

Humidification of inspired oxygen is increased with a pre-nasal cannula compared to intranasal cannula

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This research project was conducted without external financial support

None of the authors has a conflict of interest in the matter of subject.

Abstract

Background:

Oxygen therapy is usually combined with a humidification device to prevent mucosal dryness. Depending of the cannula design oxygen can be administered pre- or intra-nasally (administration of oxygen in front of the nasal ostia versus cannula system inside the nasal vestibulum). The impact of the cannula design on intra-nasal humidity however has not been investigated to date.

Objective:

First, to develop a system, that samples air from the nasal cavity and analyses the humidity of these samples. Second, to investigate nasal humidity during pre-nasal and intra-nasal oxygen application with and without humidification.

Method:

We first developed and validated a sampling and analysis system to measure humidity from air samples. By means of this system we measured inspiratory air samples from 12 individuals who received nasal oxygen with an intra-nasal and pre-nasal cannula at different flows with and without humidification.

Results:

The sampling and analysis system showed good correlation to a standard hygrometer within the tested humidity range ($r = 0.992$, $p < 0.001$).

In our subjects intranasal humidity dropped significantly from $40.3 \pm 8.7 \%$ to $35.3 \pm 5.8 \%$, $32 \pm 5.6 \%$ and $29.0 \pm 6.8 \%$ at a flow of one, two and three litres respectively when oxygen was given intra-nasally without humidification ($p=0.001$, $p<0.001$ and $p<0.001$ respectively). We observed no significant change in airway humidity when oxygen was given pre-nasally without humidification. With the addition of humidification we observed no significant change in humidity at any flow rate and independent of pre- or intranasal oxygen administration.

Conclusion:

Pre-nasal administration of dry oxygen achieves similar levels of intranasal humidity as intranasal administration in combination with a bubble through humidifier. Pre-nasal oxygen simplifies application and may reduce therapy cost

Keywords : Nasal humidity, oxygen therapy, nasal oxygen cannula, nasal mucosa

Introduction

Oxygen administration via nasal cannula has been established several decades ago ¹. The use of oxygen has increased remarkably after publication of two landmark studies in the 1980s, which have shown, that long term oxygen administration in COPD patients with hypoxemia results in a near doubling of life expectancy ^{2, 3}. For long-term oxygen therapy the usual prescribed flow is 2 L/min.

Several oxygen application systems have been marketed in the past. Especially in Europe nasal cannulas are most frequently used. Because all application systems deliver absolutely dry oxygen, humidification is recommended by some, ⁴ but not all guidelines ^{5, 6}. If humidification is used, the most widespread systems are bubble through humidifiers.

The velocity of the oxygen flow streaming out of a nasal cannula with an inner diameter of 3mm and a dose of 2 L/min is 4,7 m/s ⁷. Exposure to dry and undiluted oxygen at such a high flow velocity may cause mucosal dryness and irritation. Chronic exposure may cause local inflammation, bleeding of the mucosa and possibly nasal-septal perforation ⁸⁻¹¹.

On the other hand bubble through humidifiers may cause infections if the water is contaminated with bacteria ¹²⁻¹⁵. Additionally the noise of the bubbles may be annoying and may disturb sleep.

Oxygen masks as well as pre-nasal cannula systems have outlets of greater cross sectional area and emit oxygen outside the nostrils. The pre-nasal cannula used in this investigation (figure 1 A) has outlets towards the nose and towards mouth. This creates a little stable cloud of oxygen in front of the nose which enables a sufficient oxygen flow into the lung not only during nose but also during mouth breathing ⁷. Pre-nasal oxygen administration has been shown to be equally effective to

oxygen administration via face mask in terms of oxygenation ⁷. This on the other hand is at least as effective as intra-nasal oxygen administration ¹⁶.

In theory, the dry oxygen can absorb humidity from the surrounding air along the way from the probe outlet to the nose orifice. This process could potentially make humidification unnecessary.

To test this hypothesis we measured the humidity inside the nasal cavity with a pre- and intranasal cannula system with and without humidification. First however, we had to develop a system that was able to sample air from the nasal cavity and analyse the humidity of these samples.

Methods

Ethics

The protocol and equipment was approved by the ethics committees of the medical council and of the University of Muenster (Westfalen, Germany, 2010-583-f-S). Informed consent was obtained from all participants.

Measurement system

The modified Swan-Ganz catheter (Corodyn TD 7F , Braun, Melsungen, Germany); originally used for measurement of the vascular pressure and cardiac output is shown in figure 2. The distal catheter end was cut off directly above the temperature sensor. This temperature sensor was used to measure air temperature during the sampling procedure and two-point calibration of the temperature sensor was performed prior to measurements. The catheter with a diameter of 7F has 4 channels. The first channel contains a wire that connects to the built in temperature sensor on the catheter tip. The second channel was used to suck in air-samples. The remaining two channels were used to slide in a Constatan heating wire that was bent to build a 180 degree U-turn at the catheter tip. A small cage at the catheter tip prevents direct contact of the temperature probe and the nasal wall.

Because the humidity in the nasal cavity changes considerably within the breathing cycle, we had to measure chest excursions to ensure that air was sampled during inspiration. Thoracic movements were detected with a standard piezoelectric belt (Polymesam, MAP / ResMed, Martinsried, Germany), the amplified signal was connected to a standard analog-voltmeter to visualize the respiratory effort. The air sampling device was manually activated at onset of inspiration and was programmed to operate for a duration of 0.8 seconds

During this time the pump sucks in a volume of 12ml from the tip of the catheter into the measuring chamber. The volume of the sampling channel of our catheter was determined to be 1 ml, the content of the measurement chamber was determined to be 10 ml. In order to analyse a

representative sample, we analysed air taken from the third of three consecutive suction manoeuvres of three consecutive breaths. Air samples were kept in the measurement chamber until the hygrometer recorded stable measurement results, which was achieved within seconds. All experiments were carried out by the same scientist.

In our setting the temperature in the nostril (body temperature) was warmer than the surrounding room air. To avoid condensation of humidity in the catheter during sampling the whole catheter was heated to approximately 45 °C.

The humidity of the sampled volume was measured under steady conditions in a water bath at 37 °C (Koettermann 3041, Koettermann, Haenigsen, Germany) with an industrial sensor (Hygrotest 6400, Testo AG, Lenzkirch, Germany). The whole measurement system is shown in figure 3.

Calibration of the measurement system

To validate our measurement device we performed comparative measurements with a standard industrial hygrometer (Testo 625, Testo AG, Lenzkirch, Germany). We modified humidity inside a container by addition of water soaked cotton balls of different water content under room air conditions. Humidity was measured with a standard hygrometer inside the container as well as from air samples taken by means of our newly developed sampling device.

Comparison study

Figure 1 shows the tested cannula systems, a standard nasal cannula (Covidien nasal cannula adult REF 13300, Salter Labs, Arvin, CA, USA) and a pre-nasal cannula (Oxynasor[®] HLM.27.001; Heinen & Löwenstein, D-56130 Bad Ems, Germany).

The measurements were done in a randomized order for either oxygen application system as well as randomisation of flow and whether humidification was added or not. All volunteers inhaled oxygen flows of 0, 1, 2 and 3 L/min with and without a bubble through humidifier (Kendall Respiflo H; 500ml, Covidien, Mansfield, Massachusetts) with either cannula system. The different runs were

interrupted by a five minute pause where subjects were breathing room air only in order to guarantee equal entry criteria.

During quiet nose breathing the sampling device was activated during three consecutive breaths to assure complete washout of the measurement chamber (figure 2). At the same time the temperature in the nasal cavity was measured. We repeated every measurement three times and subsequently averaged the results. The humidity in the measurement chamber was converted to the temperature conditions measured in the nasal cavity according to the Magnus-formula.¹⁷ The twelve volunteers were recruited from the staff of different departments of our hospital.

Statistics

Data are expressed as mean and standard deviation. A p of less than 0.05 was considered significant. Differences were analysed by three factor ANOVA evaluating the effect of flow, humidification and device after performing Levene's test to proof for homogeneity of the variances. Post hoc analysis was done by means of the Scheffé procedure. Pearsons correlation test was used within the validation study after normal distribution of data was confirmed by the Kolmogorov-Smirnov test. We used the SPSS software package version 20 for analysis.

Results

Results of the system calibration measurements show excellent correlation between the standard hygrometer and our newly developed device with a Pearson correlation coefficient of 0.992, $p < 0.001$.

The data obtained from 12 volunteers (20-60y, 4 female) are shown in figure 4. The average temperature inside the nasal cavity of our subjects during inspiration was determined to be 30.8 ± 1.6 °C and thus has increased already above room temperature. With humidification no significant difference in relative humidity of the nasal cavity was observed independent of the oxygen application device and oxygen flow.

When the standard nasal cannula was applied without humidification, we observed a relevant and significant drop in relative humidity of the nasal cavity for the flow 1 L/min ($p = 0.001$), 2 L/min ($p < 0.001$) and 3 L/min ($p < 0.001$) respectively (figure 4). When oxygen is given pre-nasally without humidification, relative nasal humidity is not significantly affected at any flow (figure 4).

Discussion

In our study, we have shown, using a newly developed system for measuring relative humidity, that relative humidity in the nasal cavity drops significantly even at low flow of intra-nasally administered dry oxygen. At a flow of 3 L/min humidity dropped already by one third. Given as long term treatment, this might result in nasal discomfort due to dryness and irritation and could result in serious complication as described previously⁸⁻¹¹.

Airway humidity levels during administration of dry oxygen given by means of the oxynasor were similar to those achieved with intranasal administration in combination with a bubble through humidifier and makes the use of this humidification device unnecessary. This observation leads to the assumption that the exchange of humidity from the ambient air to the dried oxygen occurs very rapidly and before the air enters the nasal cavity. Our results are in line with previous data that compared nasal cannulas to a system that delivers oxygen via a larger opening in front of the mouth

18.

In general humidity describes the amount of water vapour in gases. Humidity can be given as the absolute mass of water per unit of volume and is called absolute humidity or as a fraction of full saturation under constant conditions of volume, temperature and pressure. The latter is called relative humidity. Usual indoor air at atmospheric pressure and at a temperature of 20 °C has a relative humidity of about 55-60 %¹⁹. During inspiration the temperature of the inspired gas will increase and approach body temperature within the distal airways. The onset of this effect can be

seen in our experiments, since the nasal temperature was already 30.8 °C and thus above room air temperature while intranasal relative humidity was determined not to be higher than 42 % even at zero flow (figure 4). Given the same absolute humidity, an increase in temperature will result in a drop in relative humidity, a phenomenon we observed as nasal temperature was above room temperature. Thus the increase in temperature appears to occur faster than the rise in relative humidity within the natural airways.

During the further passage towards the alveoli, the inspired gas will not only be heated to body temperature but will also increase relative humidity up to 100 % by water uptake from the mucosal surface of the airways^{19, 20}.

Our experiments only provide information about the impact of oxygen humidification on intranasal humidity. Whether humidity in the more distal airways is affected as well or if water uptake from the mucosal airways during inspiration might compensate this deficit is beyond the scope of our investigation. Decreased humidity in the nasal cavity by application of dry oxygen as seen in our experiment however increases the capacity and propensity for water uptake from the mucosal surface.

Whether our data are clinically relevant cannot be surely answered from this examination because the application time was short and we examined healthy individuals. The discussion about humidification of oxygen during long-term oxygen therapy is controversial. Cambell et al.²¹ did not see differences in side effects between humidified and dry oxygen given intra-nasally. In his study however he examined postoperative patients after cardiac surgery who received oxygen for an average of only less than three days. Patients received either dry or humidified oxygen and thus were not able to compare both treatment modalities. Their complaints were categorized into dry throat, dry nose, headache, chest discomfort and other complaints, overall symptoms that are quite common after cardiac surgery under general anaesthesia. Some guidelines go along with Cambells results and do not recommend the routine use of humidification systems^{5, 6}. Andres et al conducted

a similar study using a cross over design ²². He found significant differences in symptom scores but not in the incidence of nose bleeds. The latter however was unlikely to happen, given the short treatment time of only three days.

Miyamoto and co-workers confirmed these results in a carefully designed study with a comparison of humidified versus dry oxygen in a cross over design at flow between 1 and 5 L/min ¹⁰. Although the application time was very short (one minute) nasal discomfort was recognized by healthy individuals at any tested flow while patients with pulmonary disorders, who were likely to be used to oxygen administration perceived nasal discomfort only at flow of > 2 L/min. Miyamoto's findings raise the question if the subjective perception of nasal discomfort might be subjected to habituation. With a flow greater 5 L/min even bubble through humidifiers appear to have a ceiling effect since they were perceived to be inferior to heated humidifying systems ¹¹. Air from heated humidifiers is usually warmer than ambient air and thus can accumulate and deliver more humidity. A possible drawback however might be the development of condensate due to the cooling down within the tubing system.

For optimal treatment and more importantly to prevent complications one should consider the oxygen application device, the type of humidification and treatment duration.

Humidifying systems carry the potential risk of contamination. Previous studies did not find differences in bacterial contamination rates of prefilled disposable versus multiuse oxygen humidifiers ¹³. No contamination differences were found when humidifiers were filled with sterile or tap water ²³. While some authors found no or negligible contamination rates ^{13, 24, 25} and propose even multi-patient use of humidifiers ²⁵, other investigators found relevant contamination rates of potentially pathogenic organisms ^{12, 23, 26}. No epidemiologic studies exists which translate these finding into clinical outcomes such as infection rate, length of hospital stay or even death although there is evidence, that humidifier contamination is a risk for infection ^{14, 15}.

For this study, we have developed a measurement device that allows to take air samples through a catheter and determine sample-air humidity under constant conditions. With knowledge of the local temperature at the sample site, which is also being determined by means of the built in temperature sensor, one can calculate the relative humidity at the sampling site. We used this device within the nasal cavity however it appears feasible to apply this technique to more distal areas of the human respiratory tract for appropriate research questions.

Limitations:

Calibration measurements were done at room temperatures while patient measurements were conducted at 37°C. The hygrometer we built into our measurement system however has a validated measurement-range from -199.9 to 199.9 °C and thus should provide reliable data for our experiments. We did not assess nasal discomfort in our subjects and due to the short period of the exposure to the different experimental settings our data cannot assess any clinical outcome. We limited our study to one type of humidifier and cannot exclude, that different modes of humidification would have influenced our measurements differently.

Conclusion

We introduced a helpful and valid tool to measure relative humidity in air filled body cavities such as the nasal cavity. Nasal humidity drops significantly when dry oxygen is given intra-nasally even at low flow. Pre-nasal application of dry oxygen with low flow velocity at the outlet does not impact nasal humidity at least up to a flow of 3 L/min. and thus obviates the need for additional humidification. With this approach oxygen therapy might become less cumbersome, cheaper and more hygienic.

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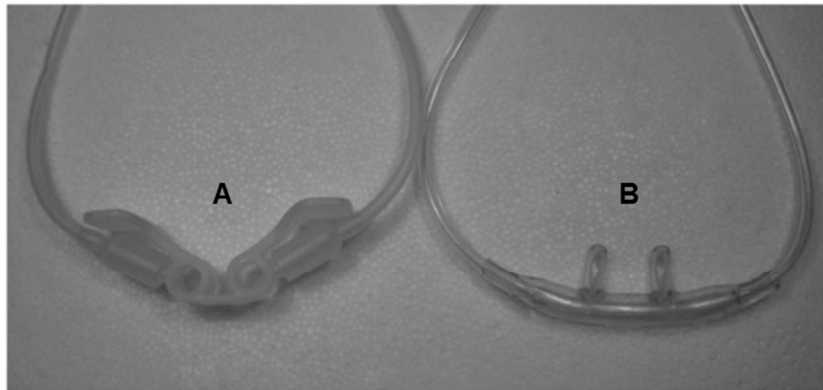
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Figure 1: Applicator systems, A: the pre-nasal cannula (Oxynasor® HLM.27.001; Heinen & Löwenstein, D-56130 Bad Ems) and B: the nasal cannula (Covidien nasal cannula adult REF 13300, Salter Labs, Arvin, CA, USA) .

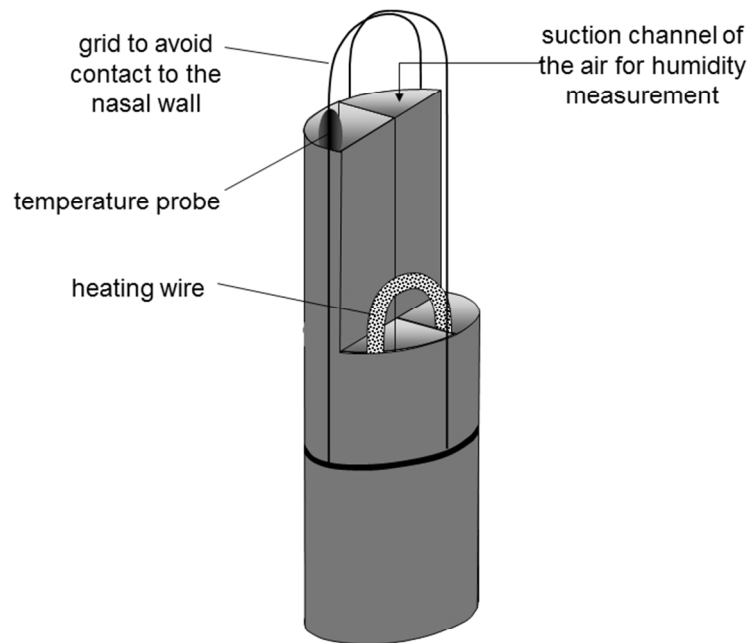
Figure 2: Tip of the modified Swan-Ganz catheter: The first channel was used to take air samples, the second channel for temperature measurements at the sampling site; the two remaining channels contain a heating wire to keep the catheter temperature constant.

Figure 3: The experimental setup. Inspiratory air samples were drawn inside the patient's nostril and humidity was analysed in a chamber that was kept constantly at 37 °C

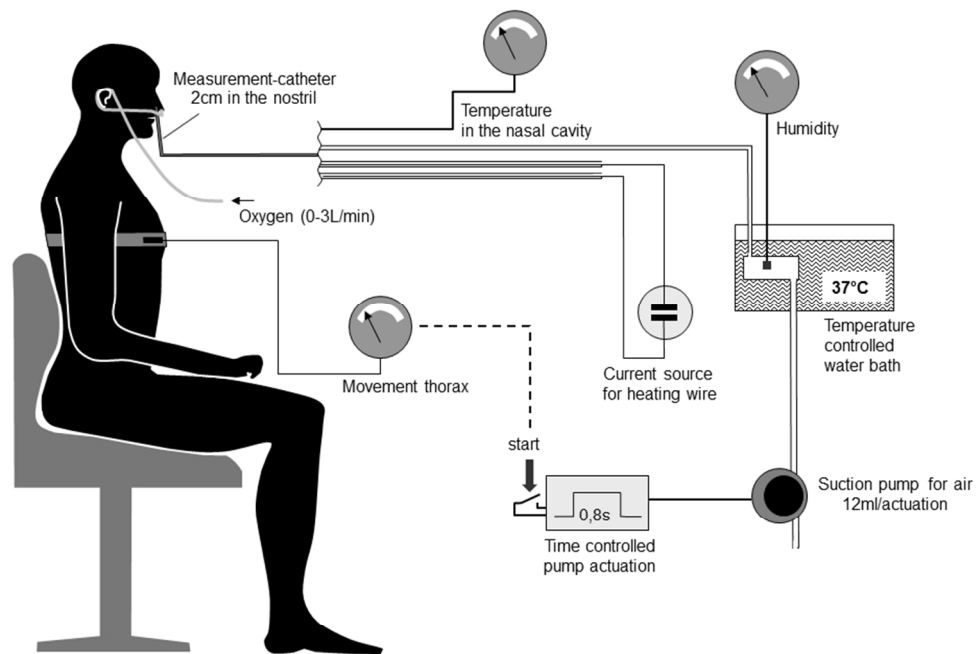
Figure 4: Relative humidity at different oxygen flow rates with the different cannula systems. ON = Oxynasor pre-nasal cannula; NC = intranasal nasal cannula; +H = + humidification. (*) = $p=0.001$, (#) = $p<0.001$ compared to zero flow.



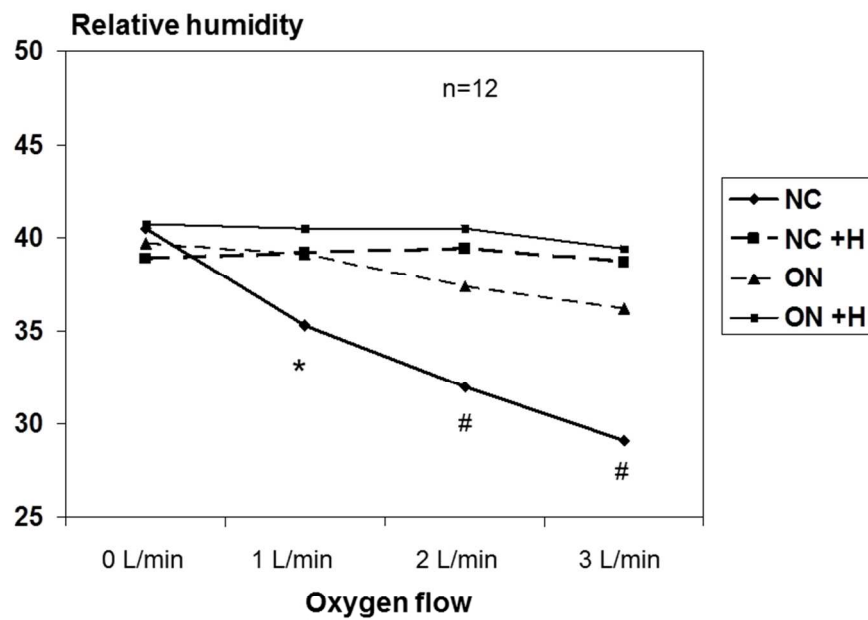
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