Influence of nose and mouth leaks on peripheral oxygen saturation during continuous positive airway pressure in neonates

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Original article

Background: **Nose and mouth leaks impair effective pressure transmission during neonatal continuous positive airway pressure (CPAP), but little is known about how these leaks affect physiological parameters. This study investigated the influence of nose leaks and spontaneous mouth opening on peripheral oxygen saturation (SpO_2) and respiratory rate (RR) using nasopharyngeal CPAP.**

Methods: **In 32 neonates with a gestational age of 30 (24-38) weeks and a birth weight of 1435 (710-2730) g, SpO_2 and RR measurements were taken with and without occlusion of the contralateral nostril in a randomized cross-over trial in 1-minute intervals over a 10-minute period during each condition. Mouth opening and newborn activity were documented.**

Results: **SpO_2 with open nostril was comparable to that with occluded nostril [93 (78.5-99.5)% *vs.* 94 (80-100)%, P=0.20]. RR decreased from 51 (26-82)/min to 48 (32-85)/min (P=0.027). In infants with an SpO_2 ≤93% during open nostril (n=17), SpO_2 increased after nostril occlusion [91 (80-96)% *vs.* 89.5 (78.5-93)%, P=0.036]. The mouth was open in 78.5% of measurements with open nostril, and in 87.4% of measurements after nostril occlusion (P=0.005). No significant influence of mouth opening or closure on SpO_2 or RR was detected.**

Conclusions: **In neonates on unilateral nasopharyngeal CPAP with an SpO_2 ≤93%, occlusion of the contralateral nostril significantly increased SpO_2 and reduced RR. The beneficial physiological effects further support using binasal prongs to minimize nose leaks in this population. Future studies should investigate the beneficial effects of reducing mouth leaks when applying CPAP to these infants.**

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Key words: **continuous positive airway pressure; neonates; oxygen saturation; respiratory rate**

Introduction

Continuous positive airway pressure (CPAP) is a mainstay in the treatment of neonatal respiratory disorders[1,2] and ventilator weaning.[3] More recently, CPAP has also been used as a primary method of respiratory support for very preterm infants.[4-6] However, questions remain about which strategies, devices and CPAP interfaces should be used.[7]

At present, short binasal prongs are the preferred CPAP interface for premature infants,[8] as they have been shown to be more effective in preventing re-intubation than single nasal or nasopharyngeal prongs.[9] This might be due to short double prongs that have the lowest flow resistance, especially if they are incorporated in devices using the Venturi effect.[10] However, the resistance to airflow through a CPAP interface is not the only factor that determines the fall in pressure from the CPAP circuit to the respiratory tract. Mouth leaks are common and may cause considerable pressure drops, regardless of whether binasal or nasopharyngeal CPAP is used.[11-13] During nasopharyngeal CPAP, leaks through the contralateral nostril pose an additional problem. From a research perspective, nose leaks during nasopharyngeal CPAP can be eliminated by nostril occlusion and can serve as an *in vivo* model to investigate the effects of leaks during neonatal CPAP. A previous study showed that leak flows during nasopharyngeal CPAP frequently exceeded 1.4 L/min.[14] To date, little is known about the impact of such high leak flows on physiological parameters and clinical outcomes. Specific concerns include impaired CPAP

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transmission to the respiratory tract[12] and an increase in associated side effects of leakages, such as noise exposure[15] and nasal congestion.[16]

We hypothesized that during neonatal CPAP therapy, nose and mouth leaks might have immediate physiological effects on oxygenation and breathing pattern. We therefore performed a reevaluation study to investigate, on the basis of nasopharyngeal CPAP and experimental nostril occlusion, the influence of nose leaks and spontaneous mouth opening on peripheral oxygen saturation (SpO_2) and respiratory rate (RR) in neonates.

Methods

The present study is a reevaluation of a prospective, randomized cross-over trial of 32 newborns on nasopharyngeal CPAP.[14] In the preceding trial, tidal volume and leak measurements were investigated with and without nostril occlusion. SpO_2 and RR were measured only to monitor patient safety. These data then provided the basis of the present study, which aimed to investigate the influence of nose and mouth leaks on SpO_2 and RR. Patients were recruited at the neonatal intensive care unit at Charité University Hospital over a six-month period. Written consent was obtained from all parents prior to measurements. Patient anonymity was preserved. The study was approved by the relevant Clinical Ethics Committee at Charité University Medicine Berlin (EA1/223/07), and complied with the ethical standards of the *Declaration of Helsinki* (revised in 2000).

Nasal CPAP was provided using the Leoni ventilator (Heinen & Löwenstein, Bad Ems, Germany). Endotracheal tubes with internal diameters of 2.5-3.5 mm (Vygon, Ecouen, France) were cut to length and used as single nasopharyngeal CPAP interfaces. The tube was advanced 3.5-4.5 cm through one nostril. Nasogastric feeding tubes were placed in the contralateral nostril. An MR850 humidifier (Fisher & Paykel, Auckland, New Zealand) was used for humidification and heating of the breathing gas in a non-heater wire ventilatory circuit. A neonatal monitor (M1094B, Hewlett Packard, Delaware, USA) was used for routine cardiorespiratory monitoring and to measure SpO_2 and RR. The averaging time of the pulse oximeter was set to 10 seconds. Ohropax Soft earplugs (Ohropax GmbH, Wehrheim, Germany) made of hypoallergenic polyurethane foam were cut to size for each patient to serve as an airtight seal for the nostril.

CPAP device, humidifier, ventilatory circuit and measurement equipment were set up in the usual way, and devices were checked as described in the user manuals. Oxygen supplementation was given to infants who failed to reach their SpO_2 target. In line with unit guidelines, premature infants born at <32 weeks of gestation had an oxygen saturation target range of 81%-91% during the first two weeks of life. With increasing corrected age, oxygen targets were raised gradually to 87%-97% in infants of ≥37+0 weeks of corrected gestational age. The CPAP parameters were set by the clinicians and were not modified during measurements. Median (range) CPAP was 5 (4-7) cm H_2O, circuit flow 6 (5-8) L/min, and FiO_2 0.21 (0.21-0.47). The sequence of nostril occlusion was allocated using a computer-generated randomization list. Each study patient was investigated in a single session, at a time that would not affect the infant's routine care. SpO_2 and RR were measured in 1-minute intervals over two 10-minute periods, with and without occlusion of the contralateral nostril as indicated. Displayed SpO_2 and RR values were recorded by one investigator (H.F.) at the predetermined times. The investigator was not blinded to the study intervention. Prior to each measurement period, at least 15 minutes of quiet breathing were allowed in order to reach a steady state. During each measurement interval, mouth position was visually assessed as "open" or "closed", with even very slight or temporary mouth opening classified as "open". The newborn's behavior was documented as "calm" or "restless". Newborns were considered "calm" if they were quietly breathing without significant body movements. "Restlessness" was defined as crying or vigorous movements (even if the SpO_2 curve seemed to be unaffected) or as minor body movements which impaired SpO_2 measurements. Infants were not tube-fed or handled during the measurement period. If restlessness occurred at any time during a 1-minute measurement interval, data from this interval were excluded from analysis.

The characteristics of the patients and the CPAP parameters were described as median and range. Median SpO_2 and RR were calculated for each patient before and after nostril occlusion. If patients showed spontaneous mouth opening or closure during the measurement period, median SpO_2 and RR values were also calculated separately for open and closed mouth. The groups were compared using Wilcoxon's rank-sum test for paired samples. Categorical data were given as percentages and compared using the Chi-square test. Statistical evaluations were performed using Statgraphics Centurion® software (Version 16.0, Statpoint Inc., Herndon, Virginia, USA). $P<0.05$ was considered statistically significant.

Results

The characteristics of the patients (n=32) are shown in Table. Indications for CPAP therapy were respiratory distress syndrome (n=18), wet lung and other transient

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respiratory insufficiencies of the newborn (*n*=9), pneumonia (*n*=2), bronchopulmonary dysplasia (*n*=1), congenital diaphragmatic hernia (*n*=1), and neuromuscular disease (*n*=1).

In 640 single measurements obtained, 52 (8.1%) were excluded owing to infant restlessness (Fig. 1). During quiet breathing, mouth opening was significantly more common with an occluded nostril than an open nostril (87.4% *vs.* 78.5% of all single measurements, *P*=0.005). A closed mouth was observed only in newborns of more than 27 weeks of corrected gestational age. Fourteen infants opened or closed their mouths at least once during measurements (Fig. 1).

Influence of nostril occlusion

Looking at the study group as a whole, nostril occlusion as an intervention had no influence on SpO_2. $SpO_2$with open nostril was comparable to that with occluded nostril [93 (78.5-99.5)% *vs.* 94 (80-100)%, *P*=0.20] However, only in those infants who had a SpO_2 ≤93% during open nostril (*n*=17), nostril occlusion was associated with a significant increase in SpO_2 [(89.5 (78.5-93)% *vs.* 91 (80-96)%, *P*=0.036)]. This increase was seen in 14 of 17 patients (Fig. 2). During nostril occlusion, RR was slightly reduced. RR was 50.5 (26-82)/min with open nostril *vs.* 48 (32-85)/min with occluded nostril (*P*=0.027).

Influence of mouth opening

Thirteen infants provided analyzable data during open and closed mouth for intra-individual comparison (Fig. 1). In these patients, no influence on SpO_2 or RR was observed during spontaneous mouth opening or closure. SpO_2 was 95 (84.5-99)% with open mouth *vs.* 95 (83-99)% with closed mouth (*P*=0.86). RR was 52 (34-76.5)/min with open mouth *vs.* 52 (34-88)/min with closed mouth (*P*=0.23). Only 4 of the 13 patients had median SpO_2 values ≤93% during open mouth. In these few patients, an increase of SpO_2 from 88 (84.5-93)% with open mouth to 93 (83-95)% with closed mouth was observed, but this was far from being statistically significant (*P*=0.58).

Discussion

The present randomized cross-over trial in neonates investigated the impact of leak reduction during CPAP therapy. It was shown that deliberate nostril occlusion during nasopharyngeal CPAP was associated with increased SpO_2 levels in study patients whose initial SpO_2 was ≤93%. When the study group was considered as a whole, there was a slight reduction in RR during occluded nostril. Because of a small number of patients who opened and closed their mouth

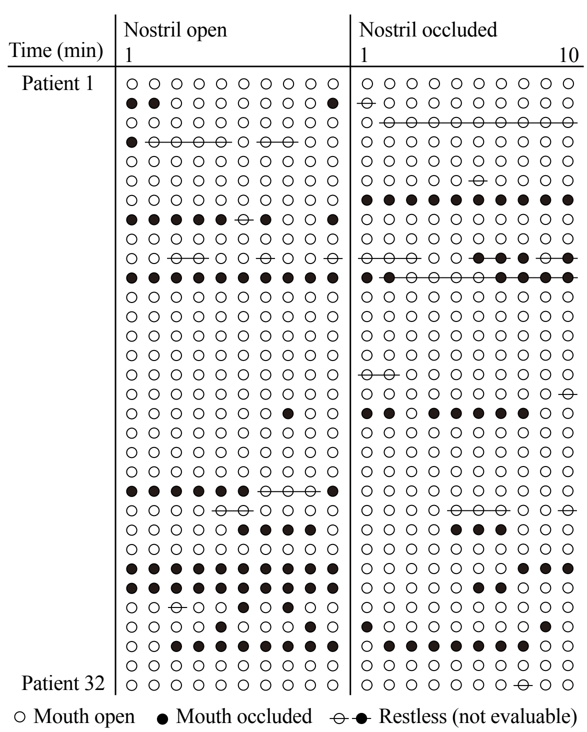

Fig. 1. Single-measurement intervals with open nostril (left column) and occluded nostril (right column) in 32 patients (rows); empty dots represent open mouth, and solid dots represent closed mouth. Measurements excluded from analysis due to restlessness are crossed out.

Table. Characteristics of the study population (*n*=32)

Variables	Median (range) or frequency (%)
Gestational age at birth (wk)	30 (24-38)
Birth weight (g)	1435 (710-2730)
Full course of antenatal steroids (%)	21 (66)
Duration of CPAP therapy (h)	33.5 (24-77)
Actual weight (g)	1395 (710-2730)
Postnatal age (d)	1 (1-36)

CPAP: continuous positive airway pressure.

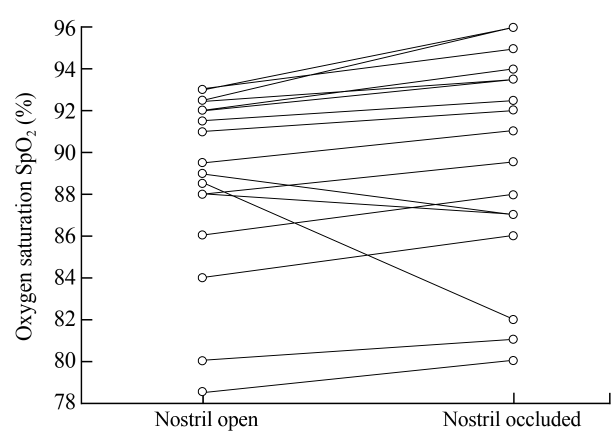

Fig. 2. Median peripheral oxygen saturation during open nostril (left) and corresponding values during occluded nostril (right) in 17 infants who had an initial SpO_2 ≤93% (*P*=0.036).

during measurements, no impact of spontaneous mouth opening or closure on SpO_2 or RR could be detected.

During nasopharyngeal CPAP, nose leaks can reach a magnitude similar to mouth leaks[14] and therefore may exert similar effects. Previous studies[11,12] of newborns showed that mouth leaks caused significant pressure drops between the nasal CPAP interface and oropharynx. The resultant decrease in lung-distending pressure might impair alveolar gas exchange and oxygenation.[17] In the present study, leak reduction by nostril occlusion caused an increase in SpO_2. However, this effect was dependent on the initial SpO_2 level and was only significant if SpO_2 was ≤93% prior to the intervention. This may be due to the sigmoid shape of the oxyhemoglobin dissociation curve, where further increase of already high arterial oxygen tensions leads to a marginal increase in SpO_2.[18]

The decrease in RR during occluded nostril can be explained by respiratory mechanics. Nostril occlusion reduces nose leak and thereby increases exhalation resistance. This results in a higher respiratory time constant and may slow down the RR. Moreover, leak reduction leads to adequate CPAP transmission,[11,12] which may help to increase functional residual capacity and improve respiratory compliance.[19] The latter facilitates adequate ventilation and CO_2 elimination, and therefore reduces respiratory drive. The flow through a nose leak may also improve alveolar gas exchange by CO_2 washout of the upper airways. The extent to which the different mechanisms contributed to the reduction in RR is unclear. In any case, the observed decrease in RR was small and not clinically significant.

In the present study, no infants aged less than 27 weeks of corrected gestational age had closed mouths. This may be due to the weaker orofacial and masseteric muscles of very premature infants, and suggests that mouth opening in these infants is mostly a passive phenomenon of air escaping due to increased oropharyngeal pressure. It would also explain why mouth opening was observed more often during nostril occlusion, when CPAP pressure is more effectively transmitted to the oropharynx. Because of the limited number of study participants who happened to open and close their mouth during the measurement period, it was not possible to detect statistically significant effects of mouth closure on SpO_2, not even in the four neonates whose initial SpO_2 was ≤93%.

If the reduction of nose leaks during nasopharyngeal CPAP is associated with an increase in median SpO_2, then inspired oxygen requirements in premature neonates may be reduced, thereby lowering the risks of chronic lung disease[20] and retinopathy of prematurity.[21] In the present study, the elimination of air leaks by nostril occlusion temporarily enhanced the beneficial impact of CPAP on SpO_2. However, the long-term risks of this intervention are unknown. To reduce nose leak for a longer period of time, a binasal CPAP interface can be used. The data of the study reinforce the recommendation to use binasal prongs in neonatal medicine, and add to existing evidence that binasal prongs are superior to single nasal or nasopharyngeal prongs.[9,10]

The present study was unable to show whether mouth closure could provide additional benefits to neonates during nasal CPAP therapy. In adults, chinstraps have been used to successfully reduce mouth leak and improve CPAP efficacy.[22,23] In neonates, manual mouth occlusion[11,12] and use of a chinstrap[24] or pacifier[13] resulted in more effective CPAP transmission to the oropharynx. Some neonatal units use chinstraps and pacifiers to reduce mouth leak,[12] and some manufacturers of CPAP systems offer chinstraps of different sizes for term and premature infants (e.g., Fisher & Paykel Healthcare, Auckland, New Zealand). This is remarkable, as the long-term effects and safety of chinstraps have never been investigated during neonatal CPAP. Possible side effects such as skin injury or abdominal distention may limit the clinical application. Nonetheless, mouth occlusion may be a promising strategy to improve the efficacy of nasal CPAP in neonates, and would be most beneficial in preterm infants who receive supplemental oxygen to reach their SpO_2 target. We therefore suggest that future leak studies should concentrate on optimizing binasal prong CPAP for the preterm subgroup.

There are several limitations to this study. Firstly, it would have been desirable to confirm the visual assessment of mouth opening with actual leak flow measurements. However, such data were not available because continuous flow measurements during nasal CPAP are not yet technically feasible.[14,25] Secondly, the observed increase in SpO_2 was merely a short-term effect, and it is unclear whether a leak reduction results in better long-term outcomes.

In conclusion, the present study showed that nostril occlusion during nasopharyngeal CPAP was associated with increased SpO_2 in neonates whose SpO_2 was ≤93% with open nostril. Nostril occlusion had no clinically significant effect on RR. The results support the use of binasal CPAP interfaces, which are better suited to permanently minimizing nose leaks during neonatal CPAP therapy. The study did not have the statistical power to answer the question of whether spontaneous mouth closure had an influence on SpO_2 or RR. The use of chinstraps or pacifiers to actively reduce mouth leaks should be investigated in future clinical trials.

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Contributors: Fischer HS and Schmalisch G designed the study, analyzed the data and wrote the main body of the article. Fischer HS carried out all measurements. All authors contributed to data interpretation, revised the article critically for important intellectual content and approved the final version. Schmalisch G is the guarantor.

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