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Research

Prophylactic non-invasive positive pressure ventilation reduces complications and length of hospital stay after invasive thoracic procedures: a systematic review

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KEY WORDS

Non-invasive ventilation
Thoracic surgery
Respiratory care
Physical therapy
Systematic review

ABSTRACT

Question: In patients undergoing invasive thoracic procedures, what are the effects of prophylactic non-invasive positive pressure ventilation (NIV)? **Design**: Systematic review with meta-analysis of randomised trials. Methodological quality was assessed using the PEDro scale and the certainty of evidence with the GRADE approach. **Participants**: Patients undergoing invasive thoracic procedures. **Intervention**: Continuous positive airway pressure (CPAP) or bi-level positive airway pressure (BiPAP). **Outcome measures**: Length of hospital stay, postoperative pulmonary complications, need for tracheal intubation, mortality, hypoxaemia, pulmonary function and adverse events. Meta-analysis was performed for all outcomes. Subgroup analyses estimated the effects of CPAP and BIPAP independently. **Results**: Sixteen trials with 1,814 participants were included. The average quality of the included studies was fair. Moderate certainty evidence indicated that NIV reduces postoperative pulmonary complications (RD −0.09, 95% CI −0.15 to −0.04) without increasing the rate of adverse events (RD 0.01, 95% CI −0.02 to 0.04). Low certainty evidence indicated that NIV reduces length of hospital stay (MD −1.4 days, 95% CI −2.2 to −0.5) compared with usual care. The effects on intubation and mortality rates were very close to no effect, indicating that NIV is safe. Subgroup analyses showed that the evidence for CPAP had more precise estimates that that for BiPAP. **Conclusion**: NIV reduces postoperative pulmonary complications and length of stay after invasive chest procedures without increasing the risk of adverse events. **Registration**: PROSPERO CRD42015019004. **[da Conceição dos Santos E, Monteiro RL, Fonseca Franco de Macedo JR, Poncin W, Lunardi AC (2024) Prophylactic non-invasive positive pressure ventilation reduces complications and length of hospital stay after invasive thoracic procedures: a systematic review. *Journal of Physiotherapy* 70:265–274]**

Introduction

Thoracic procedures are used in the diagnosis and management of diseases associated with the lungs, pleura and mediastinal viscera.[1] Over the last 20 years, thoracic surgical techniques have improved and become safer for patients;[2] nevertheless, pulmonary complications are not uncommon during or following these procedures. Such complications, which can occur in up to 30 to 50% of patients, are associated with in-hospital mortality.[3] Patients' comorbidities and complications are associated with prolonged length of hospital stay and increased costs following thoracic procedures.[4]

The prevention of complications and rate of improvement of symptoms associated with any complications that do occur can be influenced by the respiratory care delivered.[5] For example, non-invasive ventilation (NIV) has been investigated as a prophylactic technique[6,7] and as a treatment for postoperative pulmonary complications, compared with usual respiratory care.[3] However, previous systematic reviews attempting to define the role of NIV after cardiothoracic surgery have presented contradictory results and methodological weaknesses.[8,9] Reviews by Zhu et al[8] and Wu et al[9] included both studies that used NIV prophylactically and studies that used NIV as a treatment for atelectasis or acute respiratory failure in patients undergoing thoracoabdominal surgery. In addition, the reviews included studies that used NIV in both the experimental and control groups, making it difficult to interpret the results. Finally, none of the previous systematic reviews carried out an analysis of the quality of the evidence, which limits implementation of the results in clinical practice.[8,9] Additionally, previous reviews have not reported pooled estimates of the effect of NIV on length of stay, tracheal reintubation, survival, postoperative pulmonary complications and adverse events.

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Therefore, the research question for this systematic review was:

In patients undergoing invasive thoracic procedures, what are the effects of prophylactic non-invasive positive pressure ventilation?

Method

Design

The review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines.[10]

Identification and selection of trials

The search, which was not limited by year of publication or language, was performed in the following databases: Medline, the Cochrane Library, Embase, CINAHL, AMED, PsycINFO, Pubmed, LILACS, SciELO, Scopus and PEDro. The search terms were related to thoracic procedures and modalities of non-invasive positive airway pressure. The detailed search terms were pre-specified in the published protocol[11] and are presented in Appendix 1. Two researchers (ECS, RLM) independently reviewed titles and abstracts of the retrieved studies, assessing them for eligibility against predetermined criteria (see Box 1). Where eligibility was unclear from the title and abstract, the paper was obtained in full text for further appraisal. Full text copies of eligible articles were retrieved. A hand search through the reference lists of eligible articles was then performed. Any disagreement between the two researchers was resolved via discussion with a third researcher (ACL).

Assessment of characteristics of trials

Quality

When available, the attributed score was extracted from the PEDro database.[12] Where a score was unavailable on the PEDro database, two researchers independently scored the trial. The two researchers were trained to assign a quality score for each study using the PEDro scale.[13] The PEDro methodological quality scale ranges between 1 and 10, the latter being the highest (and best) possible quality score.[14]

The certainty of the evidence was classified using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach,[15] using GRADEpro GDT software[a]. The risk of bias (methodological weaknesses), inconsistency (level of heterogeneity among studies), indirectness (publication bias) and imprecision (insufficient sample size) were considered to decrease the level of certainty if they were present on most of the studies included in the meta-analysis for each outcome.

Box 1. Inclusion criteria.

Design
- Randomised controlled trials

Participants
- Adult (age > 18 years)
- Undergoing invasive thoracic procedure

Intervention
- Prophylactic non-invasive ventilation delivered as continuous positive airway pressure or bilevel positive airway pressure

Outcomes measure
- Length of stay
- Tracheal intubation
- Mortality
- Pulmonary function
- Adverse events (eg, pleural fistula, pneumothorax or aerophagia)
- Postoperative pulmonary complication (eg, pneumonia, hypoxaemia or atelectasis)

Comparison
- Non-invasive ventilation versus sham/no intervention
- Non-invasive ventilation plus other intervention(s) versus the same other intervention(s)

Participants

To be eligible for inclusion in the review, studies were required to have included people aged ≥ 18 years who were undergoing an invasive thoracic procedure. Age and type of thoracic procedure were recorded to describe the participants in each trial.

Intervention

Trials were required to have estimated the effect of prophylactic use of continuous positive airways pressure (CPAP) or bilevel positive airway pressure (BIPAP) as NIV. The comparison could be: NIV versus sham/no intervention or NIV plus other intervention(s) versus the same other intervention(s).[11]

Outcome measures

In addition, to be included in the review, the trials had to report at least one of the following outcomes: length of stay, need for tracheal intubation, mortality, pulmonary function, adverse events (eg, pleural fistula, pneumothorax or aerophagia) or postoperative pulmonary complications (eg, pneumonia, hypoxaemia or atelectasis).

Data collection and analysis

In addition to the data mentioned above, the following data were extracted: study title, year of publication, type of study, sample size, study objective, interventions, outcomes and results. Meta-analysis was conducted. Data from the included studies that were presented as median and interquartile range were transformed into mean and standard deviation.[16] When standard deviation was not reported, it was estimated from data such as mean, confidence interval, sample size and p value. Risk difference with its 95% CI was used to summarise relative effects of categorical variables, whereas mean difference with its 95% CI was used to summarise the results of continuous variables. Overall, this study meta-analysed the results of homogeneous studies using the inverse variance method and random effects model for continuous variables, and the Mantel-Haenszel method and random effects model for categorical variables. Statistical heterogeneity of data across studies was assessed using the Higgins and Thompson Inconsistence I^2 test, considering that I^2 close to 0% suggests no heterogeneity and I^2 close to 75% suggests high heterogeneity.[17] A subgroup analysis was performed according to the type of NIV that was used in the trial: CPAP or BIPAP. Following recommendations, in meta-analyses with ≥ 10 studies, funnel plot asymmetry tests were performed to distinguish chance from real asymmetry and to investigate publication bias.[18] All statistical analyses were conducted using the software Review Manager 5.3[b].

Results

Compliance with the study protocol

After reading the full text of the included articles, we focused on certain sections of the registered protocol. It was decided to only include studies that had used NIV as a prophylactic intervention because limited data are currently available to address the question of using NIV as a treatment for existing postoperative complications. It was also decided to only include studies in which NIV was compared with control because one study has compared NIV with other types of devices that generate positive pressure. The subsequent sections of the protocol will be carried out in the future, in a separate review when relevant studies are found in sufficient number.

Flow of studies through the review

A total of 5,240 records were retrieved from the search of all interrogated databases. No additional studies were found via hand search. After excluding duplicates, screening titles and abstracts, and

reading the full text, 16 randomised clinical trials remained and were included[19–34] (Figure 1). These trials involved 1,814 participants and were published between 1994[19] and 2021[34] (Table 1).

Characteristics of the included trials

Quality

The mean PEDro score for the included studies was 6 points (SD 1), ranging between 3 and 8 points (Table 2). Most unmet quality criteria were due to the lack of concealed allocation and the failure to blind study participants (100%), clinicians (100%) and assessors (67%).

Participants

The thoracic procedures used in the included trials were cardiac surgeries (six studies, n = 448), lung surgeries (nine studies, n = 1,215) and chest drainage due to trauma (one study, n = 151).

Interventions

Nine of 16 trials used CPAP as treatment and six used BIPAP; one study used both forms of NIV. The CPAP studies used pressures that ranged between 2 and 15 cmH_2O across studies, while in the BiPAP studies, the level of inspiratory positive airway pressure (IPAP) ranged between 7 and 17 cmH_2O and the level of expiratory positive airway pressure (EPAP) ranged between 2 and 10 cmH_2O. The duration of application of NIV ranged between 15 minutes/day and 24 hours/day. In most of the included trials, NIV plus other intervention(s) was compared with the same other intervention(s) only. One exception was the trial by Santos,[33] where NIV plus other interventions was compared with sham NIV plus the same other interventions. The other exceptions were two studies where NIV was compared with no intervention (Table 1).[20,22]

Outcome measures

Of the 16 included studies, 12 reported length of stay data, 12 reported postoperative complications, five reported the requirement for MV, seven reported mortality and 10 reported adverse events (Tables 1 and 3; see eAddenda for Table 3).

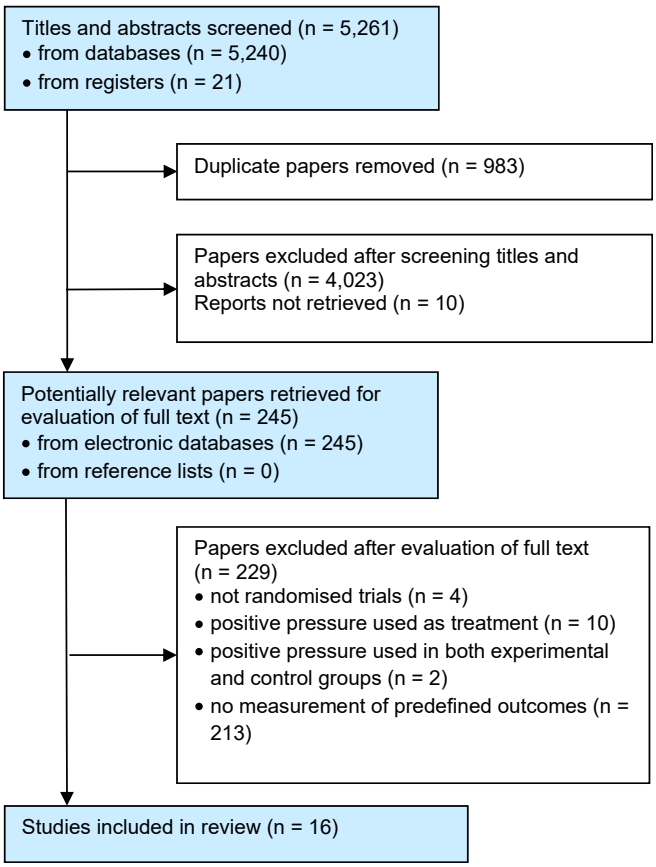

Figure 1. Flow of studies through the review.

Effect of intervention

Length of hospital stay

Meta-analysis of 12 trials showed that NIV decreased length of stay to a worthwhile extent when compared with usual respiratory care (MD –1.4 days, 95% CI –2.2 to –0.5) (Figure 2; see Figure 3 on the eAddenda for a detailed forest plot). Seven of these trials used CPAP; the pooled effect again showed a reduction in length of stay (MD –0.8 days), although the imprecision inherent in that estimate indicated uncertainty as to whether the effect was clinically worthwhile or not (95% CI –1.6 to –0.03). The other five trials used BiPAP; although the pooled effect indicated a larger effect than that estimated for CPAP (MD –1.2 days), there was marked uncertainty inherent in this estimate (95% CI –5.4 to 3.0). The certainty of evidence was low due to high heterogeneity and methodological weaknesses in studies (Table 4).

Postoperative pulmonary complications

The postoperative pulmonary complications considered among the included studies were conditions such as pneumonia, atelectasis, hypoxaemia and respiratory failure. Pooled data from 12 studies showed that NIV prevents postoperative pulmonary complications compared with usual care (RD –0.09, 95% CI –0.15 to –0.04) (Figure 4; see Figure 5a on the eAddenda for a detailed forest plot,). Note that one of the 12 trials had a CPAP arm, a BiPAP arm and a control arm, so the control group was divided between the CPAP comparison and the BiPAP comparison for the overall analysis, in accordance with guidance from the Cochrane Collaboration. Seven of the 12 trials used CPAP; the pooled effect showed a stronger reduction in the risk of postoperative pulmonary complications (RD –0.13, 95% CI –0.18 to –0.08). Six of the 12 trials used BiPAP; the pooled effect indicated an uncertain effect on the risk of postoperative pulmonary complications (RD –0.06, 95% CI –0.17 to 0.06) (Figure 4; see Figure 5b on the eAddenda for a detailed forest plot). All of these results had moderate certainty of evidence due to methodological weaknesses in studies (Table 4).

Requirement for mechanical ventilation

Meta-analysis of five trials showed that NIV had a negligible effect on the requirement for mechanical ventilation (RD 0.01, 95% CI –0.01 to 0.04) (Figure 6; see Figure 7 on the eAddenda for a detailed forest plot). One of these trials used CPAP; the pooled effect was estimated as no difference between the groups (RD 0.00) with minimal uncertainty around that estimate (95% CI –0.07 to 0.07). The other four trials used BiPAP; the pooled effect was also negligible (RD 0.01, 95% CI –0.02 to 0.04). These results had moderate certainty of evidence due to methodological weaknesses in studies (Table 4).

Mortality

Meta-analysis of seven trials showed that NIV had no effect on mortality (RD 0.00, 95% CI –0.01 to 0.01) (Figure 8; see Figure 9 on the eAddenda for a detailed forest plot). Four of these trials used CPAP; the pooled effect was estimated as no difference between the groups (RD 0.00) with minimal uncertainty around that estimate (95% CI –0.01 to 0.02). The other three trials used BiPAP; the pooled effect was also negligible (RD –0.02, 95% CI –0.04 to 0.01). These results had moderate certainty of evidence due to methodological weaknesses in studies (Table 4).

Adverse events

Meta-analysis of 10 trials showed that NIV had a negligible effect on the risk of adverse events (RD 0.01, 95% CI –0.02 to 0.04) (Figure 10; see Figure 11 on the eAddenda for a detailed forest plot). Six of these trials used CPAP; the pooled effect was estimated to be negligible (RD 0.01, 95% CI –0.03 to 0.05). The other four trials used BiPAP; the pooled effect was negligible (RD 0.01, 95% CI –0.04 to 0.06). These results have moderate certainty of evidence due to methodological weaknesses in studies (Table 4).

Table 1
Summary of included trials (n = 16).

Study	Participants	Intervention		Outcome measures
		Exp	Con	
Jousela 1994[19]	n: 30 age (*y*): 52 surgery: CABG	CPAP (10 cmH_2O; 8 hrs) + breathing exercises	Breathing exercises	• respiratory rate • haemodynamics • arterial blood gases • LOS in hospital • PPCs
Aguiló 1997[20]	n: 19 age (*y*): 54 surgery: pneumonectomy, lobectomy and segmentectomy	BIPAP (IPAP 10 cmH_2O; EPAP 5 cmH_2O; 60 min/d)	No intervention was described by the authors	• O_2 levels • ventilatory pattern • haemodynamics • adverse events
Matte 2000[21]	n: 96 age (*y*): 64 surgery: CABG	Exp 1: BiPAP (IPAP 12 cmH_2O; EPAP 5 cmH_2O; 60 to 180 min/d) + coughing exercises + aerosol therapy + mobilisation + volume oriented IS (20/2 hr) Exp 2: CPAP (5 cmH_2O; 60 to 180 min/d) + coughing exercises + aerosol therapy + mobilisation + volume-oriented IS (20/2 hr)	Coughing exercises + aerosol therapy + mobilisation + volume-oriented IS (20/2 hr)	• gas exchanges • venous admixture • lung function • cardiac output • PPCs
Altmay 2006[22]	n: 120 age (*y*): 57 surgery: CABG	CPAP (10 cmH_2O; $\geq$ 2 hr/d)	No ventilatory support	• chest tube drainage • haemodynamics • gas exchanges • lung function • LOS in hospital
Perrin 2007[23]	n: 32 age (*y*): 64 surgery: lobectomy	BiPAP (IPAP 7 cmH_2O progressing up to tolerated level; EPAP 2 to 4 cmH_2O; 60 min/d) + breathing exercises + coughing exercises (2/d)	Breathing exercises + coughing exercises (2/d)	• O_2 levels • lung function • LOS in hospital • PPCs • adverse events • requirement for MV
Franco 2011[24]	n: 26 age (*y*): NS surgery: CABG	BiPAP (IPAP 8 to 12 cmH_2O; EPAP 6 cmH_2O; 60 min/d) + diaphragmatic breathing exercises + active and/or active assisted mobilisation (upper and lower limbs) + airway clearance (assisted coughing) + lung expansion technique	Diaphragmatic breathing exercises + active and/or active assisted mobilisation (upper and lower limbs) + airway clearance (assisted coughing) + lung expansion technique	• haemodynamics • respiratory muscle strength • lung function • LOS in hospital • PPCs • adverse events
Danner 2012[25]	n: 21 age (*y*): 67 surgery: large lung resection, pneumonectomy, bilobectomy or lobectomy and segmentectomy	BiPAP (IPAP 16 cmH_2O; EPAP 0 to 4 cmH_2O; 10 hr on d 1 and 2; 6 hr on d 3) + pain control + early mobilisation + breathing exercises	Pain control + early mobilisation + breathing exercises	• lung function • O_2 levels • LOS in hospital • PPCs • requirement for MV • mortality
Barbagallo 2012[26]	n: 50 age (*y*): 67 surgery: lobectomy	CPAP (8 cmH_2O; 120 min/d) + O_2 supplementation + antibiotic prophylaxis + aerosol therapy (3/d), deep vein thrombosis prophylaxis with heparin + mobilisation + chest physiotherapy (1/d)	O_2 supplementation + antibiotic prophylaxis + aerosol therapy (3/d), deep vein thrombosis prophylaxis with heparin + mobilisation + chest physiotherapy (1/d)	• O_2 levels • LOS in hospital • PPCs • mortality • adverse events • requirement for MV
Al Jaaly 2013[27]	n: 126 age (*y*): 68 surgery: CABG	BiPAP (IPAP 12 cmH_2O and EPAP 5 cmH_2O if BMI $<$ 30; IPAP 17 cmH_2O and EPAP 10 cmH_2O if BMI $\geq$ 30; 24 hrs) + chest physiotherapy + IS + bronchodilator + assisted coughing + mobilisation	Chest physiotherapy + IS + bronchodilator + assisted coughing + mobilisation	• LOS in hospital • O_2 levels • PPCs • requirement for MV • mortality
Lorut 2014[28]	n: 360 age (*y*): 64 surgery: lung resection	BIPAP (6 $\times$ 1 hr/d) + airway clearance + aerosol therapy + deep vein thrombosis prophylaxis with heparin + mobilisation + chest physiotherapy (1/d)	Airway clearance + aerosol therapy + deep vein thrombosis prophylaxis with heparin + mobilisation + chest physiotherapy (1/d)	• PPCs • LOS in hospital • adverse events • requirement for MV • mortality

Table 1 (*Continued*)

Study	Participants	Intervention		Outcome measures
		Exp	Con	
Roceto 2014[29]	n: 40 age (*y*): 58 surgery: lobectomy, bilobectomy, pneumonectomy (posterolateral thoracotomy)	CPAP (7 to 8.5 cmH_2O; 240 min/d) + airway clearance + lung expansion + O_2 supplementation	Airway clearance + lung expansion + O_2 supplementation	• O_2 levels • dyspnoea • pain • requirement for thoracic drainage • adverse events
Garutti 2014[30]	N: 108 age (*y*): 63 surgery: lung resection by lateral thoracotomy, segmentectomy, lobectomy, and pneumonectomy	CPAP (5 to 7 cmH_2O; 6 hr/d) + O_2 supplementation	O_2 supplementation	• O_2 level • PPCs • adverse events • mortality
Araújo-Filho 2017[31]	n: 50 age (*y*): 44 surgery: heart valve replacement surgery	CPAP (10 cmH_2O; 60 min/d) + breathing exercises + mobilisation	Breathing exercises + mobilisation	• functional capacity • LOS in ICU • LOS in hospital
Palleschi 2018[32]	n: 163 age (*y*): 67 surgery: lobectomy	CPAP (8 cmH_2O on d 1, 10 cmH_2O on d 2 and 12 cmH_2O on d 3; 3 × 2 hrs/d for 3 d) + sitting position (≥ 4 hrs on d 1 to ≥ 9 hrs on d 3) + walking (≥ 30 min on d 1 to ≥ 3 hrs on d 3) + assisted cough	Sitting position (≥ 4 hrs on d 1 to ≥ 9 hrs on d 3) + walking (≥ 30 min on d 1 to ≥ 3 hrs on d 3) + assisted cough	• LOS in hospital • PPCs • adverse events • mortality
Santos 2020[33]	n: 151 age (*y*): 29 surgery: thoracic drainage for resolution of pleural effusion	CPAP (15 cmH_2O; 90 min/d) + IS (5 × 20 reps) + airway clearance manoeuvres (5 ×10 reps using a high-frequency oscillator) + walking 100 m	IS (5 × 20 reps) + airway clearance manoeuvres (5 × 10 reps using a high-frequency oscillator) + walking 100 m + sham CPAP (4 cmH_2O)	• duration of chest drainage • lung function • O_2 levels • LOS in hospital • PPCs • adverse events
Puente-Maestu 2021[34]	n: 422 age (*y*): 64 surgery: lung resection (thoracotomy or thoracoscopy)	CPAP (7 cmH_2O; 6 hrs/d) + prophylactic postural and hygienic measures to prevent pneumonia + physiotherapy + early rehabilitation	Prophylactic postural and hygienic measures to prevent pneumonia + physiotherapy + early rehabilitation	• LOS in hospital • PPCs • adverse events • mortality

BiPAP = bilevel positive airway pressure, BMI = body mass index, CABG = coronary artery bypass grafting, Con = control group, CPAP = continuous positive airway pressure, EPAP = expiratory positive airway pressure, Exp = experimental group, IPAP = inspiratory positive airway pressure, IS = incentive spirometry, LOS = length of stay, MV = mechanical ventilation, NIV = non-invasive ventilation, NS = not stated, O_2 = oxygen, PPC = postoperative pulmonary complication, reps = repetitions.

Table 2
PEDro scores for the included trials (n = 16).

Study	Eligibility criteria and source	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% loss to follow-up	Intention-to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Jousela 1994[19]	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	6
Aguiló 1997[20]	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Matte 2000[21]	N	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Altmay 2006[22]	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Perrin 2007[23]	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	6
Franco 2011[24]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Danner 2012[25]	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	6
Barbagallo 2012[26]	N	Y	N	Y	N	N	N	Y	N	Y	Y	5
Al Jaaly 2013[27]	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Lorut 2014[28]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Roceto 2014[29]	Y	Y	Y	Y	N	N	N	N	N	Y	N	4
Garutti 2014[30]	Y	Y	Y	Y	Y	N	N	Y	N	Y	Y	7
Araújo-Filho 2017[31]	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	6
Palleschi 2018[32]	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Santos 2020[33]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Puente-Maestú 2021[34]	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	7

N = no, Y = yes.

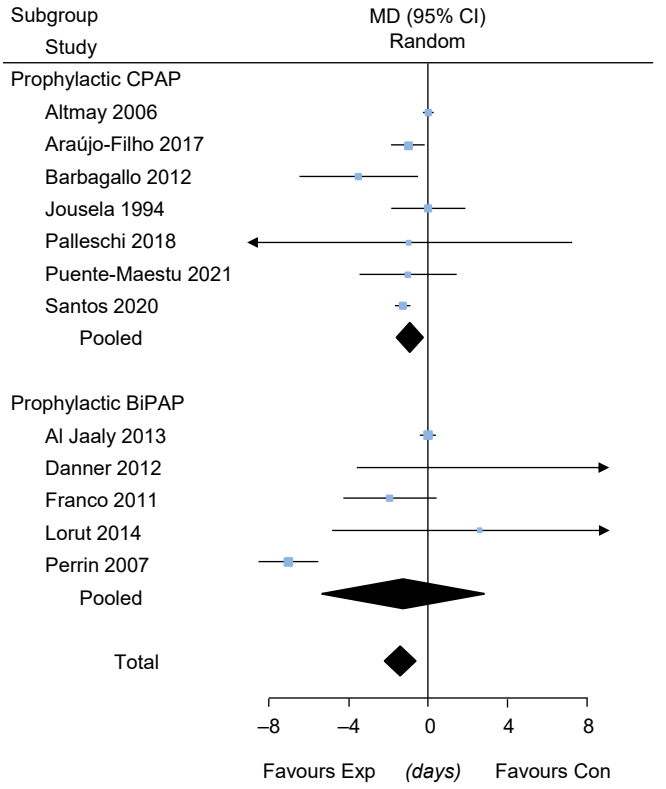

Figure 2. Forest plot of the effect of non-invasive ventilation compared with usual respiratory care on length of hospital stay. BiPAP = bilevel positive airway pressure, Con = control group, CPAP = continuous positive airway pressure, Exp = experimental group.

Visual inspection of the funnel plots did not identify publication bias among the outcomes measured in at least 10 trials (ie, length of hospital stay, postoperative pulmonary complications and adverse events). The forest plots are presented in Figure 12 on the eAddenda.

Discussion

This is the first systematic review with meta-analysis to investigate the prophylactic effects of NIV (CPAP or BIPAP) in patients undergoing invasive thoracic procedures. The results demonstrated that NIV reduces the length of hospital stay (low certainty evidence) and the risk of postoperative pulmonary complications (moderate certainty evidence) following thoracic procedures without increasing the risk of adverse events. The meta-analysis also showed that NIV did not increase the need for mechanical ventilation or worsen the mortality rate (moderate certainty evidence). Of note, most of the included studies had good methodological quality and pooled to provide evidence of low to moderate certainty.

Postoperative pulmonary complications are one of the main concerns following thoracic surgery[4] as they can severely impair respiratory function.[35] NIV may prevent postoperative pulmonary complications by reducing ventilatory muscle loading and increasing pulmonary ventilation.[36–38] Some healthcare practitioners have previously been reluctant to use NIV because of the potential for adverse events.[39] The results of this review have shown that the use of NIV following invasive thoracic procedures is not associated with increased odds of adverse events such as pleural fistula or aerophagia. On the contrary, NIV is superior to other respiratory interventions at preventing postoperative pulmonary complications. These results may help to alleviate concerns expressed by healthcare professionals using NIV in patients following invasive thoracic procedures. Furthermore, Liao et al[7] conducted a randomised trial with thoracic surgery and noted negligible difference in the rate of adverse events between usual care (11%) and NIV (17%), whilst Preisig et al[40] reported that complications traditionally attributed to NIV (eg, gastric

Table 4
Certainty of the evidence according to GRADE.

Certainty assessment							Patients (n)		Effect (95% CI)		Certainty
Studies		Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Exp	Con	Relative	Absolute	
n	design										
Length of hospital stay (*days*)											
12	RCTs	serious[a,b,c,d,e,f]	serious[f]	not serious	not serious	none	749	754		MD 1.39 fewer (2.23 to 0.54)	⨁⨁◯◯ Low[a,b,c,d,g]
Postoperative pulmonary complications											
12	RCTs	serious[a,b,c,d,e,g,h]	not serious	not serious	not serious	none	147/774 (19%)	211/754 (28%)	RD −0.09 (−0.15 to −0.04)		⨁⨁⨁◯ Moderate
Requirement for mechanical ventilation											
5	RCTs	serious[a,b,c,d,g,h]	not serious	not serious	not serious	none	10/296 (3%)	6/296 (2%)	RD 0.01 (−0.01 to 0.04)		⨁⨁⨁◯ Moderate
Mortality											
7	RCTs	serious[a,b,c,d,g,h]	not serious	not serious	not serious	none	10/621 (2%)	13/629 (2%)	RD 0.00 (−0.02 to 0.01)		⨁⨁⨁◯ Moderate
Adverse events											
10	RCTs	serious[a,b,c,d,e,g,h]	not serious	not serious	not serious	none	49/656 (7%)	47/664 (7%)	RD 0.00 (−0.02 to 0.03)		⨁⨁⨁◯ Moderate

RCT = randomised controlled trials.
[a] Studies without concealed allocation.
[b] Studies without blinded assessment.
[c] Studies without blinded patients.
[d] Studies without blinded therapists.
[e] Studies with groups not similar before the intervention.
[f] high heterogeneity.
[g] Studies with > 15% dropout.
[h] Studies without intention-to-treat analysis.

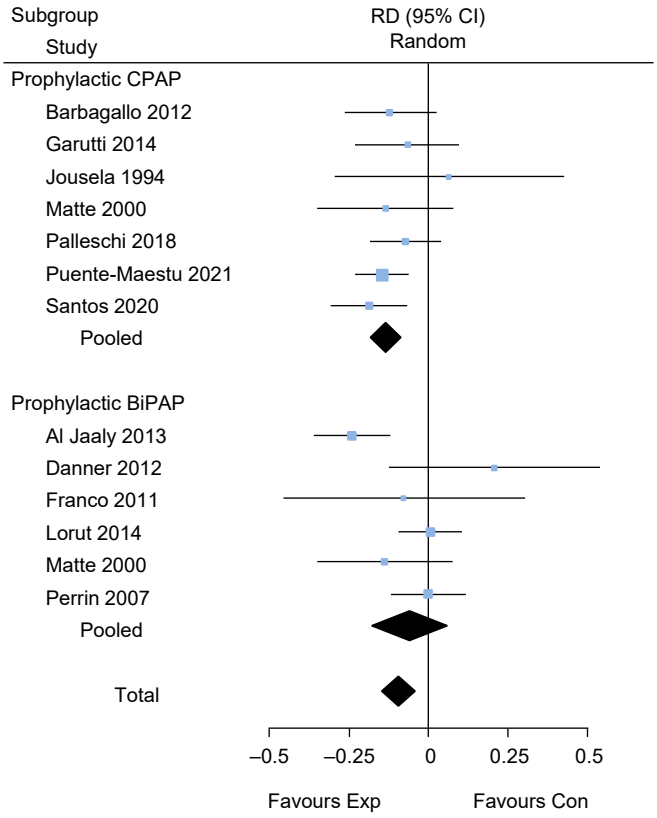

Figure 4. Forest plot of the effect of non-invasive ventilation compared with usual respiratory care on the risk of postoperative pulmonary complications.
BiPAP = bilevel positive airway pressure, Con = control group, CPAP = continuous positive airway pressure, Exp = experimental group.

distention, vomiting and facial injury) were not observed when NIV was used in patients undergoing cardiovascular surgery.

In addition to preventing postoperative pulmonary complications, NIV also reduced length of hospital stay. This could be a direct association, whereby reducing postoperative pulmonary complications means fewer treatment requirements (eg, less antibiotics to treat pneumonia or less oxygen to treat hypoxaemia). Therefore, NIV may also reduce hospital costs,[41] although this outcome was not included in this analysis.

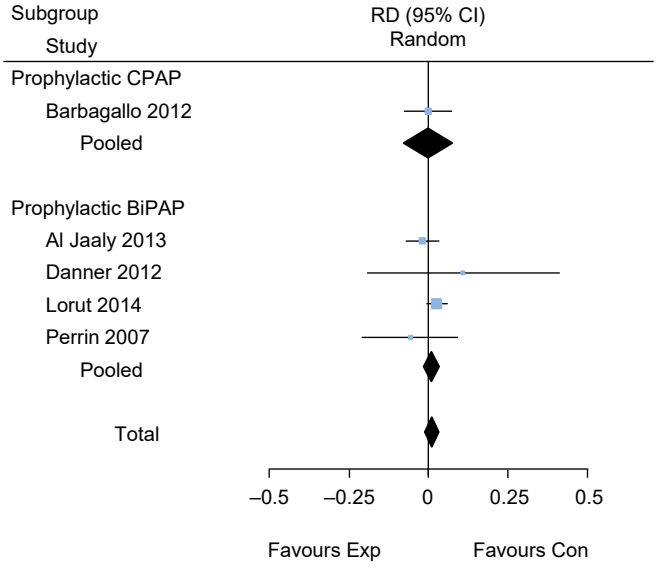

Figure 6. Forest plot of the effect of non-invasive ventilation compared with usual respiratory care on requirement for mechanical ventilation.
BiPAP = bilevel positive airway pressure, Con = control group, CPAP = continuous positive airway pressure, Exp = experimental group.

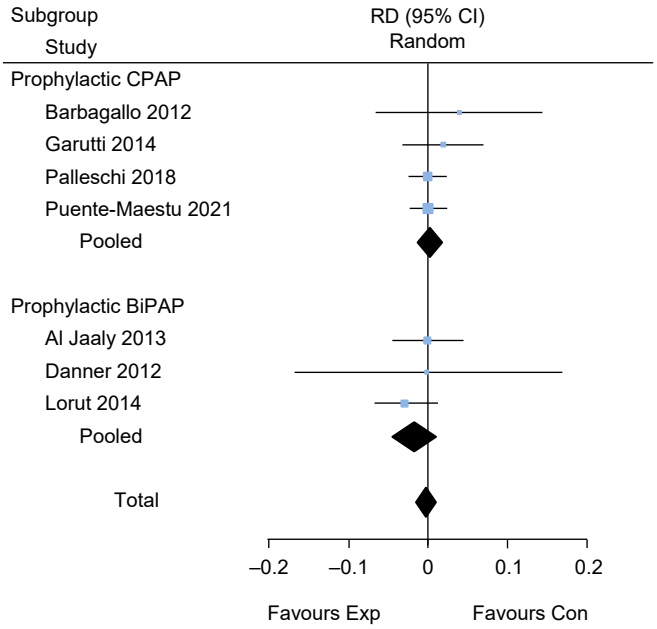

Figure 8. Forest plot of the effect of non-invasive ventilation compared with usual respiratory care on mortality.
BiPAP = bilevel positive airway pressure, Con = control group, CPAP = continuous positive airway pressure, Exp = experimental group.

Evidence about the decrease in length of stay with NIV has accumulated gradually over the years. In 2016, Zhu et al[8] carried out a systematic review of 1,740 participants who underwent cardiac or thoracic surgery; it demonstrated that NIV did not reduce length of stay. A more recent systematic review published in 2020[9] involving 830 participants undergoing cardiac surgery showed that, compared with usual care, NIV reduced the length of stay. One hypothesis is that higher pressure levels may have been used in more recent trials, increasing the effect of NIV on some clinical outcomes. Zhu et al[8] did not describe the pressure levels of

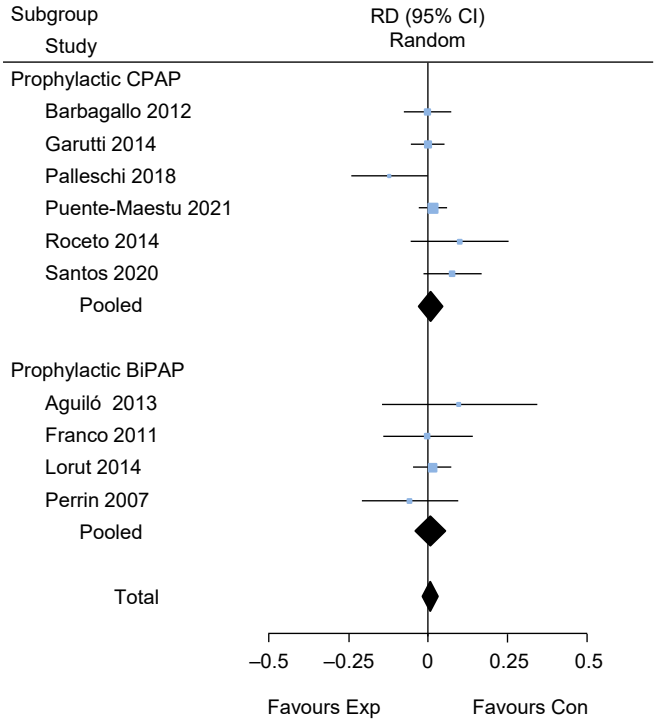

Figure 10. Forest plot of the effect of non-invasive ventilation compared with usual respiratory care on the risk of adverse events.
BiPAP = bilevel positive airway pressure, Con = control group, CPAP = continuous positive airway pressure, Exp = experimental group.

the studies they included. However, like our systematic review, Wu et al[9] included studies that used pressure levels > 10 cmH_2O in most of them, reaching up to 17 cmH_2O.

In this review, NIV had a negligible or no effect on the requirement for mechanical ventilation or the risk of mortality. Celebi et al[42] studied treatments combining invasive and non-invasive ventilation versus usual care and did not observe differences in the requirement for mechanical ventilation between the groups. The same finding was reported in the meta-analysis conducted by Zhu et al.[8] Regarding mortality, other systematic reviews also pointed out the lack of effect of NIV on this outcome in cardiac or lung surgeries.[9,43,44] A possible explanation for the lack of association between the effect of NIV in preventing postoperative pulmonary complications but not in reducing deaths could be the relative rarity of death events. A much larger number of participants would possibly be needed to find a potential effect of NIV on survival.

Subgroup analyses indicated that CPAP has a clear benefit on length of hospital stay and postoperative pulmonary complications. Subgroup analyses also confirmed that CPAP is safe, as its effects on other outcomes were negligible (ie, it does not worsen mortality or adverse events to a clinically important extent).

Subgroup analysis of the trials estimating the effect of BiPAP gave uncertain estimates with wide confidence intervals for length of hospital stay and postoperative pulmonary complications. The more favourable limit of these confidence intervals indicated effects as good as or even better than the effects estimated for CPAP. The less favourable limit of these confidence intervals indicated harmful effects. The subgroup analyses for the other outcomes indicated small to negligible effects from BiPAP.

Despite the good methodological quality of the trials included in this systematic review, the certainty of the evidence ranged from low to moderate. The accumulated evidence therefore needs to be interpreted carefully. The effects estimated in this systematic review merit further investigation in future high-quality trials. Nevertheless, this meta-analysis provides the best evidence to date.

A limitation of this review is that some data could not be obtained because some studies did not report all data that were needed. Although all author groups were contacted, no responses were received.

These results indicate that the use of NIV after invasive thoracic procedures reduces pulmonary complications with moderate certainty and length of hospital stay with low certainty compared with usual respiratory care, without increasing the risk of adverse events. However, no impact on need for mechanical ventilation or mortality was observed. The subgroup analysis showed that CPAP is a good preventive strategy in patients undergoing thoracic procedures. Most of the included studies were classified as having good methodological quality, supporting the best evidence available to date for the use of NIV in clinical practice following invasive thoracic procedures. Due to the low to moderate certainty of evidence in most outcomes, other well-designed and high-quality trials are needed.

What was already known on this topic: Non-invasive ventilation has been investigated as a tool to prevent pulmonary complications after surgeries compared with usual respiratory care. However, previous systematic reviews in this field attempting to define the role of NIV after cardiothoracic and lung surgeries have presented contradictory results.

What this study adds: Non-invasive ventilation reduces postoperative pulmonary complications and length of hospital stay after invasive chest procedures without increasing the rate of adverse events.

***Footnotes*:** [a] GRADEpro GDT software 2022, McMaster University and Evidence Prime, Ontario, Canada.

[b] RevMan 5.3 computer program, The Nordic Cochrane Centre, Copenhagen, Denmark.

eAddenda: Appendix 1, Table 3 and Figures 3, 5, 7, 9, 11 and 12 can be found online at https://doi.org/10.1016/j.jphys.2024.08.008.

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