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Research

Adding positive airway pressure to mobilisation and respiratory techniques hastens pleural drainage: a randomised trial

Elinaldo da Conceição dos Santos [a,b], Juliana de Souza da Silva [b], Marcus Titus Trindade de Assis Filho [b], Marcela Brito Vidal [b], Moisés de Castro Monte [c], Adriana Cláudia Lunardi [a,d]

[a] *Master and Doctoral Program in Physical Therapy, Universidade Cidade de São Paulo;* [b] *Department of Biological and Health Sciences, Universidade Federal do Amapá;* [c] *Department of Physical Therapy, Faculdade de Macapá, Macapá;* [d] *Department of Physical Therapy, School of Medicine, Universidade de São Paulo, São Paulo, Brazil*

KEY WORDS

Pleural effusion
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ABSTRACT

Questions: In patients with a collection of fluid in the pleural space, do mobilisation and respiratory techniques: shorten the drainage period and length of hospital stay; improve respiratory function and oxygenation; and prevent pulmonary complications? Does the addition of positive airway pressure to this regimen further improve the effects? **Design**: Randomised controlled trial with three intervention arms, concealed allocation, intention-to-treat analysis and blinded assessment. **Participants**: One hundred and fifty-six inpatients with a fluid collection in the pleural space and with chest drainage in situ. **Intervention**: Participants received usual care and were randomly assigned to: a control group that also received sham positive airway pressure (4 cmH_2O) only (Con); an experimental group that received incentive spirometry, airway clearance, mobilisation and the same sham positive pressure (Exp1); or an experimental group that received the Exp1 regimen except that the positive airway pressure was 15 cmH_2O (Exp2). Treatments were provided three times per day for 7 days. **Outcome measures**: Days of chest tube drainage, length of hospital stay, pulmonary complications and adverse events were recorded until hospital discharge. Costs in each group were estimated. **Results**: The Exp2 group had shorter duration of chest tube drainage and length of hospital stay compared with the Exp1 and Con groups. In addition, the Exp2 group had less antibiotic use (18% versus 43% versus 55%) and pneumonia incidence (0% versus 16% versus 20%) compared with the Exp1 and Con groups (all $p < 0.01$). The groups had similar rates of adverse events (10% versus 2% versus 6%, $p > 0.05$). Total treatment costs were lower in the Exp2 group than in the Exp1 and Con groups. **Conclusions**: In patients with a fluid collection in the pleural space, the addition of positive pressure to mobilisation and respiratory techniques decreased the duration of thoracic drainage, length of hospital stay, pulmonary complications, antibiotic use and treatment costs. **Registration**: ClinicalTrials.gov NCT02246946. **[dos Santos EC, da Silva JS, de Assis Filho MTT, Vidal MB, Monte MC, Lunardi AC (2020) Adding positive airway pressure to mobilisation and respiratory techniques hastens pleural drainage: a randomised trial. *Journal of Physiotherapy* 66:19–26]**

Introduction

Pleural effusion is a collection of excessive fluid in the pleural space, which can have many aetiologies.[1] Each year, pleural effusion is diagnosed in approximately 1.5 million people in the USA.[2] Among people diagnosed with a pleural effusion, mortality at 1 year differs with the aetiology: 25% if from renal failure, 46% if from hepatic failure, 50% if from cardiac failure and more if from malignancy.[3] After trauma, blood (haemothorax) and other fluid may also collect in the pleural space.[4]

Some pleural fluid collections can be managed with aspiration of the fluid via an intercostal needle – a procedure known as thoracentesis.[5] However, British Thoracic Society guidelines recommend the insertion of an intercostal tube attached to a closed drainage system in malignant pleural effusions, empyema, traumatic haemopneumothorax and after thoracic surgery.[6]

Depending on its volume and aetiology, excessive pleural fluid can cause dyspnoea and pleuritic pain. The presence of the intercostal tube causes additional pain, which is not always able to be controlled. Furthermore, various complications can develop during the period that the intercostal tube is in situ. The most common complication is drain blockage, which occurs in about 8% of small-bore tubes ($\leq$ 16 F) and 5% of large-bore tubes ($\geq$ 20 F).[6] The next most common complications include infection of the pleural fluid collection (empyema), movement of the tube into a poor position and injury to internal structures.[6] For all these reasons, facilitating rapid drainage of the pleural fluid collection is an important aim of management.

Lung expansion techniques have been proposed as one group of interventions that could be used to hasten the drainage of a pleural fluid collection and thereby reduce the opportunity for complications from the drainage tube.[7] A randomised controlled trial involving

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104 inpatients with pleural effusions with or without an intercostal drainage tube showed that the addition of breathing exercises and mobilisation to other usual care reduced the severity of pleural effusion, as judged by blinded assessment of chest radiographs, and reduced length of stay by a mean of 12 days (95% CI 8 to 16).[7]

Although those results for lung expansion techniques were very promising,[7] few clinical practice guidelines for pleural effusion have incorporated that evidence,[8] presumably because of some limitations. Although the trial was generally very rigorous, some participants who did not complete the allocated intervention were excluded, which is contrary to the recommendation to analyse by intention to treat.[9] The authors did not test whether the effects differed between the subgroups managed with or without an intercostal drainage tube. Furthermore, although the substantial effect on length of stay suggests that the time spent with the intercostal drainage tube in situ was probably also shorter, this was not measured. Perhaps most importantly, the evidence comes from a single trial[7] so an attempt to replicate the findings is warranted.

In addition to breathing exercises and mobilisation, another intervention that might expand the lungs and promote drainage is positive airway pressure, which can be applied non-invasively via a face mask. We hypothesised that increasing the intra-pleural pressure would promote drainage and reabsorption of the pleural fluid collection, thereby hastening the recovery of respiratory function, permitting earlier removal of the chest drain and shortening the hospital stay. However, the only trial of positive airway pressure for pleural effusion examined continuous positive airway pressure (CPAP) in participants with tuberculous pleural effusions and no drainage tubes.[10] Therefore, the effects of positive airway pressure in patients with intercostal tubes for pleural drainage are unknown.

Some indirect evidence suggests that positive airway pressure may have additional advantages. It may help to prevent or treat respiratory complications in patients after thoracic surgery,[11] where end-operative placement of an intercostal drainage tube is routine. For example, in patients undergoing lung resection, non-invasive ventilation significantly improved gas exchange, spirometry and length of stay.[12] In patients who had already developed acute hypoxaemic respiratory insufficiency after lung resection, non-invasive ventilation significantly improved arterial oxygenation and respiratory rate, and significantly reduced reintubation and mortality.[13] Positive effects have also been noted in other thoracic surgical procedures such as coronary artery bypass grafting[14] and resection of lung cancer.[15] However, it is important to remember that many of these patients may primarily have pleural gas with some resolving post-surgical bleeding and oedema in the pleural space, rather than an extensive pleural fluid collection. Furthermore, the beneficial effects after thoracic surgery may occur via mechanisms that are unrelated to the pleural space, such as more efficient gas exchange. Therefore, although these findings are promising, it would be hazardous to extrapolate from these studies to draw conclusions about the effects of positive airway pressure in the overall population of patients receiving drainage of fluid via an intercostal tube.

Therefore, the research questions for this randomised controlled trial were:

1. In patients with a collection of fluid in the pleural space, do mobilisation and respiratory techniques: shorten the drainage period and length of hospital stay; improve respiratory function and oxygenation; and prevent pulmonary complications?
2. Does the addition of positive airway pressure to this regimen further improve the effects?

Method

Design

This study was a randomised controlled trial with concealed allocation, blinded assessors and intention-to-treat analysis. At two university-affiliated tertiary hospitals in Macapá, Brazil, inpatients with a collection of fluid in the pleural space and an intercostal drain were invited to participate. Inpatients who met the eligibility criteria and agreed to participate had the following data collected: personal and anthropometric information; history of smoking; cause of the pleural fluid collection; type of drainage; and tomographic confirmation of a pleural fluid collection. All participants continued to receive usual medical and nursing care, and were immediately randomised to one of three groups: the control group (Con) received no additional active interventions; the first experimental group (Exp1) received breathing exercises, an airway clearance technique and mobilisation; and the second experimental group (Exp2) received the same interventions as Exp1 with the addition of periods of CPAP.

Randomisation was performed by a researcher not involved in patient selection, evaluation or intervention. The random sequence of allocations was computer-generated, with each allocation placed in a corresponding sequentially numbered opaque envelope. The envelopes were sealed and stored securely where only the researcher responsible for the randomisation had access. This researcher informed only the physiotherapist who administered the interventions of each participant's random allocation.[16] This physiotherapist remained blinded to the assessment information being collected on the participants.

The randomly allocated interventions were commenced within 24 hours of insertion of the drainage system, and were continued three times per day for 7 consecutive days. On the first day of the intervention and after the intervention protocol was completed (on the day after the intervention ended), pulmonary function and peripheral oxygen saturation were reassessed. In cases where the drain was removed before completing the intervention protocol period, the reassessments were conducted immediately before the drain was removed to homogenise the analyses. Every 24 hours while the chest drain remained in situ, the drainage rate was quantified and lung expansion was evaluated by a physician blinded to the intervention groups. At this assessment, the physician decided whether the drain should be removed or not. Treatment tolerability and adverse events were also recorded for all patients. In addition, patients were evaluated daily for the presence of pulmonary complications and to estimate treatment costs until hospital discharge. If participants presented any pulmonary complications, they received individualised treatment according to their condition.

Participants

Between December 2014 and February 2017, inpatients with a pleural fluid collection at either hospital were approached consecutively, advised about the study, screened for eligibility (if willing) and invited to participate in the study (if eligible). The inclusion criteria were: being aged $\geq$ 18 years; having a diagnosis of a fluid collection in the pleural space confirmed by computer tomography; and having an intercostal thoracic drainage system in situ for $<$ 24 hours. Exclusion criteria were drowsiness, restlessness, treatment refusal, haemodynamic instability, shock (systolic blood pressure $<$ 90 mmHg), facial trauma, ineffective cough, swallowing impairment, vomiting, upper gastrointestinal bleeding, acute myocardial infarction in the past 48 hours, or bullous emphysema.[17]

Intervention

Usual nursing and medical care were provided to all participants in all groups. Where positive airway pressure was provided, the active and sham pressure levels were based on a previous study that tested different values and evaluated the resulting lung expansion via thoracic computer tomography.[18]

Con group

Participants in this group breathed with CPAP of 4 cmH_2O (sham)[18] via an oronasal mask attached to a bedside ventilation unit[a] for 30 minutes, in order to have a similar intervention period for all groups and guarantee blind assessment (ie, presence of equipment in the room and the impression of the mask on the patient's face).

Exp1 group

Participants in this group undertook: incentive spirometry[b], performing five sets of 20 repetitions; airway clearance manoeuvres using a high-frequency oscillator[c], performing five sets of 10 repetitions; breathing with CPAP of 4 cmH_2O (sham)[18] via an oronasal mask attached to a bedside ventilation unit[a] for 5 minutes while sitting on a chair; and walking a distance of 100 metres.

Exp2 group

Participants in this group received all the same interventions as those provided to the Exp1 group, except that the CPAP was not a sham. Participants breathed with CPAP of 15 cmH_2O (active)[18] via an oronasal mask attached to a bedside ventilation unit[a] for 30 minutes while sitting on a chair.

Outcome measures

Primary outcome

The primary outcome was the duration of thoracic drainage, quantified in days until drain removal. The criteria for drain removal were $\leq$ 200 ml fluid drainage in 24 hours and complete lung expansion assessed by chest radiograph.[19] The decision about the time of drain removal was made by a physician blinded to the participant's group. The physician verified the following criteria every day during the period that drainage was in situ: drainage volume in millilitres over 24 hours, and lung expansion assessed by chest radiograph.

Secondary outcomes assessed during the treatment period

Pulmonary function was evaluated by spirometry following the performance and acceptability criteria previously established by the European Respiratory Society and American Thoracic Society.[20] Spirometry assessments were performed prior to the first intervention and at the end of the scheduled intervention protocol (Day 8). In cases where the criteria for drain removal were met before the end of the protocol, spirometry was performed immediately before the drain was removed. The spirometry measurements were performed by an assessor blinded to the participant's group. The variables forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) were calculated as a percentage of the predicted values for the Brazilian population.[21]

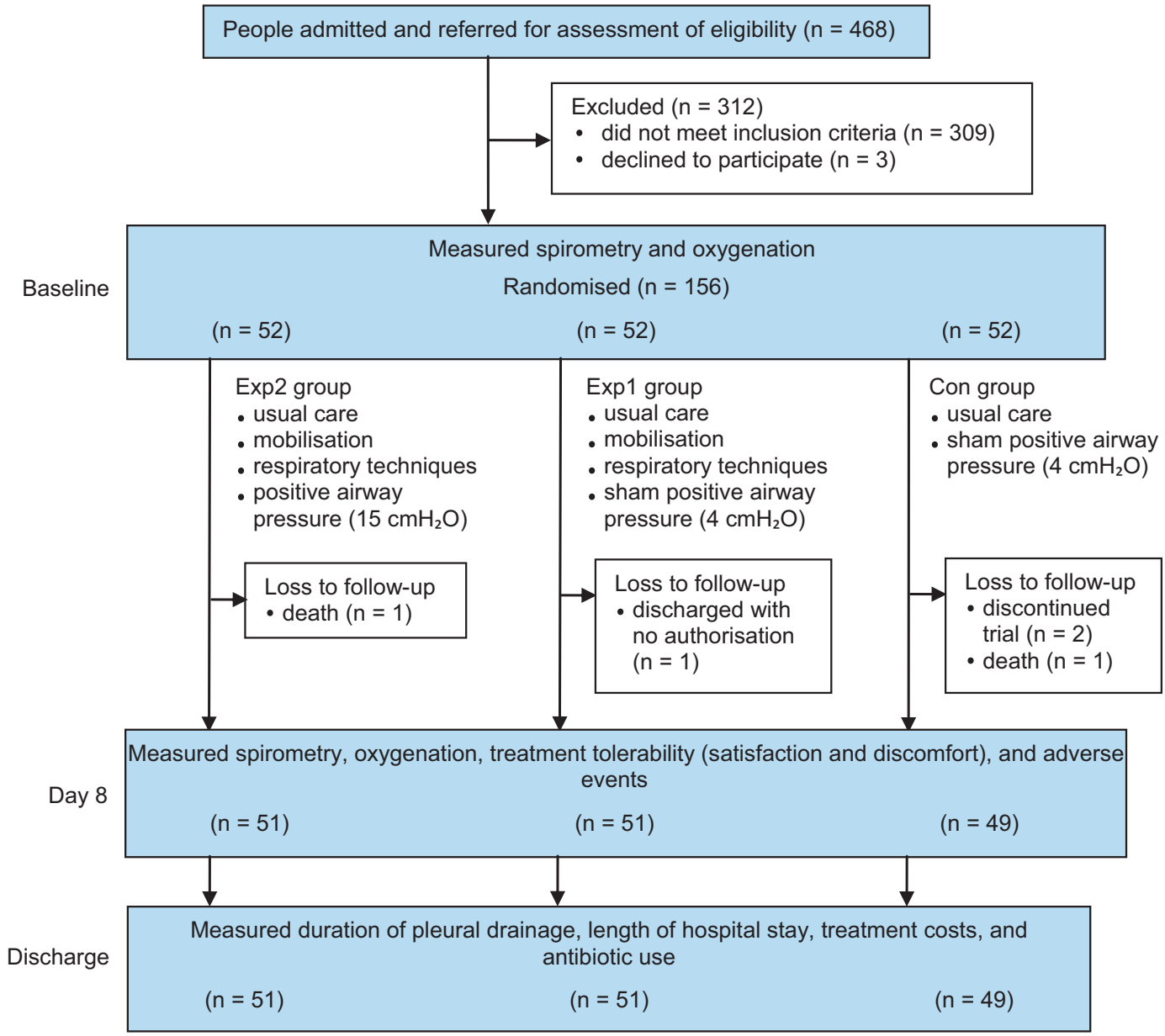

Figure 1. Design and flow of participants through the trial. Note that data obtained before loss to follow-up were included in the analysis for some outcomes. Exp2 = experimental group 2, Exp1 = experimental group 1, Con = control group.

Peripheral oxygen saturation (SpO_2) was assessed daily until completion of the intervention protocol or removal of the thoracic drain. Measurements were taken by an assessor blinded to the intervention group. Oximetry was performed with the participant breathing ambient air (ie, without oxygen supplementation) for at least 10 minutes.

Treatment tolerability was assessed using participant ratings of satisfaction and discomfort on a visual analogue scale ranging from 0 to 10 points. Participants were requested to report their satisfaction with their randomly allocated respiratory interventions using scores where 0 points indicated complete dissatisfaction and 10 points indicated complete satisfaction with the treatment. Participants were also instructed to respond about discomfort regarding the randomly allocated respiratory interventions received, where 0 points indicated no discomfort with the oronasal mask or flow and 10 points indicated unbearable discomfort.

Adverse events were recorded during the positive airway pressure treatment periods based on daily visual evaluation and questioning of participants. Whenever an adverse event was detected, it was monitored and reported to the ethics committee. In cases of confirmed air leaks or aerophagia, the respiratory care session was interrupted for 24 hours and the participant was re-evaluated the next day.

Secondary outcomes assessed until discharge from hospital

Length of hospital stay was tallied as the total number of days in hospital.

Treatment costs were estimated based on established values of overnight hospital stay (R$500.00), antibiotic use (R$313.49), physiotherapy session (R$150.00), equipment and accessories for positive airway pressure (R$2000.00 divided by the number of participants in the Exp2 group) for the whole length of hospital stay of each participant.

Pulmonary complications were assessed by a physician who was blinded to each participant's group, considering the following events: pneumonia (chest radiograph with pulmonary infiltrate associated with two of the following signs: purulent sputum, hyperthermia $>$ 38.8 °C, or increase in baseline leucocyte count $>$ 25%),[22] atelectasis (abnormal chest radiograph associated with acute respiratory symptoms)[23] and hypoxaemia (SpO_2 $<$ 85% associated with respiratory symptoms).[24] In addition to pulmonary complications, the lung entrapment rate was also verified by a physician who was blinded to the intervention groups. Lung entrapment was defined as contralateral displacement of the mediastinum[25] verified by chest radiograph or computer tomography, or reaccumulating pleural effusion within 24 to 72 hours.[26] Need for thoracotomy was also recorded until hospital discharge.

Data on antibiotic use were extracted from the medical prescription records from the inclusion of the participant in the study until hospital discharge. The type of antibiotic used was not evaluated.

Data analysis

It was calculated that a sample of 132 participants (43 per group) was required, based on the primary outcome of thoracic drainage duration. Two days was nominated as the smallest worthwhile effect, anticipating a standard deviation of 3 days,[27] and requiring statistical power of 80% and setting alpha at 5%. Incorporating an allowance for an anticipated 15% loss to follow-up (eg, deaths, refusal to continue participation in the study and hospital transfer),[27] resulted in a required sample size of 156 patients (52 per group).

All analyses were performed by a researcher who was not involved in the study participants' assessments and interventions. Statistical analysis was performed following the intent-to-treat principle.[9] The Kruskal-Wallis ANOVA was used to test the continuous variables, namely: FVC, FEV_1, SpO_2, treatment costs and treatment tolerability, which were not normally distributed. Pairwise chi-squared tests were applied to the categorical variables (pulmonary complications, adverse events and antibiotic use), with between-group comparisons reported as absolute risk reduction (95% CI). Kaplan-Meier survival analysis was used to test the time variables (duration of thoracic drainage and length of hospital stay). A significance level of 5% ($p < 0.05$) was adopted for all statistical analyses.

Results

Flow of participants, therapists, centres through the study

Four hundred and sixty-eight patients were referred for evaluation and selected for possible inclusion in this study. Of these, 309 were ineligible and three refused to participate, so 156 patients were included in the study. Figure 1 presents the flowchart of enrolment and monitoring of the research participants. Although the study allowed for an anticipated 15% loss to follow-up based on existing research,[28] a 2% loss to follow-up occurred, with two deaths and one unauthorised hospital discharge.

Compliance with the study protocol

No ineligible participants were randomised. All participants commenced on the correctly designated intervention. Treatment was interrupted in three patients who presented clinical complications unrelated to the proposed intervention (hypovolaemia and cardiac arrhythmia). No assessors were accidentally unblinded during the study. Assessors guessed group allocations correctly 17% of the time, which was less than the 33% predicted by chance alone; this suggests that blinding was well preserved.

Baseline characteristics of the participants

At baseline, all groups were similar with respect to the anthropometric and demographic characteristics, as well as to pulmonary function, SpO_2 and the variables related to thoracic drainage (Table 1).

Effect of the intervention

Duration of thoracic drainage

The total drainage time ranged from 2 to 37 days: 2 to 19 days in the Exp2 group, 2 to 37 days in the Exp1 group and 2 to 16 days in the Con group. In the Exp2 group, drainage duration was shorter compared with that in the other groups (Table 2). Over time, the following approximate probability values for participants remaining on thoracic drainage for 7 days were observed: 7% in the Exp2 group,

Table 1
Baseline anthropometric and demographic characteristics of the participants (n = 156).

Variables	Exp2 (n = 52)	Exp1 (n = 52)	Con (n = 52)
Gender, n male (%)	46 (88)	45 (87)	46 (88)
Age *(yr)*, median (IQR)	32 (23 to 38)	27 (23 to 34)	27 (23 to 34)
BMI *(kg/m^2)*, median (IQR)	25 (22 to 28)	25 (22 to 28)	24 (21 to 27)
Smoking, n (%)	24 (46)	27 (52)	25 (48)
FVC *(% pred)*, median (IQR)	61 (44 to 80)	57 (45 to 72)	64 (51 to 79)
FEV_1 *(% pred)*, median (IQR)	41 (30 to 64)	46 (38 to 60)	46 (39 to 57)
SpO_2 *(%)*, median (IQR)	97 (96 to 98)	97 (95 to 98)	97 (95 to 98)
Cause of pleural effusion, n (%)			
trauma	48 (92)	50 (96)	48 (92)
pneumonia	2 (4)	1 (2)	3 (6)
neoplasia	2 (4)	1 (2)	1 (2)
Type of drainage used, n (%)			
unilateral	50 (96)	50 (96)	50 (96)
bilateral	2 (4)	2 (4)	2 (4)
Pain scale *(0 to 10)*, median (IQR)	6 (5 to 8)	7.5 (5 to 9)	7 (5 to 8)

BMI = body mass index, Con = control group (usual care plus sham positive pressure), Exp1 = experimental group 1 (usual care plus mobilisation, respiratory interventions and sham positive pressure), Exp2 = experimental group 2 (usual care plus mobilisation, respiratory interventions and positive pressure), FEV_1 = forced expiratory volume in 1 second, FVC = forced vital capacity, SpO_2 = peripheral oxygen saturation, % pred = percentage predicted.

Table 2
Median (IQR) of each group, pairwise differences in ranks, and statistical significance of the pairwise comparisons.

Outcome	Groups			Difference in ranks (p value)		
	Exp2 (n = 51)	Exp1 (n = 52)	Con (n = 49)	Exp2 versus Con	Exp2 versus Exp1	Exp1 versus Con
Duration of drainage (*d*)	4 (3 to 4)	4 (3 to 6)	5 (3.5 to 7)	32.25 (< 0.05)	23.59 (< 0.05)	8.66 (> 0.05)
Length of hospital stay (*d*)	4 (3 to 4)	5 (3 to 7)	6 (4 to 9.5)	35.89 (< 0.05)	24.36 (< 0.05)	11.52 (> 0.05)
Treatment cost (*R$*)	2671.41 (2021.41 to 3321.41)	3933.96 (2680.00 to 6528.21)	4067.45 (2440.47 to 6537.69)	24.33 (< 0.05)	32.64 (< 0.05)	8.32 (> 0.05)

Con = control group (usual care plus sham positive pressure), Exp1 = experimental group 1 (usual care plus mobilisation and respiratory interventions and sham positive pressure), Exp2 = experimental group 2 (usual care plus mobilisation and respiratory interventions and sham positive pressure), R$ = Brazilian real.

17% in the Exp1 group and 21% in the Con group; these probabilities were maintained up to 16 days (Figure 2).

Length of hospital stay

The total length of hospital stay varied from 2 to 46 days, and it was also shorter in the Exp2 group when compared with the other groups (Table 2). Over time, the approximate probabilities for participants remaining hospitalised for 7 days were as follows: 9% in the Exp2 group, 23% in the Exp1 group and 31% in the Con group; these probabilities were maintained up to 33 days (Figure 3).

Treatment costs

The estimates of costs ranged from R$1,000.00 to R$29,980.00 per participant during hospital stay. Comparison between groups showed that the Exp2 group presented a significantly lower cost compared with the other groups (Table 2).

Pulmonary function and oximetry

These outcomes tended to improve in all groups from baseline until Day 8 (Table 3). The interventions compared in this study did not have clear differences in their effects on pulmonary function and oximetry.

Tolerability

No inability to tolerate the positive airway pressure was noted in any participants, so there was 100% adherence during each participant's period of participation in the trial. Discomfort reported by the patients was also similar between groups (Table 3).

Pulmonary complications

Pulmonary complications were less common in the Exp2 group compared with the Con group (absolute risk reduction (ARR) 0.18, 95% CI 0.06 to 0.31) and compared with the Exp1 group (ARR 0.16, 95% CI 0.04 to 0.28). This effect seemed to arise mainly through a reduction in pneumonia. Pneumonia was less common in the Exp2 group compared with the Con group (ARR 0.20, 95% CI 0.09 to 0.32) and compared with the Exp1 group (ARR 0.16, 95% CI 0.05 to 0.28). No difference was found in the rates of atelectasis and hypoxaemia between groups (Table 4).

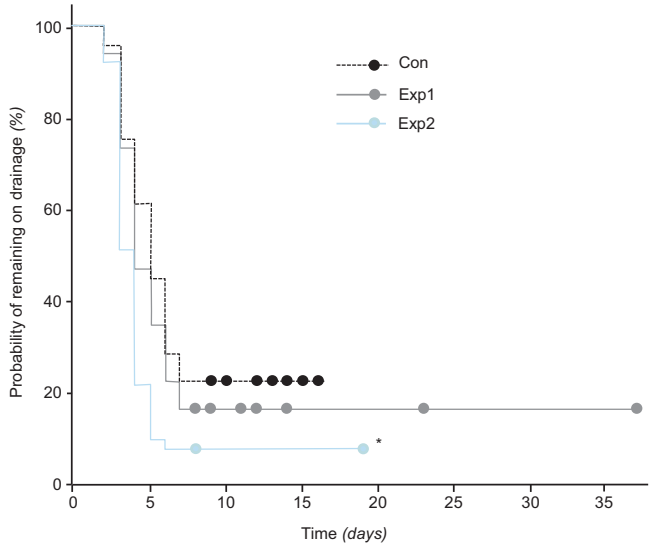

Figure 2. Kaplan-Meier curve for duration of thoracic drainage.
*$p < 0.001$.

Use of antibiotics

The Exp2 group presented less need for antibiotic use compared with the Con and Exp1 groups (Table 4). The ARRs were 0.35 (95% CI 0.17 to 0.51) and 0.25 (95% CI 0.08 to 0.41), respectively.

Adverse events

All groups showed similar rates of air leaks and aerophagia (Table 4). Individual participant data are available in Table 5 on the eAddenda.

Discussion

The results show that the combination of intermittent CPAP of 15 cmH_2O and mobilisation and respiratory care reduces the duration of chest drainage, the length of hospital stay, pulmonary complications, use of antibiotics, and treatment costs. In addition, the use of CPAP of 15 cmH_2O did not produce a higher rate of adverse events or lower tolerability compared with CPAP of 4 cmH_2O (without therapeutic effect). Despite its other beneficial effects, the addition of CPAP had no clear effect on lung function recovery and oxygenation.

This study also showed that CPAP of 15 cmH_2O added to mobilisation and respiratory physiotherapy interventions (Exp2) was more effective than mobilisation and respiratory physiotherapy alone (Exp1). The benefits were observed on the same outcomes (duration of chest drainage, the length of hospital stay, pulmonary complications, use of antibiotics, and treatment costs) and had a similar magnitude as in the comparison against the Con group. This suggests that the intermittent CPAP was mainly driving the observed benefit.

It is important to gauge whether these benefits are large enough to be clinically worthwhile. Even without well-established estimates of the smallest worthwhile effect for these comparisons, it seems reasonable to conclude that most of the estimates have confidence intervals that include both trivial and worthwhile effects. For example, the estimates of the reductions in complications generally and in pneumonia specifically all have confidence intervals around the ARRs that span from < 10% to around 30%. The reduction in risk of requiring antibiotics is stronger (ARR 0.35, 95% CI 0.17 to 0.51), so this is arguably a clinically worthwhile benefit in its own right. The clinical utility of the estimated effect on treatment cost is more difficult to interpret because the data were analysed with a test for non-parametric data. However, the difference in medians of R$1,396 between the Exp2 and Con groups is reassuring, given the other clinical benefits obtained.

Previous studies conducted on participants having open lung resection have shown divergent results from those of this research. Danner et al[29] evaluated 21 participants divided into two groups: one group received non-invasive ventilation (NIV) with an inspiratory positive airway pressure of 16 cmH_2O, whereas the other group underwent conventional respiratory physiotherapy without NIV. The authors found no between-group difference for duration of chest tube drainage. Similarly, Garutti et al[28] and Perrin et al[12] assessed the use

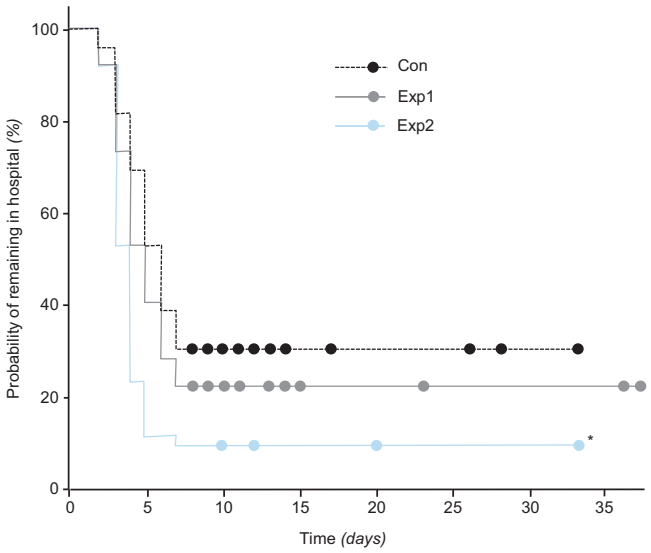

Figure 3. Kaplan-Meier curve for length of hospital stay.
*$p < 0.001$.

of NIV with lower inspiratory positive airway pressures (7 to 12 cmH_2O) for surgical patients. They also observed no difference in duration of chest drainage between intervention and control (conventional treatment) groups. Perhaps the difference detected in the present trial occurred due to the combination of two factors: the absence of surgical trauma and the use of CPAP at high pressure. We believe that respiratory physiotherapy interventions, which included airway clearance techniques and mobilisation, in addition to pulmonary expansion help patients recover more quickly and stay more active during their hospital stay. This increased activity along with the use of CPAP can accelerate the elimination of excess pleural fluid, with consequent faster resolution of pleural fluid collection and shorter duration of chest drainage.

Reduced duration of chest drainage associated with a lower rate of pneumonia in the Exp2 group presumably contributed to the 2-day reduction in the length of hospital stay. A randomised trial[30] conducted with surgical patients also showed shorter length of hospital stay for patients receiving CPAP of 10 cmH_2O when compared with conventional respiratory care. In contrast, a systematic review showed that non-invasive ventilation did not reduce the length of hospital stay in surgical patients with cancer.[15] This difference is most likely associated with the severity of clinical conditions of cancer patients. The shorter length of hospital stay and duration that antibiotics were used resulted in a reduction in the estimated treatment costs.

In the Exp2 group, despite the need to purchase positive pressure equipment and accessories and for physiotherapy assistance three times a day, costs were reduced compared with those in the Con group. This finding is consistent with evidence that adequate application of positive airway pressure seems to present good cost-effectiveness in some clinical situations, such as the postoperative period of thoracic surgeries,[14] although further evidence about cost-effectiveness is needed.[31] Although more robust evidence is still required, the results of the current study indicate that investing in positive pressure equipment and hiring physiotherapists can actually reduce costs instead of increasing them.

The current results show that the addition of CPAP at 15 cmH_2O reduced the rate of pneumonia and, consequently, the use of antibiotics in non-surgical patients with drained pleural effusions. Zarbock et al[32] evaluated 468 surgical patients randomly allocated into two groups; patients who received CPAP of 10 cmH_2O had a lower rate of pneumonia compared with a no-intervention control group. A Cochrane review[15] found no studies that have tested the efficacy of non-invasive positive airway pressure in the prevention of complications after lung resection and evaluated the use of antibiotics. One recent study of patients undergoing myocardial revascularisation showed no difference in antibiotic use between patients who received and those who did not receive postoperative non-invasive ventilation.[33] The current results revive this important aspect in the treatment of patients with chest drainage and reinforce the need for further studies assessing this outcome. It is believed that optimised pulmonary expansion through positive pressure facilitates blood perfusion[34] with possible transport of immune cells facilitating pulmonary defence.[22]

Despite the effectiveness of the interventions provided to the Exp2 group in this study, patient comfort and adherence to treatment are also important aspects to be considered. In this study, patients in all groups reported similar levels of satisfaction and tolerable discomfort in response to the use of CPAP of 4 and 15 cmH_2O. Possibly, factors like the use of a padded silicone oronasal mask as the interface and intermittent application facilitated good tolerance even at the higher pressure of 15 cmH_2O. In agreement with these results, Stéphan et al assessed tolerability by means of a comfort score in 830 patients, with half of them receiving non-invasive ventilation, and found that 17% reported slight, 29% acceptable and 53% good comfort, with no difference observed when compared with patients only using nasal highflow oxygen.[35] In another study conducted on 66 patients undergoing non-invasive ventilation, the rate of intolerability to treatment was 3.5%.[36]

Regarding adverse events, the rates of air leaks and aerophagia were similar in all groups in the current study. Liao et al[37] compared surgical patients who received NIV of 10 cmH_2O with patients who underwent usual care, and also found similar rates of air leaks in both groups: 17% versus 11%, respectively. In another trial of patients who underwent lung resection and then random allocation of CPAP of 8.5 cmH_2O, no occurrence of air leaks was observed.[36] Therefore, all of

Table 3
Change scores for pulmonary function and peripheral oxygen saturation, and final scores for discomfort and satisfaction. Median (IQR) for groups and the statistical significance of the Kruskal-Wallis ANOVA.

Outcome	Groups			*p* value
	Exp2 (n = 51)	Exp1 (n = 51)	Con (n = 49)	
FEV_1 *(% pred)*, median (IQR)	15 (3 to 28)	6 (−2 to 17)	9 (−2 to 17)	0.23
FVC *(% pred)*, median (IQR)	14 (5 to 33)	−2 (−16 to 9)	−6 (−27 to 8)	0.34
SpO_2 *(%)*, median (IQR)	0.0 (−1.0 to 1.0)	0.0 (−1.0 to 2.0)	1.0[b] (0.0 to 2.0)	0.77
Discomfort *(0 to 10)*, median (IQR)	6.5[a] (3.8 to 8.0)	7.0[a] (4.0 to 8.0)	6.0 (4.0 to 7.5)	0.37
Satisfaction *(0 to 10)*, median (IQR)	10.0[a] (10.0 to 10.0)	10.0[a] (9.0 to 10.0)	10.0 (9.0 to 10.0)	0.11

Con = control group (usual care plus sham positive pressure), Exp1 = experimental group 1 (usual care plus mobilisation and respiratory interventions and sham positive pressure), Exp2 = experimental group 2 (usual care plus mobilisation and respiratory interventions and positive pressure), FEV_1 = forced expiratory volume in 1 second, FVC = forced vital capacity, SpO_2 = peripheral oxygen saturation.
[a] n = 50
[b] n = 51

Table 4
Number (%) of complications, lung entrapment, thoracotomy, antibiotic use and adverse events, and absolute risk reduction (95% CI) for pairwise comparisons.

Outcome	Groups			Absolute risk reduction (95% CI)		
	Exp2 (n = 51)	Exp1 (n = 51)	Con (n = 49)	Exp2 relative to Con	Exp2 relative to Exp1	Exp1 relative to Con
Complications, n (%)	1 (2)	9 (18)	10 (20)	0.18 (0.06 to 0.31)	0.16 (0.04 to 0.28)	0.02 (−0.13 to 0.17)
pneumonia, n (%)	0 (0)	8 (16)	10 (20)	0.20 (0.09 to 0.32)	0.16 (0.05 to 0.28)	0.04 (−0.11 to 0.19)
atelectasis, n (%)	1 (2)	2 (4)	0 (0)	−0.02 (−0.10 to 0.05)	0.02 (−0.07 to 0.11)	−0.04 (−0.13 to 0.04)
hypoxaemia, n (%)	0 (0)	0 (0)	0 (0)	0.00 (−0.07 to 0.07)	0.00 (−0.07 to 0.07)	0.00 (−0.07 to 0.07)
Lung entrapment, n (%)	3 (6)	7 (14)	8 (16)	0.10 (−0.04 to 0.23)	0.08 (−0.04 to 0.20)	0.02 (−0.12 to 0.16)
Thoracotomy, n (%)	3 (6)	5 (10)	7 (14)	0.08 (−0.04 to 0.20)	0.04 (−0.08 to 0.16)	0.04 (−0.09 to 0.17)
Antibiotic use, n (%)	9 (18)	22 (43)	27 (55)	0.35 (0.17 to 0.51)	0.25 (0.08 to 0.41)	0.10 (−0.09 to 0.28)
Adverse events, n (%)	5 (10)	1 (2)	3 (6)[a]	−0.04 (−0.16 to 0.08)	−0.08 (−0.19 to 0.22)	0.04 (−0.05 to 0.14)

Con = control group (usual care plus sham positive pressure), Exp1 = experimental group 1 (usual care plus mobilisation and respiratory interventions and sham positive pressure), Exp2 = experimental group 2 (usual care plus mobilisation and respiratory interventions and sham positive pressure).
[a] n = 50

these results show that, unlike what many professionals fear in clinical practice, this type of intervention is safe and well tolerated by patients, even with a pressure of 15 cmH_2O.

Despite the benefits observed in this study, the groups did not markedly differ in pulmonary function recovery and oxygenation. Most likely, the performance of patients during spirometry was influenced by the high level of pain. Furthermore, SpO_2 was never outside the normal range.

The present study had some limitations. Most participants required their intercostal drains because of thoracic trauma, so the results may be more generalisable to haemorrhagic pleural effusions and haemothoraces rather than other pleural effusions. However, the high adherence of participants to the protocol and the good effect of adding CPAP of 15 cmH_2O to more traditional respiratory interventions may indicate that the treatment can be effective in various types of pleural fluid collection. Another limitation concerns the estimation of treatment costs, which was not performed by individualised cost-effectiveness analysis. The estimates were determined by the cost of each procedure and based on a chart provided by the hospital. The hospitalisation cost is estimated by the intervention costs added to the length of hospital stay, but the amount paid to the hospital is the same between 2 and 10 days of hospitalisation.[38] Data on the size of the drainage tubes were not recorded but it is assumed that randomisation would have produced similar distributions in the three groups.

In conclusion, the results of this study indicate that non-invasive positive airway pressure of 15 cmH_2O added to mobilisation and respiratory care for patients with a collection of fluid in the pleural space reduces the duration of chest drainage, length of hospital stay, pulmonary complications, use of antibiotics and treatment costs. This type of intervention showed good tolerability by the patients and a low rate of adverse events; therefore, it can be safely integrated into clinical practice.

What was already known on this topic: Fluid and/or blood can accumulate in the pleural space due to a range of conditions. An intercostal tube attached to a closed drainage system is often used to drain the pleural space. The existing evidence is unclear about whether positive airway pressure applied non-invasively at the mouth assists resolution of the fluid collection.
What this study adds: In patients with a chest tube drainage system in situ, bouts of continuous positive airway pressure via a face mask combined with mobilisation and respiratory techniques decreases the duration of thoracic drainage, length of hospital stay, pulmonary complications, antibiotic use and treatment costs. This intervention was well tolerated with few adverse events, so it can be safely integrated into clinical practice.

Footnotes: [a] Müller, Engemed, Brazil. [b] Respiron, NCS, Mexico. [c] Shaker, NCS, Mexico.

eAddenda: Table 5 can be found online at https://doi.org/10.1016/j.jphys.2019.11.006.

Ethics approval: This project was approved by the Research Ethics Committee of the Universidade Cidade de São Paulo (process number 793.133). All participants gave written informed consent before data collection began.

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Correspondence: Adriana Cláudia Lunardi, Master's and Doctoral Programs in Physical Therapy, Universidade Cidade de São Paulo, São Paulo, Brazil. Email: adriana.lunardi@unicid.edu.br

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