

Influence of the turbinate volumes as measured by magnetic resonance imaging on nasal air conditioning

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ABSTRACT

Background: Changes in nasal airflow caused by varying intranasal volumes and cross-sectional areas affect the contact between air and surrounding mucosa entailing alterations in nasal air conditioning. This study evaluates the correlation between nasal air conditioning and the volumes of the inferior and middle turbinates as measured by magnetic resonance imaging (MRI).

Methods: Fourteen healthy volunteers were enrolled. Each volunteer had been examined by rhinomanometry, acoustic rhinometry, intranasal air temperature, and humidity measurements at defined intranasal sites as well as MRI of the nasal cavity and the paranasal sinuses. The volumetric data of the turbinates was based on the volumetric software Amira.

Results: Comparable results were obtained regarding absolute humidity values and temperature values within the nasal valve area and middle turbinate area for both the right and the left side of the nasal cavity. No statistically significant differences were found in the rhinomanometric values and the acoustic rhinometry results of both sides ($p > 0.05$). No statistical correlations were found between the volumes of the inferior (mean, 6.1 cm^3) and middle turbinate (mean, 1.8 cm^3) and the corresponding humidity and temperature values. Additionally, the air temperature and humidity values did not correlate with the rhinometrical endonasal volumes (0–20 mm and 20–50 mm from the nasal entrance).

Conclusion: The normal range of volumes of the inferior and middle turbinate does not seem to have a significant impact on intranasal air conditioning in healthy subjects. The exact limits where alterations of the turbinate volume negatively affect nasal air conditioning are still unknown.

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Key words: Acoustic rhinometry, air conditioning, intranasal humidity, intranasal temperature, magnetic resonance imaging, rhinomanometry, turbinate volume

Nasal air conditioning embracing heating and humidification of the inhaled air is one of the main functions of the nose. The nasal cavity volume and the temperature of the nasal mucosa seem to be the most important factors regulating the effectiveness of nasal conditioning as shown previously by means of a theoretical computer model.¹

During inhalation air passes through the anterior nasal segment and the airflow changes from a laminar one to a turbulent one, causing an increased exposure to the nasal mucosa.² The close relation between airflow patterns and heating of inspired air could be shown in various numerical simulations of intranasal airflow and temperature during inspiration and expiration.^{3–5}

The anterior nasal segment, including the nasal valve area and the anterior turbinate area, as well as the volumes of the turbinates, significantly affect the intranasal airflow. Any changes in airflow patterns alter the contact between air and nasal mucosa, causing changes in nasal air-conditioning patterns. Too extensive surgical resection of the turbinates results in a malfunctioning intranasal air conditioning because of

disturbed airflow patterns as well as an enlargement of the nasal volume combined with a reduced mucosal surface.^{5–7}

We were able to previously establish that intranasal *in vivo* measurements of intranasal air temperature and humidity are technically feasible.^{8–10} However, data on the relation between the turbinate volumes and intranasal air conditioning in healthy subjects are still missing. Therefore, the aim of this study was to examine the possible influence of the turbinate volumes on intranasal heating and humidification of the respiratory air.

MATERIALS AND METHODS

The aim of this study and the experimental setup were explained in detail to all volunteers. Written informed consent was provided by all volunteers for their participation in the experimental measurements and magnetic resonance imaging (MRI) scan. The study was approved by the local ethical committee.

Volunteers

Fourteen healthy nonsmoking volunteers (6 men and 8 women) with a median age of 39 years (range, 20–69 years) were enrolled in the study. In total, 28 nasal cavities were examined. All volunteers underwent a complete otolaryngological examination including anterior rhinoscopy and nasal endoscopy. Exclusion criteria were septal deformities, history of nasal surgery, allergic rhinitis, or nasal infection within the last 4 weeks and the regular use of local decongestants, steroids, or antihistamines. First, all volunteers had to adapt to

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the laboratory environment (median room temperature, 22.0°C [range, 19.1–22.6°C]; relative humidity, 30.0% [range, 27.0–41.0%]) for 15 minutes while quietly breathing through the nose in an upright position.

Active anterior rhinomanometry, acoustic rhinometry, and intranasal temperature and humidity recording at defined intranasal detection sites were consecutively performed in all volunteers. Promptly after these examinations, MRI scans of the head, including the entire nasal cavity with the turbinates were performed.

The measurements were sequentially performed in the aforementioned order with breaks of 5 minutes. To avoid bias caused by the influence of periodical congestion and decongestion within nasal cycle,² the measurements were performed on a tight schedule (duration of all procedures ~1 hour).

Active Anterior Rhinomanometry and Acoustic Rhinometry

Active anterior rhinomanometry (model Rhinomanometer 300, transnasal reference pressure, 150 Pa; Atmos, Lenzkirch, Germany) was performed on both nasal cavities, after the adaptation period. The rhinomanometer had been calibrated before use. Three to five nasal breaths were used to average the results according to the congruence of the curves.

Acoustic rhinometry (model SRE 2000, RhinoMetrics, Lyngby, Denmark) was also performed in all volunteers. At least three measurements from each nostril were recorded. The following parameters were calculated: median minimal cross-sectional areas (MCA1, 0–20 mm from the nasal entrance; MCA2, 20–50 mm from the nasal entrance) and nasal volumes (Vol1, 0–20 mm from the nasal entrance; Vol2, 20–50 mm from the nasal entrance). The external noise, room temperature, and humidity conditions and the position angle of the sound wave tube were kept constant. All measurements were performed according to the recommendations of the International Standardization Committee for accomplishment of rhinomanometry and acoustic rhinometry.¹¹

Simultaneous Temperature and Humidity Recording

A miniaturized thermocouple (thermocouple type K thermoelectric wire consisting of Chromel and Alumel; Thermo-coax, Suresnes, France,) with an outer diameter of 0.34 mm was used for the measurement of the intranasal temperature. The measured temperature range is from –200 to +800°C. The actual response time of the thermocouple is 0.4 seconds in nonmoving air and 0.1 seconds in high-velocity air.

For the detection of relative humidity, a thin film sensor (Humichip 17204 HM; Vaisala, Vantaa, Finland) was used. The sensor was placed in an acrylic glass box, connected to a suction system. The intranasal air was transferred to the humidity sensor through a silicon suction probe. In high-velocity air, 90% of relative humidity could be reached in <2 seconds. Values of relative humidity between 0 and 100% could be recorded.

Simultaneous intranasal humidity and temperature measurements were obtained through the attachment of the thermocouple to the suction probe. The thermocouple and the suction probe were carefully placed in the center of the airstream at the level of the nasal valve area in front of the head

of the inferior turbinate and within the area medially from the anterior part of the middle turbinate (anterior turbinate area) by means of a nasal speculum and a headlight (Fig. 1). The correct placement of the suction probe was verified by cautious temporary nasal endoscopy without causing local irritation. The use of this technical setup had been standardized in previous studies^{7–9,12,13} being a well-established method for objective measurements of intranasal temperature and humidity values under various conditions.

Both nasal cavities of each volunteer were consecutively measured ($n = 28$), always starting on the right side. All measurements were performed by the same well-trained examiner. The volunteers were sitting in an upright position with their head stabilized in a head holder. The temperature and humidity values were continuously recorded during quiet breathing for 1 minute. During the measurements, the respiratory cycle (inspiration and expiration) was detected by means of a sensor integrated in a chest stress-sensitive belt. The signal from the sensor was amplified and continuously recorded.

Data Processing and Analysis

Respiratory cycles of 1 minute were analyzed. The mean end-inspiratory temperature and humidity of one respiratory cycle were calculated after at least five consecutive repeated inspiration efforts following each other showing a deviation of end-inspiratory temperature values of <3%. In cases of an increased deviation, measurements were repeated after an interval of 5 minutes.

The temperature and humidity data were amplified and transferred to a computer by means of an analog-digital card. Data registration was accomplished by means of the computer program Turbo Laboratory (Bressner Technology, Munich, Germany). The values of temperature and relative humidity were used for the calculation of the absolute humidity values (g/m^3).

Volumetric Measures of the Turbinates by MRI Scans

The MRI scans were performed by means of a head array coil (1.5-tesla scanner, Avanto; Siemens, Erlangen, Germany). The MRI sequences were acquired in coronal planes including the entire nasal cavity and paranasal sinuses. Three-dimensional (3D) T2 weighted sequences (3D Fourier transformation constructive interference in steady state, CISS sequence)

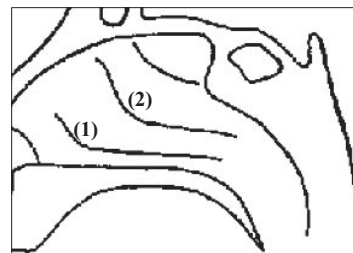


Figure 1. Intranasal detection sites of air temperature and humidity measurements: (1) nasal valve area and (2) anterior turbinate area. The combined thermocouple and the suction probe were placed in the center of the airstream.

were performed with the following parameters during the examination: TE, 3.41 ms; TR, 6.82 ms; slice thickness, 1 mm iso; matrix size, 256 × 256; rectangular FoV 200 mm; and a flip angle of 55°. A contrast medium was not applied. The duration of each MRI scan was ~15 minutes. The obtained images were transferred to a compatible workstation for digital processing.

The volumetric analysis of the inferior and middle turbinates was performed using the commercial software Amira 4.0 (Visage Imaging, Inc., Carlsbad, CA). Amira is a 3D visualization and modeling system. The volumes of the turbinates in cubic centimeters were calculated by manual slice-by-slice contour tracing (Fig. 2).

Statistical Analysis

For statistical analysis, the software Win STAT Version 2007.1 (Kalmia, Inc., Cambridge, MA) was used. The nonparametric Wilcoxon signed-rank test was used to compare the values of rhinomanometry and acoustic rhinometry, the temperature, and absolute humidity values as well as the volumes of the turbinates of the right and the left side. The null hypothesis (no difference between the values of the right and the left side) was to be rejected at the $\alpha = 0.05$ significance level. The Spearman signed-rank test was performed to calculate a possible correlation between the end-inspiratory temperature as well as humidity values and the corresponding turbinate volumes.

RESULTS

A complete set of data could be obtained in all 28 nasal cavities of the 14 volunteers. No statistically significant differences between the values of the right and left nasal cavity could be observed regarding the rhinomanometric and acoustic rhinometric results ($p > 0.05$). The values of the inspiratory flow rate, MCA1, MCA2, Vol1, Vol2, and the p values for the comparison between the two nasal cavities are shown in Table 1.

The median unilateral end-inspiratory temperature/absolute humidity was 24.0°C (range, 19.6–30.7°C)/15.4 g/m³

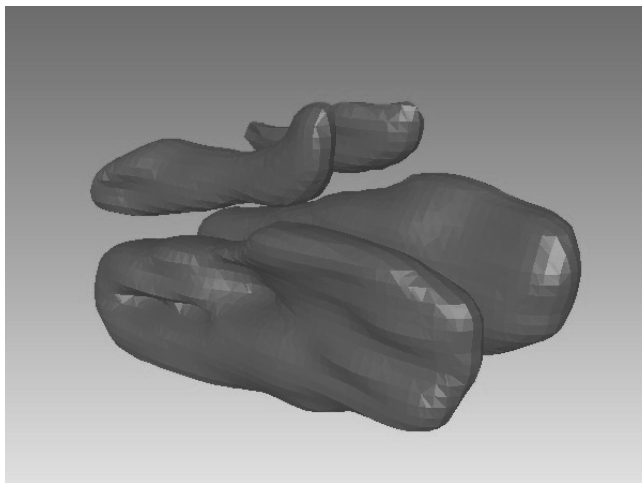


Figure 2. Three-dimensional volume model of the inferior and middle turbinate of the right and the left nasal cavity in lateral, frontal view.

(range, 11.6–23.5 g/m³) in the nasal valve area and 22.5°C (range, 19.2–30.7°C)/14.5 g/m³ (range, 10.8–23.8 g/m³) in the anterior turbinate area.

There were no statistically significant differences between the right and the left side of the nose regarding temperature and humidity values. Especially within the nasal valve area, temperature and absolute humidity measurements did not statistically significantly differ ($p = 0.41$ and $p = 0.36$). Comparable results were obtained within the anterior turbinate area ($p = 0.17$ and $p = 0.63$).

As estimated by the applied AMIRA software, the median volume of the inferior turbinate was 6.1 cm³ (range, 4.1–7.3 cm³) and the median volume of the middle turbinate was 1.8 cm³ (range, 1.0–3.6 cm³). There were no statistically significant differences between the turbinate volumes of the right and the left side. For the middle turbinate $p = 0.08$ and for the inferior turbinate $p = 0.55$.

There were no statistically significant correlations between the turbinate volumes and the measured temperature and absolute humidity values (Table 2). Additionally, the statistical analysis did not reveal any correlation between temperature and humidity values on the one side and volumes and MCAs of the nasal cavity on the other side. The resulting r values are presented in Table 2.

DISCUSSION

Heating and humidification of the respiratory air are taking place within the entire nasal cavity, particularly within the anterior nasal segment.^{12,13} The detection sites are located within the major areas contributing to the air-conditioning capacity of the nose.^{8,13} In previous studies it was shown that the main increase in temperature and humidity values of inhaled air is primarily located within the anterior nasal segment.^{8,12} On the contrary, measurements at the level of nasopharynx showed no relevant contribution of the posterior nasal segment to the overall nasal air-conditioning capacity.^{8,12}

The regions of the turbinates seem to represent the factual functional section of the nose.^{4–7} Surgical alterations of the inferior and middle turbinate, in particular radical resection, lead to a malfunctioning intranasal air conditioning caused by disturbed airflow patterns as well as an enlargement of the nasal volume combined with a reduced mucosal surface.^{5–7}

We present the first study attempting to evaluate a possible influence of the turbinate volumes on intranasal air conditioning. Correlations between MRI-based volumes of the inferior and middle turbinates and the intranasal climate had been assessed.

One of the main conclusions of this study is that there is no statistical correlation between turbinates volumes, temperature values, and humidity values. Additionally, no correlation was found between the intranasal temperature and humidity values and the endonasal volumes measured by acoustic rhinometry.

Although the enhancement of nasal cavity volume due to turbinate resections can result in a reduced intranasal heat and water exchange,^{5–7} this study shows that interindividual differences in the nasal cavity volumes and the turbinate volumes do not have a detectable impact on nasal air conditioning. The clinical relevance of this finding is that intranasal

Table 1 Median values and range (minimum and maximum) of the rhinomanometry and acoustic rhinometry for right, left, and both sides of the nasal cavity

	Median Right Side (min–max) <i>n</i> = 14	Median Left Side (min–max) <i>n</i> = 14	<i>p</i> Value (right–left)	Median Both Sides (min–max) <i>n</i> = 28
Rhinomanometry				
Inspiratory flow rate (cm ³ s ^{−1})	256.50 (216–468)	297 (18–369)	0.8017	270 (180–468)
Acoustic rhinometry				
MCA1 (0–20 mm in cm ²)	0.50 (0.16–1.04)	0.45 (0.30–0.96)	0.1981	0.5 (0.2–1.0)
MCA2 (20–50 mm in cm ²)	0.55 (0.20–2.91)	0.49 (0.13–1.59)	0.1519	0.5 (0.1–1.0)
Vol1 (0–20 mm in cm ³)	1.81 (1.22–4.54)	1.73 (1.23–3.20)	0.1874	1.8 (1.2–4.5)
Vol2 (20–50 mm in cm ³)	3.98 (1.81–16.36)	3.28 (1.46–33.10)	0.2719	3.6 (1.5–8.2)

Comparison results between values of right and left side of the nose are presented by *p* values ($\alpha \leq 0.05$).

max = Maximum; min = minimum; MCA1 = minimal cross-sectional area 0–20 mm from the nasal entrance; MCA2 = minimal cross-sectional area 20–50 mm from the nasal entrance; Vol1 = nasal volume 0–20 mm from the nasal entrance; Vol2 = nasal volume 20–50 mm from the nasal entrance.

Table 2 Correlation *r*-values (Spearman signed-rank test) between acoustic rhinometry measurements, volumes of inferior as well as middle turbinate, and temperature and absolute humidity values

		MRI-Based Measurements		Acoustic Rhinometry			
		Vinf	Vmid	MCA1	Vol1	MCA2	Vol2
Temperature	Tnva	−0.05	0.06	−0.003	0.22	−0.02	−0.05
	Tata	−0.28	−0.05	−0.08	0.06	−0.10	−0.28
Absolute humidity	aHnva	0.07	0.15	0.22	0.20	0.23	0.07
	aHata	−0.25	−0.08	−0.03	−0.02	−0.01	−0.25

MCA1 = bilateral median minimal cross-sectional area 0–2 cm from the nasal entrance; MCA2 = bilateral median minimal cross-sectional area 2–5 cm from the nasal entrance; Vol1 = nasal volume 0–2 cm from the nasal entrance; Vol2 = nasal volume 2–5 cm from the nasal entrance; Vinf = volume of inferior turbinate; Vmid = volume of middle turbinate; Tnva = temperature within nasal valve area; Tata = temperature within anterior turbinate area; aHnva = absolute humidity within nasal valve area; aHata = absolute humidity within anterior turbinate area.

air conditioning is not affected by volumetric changes within a normal range of healthy subjects when the nasal mucosa is intact and pristine.

The fact that small changes in the turbinate volumes do not significantly affect nasal air conditioning is also supported by data on the topical application of the vasoconstrictor xylo-metazoline. Despite the enlargement of the nasal cavity and the enhancement of the turbinate volume, no significant changes of intranasal humidity and the temperature profile could be observed.¹⁴

Additionally, in agreement with various previous studies, no significant differences in humidity and temperature values between the right and the left nasal cavity could be observed in healthy subjects,^{3–5,12,13,15} indicating that the state of mucosal swelling caused by the nasal cycle is not responsible for air-conditioning alterations. Furthermore, the nasal cycle does not seem to influence the end-inspiratory degree of intranasal water vapor saturation.¹⁵ The periodical congestion and decongestion of the venous sinusoids in the nasal mucosa seems to play a significant role in respiratory defense through generation of plasma exudate. This flow of plasma flushes out

invading microorganisms and contains immunoglobulins and inflammation mediators that are well-known factors of the defense mechanism of the respiratory system.² However, both the asymmetry and the state of congestion of turbinates generated by the nasal cycle are more pronounced in a condition of nasal infection and allergic inflammation, resulting in a reduced nasal volume. Interestingly, in cases of allergy the air-conditioning ability of the nose was found to be improved after provocation with cold and dry air.¹⁶

Concerning extended resection of the inferior turbinates in a fluid dynamic model, a significant disturbance of the intra-nasal temperature and humidity profile could be seen.^{5,6} *In vivo* investigations revealed that radical unilateral turbinate surgery in the treatment of unilateral inverted papilloma leads to reduced temperature and humidity values on the surgically treated side as a result of the enlarged nasal cavity volume and the loss of the mucosal surface.⁷

In contrast, nasal air-conditioning capacity seems to be significantly improved in a collective sample of septorhinoplasty cases combined with inferior turbinoplasty.¹⁷ Similar results could be obtained in another *in vivo* study regarding

postoperative air conditioning after endoscopic sinus surgery with or without septoplasty and turbinoplasty¹⁸.

The threshold of the turbinate volume decrease, where the impact on nasal air conditioning becomes negative, is unclear. Therefore, additional clinical trials assessing different types of turbinate surgery in detail are necessary. In this way, the limits of mucosal resection within the nose simultaneously protecting the important nasal functions may be revealed.

According to Mlynski *et al.*, the turbinate areas from an aerodynamic point of view, represents a slit-like space that facilitates intense contact of air and mucosa because of its small width.¹⁹ Although the head of the inferior turbinate plays a major role within this context, other structures of the nasal cavity such as the nasal valve area and cross-sectional areas may also contribute to the particular aerodynamics in this region.²⁰

Our results should be considered as values reflecting the nasal air-conditioning capacity only in adulthood. In a previous study we showed that increased nasal volumes and minimal cross-sectional areas in the elderly are accompanied by a decrease in intranasal temperature and humidity values.²¹ This could be probably associated with the functional decline of respiratory mucosa caused by atrophy rather than changes of nasal cavity dimensions.

CONCLUSION

Small variations of the turbinate volumes and the volumes of the nasal cavities do not seem to substantially influence nasal air conditioning in healthy subjects. The exact limits where alterations of the turbinate volume negatively affect nasal air conditioning are still unknown. Within this context the limits of turbinate resection also need to be clarified.

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