

An Evaluation of the Relative Efficacy of an Open Airway, an Oxygen Reservoir and Continuous Positive Airway Pressure 5 cmH₂O on the Non-ventilated Lung

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SUMMARY

The aim of this study, during one-lung ventilation, was to evaluate if oxygenation could be improved by use of a simple oxygen reservoir or application of 5 cmH₂O continuous positive airway pressure (CPAP) to the non-ventilated lung compared with an open airway. Twenty-three patients with lung malignancy, undergoing thoracotomy requiring at least 60 minutes of one-lung ventilation before lung lobe excision, were studied. After routine induction and establishment of one-lung ventilation, the three treatments were applied in turn to the same patient in a sequence selected randomly. The first treatment was repeated as a fourth treatment and these results of the repeated treatment averaged to minimize the effect of slow changes.

Arterial oxygenation was measured by an arterial blood gas 15 minutes after the application of each treatment. Twenty patients completed the study. Mean P_aO₂ (in mmHg) was 210.3 (SD 105.5) in the "OPEN" treatment, 186.0 (SD 109.2) in the "RESERVOIR" treatment, and 240.5 (SD 116.0) in the "CPAP" treatment. This overall difference was not quite significant (P=0.058, paired ANOVA), but comparison of the pairs showed that there was a significant better oxygenation only with the CPAP compared to the reservoir treatments (t=2.52, P=0.021). While the effect on the surgical field was not apparent in most patients, in one patient surgery was impeded during CPAP. Our results show that the use of a reservoir does not give oxygenation better than an open tube, and is less effective than the use of CPAP 5 cmH₂O on the non-ventilated lung during one-lung ventilation.

Key Words: ONE-LUNG ANAESTHESIA, ONE-LUNG VENTILATION: arterial oxygenation, oxygen reservoir, CPAP

One-lung ventilation is frequently associated with impaired pulmonary oxygen exchange. This is explained by a large ventilation-perfusion mismatch which is aggravated by the lateral decubitus position, surgery (open chest), anaesthesia and paralysis.

Some patients poorly tolerate the resulting hypoxaemia. In order to improve patient oxygenation, the following techniques are used commonly^{1,2}:

- Application of a continuous positive airways pressure (CPAP) of 5 cmH₂O, CPAP 10 cmH₂O to the non-dependent lung, and/or positive end-expiratory pressure (PEEP) of 5 cmH₂O, PEEP 10 cmH₂O to the dependent ventilated lung³.

CPAP, however, may impair surgical access, particularly if it is high.

- Insufflation of oxygen at 7 l/min with or without a combination of the above^{4,5}.
- High-frequency jet ventilation⁶.

One study described the use of an oxygen reservoir to improve oxygenation. However, this technique was not evaluated against other methods⁷. Most of the systems described so far to provide CPAP are complex and vary from one institution to another⁸. The commercial system to apply CPAP to the non-dependent, non-ventilated lung (Mallinckrodt Inc. St. Louis, Missouri, U.S.A.) is expensive and may not be available in every institution. The CPAP may also sometimes make surgery on the non-ventilated lung more difficult.

This study compares the effect of a simple oxygen reservoir (easy to assemble and inexpensive), CPAP 5 cmH₂O, and an open tube on the non-ventilated lung, on the arterial oxygenation and also its effect on the surgical field.

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The oxygen reservoir consists of an anaesthetic filter (Ultipor BB25, Pall Medical Corporation, Newquay, Cornwall, U.K.) connected to the non-ventilated lung with an oxygen source delivering oxygen at 6 l/min, via the sampling line port (the proximal connection to the anaesthetic circuit being left open to air). The aim of the reservoir is to prevent inspiratory movement, such as might be caused by mediastinal shift, from entraining air into the non-ventilated lung.

Breathing system filters have already been used as oxygen delivery devices with the laryngeal mask⁹ and with the endotracheal tube during recovery¹⁰.

The minimum inspired O₂ delivered by the breathing system filters at a flow of 6 l/min to 8 l/min with these systems is about 50% to 60% for a tidal volume of 500 ml and a respiratory rate of 10 per minute¹¹. For lower tidal volumes, the percentage of oxygen from the reservoir will be greater and if the inspiratory flow is not greater than 6 l/min (100 ml/s), close to 100%. The tidal volume in the unventilated lung caused by the mediastinal shift should be small and thus the inspired oxygen high.

METHODS

The Ethics Committee of the Royal Adelaide Hospital approved the study. Informed consent was obtained from each patient. Adult patients with carcinoma of the lung who were undergoing elective open thoracotomy including frozen section biopsy with an expected duration of one-lung ventilation of at least sixty minutes before lung resection were studied.

After routine induction and insertion of an intra-arterial cannula, the patients were intubated with a left double-lumen tube and positioned for surgery. The left double-lumen tube was selected as determined by the size of the left main bronchus on a standard chest X-ray¹². It was inserted with bronchial occlusion and checked by isolation of each lung demonstrating selective ventilation, and auscultation¹³. Anaesthesia was maintained with isoflurane in oxygen (inspired O₂ 100%) and muscle relaxant as required. All patients had a thoracic epidural inserted and a metaraminol infusion was used to maintain blood pressure above a systolic pressure of 100 mmHg.

An initial blood gas on two-lung ventilation was taken. Once one-lung ventilation was established, patients were ventilated with a tidal volume of 5 ml per kg with the respiratory rate adjusted to keep the PaCO₂ between 35 to 45 mmHg. Variations of arterial oxygenation due to haemodynamic changes were kept to a minimum by the use of adequate analgesia and the use of the vasopressor infusion as required. No suctioning of either lung was

performed during the one-hour duration of the study.

One of the following six treatment sequences (as selected from a table of random numbers) was applied to the lumen of the non-ventilated lung for each subject.

1. Open, CPAP5, O₂ reservoir, Open
2. Open, O₂ reservoir, CPAP5, Open
3. O₂ reservoir, Open, CPAP5, O₂ reservoir
4. O₂ reservoir, CPAP5, Open, O₂ reservoir
5. CPAP5, O₂ reservoir, Open, CPAP5
6. CPAP5, Open, O₂ reservoir, CPAP5.

Details of the treatments were as follows:

- Open: the 15 mm conical connection end of double lumen tube was left open to air
- CPAP: 5 cmH₂O of CPAP was applied to the non-ventilated lung with oxygen flowing at 2 litres per minute to a "T" piece with a CPAP valve (Laerdal Corp.) set at 5 cmH₂O
- O₂ reservoir (Ultipor BB25 filter with a dead space of 35 ml with oxygen connection to gas sampling port) oxygen flowing at 6 litres per minute.

Each treatment in the sequence was applied for a period of fifteen minutes. This stabilization period is required before oxygen delivery is reassessed¹⁴. At the end of each period, a blood gas was taken and the surgeon, who was blinded to the sequence, was asked about any effects on the surgical field.

The study was continued during the examination of the lung biopsies for immediate frozen section histology and for the initial dissection of the lung.

If a pneumonectomy or lobectomy were to be performed, the study was completed before ligation of the bronchial vessels.

Criteria for terminating the study were:

- An arterial saturation less than 90% pre-operatively.
- An arterial saturation less than 85% with any of the treatment sequences.
- Unsatisfactory surgical conditions.

Data analysis

The data are shown in Figure 1. For each sequence, the initial treatment was repeated as the final treatment of the study. Statistical comparisons were performed using Student's test or repeated measure ANOVA (see below), with $P < 0.05$ considered as statistically significant.

RESULTS

Twenty-three patients were studied. Three patients were removed from analysis because the full sequence was not completed (Table 1): two patients

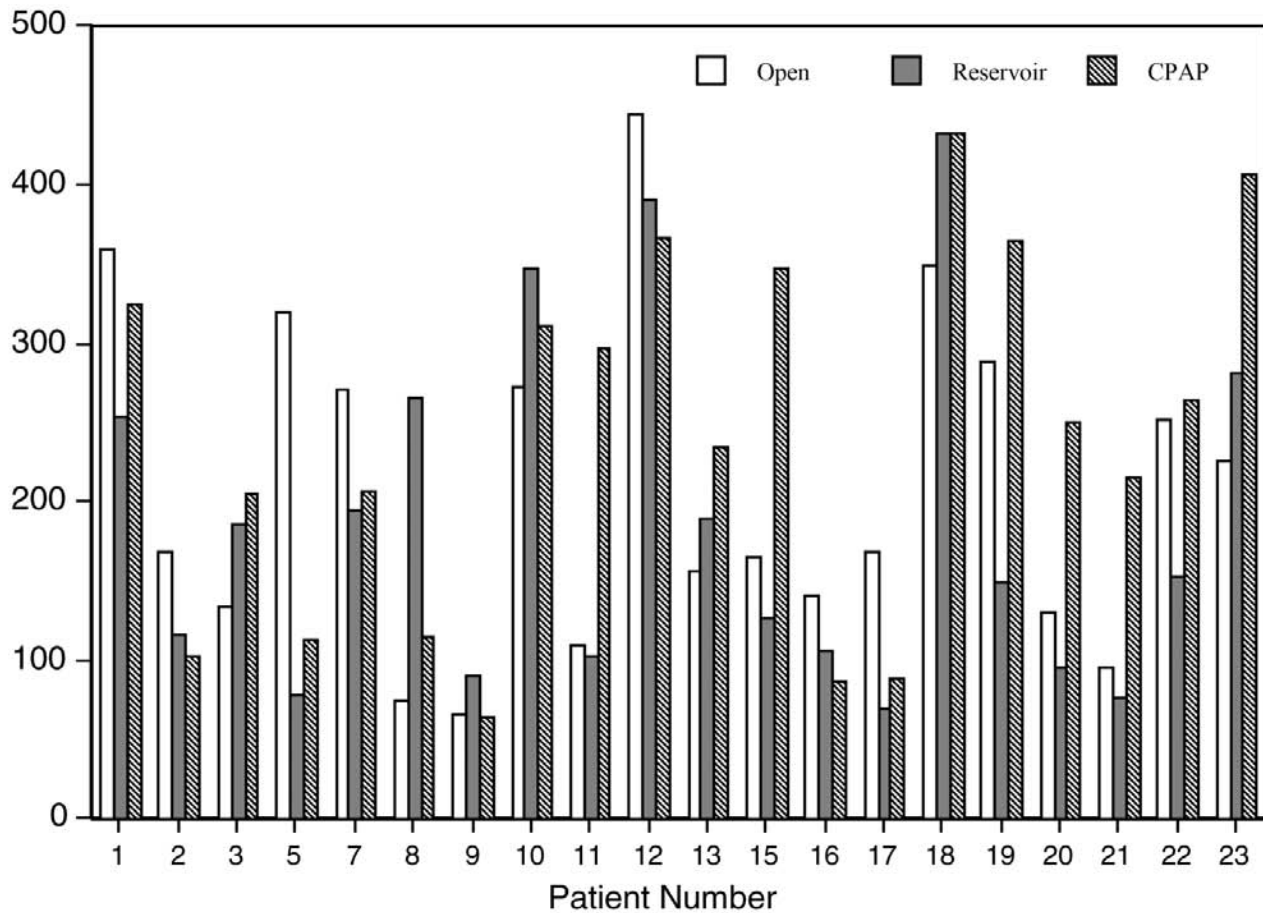


FIGURE 1: P_aO₂ in mmHg during the use of an open tube (clear columns), an oxygen reservoir (shaded columns) and CPAP (continuous airway positive pressure 5 cmH₂O, hatched columns) for each patient. Oxygenation varies markedly between patients. However, the changes within each patient are not quite statistically significant ($P=0.058$). Paired comparison showed no difference between open and CPAP treatments, nor between open and reservoir treatments. A significantly better oxygenation occurred between CPAP and reservoir treatments $P=0.021$.

because of the need to re-expand the lung for surgical reasons. The application of CPAP 5 cmH₂O in the other patient made the surgical dissection too difficult and so the study was abandoned.

TABLE 1

Patients excluded from the study: these were not included in the statistical analysis

Patients No.	Comments
4 (Seq. 3)	Long standing empyema undergoing surgical lung decortication. Two lung ventilation to re-expand right lung after 5 min CPAP 5.
6 (Seq. 3)	O ₂ reservoir done after 12 min: Two lung ventilation requested by surgeon for 3 min. ABG on CPAP5 and O ₂ reservoir not done due to operation shorter than anticipated. Left lung collapsed due to long standing pleural effusion.
14 (Seq. 1)	Lung inflation. CPAP 5 abandoned after 3 min at surgeon's request due to increase difficulty with dissection.

The results were analysed on the 20 patients who completed the study. The allocation of the treatment sequences is given in Table 2.

Examination of the initial and final P_aO₂ (in mmHg) regardless of treatment, was mean 324.1 (SD 159.0) and 189.4 (SD 104.7), (SD difference 171.3) $P=0.0023$ (paired t two-sided). Therefore the P_aO₂ estimate used for the initial treatment mode on each patient was the average between the first and

TABLE 2

Number of patients in each treatment sequence

Sequences	Number of patients
1. Open, CPAP 5, O ₂ reservoir, Open	3
2. Open, O ₂ reservoir, CPAP 5, Open	3
3. O ₂ reservoir, Open, CPAP 5, O ₂ reservoir	5
4. O ₂ reservoir, CPAP 5, Open, O ₂ reservoir	1
5. CPAP 5, O ₂ reservoir, Open, CPAP 5	4
6. CPAP 5, Open, O ₂ reservoir, CPAP 5	4

CPAP 5 (continuous airway positive pressure 5 cmH₂O).

the last treatments to derive an estimate independent of the progressive change with time.

Mean P_{aO_2} (in mmHg) in the "OPEN" group was 210.3 (SD 105.5), 186.0 (SD 109.2) in the "RESERVOIR" group, and 240.5 (SD 116.0) in the "CPAP" group.

Statistical analysis using repeat measures ANOVA showed that the difference between the three methods studied is not quite significant (Repeat Measures $F=3.07$, $P=0.058$). However, further analysis of the treatment as pairs showed: comparison between open and reservoir treatments, $t=1.154$ $P=0.263$, comparison between open and CPAP treatments, $t=1.30$ $P=0.210$ and comparison between reservoir and CPAP treatments, $t=2.52$ $P=0.021$. Thus the reservoir treatment is significantly worse than the CPAP 5 cmH₂O treatment.

Surgical assessment

In twenty of the twenty-three patients studied, the operating conditions were not impaired by the applications of the treatments. Inflation and partial inflation of the lung was noticed by the surgeon in two cases during application of CPAP, while in another case continuous positive pressure had to be abandoned due to increased difficulty with dissection. This interference with the surgical field is consistent with the findings of previous studies on CPAP¹⁵.

For the oxygen reservoir, partial inflation of the lung was noticed by the surgeon only in two cases but did not cause any surgical difficulty. No inflation was observed in any case with the open tube.

DISCUSSION

Our study aimed to examine if the simple oxygen reservoir, compared with CPAP 5 cmH₂O and the double-lumen tube left open to air, would result in an improvement of arterial oxygenation without interfering with the surgical field. In the 20 patients, whilst the application of the oxygen reservoir did not interfere with the surgical field, the oxygen reservoir was inferior to CPAP 5 cmH₂O at a marginal statistical level allowing for a Bonferroni correction of 2.5. The open tube and the reservoir achieved a similar level of arterial oxygenation.

Factors directly related to the surgery, the anaesthetic and the nature of the pulmonary and pleural pathology influence the results of a one-lung study. The surgical compression of the lung¹⁶ and the clamping of pulmonary vessels (in particular clamping of the pulmonary artery) are known to cause variation in the arterial oxygenation during one lung ventilation¹⁷. For this reason our study was done before clamping of any pulmonary arteries or veins.

The oxygenation of the patient is affected also by the duration of one lung ventilation, being the lowest at about 27 minutes with a peak at about 1 hour and 25 minutes¹⁸. To minimize the impact of this intra-operative variation in oxygenation¹⁹, we used the six possible sequences for the three treatments in a random order. The duplication of the first treatment at the end as a fourth was to compensate for any slow changes that occurred.

Although we tried to maintain the parameters of ventilation constant during the study, we had to adjust the respiratory rate to maintain the P_{aCO_2} in the normal range in some cases.

For maximum improvement in oxygenation, continuous positive pressure is usually applied with prior inflation of the lung. We deliberately used a low level of continuous positive pressure (5 cmH₂O) applied without prior inflation in order not to interfere with the surgical field. This may explain why the improvement in oxygenation with CPAP was minimal in our study.

The primary condition of the patient represents one of the major factors determining the arterial oxygenation during one-lung ventilation. This can be seen in Figure 1 where each patient tends to have similar P_{aO_2} values for each treatment but the oxygenation between patients varies markedly. Our study shows that oxygenation with an oxygen reservoir is not more effective than an open airway, but CPAP 5 cm of H₂O can achieve some benefit. It may be that a higher CPAP could have achieved a significantly better oxygenation. However, higher CPAP may even more impede the surgical exposure.

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