events, of CPAP use should be employed. With increasing availability of CPAP for our surgical patients and its potential to improve outcomes (possibly in conjunction with intraoperative lung protective ventilation strategies), unanswered questions regarding its efficacy and safety need to be addressed.

Future studies must report on all adverse effects of CPAP. These studies should standardize the equipment used for CPAP, CPAP pressures applied and duration of treatment provided. Reporting standards should be more uniform and should include such items as the number of participants with adverse effects and the duration of reporting of outcomes of interest.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Bohner 2002

Methods	Study was done in the hospitals of Heinrich-Heine University, Germany

Bohner 2002 *(Continued)*

Participants	Adults undergoing midline laparotomy for elective vascular surgery; abdominal aortic aneurysm surgery; and surgery of visceral, renal and iliac arteries or thrombectomy of IVC Excluded were emergency surgery, thoracoabdominal surgery or retroperitoneal approach Participants were randomly assigned to 2 groups with use of a random list: Control group: 105 participants; age, years: 64.5 ± 11.3; male/female: 82:23; BMI: 25.0 ± 3.3 Intervention group: 99 participants; age, years: 64.1 ± 12.3; male/female: 84:15; BMI: 25.4 ± 3.5 All participants received similar fluid regimen, analgesic routine and medications All participants were extubated soon after surgery and were admitted to intermediate care unit or intensive care unit
Interventions	Control group: Oxygen was administered at ambient pressure via a non-occlusive face mask, including mouth and nose or nose cannulas to keep oxygen saturation > 95%; FiO_2 was adjusted to achieve this Intervention group: received prophylactic nCPAP. nCPAP mask was placed on admission to the unit, using a high gas flow source and a standard PEEP valve set at 10 cm H_2O. FiO_2 was adjusted to keep SpO_2 > 95% and to keep nCPAP mask on for at least 12 hours
Outcomes	Duration of intervention: 14.0 ± 4.3 hours Duration of follow-up: longer than 7 days All-cause mortality: control group, 0/105: intervention group, 4/99 Major respiratory complications as defined in individual studies Significant atelectasis: none reported Pneumonia: control group, 5/105: intervention group, 2/99 Respiratory failure: none reported Severe hypoxia: control group, 17/105: intervention group, 5/99 Severe delirium: control group, 12/105: intervention group, 6/99 Need for tracheal intubation and invasive ventilation: control group, 5/105: intervention group, 1/99 Readmission to ICU/IMC: control group, 14/105: intervention group, 6/99 Length of stay in hospital: control group, 11.81 ± 18.61 days: intervention group, 9.45 ± 6.79 days Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): Cardiac arrest: control group, 2/105: intervention group, 1/99 Other postoperative complications (wound infection, anastomotic leak, renal failure): Renal failure: control group, 3/105: intervention group, 3/99 Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): Nose ulcers: control group, 0/105: intervention group, 4/99
Notes	BMI = body mass index FiO_2 = Inspired oxygen fraction IVC = inferior vena cava

Bohner 2002 *(Continued)*

	nCPAP = nasal CPAP PEEP = positive end-expiratory pressure ICU = intensive care unit IMC = intermediate care unit No response to email

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Randomization using a random list
Allocation concealment (selection bias)	Unclear risk	Randomization using a random list, but no description of allocation concealment
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Anaesthesiologist at the operation site did not receive any information about the results of randomization; no evidence of anyone else being blinded
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described in the text
Incomplete outcome data (attrition bias) All outcomes	Low risk	Dropouts described because 9/99 participants did not want to continue with nCPAP after 5.75 ± 4.80 hours
Selective reporting (reporting bias)	Low risk	No evidence of selective reporting in text
Other bias	Unclear risk	None reported

Carlsson 1981

Methods	Study done at University Hospital, Lund, Sweden
Participants	Healthy patients undergoing open elective cholecystectomy using right subcostal incision (no intercostal blocks) Control group: 11 participants; age, years: 68.09 ± 9.72; male/female: 2:9 Intervention group: 13 participants; age, years: 62.08 ± 9.52; male/female: 8:5 20/24 participants in total were > 20% overweight according to Broca Index
Interventions	Male/female, 10:14; age, years: 50-78 Control group: 11 participants; 30% prewarmed and humidified oxygen without a rubber bag, but with no PEEP Intervention group: 13 participants; 30% prewarmed and humidified oxygen via a rubber bag and PEEP of 5 to 10 cm H_2O

Carlsson 1981 *(Continued)*

	Treatment and control for 4 hours during the immediate postoperative period in the ward
Outcomes	Duration of intervention: 4 hours Duration of follow-up: 24 hours (1 day) All-cause mortality: none reported Major respiratory complications as defined in individual studies: Significant atelectasis (seen on 24-hour x-ray): control group, 10/11; intervention group, 10/13 Pneumonia: none reported (changes on x-ray "such as atelectasis and pneumonia" were noted but not distinguished further; hence the data are included under atelectasis) Respiratory failure: none reported Severe hypoxia: not reported Need for tracheal intubation and invasive ventilation: none reported Admission to ICU/IMC: none reported Length of stay in hospital: not reported Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Other postoperative complications (wound infection, anastomotic leak, renal failure): none reported Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): none reported
Notes	PEEP = positive end-expiratory pressure ICU = intesive care unit IMC = intermediate care unit Old study, no chance of getting additional information

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	On the postoperative ward, participants were randomly assigned to 2 groups; no details
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Radiologist was unaware of treatments
Incomplete outcome data (attrition bias) All outcomes	Low risk	All participants accounted for

Carlsson 1981 *(Continued)*

Selective reporting (reporting bias)	Unclear risk	Not sure
Other bias	Unclear risk	Not sure

Christensen 1991

Methods	Study done in Department of Anesthesiology and Respiratory Medicine, University Hospital of Aarhus, Denmark
Participants	High-risk adult patients scheduled for upper abdominal surgery (elective biliary and ventricular surgery). Participants were divided into 3 groups: control group; PEP group (PEP group used a mask similar to a CPAP mask, employs an expiratory resistance during breathing); and RMT group (RMT group is similar to PEP group, but the mask provides both inspiratory and expiratory resistance). We combined PEP and RMT groups as the intervention (CPAP) group for inclusion in the review Control group: 17 participants; male/female, 5:12; age, years: 62 (51-83); weight, kg: 68.5 (53-94) Intervention group: PEP group: 17 participants; male/female: 8/9; age, years: 63.7 (range 50-80); weight, kg: 68.7 (range 39-88) RMT group: 17 participants; male/female: 3/14; age, years: 64.2 (53-79); weight, kg: 63.5 (range 43-90)
Interventions	Control group: conventional physiotherapy, given to all participants in all groups; started during preoperative period; continued into postoperative period for 3 days; consisted of breathing exercises and forced expiration techniques; twice a day for 3 days and every hour during waking hours by participants Intervention group: conventional physiotherapy as well as CPAP using a PEEP mask; 5 to 15 cm H_2O expiratory pressure, given preoperatively for practice; continued during postoperative period, twice daily for 3 days. RMT group had PEP mask (5-7 cm H_2O) + inspiratory resistance chosen according to participants' ability to tolerate the mask We combined CPAP and RMT groups for the purpose of this review and interventions Oxygen was given only if hypoxia was present
Outcomes	Duration of intervention: 3 days Duration of follow-up: 3 days All-cause mortality: none reported Major respiratory complications as defined in individual studies: Atelectasis: control group, 9/17; intervention groups: PEP group, 11/17; RMT, 9/17 Pneumonia: control group, 5/17; intervention groups; PEP group, 6/17; RMT, 1/17 Respiratory failure: none reported Severe hypoxia: control group, 2/17; intervention groups: PEP, 4/17; RMT, 2/17 Need for tracheal intubation and invasive ventilation: control group, 0/17; intervention groups: PEP, 1/17; RMT, 1/17 Admission to ICU/IMC: none reported

Christensen 1991 *(Continued)*

	Length of stay in hospital, days: control group: 10.4 (95% CI 4 to 26) (SD = 1.9); intervention groups: PEP, 16.4 (range 5-42); RMT, 11.5 (range 5-42) Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Other postoperative complications (wound infection, anastomotic leak, renal failure): Pulmonary embolism: control group: 0/17; intervention groups: PEP, 0/17; RMT, 1/17 Wound infection: control group: 0/17, intervention groups: PEP, 4/17; RMT, 3/17 Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): none reported
Notes	CI = confidence interval CPAP = continuous positive airway pressure ICU = intensive care unit IMC = intermediate care unit PEP = positive expiratory pressure, variable, mask RMT = PEP mask with inspiratory resistance, mask SD = standard deviation

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	'Randomly allocated' into 3 groups; no other details
Allocation concealment (selection bias)	Unclear risk	No evidence for it
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	No evidence for it
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	No evidence for it
Incomplete outcome data (attrition bias) All outcomes	Low risk	Reasonable account given
Selective reporting (reporting bias)	Unclear risk	Not sure
Other bias	Unclear risk	Not sure

Denehy 2001

Methods	RCT done at Austin and Repatriation Medical Centre, Melbourne, Australia

Denehy 2001 *(Continued)*

Participants	Adult patients undergoing upper abdominal surgery. Inclusion criteria: incision above the umbilicus; FEV_1 greater than 50% predicted
Interventions	All participants received preoperative education on effects of surgery on lung function and were instructed on deep breathing exercises, including sustained maximal inspiration Post surgery, all participants received physiotherapy twice daily for 3 days, for a minimum of 10 minutes each session. This traditional physiotherapy consisted of deep breathing exercises, forced expiration technique and supported cough. Early ambulation was encouraged, and physiotherapy was done in the sitting position on bed or chair Control group: received the above traditional physiotherapy Intervention groups (CPAP, 15 minutes; CPAP, 30 minutes): nasal mask for CPAP, PEEP set at 10 cm H_2O. 30% O_2 was used for CPAP. This was given 4 times each day, following traditional physiotherapy Control group: 18 participants; male/female: 15:3; age, years: 73.3 ± 5.8; no data on BMI Intervention group (2 groups combined): 17 and 15 participants; male/female: 12:5 and 12:3; age, years: 72.5 ± 6.5 and 70.5 ± 6.3; no data on BMI
Outcomes	Duration of intervention: 3 postoperative days Duration of follow-up: at least 5 days No differences in pain scores between groups All-cause mortality: 1 participant died after 32 days, but no details of surgical complications are given Major respiratory complications as defined in individual studies: Postoperative pulmonary complications: control, 4/18; intervention, 2/17 and 1/15 Significant atelectasis: not reported Pneumonia: not reported ("chest radiograph changes" reported but not significant (88% control group, 58.5% intervention group)) Respiratory failure: not reported Severe hypoxia: not reported Severe delirium: not reported Need for tracheal intubation and invasive ventilation: not reported Readmission to ICU/IMC: intervention group: not reported Length of stay in hospital, days: control group, 12.3 ± 4.8; intervention group, 11.5 ± 4.1 and 12.5 ± 4.8 Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Cardiac arrest: not reported Other postoperative complications (wound infection, anastomotic leak, renal failure): not reported Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): not reported
Notes	BMI = body mass index CPAP = continuous positive airway pressure FEV_1 = forced expiratory volume in 1 second

Denehy 2001 *(Continued)*

ICU = intensive care unit

IMC = intermediate care unit

PEEP = positive end-expiratory pressure

RCT = randomized controlled trial

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Randomly allocated into 3 groups with use of sealed envelopes
Allocation concealment (selection bias)	Low risk	Randomly allocated into 3 groups with use of sealed envelopes, but no details of allocation concealment provided
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not discussed, but physiotherapists blinded to FRC (functional residual capacity) values, so only partially blinded
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Only radiologist possibly blinded (partial blinding only)
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not described, but only those who completed 5 days of lung volume measurements (40/50) were included in FRC and VC (vital capacity) analyses
Selective reporting (reporting bias)	High risk	Poor reporting of participant demographics (no weight) and no details on complications
Other bias	Unclear risk	Not sure

Gaszynski 2007

Methods	Study done at Medical University of Lodz, Poland
Participants	Patients undergoing open Roux-en-Y gastric bypass Male/female, 8:11; BMI, kg/m^2: 42.43 ± 3.3; age, years: 35.84 ± 9.05
Interventions	After surgery, participants were monitored in PACU (postanaesthesia care unit) for 8 hours Control group: 9 participants; oxygen via nasal cannula, 4 L/min Intervention group: 10 participants; CPAP Boussignac device, + 9.4 cm H_2O Continuous SpO_2 monitoring and frequent blood gases
Outcomes	Duration of intervention: 8 hours Duration of follow-up: most likely less than 1 day No differences in pain scores between groups

Gaszynski 2007 *(Continued)*

	All-cause mortality: none Major respiratory complications as defined in individual studies: Postoperative pulmonary complications: none Significant atelectasis: not reported Pneumonia: not reported Respiratory failure: not reported Severe hypoxia: not reported Severe delirium: not reported Need for tracheal intubation and invasive ventilation: no Admission to ICU/IMC: intervention group: not reported Length of stay in hospital: not reported Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Other postoperative complications (wound infection, anastomotic leak, renal failure): none, not sure for how long Adverse effects of intervention (pulmonary aspiration, upper airway or facial injury): not reported
Notes	BMI = body mass index CPAP = continuous positive airway pressure ICU = intensive care unit IMC = intermediate care unit PACU = postanaesthesia care unit SpO_2 = oxygen saturation

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	'Randomly divided into two groups,' no further description
Allocation concealment (selection bias)	Unclear risk	No description in text
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not stated
Blinding of outcome assessment (detection bias) All outcomes	High risk	Not stated
Incomplete outcome data (attrition bias)	Unclear risk	Not clear

Gaszynski 2007 *(Continued)*
All outcomes

Selective reporting (reporting bias)	Unclear risk	Not clear
Other bias	Unclear risk	Not sure

Lindner 1987

Methods	Study done at Ulm University Clinic, Ulm, Germany
Participants	Participants undergoing elective major upper abdominal surgery; all were moderately healthy patients Control group: 17 participants; male/female: 6:11; age, years: 65 (range 52-77); weight, kg: 65 (range 47-85) Intervention group: 17 participants; male/female: 12:5; age, years: 66 (range 50-77); weight, kg: 66 (50-95)
Interventions	Control group: standard physiotherapy (deep breathing and coughing) at 3-hourly intervals during daytime for 48 hours Intervention group: standard physiotherapy as well as continuous CPAP at FiO_2 of 0.35, 12 cm H_2O, 3 hours per day for 5 days
Outcomes	Duration of intervention: 5 days Duration of follow-up: 5 days All participants received same analgesic routine All-cause mortality: none reported Major respiratory complications as defined in the study by radiograph (3rd day): Atelectasis: control group, 4/17; intervention group, 0/17 Consolidation: control group, 1/17; intervention group, 1/17 Need for tracheal intubation and invasive ventilation: none in either group Admission to ICU/IMC: intervention group: not reported Length of stay in hospital: not reported Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Other postoperative complications (wound infection, anastomotic leak, renal failure): none reported Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): not reported
Notes	CPAP = continuous positive airway pressure FiO_2 = inspired oxygen fraction ICU = intensive care unit IMC = intermediate care unit

Lindner 1987 *(Continued)*

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	'Randomized' into 2 groups
Allocation concealment (selection bias)	High risk	No description for it (randomly assigned into 2 groups)
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not stated
Blinding of outcome assessment (detection bias) All outcomes	Low risk	"Pulmonary function measurements were performed by a researcher who was not aware of which group the patients were in" Radiologist interpreted x-ray films "without knowledge of whether the patient was receiving CPAP or not"
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Probably OK
Selective reporting (reporting bias)	Unclear risk	Not sure
Other bias	Unclear risk	Not sure

Lotz 1984

Methods	Study done at Universitat Ulm/Donau, Germany
Participants	Patients undergoing upper abdominal surgery. Participants were randomly allocated into 4 groups. ZEEP (zero end-expiratory pressure) or PEEP (positive end-expiratory pressure) was given during surgery, followed by oxygen via mask or CPAP, thus making up 4 groups. For this review, we have chosen only 2 groups: control group, received ZEEP (no PEEP) and no CPAP after surgery. Intervention group received ZEEP during surgery and CPAP after surgery Control group: ZEEP during anaesthesia, followed by oxygen via mask during the postoperative period: 16 participants; male/female, 9:6; age, years: 58 ± 8; BMI: weight not given (only Broca Index given) Intervention group: ZEEP during anaesthesia, followed by CPAP during postoperative period: 16 participants; male/female: 8:8; age, years: 58 ± 10; BMI: weight not given (only Broca Index given)
Interventions	Control group: Participants received oxygen via nasal cannula in the recovery ward Intervention group: Participants received CPAP (+ 5 cm H_2O) for 2 hours in the recovery ward
Outcomes	Duration of intervention: 2 hours in the recovery ward Duration of follow-up: up to 10 days (days 2, 5 and 10) All-cause mortality: not indicated Major respiratory complications as defined in the study: not differentiated between atelectasis, pneumonia and consolidation, but we have included it as atelectasis on day 2

Lotz 1984 *(Continued)*

	Atelectasis (day 2): control group, 6/16; intervention group, 3/16 Consolidation/Pneumonia: not sure Need for tracheal intubation and invasive ventilation: control, 0/16; intervention, 0/16 Admission to ICU/IMC: no data Length of stay in hospital: no data Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): Other postoperative complications (wound infection, anastomotic leak, renal failure): no data Adverse effects of intervention (pulmonary aspiration, upper airway or facial injury): no data
Notes	CPAP = continuous positive airway pressure ICU = intensive care unit IMC = intermediate care unit PEEP = positive end-expiratory pressure ZEEP = zero end-expiratory pressure

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Yes, randomly assigned to 4 groups
Allocation concealment (selection bias)	Unclear risk	No details given, but possible
Blinding of participants and personnel (performance bias) All outcomes	High risk	No details given
Blinding of outcome assessment (detection bias) All outcomes	High risk	No details
Incomplete outcome data (attrition bias) All outcomes	High risk	No outcome data of interest reported
Selective reporting (reporting bias)	High risk	No information in text
Other bias	Unclear risk	Not sure

Ricksten 1986

Methods	Study done at Sahlgren's Hospital, Gothenburg, Sweden

Ricksten 1986 *(Continued)*

Participants	Patients having elective upper abdominal surgery Groups were stratified by preoperative lung function, age, sex, body weight and smoking habit
Interventions	General anaesthesia and epidural morphine (for at least 2 days) were given to all participants Participants were randomly assigned to 3 groups: Control group: deep breathing exercises every waking hour (30 breaths) CPAP group: hourly 30 breaths with CPAP mask (+ 10-15 cm H_2O) given every waking hour PEP (positive expiratory pressure) group: hourly 30 breaths with a mask, which generated + 10 to 15 cm H_2O during expiration, given every waking hour We combined CPAP and PEP groups for the purpose of this review All treatments continued for 3 postoperative days if participants tolerated it Control group: 15 participants; male/female, 6:9; age, years: 51.7 ± 4.7; weight, kg: 90.4 ± 7.4 CPAP: 13 participants; male/female, 7:6; age, years: 52.5 ± 3.5; weight, kg: 93.4 ± 6.3 PEP group: 15 participants; male/female, 8:7; age, years 56.9 ± 3.8; weight, kg: 89.0 ± 7.0
Outcomes	Duration of intervention: 3 days Duration of follow-up: 3 days All-cause mortality: none reported Major respiratory complications as defined in individual studies: Postoperative pulmonary complications: Significant atelectasis/consolidation (radiology confirmation): 1st postop day: control, 5/15; CPAP group: 2/13; PEP group, 1/15 Significant atelectasis/consolidation (radiology confirmation): 3rd postop day: control, 6/15; CPAP group: 1/13; PEP group, 0/15 Pneumonia: not reported Respiratory failure: not reported Severe hypoxia: lower A-a difference reported, but no numbers given Need for tracheal intubation and invasive ventilation: none reported Admission to ICU: intervention group: not reported Length of stay in hospital: not reported Cardiovascular complications (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia): none reported Other postoperative complications (wound infection, anastomotic leak, renal failure): none reported Adverse effects of the intervention (pulmonary aspiration, upper airway or facial injury): not reported
Notes	CPAP = continuous positive airway pressure ICU = intensive care unit PEP = positive expiratory pressure

Ricksten 1986 *(Continued)*

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	After stratification, randomly assigned into 3 groups, not sure how
Allocation concealment (selection bias)	High risk	No evidence
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not sure
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Radiologist blinded, not sure whether anyone else was blinded
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not clear
Selective reporting (reporting bias)	Unclear risk	Not clear
Other bias	Unclear risk	Not sure

Squadrone 2005

Methods	Patients undergoing elective abdominal surgery from centres of the Piedmont Intensive Care Units Network, Italy
Participants	Adult patients undergoing elective abdominal surgery, requiring laparotomy and visceral exposure for longer than 90 minutes
Interventions	Randomization was done after surgery and 1 hour of monitoring (and $PaO_2/FiO_2 < 300$). Inclusion and exclusion criteria clearly detailed Control group: 104; male/female: 64:40; age, years: 65 ± 10; BMI, kg/m^2: 26.3 ± 4.5 Intervention group: 105; male/female: 71:34; age, years: 66 ± 9; BMI, kg/m^2: 26.5 ± 4.7 Control group: Venturi mask with FiO_2 of 0.5 for 6 hours, followed by further assessment of PaO_2/FiO_2, followed by further treatment of Ventimask with FiO_2 of 0.5 if PaO_2/FiO_2 ratio < 300 Intervention group: CPAP mask with FiO_2 of 0.5 and CPAP of + 7.5 cm H_2O for 6 hours, followed by further assessment of PaO_2/FiO_2, followed by further use of CPAP mask with FiO_2 of 0.5 and CPAP of + 7.5 cm H_2O if PaO_2/FiO_2 ratio < 300
Outcomes	Duration of intervention: minimum of 6 hours Duration of follow-up: longer than 3 days (up to 7 days) All-cause mortality: control group, 3/104; intervention group, 0/105 Major respiratory complications as defined in individual studies:

Squadrone 2005 *(Continued)*

	Pneumonia: control group, 10/104; intervention group, 2/105 Need for tracheal intubation and invasive ventilation: control group, 10/104; intervention group, 1/105 ICU length of stay: control group, 2.6; intervention group, 1.4 Length of stay in hospital: control group: 17 ± 15 days; intervention group, 15 ± 13 days Other postoperative complications (wound infection, anastomotic leak, renal failure): Infection: control group, 11/104; intervention group, 3/105 Sepsis: control group, 9/104; intervention group, 2/105 Anastomotic leakage: control group, 6/104; intervention group, 1/105
Notes	BMI = body mass index CPAP = continuous positive airway pressure FiO_2 = inspired oxygen fraction ICU = intensive care unit PaO_2 = arterial oxygen pressure

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Concealed randomization was conducted centrally through dedicated website using computer-generated block randomization schedule
Allocation concealment (selection bias)	Low risk	Concealed randomization was conducted centrally through dedicated website using computer-generated block randomization schedule
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	Outcomes reported
Selective reporting (reporting bias)	Unclear risk	Not sure; premature stopping of trial by data monitoring committee
Other bias	Unclear risk	Not sure

Stock 1985

Methods	Study done at Mercy Hospital, Northwest University, Chicago, USA

Stock 1985 *(Continued)*

Participants	Patients having elective upper abdominal surgery were selected.
Interventions	A computer random number generator was used to assign each participant to 1 of 3 treatment groups for postoperative respiratory therapy Three groups were studied CBD group was given coughing and deep breathing exercises, starting 4 hours after extubation. This was given for 15 minutes, every 2 hours during waking hours. Duration of treatment was 4 to 72 hours IS group received incentive spirometry for 15 minutes, every 2 waking hours, for 4 to 72 hours (starting 4 hours after extubation) We combined CBD and IS groups as controls for the purpose of this review CPAP group received continuous positive airway pressure using a soft self-sealing mask, + 7.5 cm H_2O, for 15 minutes, every 2 waking hours, for 4 to 72 hours (starting 4 hours after extubation) Control groups: CDB group: number of participants, 20; male/female: 9:11; weight/ BMI, not given; age, years: 48 ± 4 (SEM); duration: 4 to 72 hours IS group: number of participants, 22; male/female: 8:14; weight/BMI: not given; age, years: 54 ± 4 (SEM); duration: 4 to 72 hours Intervention group: 23 participants; male/female: 8:15; weight/ BMI: not given; age, years: 49 ± 5 (SEM); duration: 4 to 72 hours
Outcomes	Duration of intervention: 4 to 72 hours Duration of follow-up for 3 days All-cause mortality: not given Major respiratory complications as defined in individual studies: X-ray confirmed atelectasis at 24 hours: control group: CDB, 6/20; IS, 11/22 = 17/42; intervention group, 9/23 X-ray confirmed atelectasis at 72 hours: control group: CDB, 8/20; IS, 9/22 = 17/42; intervention group, 5/23 Pneumonia: CDB, 1/20, IS, 1/22 (control, 2/42); intervention group, 0/23 No other information offered in the paper
Notes	BMI = body mass index CDB = coughing and deep breathing CPAP = continuous positive airway pressure IS = incentive spirometry SEM = standard error of the mean

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	A computer random number generator was used to assign each participant to 1 of the different groups

Stock 1985 *(Continued)*

Allocation concealment (selection bias)	Unclear risk	A computer random number generator was used to assign each participant to 1 of the different groups; most likely adequate, but no description of allocation concealment
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Radiologists blinded for x-ray interpretation, but not sure of others
Incomplete outcome data (attrition bias) All outcomes	Low risk	Probably all participants accounted for
Selective reporting (reporting bias)	Unclear risk	Probable
Other bias	Unclear risk	Probable

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Anderes 1979	Participants in one group were intubated for 3 hours, whereas participants in the other group were extubated soon after surgery. Unequal treatment of groups
Celli 1984	Intervention is not CPAP, but positive-pressure breathing
Conti 2007	Study is a case-controlled study, not an RCT
Drummond 2002	Even though this is an RCT (stratified), study was done mainly to observe effects of CPAP on sleep pattern and hypoxaemia. Study lasted only 1 day; no relevant data available from this publication for the purpose of the review
Ebeo 2002	This RCT deals with BiPAP ventilation, which is different from CPAP; hence excluded from this review
Huerta 2002	This is not an RCT
Jaber 2005	This study of participants who already have established respiratory failure is not an RCT; it also falls into the exclusion criteria for the review
Joris 1997	This RCT uses BiPAP (bilevel positive airway pressure) during the postoperative period. This is an exclusion criterion
Kindgen-Milles 2005	This RCT is dealing with thoraco-abdominal aortic surgery and does not conform with inclusion criteria
Neligan 2009	A randomized trial, but the intervention group receives the same treatment as the control group, except that onset of treatment is delayed by 30 minutes. Therefore, this study was excluded

Study	Reason for exclusion
Olsen 2002	This RCT is dealing with thoraco-abdominal operations, an exclusion criterion for the review
Rieg 2012	This is not an RCT; participants were allocated into 2 groups on 2 different timelines
Roeseler 1982	Study population is a mixture of randomized and non-randomized cases, allocated into 2 groups. Therefore, excluded from review
Vartanov 2007	Intervention group received BiPAP ventilation during the postoperative period, even though the study was an RCT
Wong 2011	Used PEEP during surgery; follow-up with CPAP in the recovery ward, but only for 1 hour

BiPAP = bilevel positive airway pressure
CPAP = continuous positive airway pressure
PEEP = positive end expiratory pressure
RCT = randomised controlled trial

Characteristics of studies awaiting assessment *[ordered by study ID]*

Damgaard 1982

Methods	Waiting for a translation
Participants	Waiting for a translation
Interventions	Waiting for a translation
Outcomes	Waiting for a translation
Notes	Waiting for a translation

Characteristics of ongoing studies *[ordered by study ID]*

McKay 2012

Trial name or title	Prophylactic nCPAP Following Bowel Surgery (Bio-REB File 11-27)
Methods	Randomized controlled trial
Participants	Adults undergoing bowel surgery
Interventions	Oxygen via nCPAP vs via masks in the postoperative period
Outcomes	Some relevant to this review
Starting date	2012
Contact information	Dr William McKay, University of Saskatchewan, Canada
Notes	Study being repeated

Wong 2010

Trial name or title	Oxygenation and Pulmonary Function in Morbidly Obese Patients Undergoing Bariatric Surgery
Methods	Boussignac(TM) CPAP compared with Venturi mask
Participants	Adult patients undergoing bariatric surgery
Interventions	Boussignac(TM) CPAP
Outcomes	PaO_2/FiO_2 ratio for 24 hours
Starting date	2010
Contact information	Emailed lead author, Dr David Wong, University Health Network, Toronto, Canada
Notes	Study should have been finished by 2012, but not yet published

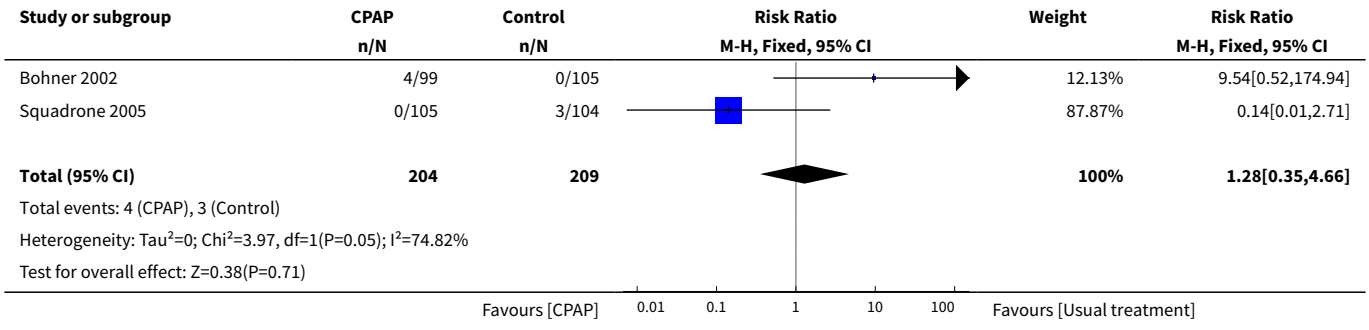
CPAP = continuous positive airway pressure
FiO_2 = inspired oxygen fraction
nCPAP = nasal CPAP
PaO_2 = arterial oxygen pressure

DATA AND ANALYSES

Comparison 1. Reported mortality

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Mortality	2	413	Risk Ratio (M-H, Fixed, 95% CI)	1.28 [0.35, 4.66]

Analysis 1.1. Comparison 1 Reported mortality, Outcome 1 Mortality.

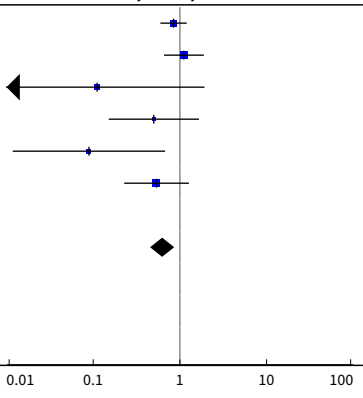


Comparison 2. Adverse outcomes

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Significant atelectasis	6	249	Risk Ratio (M-H, Fixed, 95% CI)	0.62 [0.45, 0.86]
2 Pneumonia	5	563	Risk Ratio (M-H, Fixed, 95% CI)	0.43 [0.21, 0.84]
3 Severe hypoxia	2	255	Risk Ratio (M-H, Fixed, 95% CI)	0.48 [0.22, 1.02]
4 Reintubation	2	413	Risk Ratio (M-H, Fixed, 95% CI)	0.14 [0.03, 0.58]

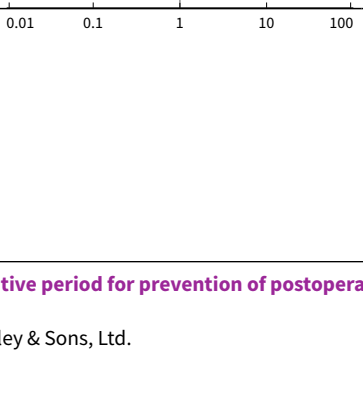
Analysis 2.1. Comparison 2 Adverse outcomes, Outcome 1 Significant atelectasis.

Study or subgroup	CPAP n/N	Control n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Carlsson 1981	10/13	10/11		20.37%	0.85[0.6,1.2]
Christensen 1991	20/34	9/17		22.57%	1.11[0.65,1.89]
Lindner 1987	0/17	4/17		8.46%	0.11[0.01,1.92]
Lotz 1984	3/16	6/16		11.28%	0.5[0.15,1.66]
Ricksten 1986	1/28	6/15		14.69%	0.09[0.01,0.67]
Stock 1985	5/23	17/42		22.62%	0.54[0.23,1.27]
Total (95% CI)	**131**	**118**		**100%**	**0.62[0.45,0.86]**
Total events: 39 (CPAP), 52 (Control)					
Heterogeneity: Tau^2=0; Chi^2=12.68, df=5(P=0.03); I^2=60.57%					
Test for overall effect: Z=2.89(P=0)					



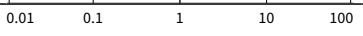
Analysis 2.2. Comparison 2 Adverse outcomes, Outcome 2 Pneumonia.

Study or subgroup	CPAP n/N	Control n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Bohner 2002	2/99	5/105		19.92%	0.42[0.08,2.14]
Christensen 1991	7/34	5/17		27.37%	0.7[0.26,1.88]
Lindner 1987	1/17	1/17		4.11%	1[0.07,14.72]
Squadrone 2005	2/105	10/104		41.25%	0.2[0.04,0.88]
Stock 1985	0/23	2/42		7.35%	0.36[0.02,7.16]
Total (95% CI)	**278**	**285**		**100%**	**0.43[0.21,0.84]**
Total events: 12 (CPAP), 23 (Control)					
Heterogeneity: Tau^2=0; Chi^2=2.38, df=4(P=0.67); I^2=0%					
Test for overall effect: Z=2.44(P=0.01)					



Analysis 2.3. Comparison 2 Adverse outcomes, Outcome 3 Severe hypoxia.

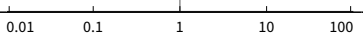
Study or subgroup	CPAP n/N	Control n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Bohner 2002	5/99	17/105		86.09%	0.31[0.12,0.81]
Christensen 1991	6/34	2/17		13.91%	1.5[0.34,6.66]
Total (95% CI)	**133**	**122**		**100%**	**0.48[0.22,1.02]**
Total events: 11 (CPAP), 19 (Control)					
Heterogeneity: Tau^2=0; Chi^2=3.02, df=1(P=0.08); I^2=66.92%					
Test for overall effect: Z=1.9(P=0.06)					



Favours [CPAP] Favours [Usual treatment]

Analysis 2.4. Comparison 2 Adverse outcomes, Outcome 4 Reintubation.

Study or subgroup	CPAP n/N	Control n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Bohner 2002	1/99	5/105		32.57%	0.21[0.03,1.78]
Squadrone 2005	1/105	10/104		67.43%	0.1[0.01,0.76]
Total (95% CI)	**204**	**209**		**100%**	**0.14[0.03,0.58]**
Total events: 2 (CPAP), 15 (Control)					
Heterogeneity: Tau^2=0; Chi^2=0.26, df=1(P=0.61); I^2=0%					
Test for overall effect: Z=2.68(P=0.01)					



Favours [CPAP] Favours [Usual treatment]

ADDITIONAL TABLES

Table 1. Details of study groups

Study ID	Surgical procedure	Duration of trial	Duration of follow-up	Control group: details	Control group: number	Intervention group: details	Intervention group: number	Comments
Bohner 2002	Midline laparotomy	14.0 ± 4.3 hours	Longer than 7 days	O_2 via mask	105	nCPAP at + 10 cm H_2O	99	
Carlsson 1981	Open cholecystectomy	4 hours	1 day	30% O_2 via bag	11	30% O_2 via bag, + 5 to 10 cm H_2O	13	
Christensen 1991	Upper abdominal surgery	3 days postop	3 days	Conventional physiotherapy	17	Conventional physio + CPAP using PEP mask	17	High-risk patients; O_2 only if hypoxia
Denehy 2001	Upper abdominal surgery	3 days postop	5 days	Traditional physiotherapy	13	Traditional physiotherapy + nasal CPAP at + 10 cm H_2O	32	Intervention groups × 2, CPAP for 15 and 30 minutes each
Gaszynski 2007	Roux-en-Y gastric bypass	8 hours	1 day?	O_2 via nasal cannula	9	CPAP Boussignac device, + 9.4 cm H_2O	10	
Lindner 1987	Upper abdominal surgery	5 days	5 days	Standard physiotherapy	17	Standard physio + CPAP for 5 days	17	
Lotz 1984	Upper abdominal surgery	2 hours in recovery ward	10 days	O_2 by face mask	16	CPAP during postoperative period	16	2 further groups, both receiving PEEP during anaesthesia, excluded
Ricksten 1986	Upper abdominal surgery	3 days	3 days	Deep breathing, hourly	15	Hourly, CPAP + 10 to 15 cm H_2O	28	Combined CPAP and PEP groups combined
Squadrone 2005	Abdominal surgery	12 hours	3-7 days	Venturi mask (FiO_2 0.5)	104	CPAP mask, + 7.5 cm H_2O (FiO_2 0.5)	105	

Table 1. Details of study groups *(Continued)*

Stock 1985	Upper abdominal surgery	4-72 hours	3 days	Cough and deep breathing or incentive spirometry	42	CPAP mask	23	Combined 2 groups as control

Table 2. Reported outcomes

Study ID	All cause mortality	Major respiratory complications	Length of hospital stay, days	Cardiovascular complications	Other postop complications	Adverse effects of intervention	Comments
Bohner 2002	0/105; 5/99	Pneumonia: 5/105; 2/99 Severe hypoxia: 17/105; 5/99 Intubation: 5/105; 1/99	11.8 ± 18.6; 9.5 ± 6.8	Cardiac arrest: 2/105; 1/99	Delirium: 12/105; 6/99 Renal failure: 3/105; 3/99	Nose ulcers: 0/105; 4/99	ICU admission: 14/105; 6/99
Carlsson 1981	-	Atelectasis (24 hours): 10/11; 10/13	-	-	-	-	-
Christensen 1991	-	Atelectasis: 9/17; 11/17 Pneumonia: 5/17; 6/17 Intubation: 0/17; 1/17	10.4 ± 1.9/ 16.4 ± 3.2	-	0/17; 0/17	-	Converted 95% CI into SD: Mean 10.4; 95% CI 4 to 26; 26 to 10.4 = 15.6 95% CI implies z = 1.96 Error = z (SE) 15.6= 1.96 (SE) 8.0 = SE SE = SD/SQRT (N)

Table 2. Reported outcomes *(Continued)*

							8.0 = SD/SQRT (17) 1.9 = SD
Denehy 2001	1 death (no group)	Postop pulmonary complications: 4/18; 3/32	12.3 ± 4.8; 12.0 ± 4.5	-	-	-	-
Gaszynski 2007	0/9; 0/11	Intubation: 0 /9; 0/11	-	-	-	-	-
Lindner 1987	-	Atelectasis: 4/17; 0/17 Consolidation: 1/17; 1/17 Intubation: 0/17; 0/17	-	-	-	-	-
Lotz 1984	-	Respiratory complications (?atelectasis): 6/16; 3/16	-	-	-	-	-
Ricksten 1986	-	Atelectasis: 6/15; 1/28	-	-	-	-	-
Squadrone 2005	3/104; 0/105	Pneumonia: 10/104; 2/105	17 ± 15; 15 ± 13	-	Infection: 11/104; 3/105 Sepsis: 9/104; 2/105	-	-
Stock 1985	-	Atelectasis: 17/42; 5/23	-	-	-	-	-

Table 3. Risk of bias data

Study ID	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias	Overall risk of bias judgement
Bohner 2002	Randomization using a random list	No description of allocation concealment	Anaesthesiologist; not sure of anyone else	Not described in the text	Dropouts described	No evidence for this	None reported	Unclear
Carlsson 1981	No details of randomization	Not described	Not described	Radiologist was unaware of treatments	All participants accounted for	Not sure	Not sure	Unclear
Christensen 1991	Randomly allocated into 3 groups	No evidence for it	No evidence for it	No evidence for it	Reasonable account	Not sure	Not sure	Unclear
Denehy 2001	Randomly allocated into 3 groups with use of sealed envelopes	Sealed envelopes	Not described	Only radiologist possibly blinded (partial blinding only)	Not described	No detailed demographics of any complications	Not sure	High
Gaszynski 2007	'Randomly divided into two groups,' no further description	No description	Not stated	Not stated	Not clear	Not clear	Not sure	High
Lindner 1987	Randomized into 2 groups	No description for it	Not stated	Not stated	Probably OK	Not sure	Not sure	High
Lotz 1984	Randomized into 4 groups	No description in text, but possible	No details	No details	Scarcity of outcomes of interest	No information	Not sure	High
Ricksten 1986	Stratification and randomization (unclear method)	No evidence	Not sure	Blinded radiologist, not sure of others	Not clear	Not clear	Not sure	High
Squadrone 2005	Centrally through dedicated website using computer-generated block randomization schedule	Yes, concealed central randomization	Not described	Not described	Yes	Premature stopping of trial	Not sure	Unclear

Table 3. Risk of bias data *(Continued)*

Stock 1985	A computer random number generator was used to assign each participant	Most likely adequate	Not described	Not described	Probably all participants accounted for	Probable	Probable	High

APPENDICES

Appendix 1. Ovid MEDLINE search strategy

1. exp Positive-Pressure Respiration/ or exp Continuous Positive Airway Pressure/ or Respiration, Artificial/
2. (positive adj5 (airway or pressure)).mp. or (sustained adj3 inflation).ti,ab. or CPAP.mp.
3. 1 or 2
4. (((surger* or surgic* or perat*) adj3 (abdom?n* or hepar* or hepat* or gastro* or pancrea* or biliar* or chole* or stomach* or intestin* or bowel* or colon*)) or post?operat*).ti,ab.
5. exp Postoperative Care/ or exp Postoperative Complications/ or exp Postoperative Period/ or Pulmonary Atelectasis/ or exp General Surgery/ or exp Surgical Procedures, Operative/ or Surgical Procedures, Elective/ or exp Colorectal Surgery/ or exp Bariatric Surgery/ or exp Digestive System Surgical Procedures/ or exp Biliary Tract Surgical Procedures/
6. 5 or 4
7. ((randomized controlled trial or controlled clinical trial).pt. or randomized.ab. or placebo.ab. or clinical trials as topic.sh. or randomly.ab. or trial.ti.) not (animals not (humans and animals)).sh.
8. 3 and 7 and 6

Appendix 2. EMBASE search strategy

1 positive end expiratory pressure/ or ((sustained adj3 inflat*) or CPAP or (spontaneous adj3 breathing) or (Continuous adj3 Airway Pressure)).ti,ab.
2 postoperative care/ or postoperative period/ or postoperative complication/ or atelectasis/ or general surgery/ or surgical technique/ or elective surgery/ or colorectal surgery/ or bariatric surgery/ or abdominal surgery/ or biliary tract surgery/ or (((surger* or surgic* or perat*) adj3 (abdom?n* or hepar* or hepat* or gastro* or pancrea* or biliar* or chole* or stomach* or intestin* or bowel* or colon*)) or post?operat* or prevent* or treatment*).ti,ab. or (elective adj3 emergenc*).ti,ab.
3 (placebo.sh. or controlled study.ab. or random*.ti,ab. or trial*.ti,ab.) not (animals not (humans and animals)).sh.
4 1 and 2 and 3

Appendix 3. CENTRAL search strategy

#1MeSH descriptor Continuous Positive Airway Pressure explode all trees
#2(((sustained adj3 inflat*) or CPAP or (spontaneous adj3 breathing))):ti,ab
#3(#1 OR #2)
#4MeSH descriptor Postoperative Care explode all trees
#5MeSH descriptor Postoperative Complications explode all trees
#6MeSH descriptor Postoperative Period explode all trees
#7MeSH descriptor Pulmonary Atelectasis explode all trees
#8MeSH descriptor General Surgery, this term only
#9MeSH descriptor Surgical Procedures, Operative, this term only
#10MeSH descriptor Surgical Procedures, Elective explode all trees
#11MeSH descriptor Colorectal Surgery explode all trees
#12MeSH descriptor Bariatric Surgery explode all trees
#13MeSH descriptor Digestive System Surgical Procedures explode all trees
#14MeSH descriptor Biliary Tract Surgical Procedures explode all trees
#15(((surger* or surgic* or perat*) adj3 (abdom?n* or hepar* or hepat* or gastro* or pancrea* or biliar* or chole* or stomach* or intestin* or bowel* or colon*)) or post?operat* or prevent* or treatment*):ti,ab
#16(elective and emergenc*):ti,ab
#17(#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16)
#18(#3 AND #17)

Appendix 4. Web of Science search strategy

#1 TS=(Continuous SAME (Airway Pressure)) or TS=(sustained SAME inflat*) or TS=(spontaneous SAME breathing) or TS=CPAP

#2 TS=((surger* or surgic* or perat*) SAME (abdom?n* or hepar* or hepat* or gastro* or pancrea* or biliar* or chole* or stomach* or intestin* or bowel* or colon*)) or TS=(post?operat* or prevent* or treatment*) or TS=(elective and emergenc*)

#3 TS=(random* or (clinical SAME trial*) or placebo* or multicenter* or prospectiv* or ((single or double or triple) SAME (mask* or blind*)))

#4 #3 AND #2 AND #1

Appendix 5. CINAHL search strategy

S1 MH Continuous Positive Airway Pressure

S2 (sustained adj3 inflat*) or CPAP or (spontaneous adj3 breathing)

S3 S1 or S2

S4 MH Postoperative Care or MH Postoperative Complications or MH Postoperative Period or Pulmonary Atelectasis or MH General Surgery or MH Surgical Procedures, Operative or Surgical Procedures, Elective or MH Colorectal Surgery or MH Bariatric Surgery or MH Digestive System Surgical Procedures or MH Biliary Tract Surgical Procedures

S5 AB (surger* or surgic* or perat*) and (abdomen* or hepar* or hepat* or gastro* or pancrea* or biliar* or chole* or stomach* or intestin* or bowel* or colon*)

S6 TX elective and emergenc*

S7 AB post?operat* or prevent* or treatment*

S8 S4 or S5 or S6 or S7

S9 (MH "Random Assignment")

S10 (MH "Clinical Trials+")

S11 (MM "Double-Blind Studies") or (MM "Single-Blind Studies") or (MM "Triple-Blind Studies")

S12 (MH "Placebos")

S13 (MM "Multicenter Studies")

S14 (MH "Prospective Studies+")

S15 S9 or S10 or S11 or S12 or S13 or S14

S16 S3 and S8 and S15

Appendix 6. Data extraction form

Author who extracted data?	CI/TC/MZ	Date:	
Article	MEDLINE ID	Language	
Authors	Year of publication	Volume/No.	Pages
Include?	Yes/No		
Reasons for exclusion			
Need further details			
Study type	RCT	CCT	
Intervention group	No.	Duration	Sex

(Continued)

Nature of CPAP	Duration of CPAP	Weight/BMI	
Control group	No.	Duration	Sex
Nature of control	Duration of control	Weight/BMI	
Randomization	Intervention	Control	Bias level
Concealment of allocation	Intervention	Control	Bias level
Blinding	Intervention	Control	Bias level
Dropouts	Intervention	Control	Bias level
Outcome details	Intervention	Control	Bias level
Reporting			Bias level
Overall risk of bias			Bias level
Mortality	Intervention	Control	
Major respiratory complications: (significant atelectasis, pneumonia, significant hypoxia, tracheal reintubation, ICU admission)	Intervention	Control	
Length of hospital stay	Intervention	Control	
Cardiovascular complications: (myocardial infarction, unstable angina, acute cardiac failure, arrhythmia)	Intervention	Control	
Other postoperative complications: (wound infection, anastomotic leak, renal failure)	Intervention	Control	

(Continued)

Adverse effects of the intervention:	Intervention	Control
(pulmonary aspiration, upper airway or facial injury)		

HISTORY

Protocol first published: Issue 1, 2011
Review first published: Issue 8, 2014

Date	Event	Description
18 January 2012	Amended	Contact details updated.

CONTRIBUTIONS OF AUTHORS

Conceiving of the review: Claire Ireland (CI).

Designing the review: CI.

Co-ordinating the review: Tim Chapman (TC).

Undertaking manual searches: CI, TC.

Screening search results: CI, TC.

Organizing retrieval of papers: Mathew Zacharias (MZ).

Screening retrieved papers against inclusion criteria: CI, TC.

Appraising quality of papers: CI, TC, MZ.

Abstracting data from papers: CI, TC, Suneeth Fiona Mathew (SFM).

Writing to authors of papers for additional information: MZ.

Providing additional data about papers: CI, TC, MZ.

Obtaining and screening data on unpublished studies: CI, TC.

Managing data for the review: CI, TC, MZ, G Peter Herbison (PH).

Entering data into Review Manager (RevMan 5.2): CI, TC.

Handling RevMan statistical data: PH.

Performing double entry of data: data entered by person one: MZ; data entered by person two:SFM.

Interpreting data: CI, TC, MZ, SFM.

Making statistical inferences: PH.

Writing the review: CI, TC.

Providing guidance on the review: MZ.

Securing funding for the review: MZ.

Performing previous work that served as the foundation of the present study: CI, MZ, TC.

Serving as guarantor for the review (one review author): MZ.

Taking responsibility for reading and checking the review before submission: MZ.

DECLARATIONS OF INTEREST

Claire J Ireland: none declared.

Timothy M Chapman: none declared.

Suneeth F Mathew: none declared.

G Peter Herbison: none declared.

Mathew Zacharias: none declared.

SOURCES OF SUPPORT

Internal sources

- Southern District Health Board and Dunedin School of Medicine, University of Otago, New Zealand.

  Library access, sourcing of article reprints, photocopying

External sources

- None received, Other.

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

1. A new author joined the review team: Suneeth F Mathew.
2. We planned, but were unable, to complete many of the tasks planned in the protocol (Ireland 2011), mostly because of insufficient data.
3. We excluded those who received bilevel positive airway pressure (BiPAP) during the postoperative period.
4. We searched www.controlled-trials.com and http://clinicaltrials.gov/ct2/ instead of www.who.int/ictrp/en/, as per the protocol.
5. We planned, but were unable, to perform subgroup analysis or sensitivity analysis because of inadequate studies/data.
6. Results section in the protocol included differences under "major respiratory complications" listed as "significant atelectasis, pneumonia, respiratory failure, need for tracheal intubation and invasive ventilation." In this review, we recorded "significant atelectasis, pneumonia, significant hypoxia, tracheal reintubation, ICU admission." This was necessitated by the reporting pattern noted in the selected studies.

INDEX TERMS

Medical Subject Headings (MeSH)

*Continuous Positive Airway Pressure; Abdomen [*surgery]; Cause of Death; Hypoxia [prevention & control]; Intensive Care Units; Laparotomy; Length of Stay; Pneumonia [*prevention & control]; Postoperative Complications [mortality] [*prevention & control]; Postoperative Period; Pulmonary Atelectasis [*prevention & control]; Randomized Controlled Trials as Topic; Retreatment [statistics & numerical data]

MeSH check words

Adult; Female; Humans; Male