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Influence of mouth opening on oropharyngeal humidification and temperature in a bench model of neonatal continuous positive airway pressure

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ABSTRACT

Clinical studies show that non-invasive respiratory support by continuous positive airway pressure (CPAP) affects gas conditioning in the upper airways, especially in the presence of mouth leaks. Using a new bench model of neonatal CPAP, we investigated the influence of mouth opening on oropharyngeal temperature and humidity.

The model features the insertion of a heated humidifier between an active model lung and an oropharyngeal head model to simulate the recurrent expiration of heated, humidified air. During unsupported breathing, physiological temperature and humidity were attained inside the model oropharynx, and mouth opening had no significant effect on oropharyngeal temperature and humidity. During binasal CPAP, the impact of mouth opening was investigated using three different scenarios: no conditioning in the CPAP circuit, heating only, and heated humidification. Mouth opening had a strong negative impact on oropharyngeal humidification in all tested scenarios, but heated humidification in the CPAP circuit maintained clinically acceptable humidity levels regardless of closed or open mouths.

The model can be used to test new equipment for use with CPAP, and to investigate the effects of other methods of non-invasive respiratory support on gas conditioning in the presence of leaks.

1. Introduction

The human airways have an important role in heating and humidifying air during inhalation [1]. Under normal conditions, the respiratory tract heats and humidifies inspired air so that the alveoli remain at 37 °C and 100% relative humidity [2–4]. However, invasive ventilation via an endotracheal tube or a tracheostomy bypasses most areas of heat and moisture exchange. Breathing of under-humidified gas may cause loss of heat and moisture, mucociliary dysfunction, excessive mucous production, increased risk of infection, atelectasis, and inspissated airway secretions [3,5].

The effects of non-invasive respiratory support, such as continuous positive airway pressure (CPAP), on gas conditioning are even more complex. On the one hand, nasal and oronasal interfaces allow some heat and moisture exchange in the upper airways [6]. On the other hand, CPAP devices deliver inspired air at high flow rates and may therefore overwhelm the usual mechanisms for airway humidification, especially in the presence of mouth leaks [7,8]. Non-invasive modes of respiratory support have become widely used to treat full-term and preterm neonates, both as support immediately after birth and to prevent extubation failure after initial stabilization with invasive mechanical ventilation [9]. Recent meta-analyses have shown that avoidance of mechanical ventilation by using CPAP in preterm infants with respiratory distress syndrome may prevent long-term sequelae of prematurity, such as bronchopulmonary dysplasia [10,11]. During nasopharyngeal CPAP in neonates, however, insufficient humidification of inspired air can cause mucous plugging and tube obstruction [12]. A recent survey in neonatal units using CPAP with superimposed nasal high frequency oscillation ventilation indicated the development of highly viscous secretions and airway obstruction due to inspissated secretions, regardless of whether nasopharyngeal or binasal CPAP interfaces were used [13].

Abbreviations: AH, absolute humidity; CPAP, continuous positive airway pressure; CV, coefficient of variation; ICC, intraclass correlation coefficient (absolute agreement); ISO, International Organization for Standardization; RH, relative humidity; RR, respiratory rate; *T*, temperature.

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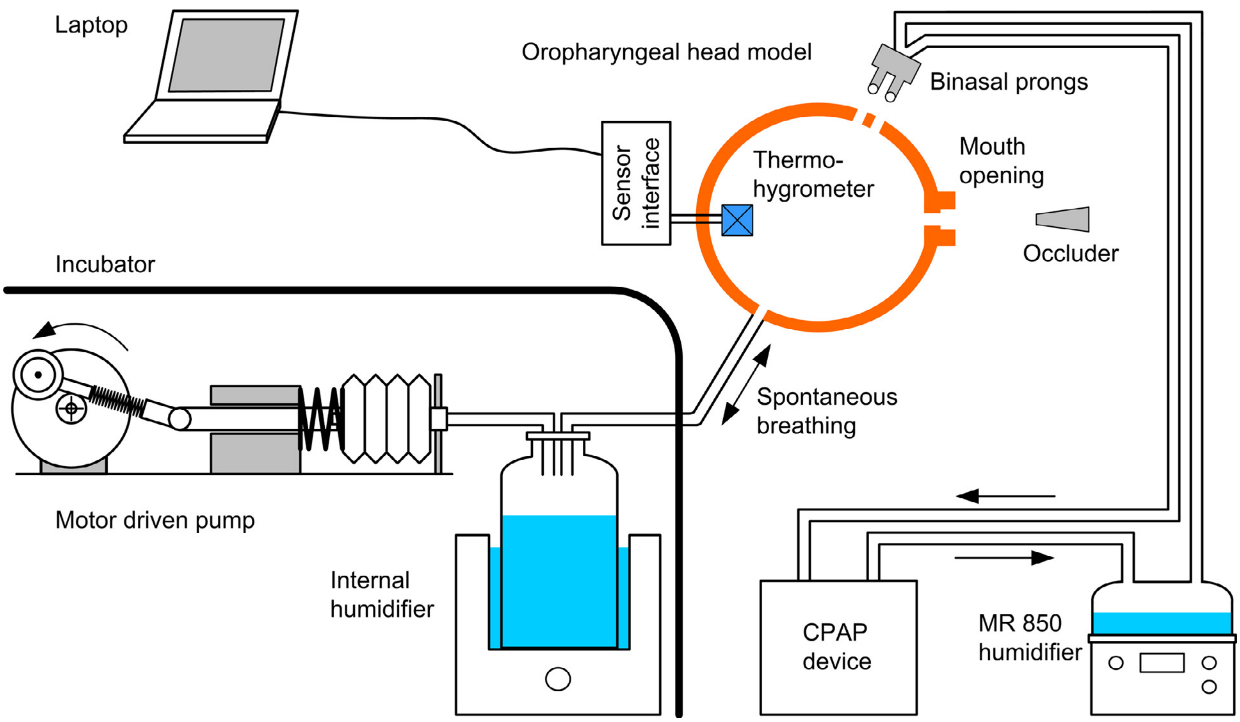

Fig. 1. Experimental set-up used to investigate the influence of mouth opening on temperature and humidity in the model oropharynx. The model mouth was occluded with a cone-shaped silicone stopper as needed. Binasal prongs and the CPAP circuit were used in the second series of experiments.

Interestingly, although heated humidification is a clinically important issue during neonatal CPAP, only limited quantitative data are available. Bench studies of invasive mechanical ventilation have shown that a multitude of factors may impair humidifier performance [14], including high ventilator flows [15,16], increased minute ventilation [17–19], low heater plate temperature [18,20] and elevated gas temperature at the inlet of the humidifier chamber [16,18,21]. Clinical studies of nasal CPAP in adults have reported desiccation of the upper airways due to mouth leaks [8,22]. A recent study investigated the influence of different CPAP equipment and CPAP flow on oropharyngeal temperature and humidification in a neonatal manikin [23]. The experimental set-up was a static environment, however, and there was no simulation of active breathing, so this study did not examine the effects of spontaneous breathing and mouth leaks. Mouth opening occurs frequently during neonatal CPAP [24], and may interfere with effective gas conditioning [8,22].

Therefore, the aims of the present study were to develop a bench model of neonatal CPAP that better simulates physiological gas conditions in the oropharyngeal cavity and to investigate the influence of mouth opening on oropharyngeal humidification and temperature.

2. Materials and methods

2.1. Oropharyngeal head model

Fig. 1 shows the experimental set-up used to simulate oropharyngeal temperature and humidity during spontaneous breathing. An empty ball made of polyvinyl chloride (component of a manual breast pump, model Nr. 766, Glaswarenfabrik Karl Hecht GmbH, Germany; outer diameter: 51 mm, wall thickness: 4 mm, filling volume: 42 mL, internal diameter of one-sided opening: 5 mm) was used to simulate an infant's oropharynx. The opening in the ball served as the model mouth that was occluded with a cone-shaped silicone stopper as needed. Opposite to the model mouth, a digital thermo-hygro sensor (HYT-939, IST AG, Ebnat-Kappel, Switzerland) was fixed inside the ball. Two additional holes were drilled into the ball to create "nostrils" suitable for insertion of a binasal CPAP interface. Another hole was created at the bottom of the ball to introduce breathing flow.

A custom-made mechanical model lung (motor-driven pump; tidal volume: 15 mL, compliance: 5.5 mL kPa^{-1}, resistance: 4.17 kPa s L^{-1}) with adjustable respiratory rate (RR) was used to simulate patient breathing, as described previously [25]. Heating and humidification of inspired air was simulated by a custom-made pass-over humidifier inserted between the model lung and the model oropharynx. This internal humidifier was constructed from a thermostable baby glass bottle with volume graduation marks (perimeter: 170 mm, volume: 290 mL, Pyrex, France) that was placed in a heated water-bath (baby food warmer 3310, Reer GmbH, Leonberg, Germany). The model lung and the humidifier were placed in a heated infant incubator (Incu i, Atom Medical Corporation, Tokyo, Japan) to reduce water condensation in the silicone tubing (internal diameter: 4 mm) and prevent the heated water-bath from impacting measurements in the model oropharynx, which was fixed just outside the incubator. The distance between the internal heated humidifier and the model oropharynx was 8 cm.

2.2. Temperature and humidity measurements

The Hygrochip® humidity sensors LabKit, with the software Hygrosens Recorder, version 3.0 (Hygrosens Instruments, Germany) and the HYT-939 thermo-hygro sensor were used to measure temperature (*T*) and relative humidity (RH) inside the model oropharynx, and the software calculated absolute humidity (AH) from RH and *T* [4]. According to the manufacturer, the HYT-939 measures temperatures between −40°C and 125°C with an accuracy of ±0.2°C and a resolution of 0.015°C, and measures RH between 0% and 100% with an accuracy of ±1.8% and a resolution of 0.02%. Prior to measurements, the precision of the thermohygrometer was