Measurement of airflow resistance 
in neonatal prongs of nasal CPAP

Viviana Intríago Sampietro,¹ Maria Paulina de Oliveira Azevedo,² Jefferson Guimarães de Resende³

Abstract

Objective: to measure airflow resistance in nasal prongs administering continuous positive airway pressure, using different gas admission flow in the ventilation circuit and different internal diameters for nasal prongs. To verify whether a gas admission flow that corresponds only to three times the minute-volume demand is enough to prevent the circuit from being the cause of CO₂ retention.

Methods: we used nasal prongs, assembled in original circuits, with open prongs. A pressure monitor was used for pressure readings in cm H₂O; the monitor was connected to pertinent circuit opening. We used a flowmeter with pressure compensation, gauged at 50 psi, connected to the oxygen network of the hospital and to the afferent end of the continuous positive airway pressure circuit. Initially, by using a flow of 8 l/min and keeping the exhaling end of the circuit closed, we excluded the nasal prongs larger than number 2 since the resistance measured was zero. With nasal parts number 0, 1, and 2 selected for this study, the system was assembled for newborns with the inhaling end connected to gas source and the exhaling end sunk to different depths in the water seal (2, 4, 6, and 8 centimeters). In order to assess CO₂ retention, a mechanical pulmonary ventilation device was used as gas source, and a nasal CPAP circuit was mounted to the device. Gas admission flow values and FiO₂ were set at the mechanical ventilation device. Assessment of gas concentration in the ventilation circuit was carried out while two newborns were being assisted. Gas samples were obtained within the ventilation circuit at afferent end (samples A) and at nasal prong distal to the gas entrance (samples B). To determine minute volume, we multiplied tidal volume (10 ml/kg) by respiratory frequency of patients; gas admission flow was three times minute volume.

Results: considering a maximum gas admission flow of 8 l/min, only prongs sized 0, 1, and 2 presented flow resistance measurable by our methods. We perceived an increase in resistance proportional to the increase of gas admission flow and inversely proportional to the internal diameter of certain prongs. Average maximum difference in CO₂ partial pressure between gas pumped into the ventilation circuit and gas obtained from nasal prongs was 0.43 mmHg (P<0.5).

Conclusion: considering that in ventilation support with nasal CPAP there is the possibility of the gas admission flow to cause an increase in resistance, which would require a greater respiratory effort from the newborn (maybe generating an unexpected CPAP), and also that the determined minimum gas admission flow is equal to three times the minute volume, we conclude that it is necessary to use prongs with the largest internal diameter possible, and gas admission flow three times the minute volume.


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Introduction

Since 1971, following the pioneer work of Gregory, continuous positive airway pressure (CPAP) has been widely used as a therapeutic method for many neonatal diseases, especially the hyaline membrane disease of the newborn. In 1973, Kattwinkel described a device for administering CPAP, considering that newborns require ventilatory support.

Stimulated by the results of Wung, who obtained great success in the United States in increasing survival rates of premature babies and decreasing rates of bronchopulmonary dysplasia, the use of nasal CPAP has also been increasing in Brazil.

One of the purposes of the ventilatory support is to facilitate ventilation and reduce respiratory work. Energy expenditure due to respiratory work in restrictive or obstructive pulmonary diseases can be demanding and thus cause respiratory distress in newborns and infants. Respiratory work is the product of the pressure gradient required for producing tidal volume. Increased resistance will result in increased respiratory work.

The nasal prongs employed in this study were manufactured by Hudson Respiratory Care Inc. (Temecula, California), in silicone - two prongs of about 1 cm in length and variable internal diameter. Prongs are introduced into the nostril of the newborn and connected to two corrugated plastic tubes by plastic elbows, one of which has a Luer connection to a pressure monitor. Nasal prongs are dimensioned for better insertion into nostrils of newborns; internal diameter of nasal prongs varies according to the newborn’s weight. Considering that there is a flow of gases in the ventilation circuit and, consequently, through the nasal prongs, airflow resistance is to be expected. The higher the flow or the smaller the internal diameter of nasal prongs, the greater the resistance.

Other works have determined that a minimal airflow should be established within ventilation circuits in order to both attend the demand of tidal volume and sweep carbon dioxide eliminated by the patient. Gas admission flow should supply 2.5 to 3 times the minute volume. Accumulation of blood CO₂ can cause a drop in pH at the ratio of 0.005 point for each mmHg of CO₂, as well as packing of the nostrils.

Our objective was to assess airflow resistance in nasal prongs with different internal diameters, and to verify if, in using a gas admission flow that supplies three times the minute volume, there is any accumulation of CO₂ in the ventilation circuit.

Materials and methods

We employed full CPAP circuits (Hudson). Afferent flow was administered by an oxygen flowmeter (White-Martins, Brazil) with pressure compensation, gauged at 50 psi, and connected to the oxygen network of the hospital. A vacuum manometer, in cm H₂O (Schinköeth Equipamentos Médico-Hospitalares, Brasília, Brazil), was connected to the pertinent opening for calibration of nasal prong pressure. This connection was made using a plastic tube with zero compliance.

Nasal prongs were kept open to the surrounding environment, and, initially, the exhalation end was kept completely closed. We determined that, considering a gas admission flow of 8 liters per minute, only nasal prongs sized 0, 1, and 2 provided resistance to this level of flow and thus that these prongs offered practical importance, since that same gas admission flow is normally used in administering CPAP to newborns.

Subsequently, the ventilation circuit was assembled as it is used with patients, that is, we inserted the exhalation end into a water container with a centimeter scale using zero set to water level. Gas admission flow was set using the flowmeter, and the exhalation end was inserted 2, 4, 6, or 8 centimeters into the water according to each nasal prong (number 0, 1, and 2). Nasal prongs were kept open to the surrounding environment (pressure of zero cm H₂O) so that manometer readings would indicate pressure of the resistance to gases flowing through nasal prongs. Airflow inside nasal prongs was indicated by the excess flow in relation to the flow in the water column; if there was no resistance in nasal prongs, there should be no flow of gases through the water column, and manometer pressure readings would be zero. In this sense, in case of maximum airflow resistance in nasal prongs, airflow would be released only through the water column.

In order to assess possible retention of carbon dioxide in the ventilation circuit, concentration of CO₂ was measured using gas samples collected at the afferent ventilation circuit (sample A) and at the nasal prong distal to gas admission flow (Figure 1) (sample B). Samples were taken from two patients receiving nasal CPAP. The location for the collection of efferent gas sample was chosen observing a higher possibility of finding gases, contamination with other fluids, in addition to measuring gas in different gas samples.
Results

Table 1 and Figures 2, 3, and 4 indicate an increased resistance according to the increase in gas admission flow and to the reduction of the internal diameter of nasal prongs. This was more serious in using nasal prongs number 0, according to Figure 4. Results related to nasal prong number 2 are shown only in Table 1, since resistance, measured by our methods, was present only when gas admission flow was 8 liters per minute.

Table 2 presents average gas concentrations at gas admission flow source, at efferent end, and in blood sample of patient 1. This patient was being administered CPAP using nasal prongs number 0 and gas admission flow of 1.5 l/min; values are in accordance with patient’s weight (875 g) and breathing frequency (48 breaths per minute). Student’s t-test indicated P<0.5, that is, there was no statistically significant difference in PCO₂ of gas samples.

Table 3 presents average gas concentrations at gas admission flow emission source, at efferent end, and in blood samples of patient 2. This patient was being administered CPAP using nasal prongs number 0 and gas admission flow of 2.5 l/min; values are in accordance with patient’s weight (1,070 g) and breathing frequency (80 breaths per minute). Student’s t-test indicated P<0.5, that is, in this patients there was also no statistically significant difference in PCO₂ of gas samples.

Discussion

In using a higher gas admission flow together with smaller-diameter nasal prongs, we have found a measurable and non-intentional resistance. Resistance may affect patients by demanding greater respiratory effort in order to overcome airflow resistance and exhale. Consequently, resistance may lead to incomplete exhalation and to an unexpected

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**Table 1**

<table>
<thead>
<tr>
<th>Nasal prong</th>
<th>GAF = 2 l/min</th>
<th>GAF = 4 l/min</th>
<th>GAF = 6 l/min</th>
<th>GAF = 8 l/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2,4,6,8/0</td>
<td>2/2/4/6/2/8/2</td>
<td>2/4/6/4/8/4</td>
<td>2/4/6/8/7</td>
</tr>
<tr>
<td>1</td>
<td>2,4,6,8/0</td>
<td>2,4,6,8/0</td>
<td>2/4/6/1/8/1</td>
<td>2/4/6/2/8/2</td>
</tr>
<tr>
<td>2</td>
<td>2,4,6,8/0</td>
<td>2,4,6,8/0</td>
<td>2,4,6,8/0</td>
<td>2/4/1/6/1.8/1</td>
</tr>
</tbody>
</table>

Numbers to the left of the slash represent the depth of exhalation hoses in water; numbers to the right of the slash represent pressure readings indicated by the manometer (cm of water).
positive pressure at the end of exhalation. Accordingly, this may also lead to undesirable hemodynamic and pulmonary effects on patients.12

Manometer readings (cm H₂O) indicated resistance to gas flow in nasal prongs. In case of zero resistance, manometer readings should have also been equal to zero, since the ends of nasal prongs were open to the surrounding environment.

We did not determine flow values using nasal prongs, since part of the gas admission flow would overcome water resistance and reach the surrounding environment. Conversely, our objective was to assess resistance that newborns would actually have to overcome in order to exhale in a hypothetical situation of using nasal prongs; water pressure would indicate the pressure to be overcome by afferent flow of nostrils in case the latter was greater than that exerted by the earlier, in which the exhalation end was sunk into.

**Table 2** - Calibration of afferent and efferent CO₂ in nasal CPAP circuit using the minimal gas admission flow possible. Patient 1: weight = 875 g; breathing frequency = 48; nasal prong = 0; gas admission flow = 1.5 l/min

<table>
<thead>
<tr>
<th></th>
<th>X samples</th>
<th>X samples</th>
<th>Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A ± standard deviation</td>
<td>B ± standard deviation</td>
<td></td>
</tr>
<tr>
<td>% O₂</td>
<td>38.2 ± 02</td>
<td>37.96 ± 0.24</td>
<td></td>
</tr>
<tr>
<td>% CO₂</td>
<td>0.10 ± 0.03</td>
<td>0.12 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>PaCO₂ mmHg</td>
<td>0.30 ± 0.22</td>
<td>0.73 ± 0.43</td>
<td>P&lt;0.5</td>
</tr>
<tr>
<td>PaO₂</td>
<td>238.50 ± 0.94</td>
<td>237.50 ± 1.5</td>
<td>31.1 mmHg</td>
</tr>
</tbody>
</table>

Sample A = source; sample B = efferent end

**Table 3** - Patient 2: weight = 1,070 g; breathing frequency = 80; nasal prong = 0; gas admission flow = 2.5 l/min

<table>
<thead>
<tr>
<th></th>
<th>X samples</th>
<th>X samples</th>
<th>Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A ± standard deviation</td>
<td>B ± standard deviation</td>
<td></td>
</tr>
<tr>
<td>% O₂</td>
<td>30.06±0.05</td>
<td>29.87±0.13</td>
<td></td>
</tr>
<tr>
<td>% CO₂</td>
<td>0.10±2.4</td>
<td>0.11±0.01</td>
<td></td>
</tr>
<tr>
<td>PaCO₂ mmHg</td>
<td>0.43±0.1</td>
<td>0.62±0.19</td>
<td>P&lt;0.5</td>
</tr>
<tr>
<td>PaO₂</td>
<td>187.85±0.33</td>
<td>186.8±0.70</td>
<td>11.1 mmHg</td>
</tr>
</tbody>
</table>

Sample A = source; sample B = efferent end
The difference of 0.43 mmHg in CO$_2$ levels in the ventilation circuit was not statistically significant (P<0.5). This difference, however, would be enough to decrease patient’s pH in 0.002 point, which is considered clinically unimportant and thus safe for the patient.

In assessing gasometry of arterial blood sample taken from patient 1, we observed that PCO$_2$ in blood was 31.1 mmHg, which represents the amount of CO$_2$ being exhaled through the ventilation system (PetCO$_2$). Since the difference measured in efferent gas (sample B) was of 0.43 mmHg, we may infer that sweep of CO$_2$ was of 98.6%. Data from patient 2 suggest a sweep of 98.3%. Even though it was not our objective to directly assess sweep percentages of CO$_2$ - but rather to assess whether nasal prongs were a factor of CO$_2$ retention -, these percentages corroborate our confidence that it is safe to use three times the minute volume for gas admission flow in a nasal CPAP circuit.

Our findings are in accordance with the Poiseuille equation, in which airflow resistance within a tube is directly proportional to the speed in which the gas is being administered through the tube, and inversely proportional to the diameter of the tube. This may be the reason for some newborn babies presenting pulmonary hyperinsufflation at X-ray examination, even with small levels of CPAP according to the depth of the exhalation end in the water column.

Our results also demonstrate that only nasal prongs number 0 presented practical importance in this study, at least considering gas admission flow of up to 8 l/min. In considering that the survival of younger and lighter babies might require smaller nasal prongs, we believe it is important to consider the results of our study in order to improve healthcare quality of newborn babies.

At the Neonatal Intensive Care Unit, at Hospital Materno-Infantil de Brasília, we have assisted, from 1987 to 1997, 2,305 newborns with nasal CPAP or mechanical ventilation. Out of these, 995 were assisted exclusively with nasal CPAP, a practice that was adopted at our hospital in 1990. In 1997, we have provided assistance to 556 newborns at the Neonatal Intensive Care Unit, out of which 8.45% weighed less than 1,000 g; also, out of the 556 newborns admitted, 232 were submitted to nasal CPAP. Our study aimed especially at improving healthcare of these lighter and younger newborn babies.

**Figure 4** - Y-axis indicates pressures obtained at the manometer; x-axis indicates different depths of exhalation end in water column.

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**References**