Humidity and temperature profile in the nasal cavity*

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SUMMARY

Objectives/Hypothesis: Adequate air conditioning in the nasal airways is mandatory for respiration and gas exchange in the lower respiratory tract. The aim of the present study was to measure relative humidity and temperature in the airstream at different sites within the nasal cavity for mapping of relative humidity and temperature in the upper airways.
Study design: Intranasal relative humidity and temperature of 23 volunteers was measured during respiration at different locations in the nasal cavity. Methods: The end-inspiratory temperature and humidity data, obtained with a miniaturized thermocouple and a capacitive humidity sensor, were determined. Results: A high increase of humidity and temperature at the end of inspiration, in relation to the environmental conditions, was found in the anterior nasal segment. The further increase of both parameters between turbinate area and nasopharynx was less pronounced in spite of the longer distance. Conclusions: The anterior part of the nasal cavity contributes within a short nasal passage to air conditioning of inspired air.

Key words: air conditioning, intranasal humidity, intranasal temperature, nasal airways

INTRODUCTION

The respiratory function includes the preparation of the inspired air for the lower respiratory tract (Ingelstedt and Ivstam, 1951; Cole, 1953; Keck et al., 2000). Within the short distance from the nostrils to the nasopharynx the air is heated, humidified and partially cleaned from particles (Naclerio and Togias, 1992). During expiration water is retained on the nasal mucosa and preserved.

Heating and humidifying of the air are closely related (Ingelstedt and Ivstam, 1951). Temperature increase and especially temperature differences between mucosal surface and ambient air are important for water transfer to the air (Walker and Wells, 1961). However, the detailed processes of air conditioning in the nose are not completely understood yet (Cole, 1951; Ingelstedt and Ivstam, 1951; Dick, 1974; Hanna and Scherer, 1986; Naclerio and Togias, 1992).

In several investigations, an air temperature of about 31 to 34°C and relative humidity of about 90 to 95% in the nasopharynx after inspiration could be observed (Ingelstedt and Ivstam, 1951; Rouadi et al., 1999).

Measurements of temperature at different sites within the nasal cavity showed that the anterior nasal segment seems to be a main area of heating of inspired air (Keck et al., 2000).

However, the most important area for humidification could not be demonstrated yet (Williams et al., 1996; Rouadi et al., 1999). Besides morphological characteristics of the respiratory nasal epithelium, humidification in the nose may depend on the cross-sectional area of the nasal cavity and the direction of the airstream (Hanna and Scherer, 1986). The nasal airflow at different parts of the nasal cavity, depending on the respiratory cycle, determines the contact time between the air and the mucosal surface (Cole, 1992).

The aim of the present study was to measure relative humidity and temperature in the airstream at different locations of the nasal cavity for mapping of both parameters and their relationship.

MATERIAL AND METHODS

Healthy volunteers were included in the study. All experimental procedures were explained in full detail to the participants,

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who provided written informed consent. The study was performed in accordance with the Declaration of Helsinki/ Hongkong (1964/1989) after receiving approval of the local ethic committee.

Volunteers

Twenty-three volunteers were entered into the study (22-42 years; 15 females and 8 males) with an average age of 29 years. The volunteers had no history of nasal surgery or nasal trauma and were nonallergic subjects. All study participants underwent an otorhinolaryngological examination including anterior rhinoscopy and endoscopy of the nasal cavity without application of decongestants or local anesthesia.

Temperature recording equipment

The temperature probe used had a very small outer diameter of 0.34 mm (thermocouple type K, thermo-electric wire consisting of Chromel® and Alumel®, Thermocoax, Suresnes, France; technical temperature range, −200 to +800°C). The actual response time in non moving air is 0.4 s, in high-velocity air 0.1 s. The thermocouple was attached to the suction probe for humidity detection as explained below.

Humidity recording equipment

For detection of relative humidity (RH), a capacitive thin-film humidity sensor (Humichip 17204 HM, Vaisala, Vantaa, Finland) was used. The capacitance of the sensor's polymer film changes sensitively with the absorption of water and is a measure of relative humidity (Ohhashi et al., 1998). The humidity sensor was incorporated in an acrylic glass box and connected to a suction system. Via a silicone suction probe with a length of 7 cm, an outer diameter of 2.5 mm and an inner diameter of 1.5 mm, air was transported to the humidity sensor. The humidity detector was attached to a home made electronical signal processing system.

With this equipment, relative humidity between 0 and 100% could be measured. In high-velocity air it took less than 2 s to reach 90% of the steady-state.

Data processing and calibration system

Temperature and humidity data were transferred to a computer via an analogue-to-digital card and continuously visualized, using the computer program TurboLab (Bressner Technology, Munich, Germany).

Calibration of the humidity sensor was carried out against saturated calibration salt solutions (LiCl 11.3±0.3%, NaCl 75.5±0.1%; HMK15 humidity calibrator, Vaisala, Vantaa, Finland) and results were compared to humidity values obtained by a standardised reference humidity indicator (HM14 and HMP41, Vaisala, Vantaa, Finland).

Registration of the respiratory cycle

The phase of inspiration and expiration during the respiratory cycle was continuously detected using a stress-sensitive belt around the chest of each volunteer (MAP, Martinsried, Germany). The signal of the sensor, integrated in the belt, was amplified and continuously recorded.

Simultaneous temperature and humidity recording

Initially the volunteers had to adapt for 20 to 30 min to the laboratory environment with a room temperature of 25±1°C (±SD) and relative humidity of 35±2% (±SD) while breathing quietly through the nose in an upright position.

Simultaneous humidity and temperature measurements were done by attaching the thermocouple to the suction probe. For measuring at different sites of the nasal cavity, the suction probe was placed 1.5 cm (nasal valve area), 2.5 cm (anterior turbinate area), and 6.0 cm (nasopharynx) posterior to the nostril under endoscopic control without decongestion (Figure 1). During recording, the head of the volunteer was fixed on a head holder. The right side of the nasal cavity of each volunteer was examined.

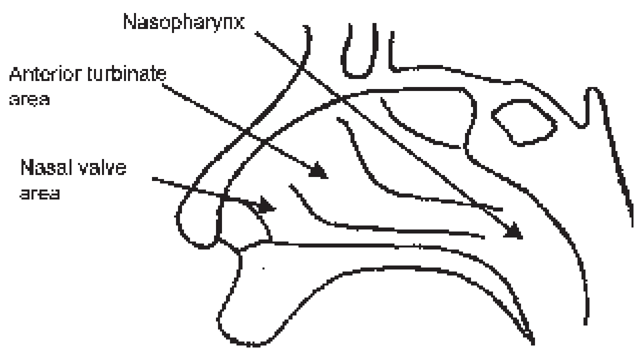

Figure 1. Location of intranasal measurement (arrowheads). The thermocouple and the suction probe are inserted through the nostril to the desired position.

Humidity and temperature in the airstream at each site of the nasal cavity was continuously recorded during respiration at quiet breathing for 1 minute. An interval of 3 minutes between each measurement at different locations within the nasal cavity allowed for mucosal adaption.

Data processing and analysis

For calculation respiratory cycles of 1 minute at each detection site in the nasal cavity were analysed. The mean end-inspiratory and end-expiratory relative humidity (RHaI=relative humidity after inspiration; RHaE=relative humidity after expiration) of one respiratory cycle of 1 minute was calculated. When the end-inspiratory values differed more than 3% RH, measurements were repeated after an interval of 3 minutes. The relative humidity of the ambient air (RHAA) was the reference value and was subtracted from the humidity at the end of inspiration (RHaI) to describe the increase in humidity after inspiration (RHaI-RHAA).

Analysis of temperature was done in the same way (TaI=temperature after inspiration; TaE=temperature after expiration; TAA=temperature of the ambient air; TaI-TAA=temperature at the end of inspiration minus temperature of the ambient air).

The mean of three repeated measurements was used for further calculation and analysis.

RESULTS

A complete set of data could be obtained in all volunteers. There were no individual or technical problems in inserting the probe in the nasal valve area (1.5 cm) or in the anterior turbinate area (2.5 cm). While moving the suction probe towards the nasopharynx (6.0 cm), some discomfort appeared in a few volunteers without the need to interrupt the experiment. Endoscopic control and mucosal adaption prior to measurements were sufficient to avoid influences by mucosal irritation. In rare cases mucus was suctioned while moving the suction probe intranasally. This was indicated by permanent high humidity values (≥93% RH). In this case the silicone probe was removed and a new probe connected to the humidity detector. The intra-individual deviation of humidity was about ±3% RH during repeated measurements. The intra-individual deviation of temperature was approximately ±0.5°C.

Intranasal humidity and temperature recording

The suction probe was first positioned 1.5 cm posterior to the nostril. During inspiration, relative humidity and temperature decreased. During expiration an increase in humidity and temperature was detected. The highest humidity and temperature values were measured at the end of expiration, the lowest humidity and temperature at the end of inspiration. The end-inspiratory humidity and temperature values at the anterior turbinate area (2.5 cm) were higher than at the nasal valve area (1.5 cm), whereas the end-expiratory values did not differ from the values at the nasal valve area. In the nasopharynx (6.0 cm) the difference of end-inspiratory and end-expiratory values (RHaI-RHaE; TaI-TaE) was smaller than at any other location in the nose (Figure 2).

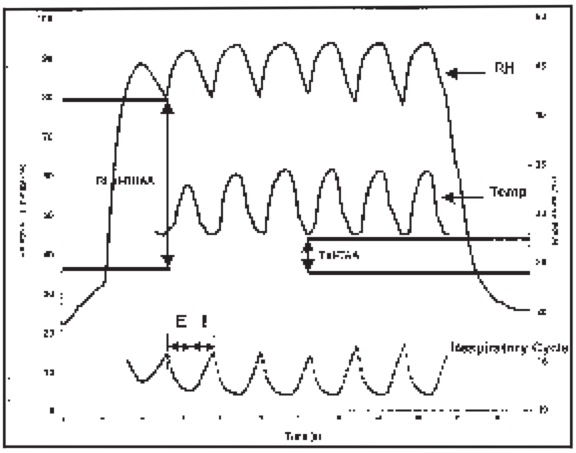

Figure 2. Humidity and temperature recording curve in the nasal cavity of a representative volunteer. The curves of relative humidity (RH) and temperature (Temp) have a sinus-shape. The lowest values indicate the end of inspiration (RHaI;TaI), the highest values indicate the end of expiration (RHaE;TaE). The differences between RHaI and TaI and the ambient air (RHaI-RHAA and TaI-TAA) were used for calculation of saturation and temperature increase during inspiration. The respiratory cycle is simultaneously visualized. Expiration (E) is expressed by a decrease of the curve, inspiration (I) by an increase of the curve.

Relative humidity and temperature at the end of inspiration (RHaI; TaI)

Temperature and relative humidity at the end of inspiration (TaI and RHaI) were used for calculation. Previous experiments had shown that relative humidity at the end of inspiration did not differ significantly from relative humidity detected during a short period of stop of breathing after inspiration, whereas the temperature in the nasal cavity increased during stop of breathing (unpublished data).

The mean temperature at the nasal valve area (1.5 cm) was 28.9±2.3°C (SD), the RH was 69.0±6.5%. At the anterior turbinate area (2.5 cm) temperature and relative humidity increased to 30.3±1,6°C and 78.7±7.2%. In the nasopharynx (6.0 cm) the temperature at the end of inspiration was 32.6±1.5°C. The mean relative humidity was 90.3±5.3% (Figure 3).

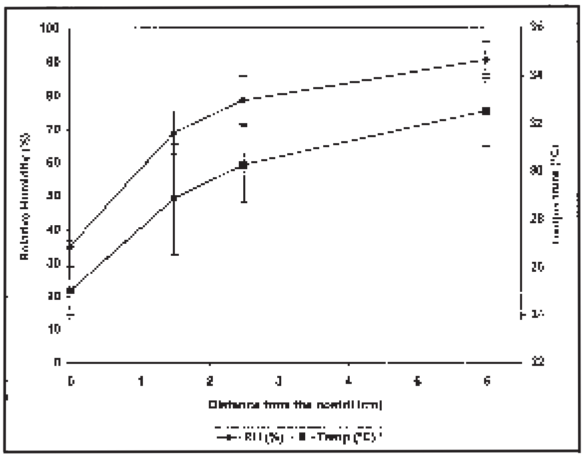

Figure 3. Mapping of temperature and relative humidity in the nasal cavity at the end of inspiration (RHaI;TaI) in 23 volunteers (mean+SD). The temperature and RH of the ambient air are indicated on 0 cm.

Mapping of saturation and temperature increase in the nasal cavity (RHaI-RHAA; TaI-TAA)

The mean differences of relative humidity and temperature at one detection site to the ambient air are shown in Table I. Saturation of air (RH) and temperature (shown as mean±SD) already increased in the anterior part of the nose.

The highest mean end-inspiratory increase in RH and temperature in all volunteers was found between the environment of the volunteer and the nasal valve area (area 1). From the anterior turbinate area to the nasopharynx (area 3) the increase in RH and temperature was the second highest. The lowest increase in RH and temperature could be measured from the nasal valve area to the anterior turbinate area (area 2; Table II).

Table 1. Increase in relative humidity and temperature within the nasal cavity compared to the ambient air (Rhal-RHAA; Tal; TAA; n=23; mean ±SD).

Intranasal location	Relative Humidity (%)	Temperature (°C)
1.5 cm	34.0 ± 7.2 (±SD)	3.9 ± 1.6 (±SD)
2.5 cm	43.7 ± 8.4 (±SD)	5.3 ± 1.1 (±SD)
6.0 cm	55.3 ± 6.6 (±SD)	7.6 ± 0.9 (±SD)

Table 2. Saturation and temperature differences between two intranasal locations (n=23, mean ± SD)

Nasal Segment	Relative Humidity (%)	Temperature (°C)
area 1	34.0 ± 7.2 (±SD)	3.9 ± 1.6 (±SD)
area 2	9.7 ± 6.1 (±SD)	1.4 ± 1.0 (±SD)
area 3	11.6 ± 6.2 (±SD)	2.3 ± 0.8 (±SD)

DISCUSSION

Adequate air conditioning in the nasal airways is mandatory for respiration and gas exchange in the lower respiratory tract. So far, no data for humidity changes in the nasal cavity during inspiration have been published. The present study was designed to demonstrate the increase in relative humidity and temperature at different parts of the nasal airways during respiration.

For this purpose, modern technology was used. Humidity data were obtained by a capacitive humidity sensor connected to a suction tube. To reduce condensation of water in the tube the whole distance of the tip of the probe to the humidity sensor was only 7 cm. Previous studies showed that the loss of water was negligible with this equipment (unpublished data). The outer diameter of the probe (2.5 mm) was small enough to allow insertion without decongestion. Temperature was measured with a thermocouple at the tip of the suction probe. This device previously demonstrated to be suitable for intranasal measurements within the airsteam (Keck et al., 2000). Both components of our measurement setup allowed to obtain data to describe air conditioning within the nasal airways.

The in-vivo measurements are complicated and influenced by a variety of factors. These can partially be eliminated by comparing values of different locations obtained with the same equipment. On the other hand, reproducibility of the measurements is obvious within a certain range as shown by the intra-individual deviations of ±0.5°C and ±3% RH, respectively.

While former measurements of humidity were done by means of psychrometers (Ingelstedt and Ivstam, 1951), mass spectrometers were nowadays used for detection of absolute humidity (mg/L) in the upper respiratory tract (Hair et al., 1969; Primiano et al., 1984; Nahr et al., 1994). Wissing et al., and Rouadi et al., used a measurement setup for relative humidity that is similar to our equipment (Wissing et al., 1997; Rouadi et al., 1999). Setups for detection of relative humidity can demonstrate how close a gas is to saturation. With a near-infrared hygrometer, presented by Wilson et al., the fastest detection of short-term absolute humidity changes was feasible, whereas clinical data on the basis of this equipment were not yet reported (Wilson et al., 1995).

In our study relative humidity (reflecting the saturation of air at a certain temperature) could be detected during respiration at different locations within the nasal cavity. Different sites of the nasal airways showed different end-inspiratory characteristics of relative humidity. A high increase in saturation of air at the end of inspiration, compared to the relative humidity of the ambient air, was found in the anterior nasal segment. During the nasal passage the saturation of inspired air increased and reached values between 90 and 95% RH in the nasopharynx. The mapping of relative humidity increase in the nasal cavity at the end of inspiration was parallel to the temperature increase. It can be assumed that already the anterior part of the nasal cavity is important for air conditioning of inspired air of normal temperature and humidity.

Ingelstedt measured temperatures of about 31°C and about 95% relative humidity in the nasopharynx under normal environmental conditions (Ingelstedt and Ivstam, 1951). However, the psychrometer in his experiments did not respond fast enough to be used during respiration. In a theoretical model of heat and water transport in the airways, a similar air conditioning pattern in the nose was described on the basis of ambient air of 23°C and 30% RH (Hanna and Scherer, 1986). Changes of relative humidity during inspiration and expiration in the nasopharynx were similar to our results even if measurements were performed during nasal breathing only through one nostril because the other nasal cavity was closed by the detection equipment (Rouadi et al., 1999).

While data for humidity in the nasopharynx are available, humidity at different locations within the nasal airways has not been exactly detected yet. Webb performed temperature, but not humidity measurements within the upper airways at depths of 1, 5, and 9 cm from the nostrils (Webb, 1951). According to our results (Keck et al., 2000), the anterior part of the nose seemed to contribute remarkably to heating of the inspired air.

To explain the specific role of the anterior nasal segment in air conditioning of inspired air, anatomical aspects and airflow characteristics of this area have to be discussed.

During inspiration water is added intranasally to the inspired air by recovery from expiratory air and secretions of the nasal mucosa, while other sources of water supply have been suggested to be of minor importance (secretions from the paranasal sinuses and lacrimal glands) (Aust and Drettner, 1974). Small seromucous glands, which were found in higher density in the anterior part of the nasal septum and the turbinates than in the posterior parts (Tos and Mogensen, 1976), may act as important water sources. Serous anterior nasal glands, which are located in the nasal vestibule and the nasal valve area, may also add water to the inspired air (Bojsen-Moller, 1965), even if their importance in humans could not be demonstrated yet. Water supply by glandular secretions may increase the water content of the inspired air and, due to the high specific heat and thermal conductivity of water, a high increase in temperature of the air may follow rapidly. The decrease of the humidifying capacity of the nose after suppression of glandular secretion by atropine (Ingelstedt and Ivstam, 1951) underline the role of the nasal glands in moistening of the inhaled air.

Even if the saturation of air already increases in the anterior nasal segment, there is still further need of water supply in the middle and posterior part of the nose which is mainly characterised by the turbinates. The temperature of the inspired air continues to increase during the nasal passage and, therefore, the air can keep a bigger amount of water vapor (i.e., increased maximum capacity at an increased temperature of the air) which is mainly supplied by the mucosa of the turbinates. However, our results may indicate a minor role of the turbinates in humidifying and heating of the inhaled air as previously suggested (Webb, 1951). Observations in animals with simple turbinates, but sufficient air conditioning capacity of the nose (Scott, 1953), support our results of nasal air conditioning not only being related to turbinate function. A smaller contribution of the nasal mucosa to air conditioning as previously suggested, was also found when experiments with a heat- and moisture-exchanger in front of the mouth during oral respiration showed effective air conditioning in spite of excluding the nose from respiration (Cole, 1953).

The nasal airflow pattern has also to be considered in discussing air conditioning during inspiration. Already in the nasal valve area the laminar flow pattern of the inspired air gets disrupted and the air comes into closer contact to the nasal mucosa. The change of airflow allows mixing of the air of the centre of the airstream with the boundary layer of air on the surface of the mucosa which gets rapidly humidified and heated. Because of a secondary flow with a lateral movement of the airflow in the anterior nasal segment (Cole, 1992), the contact time of the inspired air with the nasal mucosa seems to be long enough to allow heating and sufficient water vapor evaporation from the mucosal surface in this area in spite of the overall high air speed velocity.

Because of the special importance of the anterior nasal segment in air conditioning, medical or surgical treatment of this area can interfere with heating and humidification of air in the nose. Since the discussed observations in the nasal airways were found during respiration in normal conditions, further studies on air conditioning during respiration of air of more extreme temperatures and humidities will be performed.

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