Comparison of gas exchange after lung resection with a Boussignac CPAP or Venturi mask

I. Garutti1*, L. Puente-Maestu2, J. Laso1, R. Sevilla1, A. Ferrando1, I. Frias1, A. Reyes1, E. Ojeda2 and F. González-Aragoneses3

1 Department of Anaesthesia and Postoperative Care
2 Department of Pneumology and 3 Department of Thoracic Surgery, Hospital General Universitario Gregorio Marañón, Dr. Esquerdo 56, Madrid 28007, Spain
*
Corresponding author. E-mail: ngaruttimartinez@yahoo.es

Background. Postoperative pulmonary complications are common after lung resection surgery. In this study, the use of continuous positive airway pressure (CPAP) for 6 h after surgery improved oxygenation at 24 h. However, postoperative CPAP had no effect on clinical outcomes. The optimum duration of CPAP after lung resection remains unclear.

Methods. The study population comprised 110 patients undergoing LRS. On arrival in the postanaesthesia care unit (PACU), patients were randomized to receive CPAP at 5–7 cm H2O during the first 6 h after surgery (CPAP group) or supplemental oxygen through a Venturi mask (Venturi group). The PaO2/FIO2 ratio was measured on arrival in the PACU, 7 h after admission, and the day after surgery. The PaO2/FIO2 ratio is the primary endpoint of our study. We also analysed the chest radiograph and assessed the postoperative course. We then analysed the impact of ventilatory management in the PACU depending on the respiratory risk of the patient.

Results. Baseline characteristics were similar in both groups. Patients who received CPAP had significantly higher PaO2/FIO2 at 24 h after surgery compared with patients managed conventionally (Venturi group) (48.6 ± 14 vs 42.3 ± 12, P = 0.031), but there were no differences at 7 h. On subgroup analysis, we found that the benefits of CPAP were greater in higher risk patients. The incidence of postoperative pulmonary complications and stay in the PACU and hospital were similar in both groups.

Conclusions. In patients undergoing LRS, prophylactic CPAP during the first 6 h after surgery with a pressure of 5–7 cm H2O improved the PaO2/FIO2 ratio at 24 h. This effect was more evident in patients with increased risk of postoperative pulmonary complications.

Keywords: continuous positive airway pressure; gas exchange; lung resection surgery

The incidence of postoperative pulmonary complications (PPCs) after lung resection surgery (LRS) is high, because of procedure- and patient-related factors. In recent years, the role of atelectasis in postoperative respiratory dysfunction has been recognized. Decreased lung compliance and functional residual capacity (FRC) is manifest clinically by impaired gas exchange, the development of pneumonia or acute lung injury in some cases.

The immediate postoperative period is considered a key period in the treatment or prophylaxis of atelectasis, because the residual effects of anaesthesia combined with reduced muscle strength prevents deep inspiration and expansion of collapsed alveolar units. Therefore, the lung recruitment manoeuvres proposed to prevent or treat atelectasis, include taking deep breaths (sighs), incentive spirometry, chest physiotherapy, and non-invasive ventilation (NIV). Furthermore, atelectasis may predispose a patient to pneumonia. Although lung recruitment manoeuvres are not universally considered useful, they are considered to be helpful for patients at increased risk of developing PPC.

Several studies have investigated the usefulness of NIV in the prevention of PPC after thoracic surgery, although most were carried out with mechanical ventilators using biphasic positive airway pressure (BiPAP). Continuous positive airway pressure (CPAP) is a simple way to provide continuous positive pressure in the airway throughout the respiratory cycle without the use of complex equipment, which is usually available only in intensive care units (ICUs). The application of CPAP after surgery can help open collapsed alveolar units, prevent alveolar closure or both, thus increasing postoperative FRC and forced vital capacity, and is associated with decreased respiratory workload and improved gas exchange.
Although CPAP appears to be more effective than routine chest physiotherapy,\textsuperscript{18} its benefits have not been clearly demonstrated. CPAP is widely accepted for the management of patients with respiratory failure, but there are few data on its use to prevent PCC after LRS.

The aims of our study were to assess the effect of prophylactic CPAP on the $P_{aO_2}/F_{IO_2}$ ratio on the day after surgery in patients undergoing LRS and to identify those patients in whom its preventive effect is greatest.

**Methods**

**Patients and ethics**

This study was approved by the Clinical Research Ethics Committee of Hospital General Universitario Gregorio Marañón. All patients signed an informed consent detailing the content of our research. The study was performed following the principles of the Declaration of Helsinki.

We included 110 consecutive patients undergoing pulmonary resection by lateral thoracotomy between April 2011 and May 2012. The primary outcome of the study was the $P_{aO_2}/F_{IO_2}$ ratio the morning after surgery. The exclusion criteria were: a diagnosis of obstructive sleep apnoea syndrome or any other process that required non-invasive mechanical ventilation before surgery, important bullous emphysema detected on preoperative computed tomography, bronchopleural fistula suspected on admission to the post-anesthesia care unit (PACU), facial problems, a history of intolerance to CPAP, acidosis or respiratory rate $>120$, or respiratory rate $<8$ or $>25$ rpm. All patients underwent spirometry and a CO diffusion test (Masterscreen-PFT, Viasys, Hocheberg, Germany) as part of routine preoperative evaluation.

In the PACU, we continuously measured heart rate (HR), arterial blood pressure (BP) from the radial artery, and $Sp_{O_2}$. Blood gases were determined on arrival at the PACU, 7 h later, and 24 h later via a sample of arterial blood taken through a radial artery catheter. The $Fi_{O_2}$ used at that time was recorded. The sample was analysed using GEM 4000 (Instrumentation Laboratory, Lexington, MA, USA). $Fi_{O_2}$ during use of the Venturi mask was determined according to the manufacturer’s recommendations and set using the rotating attachment. We used a flow rate of 6 litre min$^{-1}$ for $Fi_{O_2}$ values $<35\%$ and 12 litre min$^{-1}$ for $Fi_{O_2}$ values between 35 and 50%. In the CPAP group, we used a flow rate (air and oxygen) to reach a pressure of 5–7 cm H$_2$O, and $Fi_{O_2}$ was calculated based on the ratio of litres delivered by the air flow meter and oxygen according to the formula: litres of oxygen + (litres of air $\times$ 0.21)/total amount of litres provided by both flow meters.

The criteria for discharge from the PACU were haemodynamic stability, $Sp_{O_2} > 90\%$ with $Fi_{O_2} < 0.4$, absence of clinical signs of respiratory distress, full consciousness, and sufficient diuresis ($> 0.3$ ml kg h$^{-1}$). Patients were discharged to the ward the following morning by the attending physician of the PACU, who had not dealt with the patient the day before and therefore did not know to which group the patient had been assigned.

The criteria for readmission to the PACU were those commonly used in our institution, namely decreased level of consciousness, haemodynamic instability (SBP $< 90$ mm Hg or HR $< 40$ bpm or $> 120$ bpm), or respiratory problems (breathing rate $< 8$ or $> 25$ rpm, $Sp_{O_2} < 90\%$ with $Fi_{O_2} > 0.5$). The indication for reintubation was consistent with the usual criteria for this unit ($P_{aO_2} < 8$ kPa or $Sp_{O_2} < 90\%$ with $Fi_{O_2} > 0.5$ or respiratory acidosis or respiratory rate $> 25$ bpm). All patients underwent at least three chest radiographs: one on admission to the PACU, another 24 h later, and a third at discharge. Depending
on the clinical course, further radiographs were ordered by thoracic surgeons when considered appropriate for management during postoperative hospital stay. All chest radiographs ordered during the postoperative period were evaluated by a single pulmonologist, who was unaware of the postoperative clinical course and of the treatment group to which the patient had been assigned. The thoracic surgeons in charge of evaluating the postoperative course were also blind to the group.

**Secondary outcome variables**

The incidence of atelectasis, pneumonia or both was recorded as a secondary variable. Atelectasis was evaluated using the scale of Wisconsin. Pneumonia was diagnosed based on the criteria of Garner and colleagues. The remaining variables studied were the presence of a persistent air leak, reintubation, and readmission to the ICU after being discharged to the ward, and durations of PACU and hospital stay.

**Respiratory risk stratification**

All patients were assessed based on the respiratory risk classification of Arozullah and colleagues, as follows: general anaesthesia = 4 points; thoracic surgery = 14 points; age > 80 yr = 17 points, 70–79 yr = 13 points, 60–69 yr = 9 points, and 50–59 yr = 4 points; history of chronic obstructive pulmonary disease = 5 points; history of cerebrovascular accident = 4 points; blood urea nitrogen concentration < 8 mg dl\(^{-1}\) = 4 points, 22–30 mg dl\(^{-1}\) = 2 points, and > 30 mg dl\(^{-1}\) = 3 points; corticosteroid use for chronic condition = 3 points; current smoker (last year) = 3 points; alcohol intake (2 drinks day\(^{-1}\) in past 2 weeks) = 2 points. We then applied a modified stratification of risk according to Arozullah and colleagues by joining patients from group class 1 and 2 who had < 25 points (if only general anaesthesia plus thoracic surgery, add 18 points), whom we classified as ‘low-risk’. Patients with 26–40 points were classed as ‘intermediate risk’, and patients with ≥ 41 points (group class 4 and 5 in the Arozullah classification) were classed as ‘high-risk’.

**Statistical analysis**

The study was designed to include 110 patients to demonstrate a difference of more than 6 points in the \(\frac{P_{a}O_{2}/F_{I}O_{2}}{\text{ratio}}\) the morning after surgery between the two groups with a 5% risk of type I error and power of 80% and an expected population standard deviation of 11 points derived from previous measurements in our PACU. Because values were normally distributed, the results are expressed as mean (SD). We also performed a multiple comparison test by repeated-measures ANOVA. Continuous variables were compared using an unpaired \(t\)-test. Categorical variables were compared using the \(\chi^2\) test, or the Fisher’s exact test if the value of any cell was < 5. Statistical significance was set at \(P<0.05\). The statistical analysis was performed using SPSS statistical software (version 15.0, Hispanoportuguesa SPSS, Madrid, Spain).

**Results**

Fifty-five patients were included in each group (Fig. 1). No differences were found between the patients in preoperative characteristics or between the groups in average duration of surgery, unilateral ventilation time, type of surgical resection, or side of surgery (Table 1).

All patients included in the study were extubated in the operating theatre at the end of the intervention. Arterial blood gases and the haemodynamic variables analysed (HR and BP) showed no significant differences within 15 min after admission to the PACU or within 7 h (in the CPAP group immediately after CPAP was removed). However, the day after surgery, patients in the CPAP group showed a significantly higher \(\frac{P_{a}O_{2}/F_{I}O_{2}}{\text{index}}\) than those in the Venturi group (\(P=0.031\)) (Table 2).

Two patients in the CPAP group refused treatment in the first half hour of application of the mask: one because of the sensation of suffocation and the other because of pain in the area where the mask made contact with the skin of the face. These symptoms disappeared immediately after application of the Venturi mask.

No significant differences were observed between the groups in postoperative complications (Table 3). Chest radiographs revealed no differences between the groups. Postoperative course was similar in both groups. Only three of the treated patients (2.6%) required readmission to the ICU. In two cases, this was because of surgical problems (bronchopleural fistula and prolonged air leak, one in each group); in
the other, the patient (CPAP group) was readmitted to the ICU for acute lung injury and died of multiorgan failure a week later.

When we stratified patients based on respiratory risk score, we noted that in those with a lower risk, the use of CPAP did not improve $P_{aO2}/F_{IO2}$ at 24 h compared with those of the Venturi group. On the contrary, in the other two groups (intermediate or high respiratory risk), we observed a significant improvement in gas exchange in patients from the CPAP group compared with those of the Venturi group (Fig. 2). In accordance with the Arozullah classification, patients with a significantly lower respiratory risk had a significantly lower incidence of pneumonia/atelectasis than patients in the intermediate and high-risk groups ($P = 0.05$). However, we did not detect significant differences between the CPAP or Venturi groups in the incidence of pneumonia/atelectasis for each degree respiratory risk.

**Discussion**

We found that prophylactic postoperative CPAP administered to patients with a Boussignac mask (5–7 cm H$_2$O) during the first 6 h after LRS improved gas exchange at 24 h compared with patients receiving oxygen therapy via a Venturi mask.

Given the high incidence of atelectasis caused by the anesthetic technique (a collapsed lung for longer than 1 h and the other under compression by the pressure of the abdominal viscera, mediastinum, and rollers) in patients undergoing LRS and the special characteristics of these patients (high prevalence of smokers and chronic obstructive pulmonary disease [COPD]), prophylactic measures to reduce PPCs have been proposed. Continuous application of air pressure improves FRC and prevents airway collapse, thus reducing respiratory effort. CPAP has been used successfully in two studies for the treatment of respiratory failure in both surgical and non-surgical patients. However, the authors of these studies do not clarify the role of CPAP in the postoperative prophylaxis of PPCs. In patients undergoing bariatric surgery, the beneficial

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**Table 1** Preoperative data and intraoperative data. Data are expressed as mean (SD) or [range]. Preop., Preoperative; FEV1, forced expired volume in the first second; FVC, forced vital capacity; OLV, one-lung ventilation; S, segmentectomy; L, lobectomy; P, pneumonectomy; R, right; L, left

<table>
<thead>
<tr>
<th>Group</th>
<th>CPAP (n = 55)</th>
<th>Venturi (n = 55)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>62.1 [19–85]</td>
<td>63.1 [32–88]</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.7 (15)</td>
<td>70.3 (15)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.5 (9)</td>
<td>165.1 (8)</td>
</tr>
<tr>
<td>pH preop.</td>
<td>7.44 (0.04)</td>
<td>7.44 (0.05)</td>
</tr>
<tr>
<td>$P_{aO2}$ preop. (kPa)</td>
<td>10.1 (2)</td>
<td>10.2 (2)</td>
</tr>
<tr>
<td>$P_{aCO2}$ preop. (kPa)</td>
<td>4.8 (0.5)</td>
<td>4.8 (1)</td>
</tr>
<tr>
<td>$SaO2$ preop. (%)</td>
<td>95.6 (2)</td>
<td>96.2 (2)</td>
</tr>
<tr>
<td>FEV1 predicted (%)</td>
<td>92.2 (23)</td>
<td>95.5 (23)</td>
</tr>
<tr>
<td>FVC predicted (%)</td>
<td>100.8 (19)</td>
<td>107.0 (23)</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>70.2 (13)</td>
<td>71.5 (11)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>35/20</td>
<td>30/25</td>
</tr>
<tr>
<td>ASA grade (I/II/III/IV)</td>
<td>4/30/21/0</td>
<td>3/35/16/1</td>
</tr>
<tr>
<td>Surgery length (min)</td>
<td>237 (86)</td>
<td>238.7 (76)</td>
</tr>
<tr>
<td>OLV length (min)</td>
<td>147.1 (69)</td>
<td>152 (69)</td>
</tr>
<tr>
<td>Type of surgery (S/L/P)</td>
<td>21/32/2</td>
<td>25/25/5</td>
</tr>
<tr>
<td>Side of surgery (R/L)</td>
<td>28/27</td>
<td>31/24</td>
</tr>
</tbody>
</table>

**Table 2** Arterial oxygenation, $F_{IO2}$, and $P_{aO2}/F_{IO2}$ ratio during the first 24 h after surgery. Data are expressed as mean (SD). PACU, postoperative care unit. $^*P=0.031$; $^†P=0.012$

<table>
<thead>
<tr>
<th>Group</th>
<th>PACU</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 min</td>
<td>7 h</td>
</tr>
<tr>
<td>$P_{aO2}$ (kPa)</td>
<td>CPAP 13.1 (4)</td>
<td>15.0 (5.1)</td>
</tr>
<tr>
<td></td>
<td>Venturi 13.9 (4.6)</td>
<td>13.8 (3.4)</td>
</tr>
<tr>
<td>$F_{IO2}$</td>
<td>CPAP 0.34 (0.07)</td>
<td>0.33 (0.06)</td>
</tr>
<tr>
<td></td>
<td>Venturi 0.34 (0.08)</td>
<td>0.31 (0.05)</td>
</tr>
<tr>
<td>$P_{aO2}/F_{IO2}$ (kPa)</td>
<td>CPAP 39.4 (12)</td>
<td>46.4 (13)</td>
</tr>
<tr>
<td></td>
<td>Venturi 40.5 (11)</td>
<td>45.5 (14)</td>
</tr>
</tbody>
</table>

**Table 3** Postoperative course. Data are expressed as mean (SD) or number of events. ICU, intensive care unit

<table>
<thead>
<tr>
<th>Group</th>
<th>CPAP (n = 53)</th>
<th>Venturi (n = 55)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length postoperative (days)</td>
<td>8 (4)</td>
<td>7.6 (3)</td>
</tr>
<tr>
<td>Length drainages (days)</td>
<td>5.7 (6)</td>
<td>3.6 (3)</td>
</tr>
<tr>
<td>Readmission ICU</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Infection wound</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Cardiac complications</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Fibrobronchoscopy</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Atelectasis Rx</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Death 30 days</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fig 2** $P_{aO2}/F_{IO2}$ at 24 h after surgery and respiratory risk group. Data are expressed as mean (SD).
effects observed were probably because of the ability of CPAP to prevent collapse of the upper airway, which would add to the potential effects on the lower respiratory tract.\textsuperscript{27–29} Although both CPAP and BiPAP are considered methods of lung expansion, the advantage offered by CPAP is its ease of use, and that it can be used in parts of the hospital other than the ICU. The prophylactic use of CPAP in patients undergoing LRS has received little attention. Many previous studies on the prophylactic effect of NIV in LRS were performed with BiPAP\textsuperscript{14–16} and generally showed good results in terms of improved lung function and decreased PPCs; however, most studies either had small samples or were not prospective randomized or controlled trials.

Stock and colleagues studied the effect of prophylactic CPAP on an uninterrupted postoperative period of 4 h in nine patients undergoing sternotomy and observed a temporary improvement in FRC that lasted <10 min after the withdrawal of CPAP.\textsuperscript{30} Another study, also in a small sample (30 patients), compared the effects of CPAP on the control group in LRS, and, although no differences were detected between the groups, an improvement in arterial oxygenation and FVC was observed between the first and seventh days after surgery only in the CPAP group.\textsuperscript{31} In our study, we observed that the effects on gas exchange were evident the morning after surgery in the CPAP group compared with patients in the Venturi group.

No differences were observed between the groups at 7 h after surgery, possibly because of a methodological error: in the CPAP group, the blood gas analysis was stopped at the end of CPAP, and we calculated FIO\(_2\) based on the proportion of air and oxygen flow. However, FIO\(_2\) could be overestimated when the patient has both a higher breathing rate and a higher tidal volume.\textsuperscript{32} The lack of differences between the groups at 7 h could also be because of the lung effects of CPAP. Unlike high-flow systems (e.g. Venturi), CPAP decreases respiratory effort and muscle fatigue. Therefore, patients in the Venturi group may have had more respiratory muscular fatigue during the 12 h after surgery in the PACU with decreasing ventilator function, seen as a deteriorating PAO\(_2\)/FIO\(_2\). We did not find that use of CPAP was associated with better radiological assessment of patients in the Venturi group. Although chest radiography is the standard method in most hospitals for determining the presence of atelectasis and pneumonia, it is not very accurate or sensitive when assessing atelectasis (especially in bedridden patients), as detection is possible only when large areas of lung parenchyma are involved. The absence of differences between the groups may be because micro-atelectasis is poorly visible on the chest radiograph, even though this condition leads to a decrease in the PAO\(_2\)/FIO\(_2\) ratio. Moreover, the PAO\(_2\)/FIO\(_2\) ratio is one of the most commonly used laboratory tests in the assessment of the respiratory status of patients before discharge to the ward. Therefore, we thought that analysis of this ratio would be more sensitive when evaluating the effectiveness of CPAP. The higher PAO\(_2\)/FIO\(_2\) ratios observed in the CPAP group than that in the Venturi group were probably because of the existence of fewer areas affected by micro-atelectasis in the CPAP group.

Surprisingly, we found no studies evaluating the utility of prophylactic postoperative NIV based on respiratory risk. We believe that the usefulness of any manoeuvre to improve postoperative respiratory function will largely depend on the patient’s preoperative condition and respiratory risk associated with the surgical procedure. Respiratory risk attributable to surgery was similar in all our patients, although preoperative status was not. We observed that, in patients in whom CPAP was not used, the PAO\(_2\)/FIO\(_2\) ratio decreased with the increasing respiratory risk, whereas patients in the CPAP group had similar PAO\(_2\)/FIO\(_2\) values, regardless of their respiratory risk score. In other words, the CPAP use had more clinical relevance in patients with higher respiratory risk. We therefore believe that the prophylactic use of CPAP in LRS should be reserved for those patients.

There are some limitations to our study. First, our original study design was based on pressures of 5–7 cm H\(_2\)O, because higher pressures may affect surgical sutures or increase air leak, although there is insufficient evidence to determine the optimal CPAP pressure. In general, we recommend pressures of 7–10 cm H\(_2\)O.\textsuperscript{33} One study of 10 patients undergoing cardiac and thoracic surgery showed that the effect on gas exchange of a pressure of 10 cm H\(_2\)O was greater than that of a pressure of 5 cm H\(_2\)O with no haemodynamic differences.\textsuperscript{34} Another study reported that pressure of 5 cm H\(_2\)O seemed to cause little increase in pulmonary ventilation in COPD patients, although CPAP pressures (10–5 cm H\(_2\)O) increased emphysematous areas in the CT scan.\textsuperscript{35} We decided to use pressure of 5–7 cm H\(_2\)O based on previous studies in which these pressures had proved useful in the postoperative period.\textsuperscript{36–38} Therefore, we cannot rule out that the use of higher levels of CPAP may have provided different results. Moreover, in our study, it was difficult to reach pressures >5 cm H\(_2\)O with CPAP, despite using flows of up to 40–50 litre min\(^{-1}\).

Secondly, there is not enough evidence on both the duration and the optimum time to apply CPAP. Some authors have proposed applying it discontinuously several times a day and for several days after the postoperative course.\textsuperscript{33} We believe CPAP would be more useful during the first hours after surgery, because patients remain under the residual effects of anaesthesia. Consequently, cooperation with respiratory physiotherapy will be poorer than in the days after surgery. The optimum time would probably be immediately after extubation.\textsuperscript{27} When we designed the study, we sought a simple method that would allow us to apply the simplest possible lung expansion manoeuvre; therefore, we thought that transferring the patient to the PACU with CPAP, in the absence of clear evidence of greater benefits, represented an effort that would reduce the applicability of the procedure.

Thirdly, inability of patients to tolerate these devices can be a barrier to use. In order to make CPAP more tolerable, its use has been proposed for short and repeated periods (e.g. 15 min every hour). However, we believe that if we had applied it intermittently during the first 24 h, we would have probably disrupted the patient’s rest several times during the night stay in the PACU.

Finally, the sample size was chosen to detect a difference in PAO\(_2\)/FIO\(_2\) ratio >10% between groups and it may not be
clinically very relevant. However, to our knowledge, this is one of the larger studies that have investigated the prophylactic use of postoperative CPAP.

In conclusion, the prophylactic use of the Boussignac mask with CPAP of 5–7 cm H2O immediately after surgery improves the PaO2/FI02 ratio at 24 h after LRS compared with the Venturi mask, but not earlier. This effect was more evident in surgical patients who previously presented a higher risk for respiratory complications.

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**Declaration of interest**

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