In conclusion, pretreatment with a small subparalytic dose of SCh before administration of the full paralyzing dose may increase IOP and cannot safely be used for patients in whom the integrity of an eye is lost or threatened.

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Treatment of Unilateral Pulmonary Insufficiency by Selective Administration of Continuous Positive Airway Pressure Through a Double-lumen Tube

Bahman Venus, M.D.,* Kurra S. Pratap, M.D.,† Timothy Op’Tholt, R.R.T.‡

Continuous positive airway pressure (CPAP), when titrated to provide optimal oxygenation without hemodynamic embarrassment, has been shown to be successful in the treatment of acute respiratory insufficiency.1 In patients with unilateral pulmonary disease and refractory hypoxemia, provision of equal levels of CPAP to both lungs may increase the dead space-to-tidal volume ratio (Vd/Vt) and increase intrapulmonary shunt (Qs/Qt) by hyperinflation of the compliant lung and shift of blood flow to the diseased lung by mechanical compression of pulmonary vessels.2 The use of selective CPAP in the treatment of unilateral pulmonary disease has not been previously reported. We treated a patient with acute unilateral pulmonary insufficiency with a two-CPAP system involving the selective application of optimal CPAP to each lung with the aid of a double-lumen endobronchial tube.

* Assistant Professor of Anesthesiology and Medical Director of Respiratory Therapy.
† Resident in Anesthesiology.
‡ Educational Director, Division of Respiratory Therapy.

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Address reprint requests to Dr Venus: Respiratory Care Service, University of Illinois Hospital, 840 S. Wood Street, Chicago, Illinois 60612.

Key words: Ventilation: continuous positive airway pressure, distribution; Equipment: tubes, endobronchial, double-lumen.


Report of a Case

A 70-year-old man was admitted for treatment of unilateral (right-sided) pneumonia of three days’ duration with signs of cough, shortness of breath, diarrhea, fever and chills. During the next 36 hours, his condition became worse and he was transferred to the intensive care unit. The temperature was 39.5°C, blood pressure 130/76 torr, and heart rate 110 beats/min. Respiratory rate was 57–59 breaths/min, and accessory muscles of respiration were actively used. Auscultation of the lungs revealed coarse rales, rhonchi, and wheezing over the right lung field. During breathing of 70 per cent oxygen, Pao2 was 51 torr, Paco2 28 torr, and pHa 7.50. Repeat roentgenogram of the chest showed right-lower-lobe infiltration and right-upper-lobe consolidation. The left lung was essentially normal except for a slight increase in pulmonary vascular markings. Permission for flexible fiberoptic bronchoscopy was denied by the patient. A nasotracheal tube was inserted and aggressive tracheobronchial toilet instituted. Repeat of the chest roentgenogram showed no improvement (fig. 1).

Because of progressive hypoxemia in the presence of marked tachypnea with the use of accessory muscles of respiration and decrease of lung volume (forced vital capacity = 700 ml), with the diagnosis of acute unilateral pulmonary insufficiency secondary to viral, mycoplasma or Legionnaires’ disease, CPAP was instituted. A cannula was inserted into the radial artery, and a Swan-Ganz catheter was introduced percutaneously via the internal jugular vein and was floated into the pulmonary artery. The arterial blood oxygen content (Cao2), pulmonary arterial blood oxygen content (CaO2), and pulmonary capillary blood oxygen content (CpcO2) were calculated according to the formula:

\[ \text{Cao}_2 = (\text{hemoglobin concentration} \times \text{oxygen saturation}) \times 1.34 + (0.0031 \times \text{Pao}_2) \]

The Qs/Qt was calculated from Berggren’s formula for shunt:

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\[ \frac{Q_s}{Q_e} = \frac{C_{CO_2} - C_{CO_2e}}{C_{CO_2} - C_{CO_2e}} \]

Calculations of shunt were made at the therapeutic level of inspired oxygen necessary to prevent an increase in \( Q_s/Q_e \) as a result of administration of 100 per cent O₂.

Optimal CPAP was then achieved in the following manner. The CPAP was increased in increments of 5 cm H₂O every 30 min; cardiac output, pulmonary-artery occlusion pressure, mixed venous blood oxygen tension, arterial pressure, and intrapulmonary shunt fraction (\( Q_s/Q_e \)) were measured and calculated during CPAP; airway pressure was increased as long as the shunt was more than 15 per cent and no deterioration of hemodynamic status was evident. Whenever an increase in CPAP caused depression of cardiac output or a decrease in venous oxygen tension, accompanied by a pulmonary arterial occlusion pressure less than 18 torr, lactated Ringer’s solution was infused to stabilize the hemodynamic measurements. An increase of CPAP to 30 cm H₂O failed to improve oxygenation but caused deterioration of hemodynamic status (table 1).

At this time, a medium-sized, right-sided Robertshaw double-lumen endobronchial tube was inserted. Separate CPAP systems were connected to the two lumens of the endobronchial tube. The CPAP systems allowed no rebreathing of exhaled gas by a continuous flow (20 l/min for the left-lung system and 50 l/min for the right-lung system) of a humidified and warmed mixture of air and oxygen from a 5-l reservoir bag into the inspiratory limb. During spontaneous inspiration, the patient inhaled the fresh gas from the inspiratory limb, and during exhalation, the continuous flow of fresh gas directed the exhaled gas to the expiratory limb. The CPAP was produced by adding sufficient water to a threshold resistor§ which was placed at the end of the expiratory limbs to maintain the desired CPAP through the respiratory cycle. The left lung was maintained on 5-cm H₂O CPAP; at the same time, optimal CPAP for the right lung was sought by incrementally increasing CPAP while monitoring pulmonary and hemodynamic status. This system enabled us to improve oxygenation and to decrease \( Q_s/Q_e \) by selective administration of as much as 20 cm H₂O CPAP to the affected lung, without causing cardiovascular embarrassment (table 2).


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**Table 1. Hemodynamic and Pulmonary Data during Titration of CPAP with Nasotracheal Tube**

<table>
<thead>
<tr>
<th>Hours after Admission to ICU</th>
<th>CPAP (cm H₂O)</th>
<th>( P_{aCO_2} ) (torr)</th>
<th>( P_{ao2} ) (torr)</th>
<th>( Q_s/Q_e ) (Per Cent)</th>
<th>RR (breaths/min)</th>
<th>FVC (ml)</th>
<th>( Q_e ) (ml/min)</th>
<th>PAOP (torr)</th>
<th>RAP (torr)</th>
<th>PAP (torr)</th>
<th>MV (l/min)</th>
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<tbody>
<tr>
<td>0</td>
<td>0.7</td>
<td>0</td>
<td>28</td>
<td>51</td>
<td>57</td>
<td>700</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<td>10</td>
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<td>50</td>
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<tr>
<td>4</td>
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<td>20</td>
<td>32</td>
<td>64</td>
<td>50</td>
<td>800</td>
<td>5.4</td>
<td>18</td>
<td>7</td>
<td>59/28</td>
<td>14.2</td>
</tr>
<tr>
<td>8</td>
<td>0.6</td>
<td>30</td>
<td>34</td>
<td>61</td>
<td>53</td>
<td>800</td>
<td>4.8</td>
<td>22</td>
<td>8</td>
<td>60/30</td>
<td>13.8</td>
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</table>

**Abbreviations:** \( Q_s/Q_e \), Pulmonary shunt fraction; \( P_{aCO_2} \), mixed venous oxygen tension; RR, respiratory rate; FVC, forced vital capacity; \( Q_e \), cardiac output; PAOP, mean pulmonary arterial occlusion pressure; RAP, mean right atrial pressure; PAP, pulmonary arterial pressure; MV, minute ventilation.

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**Table 2. Hemodynamic and Pulmonary Data during Selective Titration of CPAP for Diseased Lung after Insertion of Double-lumen Tube**

<table>
<thead>
<tr>
<th>Hours after Admission to ICU</th>
<th>CPAP (cm H₂O)</th>
<th>( P_{aCO_2} ) (torr)</th>
<th>( P_{ao2} ) (torr)</th>
<th>( Q_s/Q_e ) (Per Cent)</th>
<th>RR (breaths/min)</th>
<th>FVC (ml)</th>
<th>( Q_e ) (ml/min)</th>
<th>PAOP (torr)</th>
<th>RAP (torr)</th>
<th>PAP (torr)</th>
<th>MV (l/min)</th>
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<td>35</td>
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<td>30</td>
<td>500</td>
<td>800</td>
<td>5.0</td>
<td>12</td>
<td>4</td>
<td>40/15</td>
</tr>
</tbody>
</table>

**Abbreviations:** \( Q_s/Q_e \), Pulmonary shunt fraction; \( P_{aCO_2} \), mixed venous oxygen tension; RR, respiratory rate; FVC, forced vital capacity; \( Q_e \), cardiac output; PAOP, mean pulmonary arterial occlusion pressure; RAP, mean right atrial pressure; PAP, mean pulmonary arterial pressure; MV, minute ventilation; RL, right lung; LL, left lung.
Fig. 2. Chest roentgenogram taken after selective administration of 20 cm H₂O CPAP to the right lung. Notice the Robertshaw endobronchial tube and the Swan-Ganz catheter in place.

During the next 48 hours, cardiopulmonary variables and chest roentgenograms of the affected lung showed further improvement, and respiratory rate decreased to 30 breaths/min (Fig. 2 and Table 2). Obstruction of the right lumen by retained secretions forced us to replace the endobronchial tube with a regular tube. At this time, while the patient was breathing 40 per cent oxygen at 10 cm H₂O CPAP, PAO₂ was 81 torr, PAO₂ 34 torr, and pH 7.44. Indirect fluorescent serum antibody titers confirmed the diagnosis of Legionnaires’ disease. Subsequently, the patient was weaned from CPAP and the trachea was extubated unevenly. He was discharged from the intensive care unit in four days and from the hospital two weeks later.

DISCUSSION

In the early stages of acute respiratory failure, hypoxemia generally precedes hypercarbia. Administration of positive-pressure ventilation for selective ventilation not only requires sophisticated equipment, but may also result in a further reduction of PaCO₂ and a higher incidence of cardiac depression. Application of CPAP in this early stage of the disease has been shown to result in improvement of oxygenation and alleviation of respiratory alkalosis without any detrimental effect on the hemodynamic status.¹

Double-lumen endobronchial tubes have been used for differential pulmonary function studies and isolation of the affected lung during pulmonary surgical procedures in the past.³⁻⁴ Although unilateral acute respiratory failure has been treated by simultaneous, but separate, ventilation of the lungs with and without differently applied positive end-expiratory pressures (PEEP),⁵⁻⁶ selective application of CPAP to individual lungs for the treatment of unilateral pulmonary insufficiency has not been reported. The rationale behind this new form of respiratory therapy is based on the differential involvement of the two lungs by a pathologic process. If one lung has a compliance or resistance markedly different from that of the other, application of any type of positive pressure is expected to be preferentially directed to the normal lung. The abnormal lung, although requiring a larger volume of air to correct its decreased volume, would receive less than the normal lung. Elevation of airway pressure for achievement of optimal PEEP in unilateral pulmonary insufficiency may produce further deterioration of oxygenation, with a shift of blood flow to the affected lung occurring when equal levels of PEEP are applied to both lungs.² Selective CPAP with the use of a double-lumen tube would prevent hyperinflation of the normal lung and improve oxygenation by selective application of optimal CPAP to the diseased lung.

This case shows an example of a condition that can benefit significantly from this technique. A marked ventilation–perfusion inequality had occurred suddenly, probably as a result of alveolar collapse. Presence of marked tachypnea, use of accessory muscles of respiration, and severe decrease in vital capacity and refractory hypoxemia in the presence of hyperventilation (Tables 1 and 2) confirmed the diagnosis of acute pulmonary insufficiency. The fact that 30 cm H₂O CPAP did not improve the oxygenation and caused cardiac depression strongly suggests that the presence of unilateral lung disease directed the positive pressure into the normal lung and thereby caused a shift of the blood flow to the diseased lung. Selective titration of CPAP for the diseased lung by separating the lungs with the aid of the double-lumen tube caused significant reduction of the ventilation–perfusion inequality without causing any hemodynamic embarrassment.

Use of the standard “red rubber” double-lumen tubes for long-term intubation is not practical. Small tube diameters increase resistance to ventilation and create an unusual nursing care demand for adequate suctioning, which may cause obstruction of the lumens of the tube. Airway trauma secondary to difficulty with tube insertion, rubber composition, and the use of low-volume, high-pressure cuffs further limit clinical application of these tubes for prolonged periods.⁹⁻¹⁰ Recently, a double-lumen tube with a larger internal diameter, constructed of nontoxic material with high-volume, low-pressure cuffs, has been introduced. Availability of this tube should encourage clinicians to use the differential CPAP technique in early stages of unilateral pulmonary insufficiency and thereby broaden its clinical applications.

¹ National Catheter Co., Argyle, N. Y.
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