Nasal-Air Conditioning in Patients With Chronic Rhinosinusitis and Nasal Polyposis

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Objectives: To compare nasal-air conditioning in patients with chronic rhinosinusitis with nasal polyposis with healthy control subjects without nasal pathologic conditions, to investigate nasal-air conditioning after endoscopic sinus surgery with and without septoplasty and turbinoplasty 4 to 6 weeks after surgery, to examine the parameters of nasal patency and nasal geometry that possibly influence nasal-air conditioning before and after endonasal surgery, and to determine their relationship to nasal-air conditioning parameters.

Design: Prospective cohort study.

Setting: Tertiary referral center.

Participants: Twenty-five patients (median age, 51 years; age range, 20-74 years) having a diagnosis of chronic rhinosinusitis with nasal polyposis refractory to medical treatment and 22 healthy control subjects (median age, 25 years; age range, 18-52 years).

Intervention: Patients underwent endoscopic sinus surgery with or without septoplasty and turbinoplasty during 6 months and were followed up 4 to 6 weeks after surgery.

Main Outcome Measures: Nasal-air conditioning was measured and acoustic rhinometry and active anterior rhinomanometry were performed before and after nasal surgery.

Results: Nasal airflow and nasal volume were significantly higher postoperatively than preoperatively. The preoperative heat increase and water gradient were lower in the patients compared with the controls. The postoperative heat increase was significantly higher than the preoperative values. The water gradient did not change after endonasal surgery. Nasal patency and volume were positively correlated with nasal heating, whereas nasal humidification showed a significant negative correlation with nasal volume.

Conclusions: Patients with chronic rhinosinusitis with nasal polyposis seem to benefit from endoscopic sinus surgery with or without septoplasty and turbinoplasty because nasal heating is improved postoperatively. Four to 6 weeks after endonasal surgery, nasal humidification is neither improved nor worsened compared with preoperative values.

nasal patency and nasal geometry that possibly influence nasal-air conditioning before and after endonasal surgery and determined their relationship to nasal-air conditioning parameters.

**METHODS**

**PATIENTS**

After receiving approval of the Institutional Review Board of the Ethics Committee of the University of Ulm (Ulm, Germany; application 02/2000), 38 patients with CRSNP+ who were scheduled to undergo ESS were enrolled in this prospective cohort study. Each patient had undergone a course of unsuccessful conservative treatment. The diagnosis was established on the basis of a thorough medical history, examination of the internal nose, nasal endoscopic findings, active anterior rhinomanometry, acoustic rhinometry, skin prick tests, and computed tomography (CT) of the paranasal sinuses. Exclusion criteria were age younger than 18 years or older than 80 years, pregnancy, serious internal or neurologic disease, previous nasal surgery, and receipt of long-term corticosteroid therapy (>2 months). Antiallergy therapy (ie, treatment with oral or nasal antihistamines, cromolyn sodium, or nasal decongestants) was discontinued at least 5 days before enrollment in the study.

To achieve a homogeneous study group, only patients with a CT score exceeding the minimum for 1 side of the nose (≥4) and endoscopically visible nasal polyps (Malm score ≥1) were included. Twenty-five patients (median age, 51 years [age range, 20-74 years]; 10 women and 15 men) fulfilled the criteria for the present study and were followed up 4 to 6 weeks postoperatively. According to the staging system for nasal polyps recommended by Malm, the median poly score before ESS was 2 (mean, 2.0; range, 1-3). According to the CT staging system of Lund and Mackay, the median CT score of 48 nose sides in 25 patients before surgery was 7 (mean, 7.46; range, 4-12). Data for the patients were compared with data for 22 healthy control subjects (median age, 25 years [age range, 18-52 years]; 12 women and 10 men). The controls had no medical history of chronic sinusitis. No pathologic findings were noted in the paranasal sinuses as examined at both nasal endoscopy and B-scan ultrasonography.

**SURGICAL PROCEDURES**

Nasal surgery was performed using general anesthesia. All surgical interventions were performed at the Department of Otorhinolaryngology, University of Ulm. Interventions included unilateral ESS in 2 patients and bilateral ESS in 23 patients. Sinus surgery was performed using the technique described by Stammberger and Posavetz and Wigand. The first step of the procedure consisted of polypectomy. In the second step, infundibulotomy was followed by middle meatal antrostomy, opening of the bulla, clearance of the anterior and posterior ethmoidal cells, and opening of the nasal lamella in all cases. Further clearance of the frontonasal recess and sphenoethmoid sinus was performed as indicated by the pathologic findings. The middle turbinates were routinely left intact.

In 14 patients, septoplasty was performed. In these cases, polymeric silicone splints were sutured to the nasal septum with a through-and-through septal suture at the end of surgery. In 5 patients, a submucosal anterior turbinateplasty of the inferior turbinate including resection of the turbinate bone after submucous separation was performed on both sides. Bilateral, expandable, fiber-free, cellulose-free polyvinyl acetate sponges (Merocel; Medtronic ENT, Jacksonville, Florida) were used routinely in all patients for 1 day.

Postsurgical follow-up examinations and cleaning of the ethmoid cavity were performed weekly for 4 to 6 weeks. No complications occurred during or after sinus surgery in the patient group. Four to 6 weeks after surgery, the ethmoid cavities and middle meatal antrostomies were patent in all patients.

**ACOUSTIC RHINOMETRY**

Acoustic rhinometry (SRP 2000; Rhinometrics A/S, Lyngby, Denmark) was used for evaluation of nasal geometry on both sides. The mean total volume of the anterior nasal cavity (22 mm [vol 1]) and the mean total volume of the nasal cavity (22-54 mm [vol 2]) were measured. The mean minimal cross-sectional areas (MCA1, 0-22 mm from the nasal entrance, and MCA2, 22-54 mm from the nasal entrance) were measured according to current recommendations. The intranasal volume of the nasal cavity (22 and 54 mm from the nasal entrance) was used for further analysis because it is the best parameter to characterize changes after ESS and resection of nasal polyps.

**ACTIVE ANTERIOR RHINOMANOMETRY**

Active anterior rhinomanometry (Rhinomaster 300; ATMOS Medizintechnik GmbH & Co KG, Lenzkirch, Germany) (transnasal reference pressure, 150 Pa) before and after nasal surgery was performed in all participants according to current recommendations of the Committee Report on Standardization of Rhinomanometry. Values were obtained before and after nasal decongestion. Only values without decongestion were analyzed.

**MEASUREMENT OF NASAL-AIR CONDITIONING**

Intranasal measurements of temperature and humidity before and 4 to 6 weeks after sinus surgery were performed as described previously. Humidity and temperature of the air in the choanae of both nasal cavities (ie, a total of 48 values for each parameter) were detected and used for further calculation. The temperature of the nasal mucosa was not used to describe changes in nasal-air conditioning in this study.

Initially, the patients were allowed to adapt for 20 to 30 minutes to the laboratory environment with a mean (SD) room temperature of 22°C (1°C), relative humidity of 26% (5%), and absolute humidity of 5.3 (1.2) g/kg of air while breathing quietly through the nose while they were in an upright position. In brief, signals of an intranasally placed thermocouple that was connected to a relative humidity sensor were compared with temperature and relative humidity signals that were simultaneously recorded directly in front of the participant’s nostrils. The relative humidity sensor used was a capacitive thin-film humidity sensor (Humichip 17204 HM; Vaisala Oyj, Vantaa, Finland) incorporated in an acrylic box and connected to a suction system. With this equipment, relative humidity between 0% and 100% could be measured. In high-velocity air, less than 2 seconds were required to reach 90% of steady state. A thermocouple device with an outer diameter of 0.34 mm (thermocouple type K, thermoelectric wire consisting of nickel-chrome alloys [chromel and alunel]; Thermocoax SAS, Suresnes, France) was used for temperature recording. Its actual response time in nonmoving air was 0.4 seconds; the response time in high-velocity air was 0.1 second. The reference humidity and temperature outside of the nose were obtained using a standardized reference temperature and humidity indicator (HM41 and HM45; Vaisala Oyj). Continuous registration was achieved using a commercially available computer program (Visual Designer 4.0; Intelligent Instrumentation Inc, Tucson, Arizona). Calibration of the humidity sensor was regularly carried out against saturated calibration salt solutions (mean [SD]: temporal parameters.
Table 1. Values Detected Using Acoustic Rhinometry (Nasal Volume 2) and Active Anterior Rhinomanometry Before and After Endoscopic Sinus Surgery With or Without Septoplasty and Turbinoplasty in 25 Patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic rhinometry, cm³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>4.79</td>
<td>4.66</td>
<td>4.20</td>
<td>5.16</td>
<td>.004</td>
</tr>
<tr>
<td>Postoperative</td>
<td>5.91</td>
<td>4.66</td>
<td>2.55</td>
<td>11.59</td>
<td>.03</td>
</tr>
<tr>
<td>Postoperative minus preoperative value (95% CI)</td>
<td>1.12</td>
<td>0.85</td>
<td>-.65</td>
<td>9.83</td>
<td></td>
</tr>
<tr>
<td>Rhinomanometry, cm³/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>157</td>
<td>144</td>
<td>0</td>
<td>420</td>
<td></td>
</tr>
<tr>
<td>Postoperative</td>
<td>249</td>
<td>226</td>
<td>76</td>
<td>868</td>
<td></td>
</tr>
<tr>
<td>Postoperative minus preoperative value (95% CI)</td>
<td>92</td>
<td>82</td>
<td>-177</td>
<td>427</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: CI, confidence interval.

The end-inspiratory endonasal relative humidity (RH) and temperature (TEMP) were detected in both sides of the nose separately. The mean end-inspiratory RH and TEMP of a respiratory cycle of 2 minutes were calculated. Measurements of RH and TEMP obtained simultaneously in front of the nostrils and in the choanae were used for calculation of the temperature gradient (heat increase) across the nasal airways, the total water content (TWC) of the air in the choanae, and the water gradient across the nasal airways (in milligrams per liter), analogous to calculation processes of other working groups.6,7 The heat increase was defined as the difference of the TEMPchoana minus TEMPnostrils. The water gradient was defined as the difference of the TWC choana minus TWC nostrils. The heat increase and water gradient were established independently for both nasal airways.

A complete set of preoperative and postoperative data recorded within both choanae could be obtained in 23 patients (n=46). In the 2 patients undergoing unilateral ESS, measurements of the healthy side not operated on were disclosed (n=2 nasal airways measured). Patient values were compared with values from unilateral nasal airways in 22 controls. Intergroup and intragroup comparisons were performed using non-parametric tests: Wilcoxon and Mann-Whitney tests when appropriate. To compare the air conditioning data with data obtained at acoustic rhinometry and active anterior rhinomanometry, the Spearman rank correlation test was used. Significance was accepted at the 95% confidence level (P≤.05). Statistical analysis was performed using commercially available statistical software (WinSTAT; Kalmia Inc, Cambridge, Massachusetts).

RESULTS

NASAL PATENCY AND NASAL GEOMETRY

The median polyp score before endonasal surgery was 2 (mean, 2.0; range, 1-3) and decreased significantly (P<.05) after endonasal surgery to 0 (mean, 0.12; range, 0-1). Significant improvement of nasal airflow, detected using active anterior rhinomanometry, was measured (preoperative median airflow, 144 cm³/s; and postoperative median airflow postoperatively, 226 cm³/s) (Table 1). Nasal geometric analysis, measured using acoustic rhinometry, showed significant increase in nasal vol 2 (median vol 2 preoperatively, 3.81 cm³; median vol 2 postoperatively, 4.66 cm³) (Table 1).

NASAL-AIR CONDITIONING IN PATIENTS AND CONTROLS

Some patients received topical corticosteroids postoperatively. Before obtaining the control measurements 4 to 6 weeks postoperatively, the patients were not allowed to take corticosteroids or other adjunctive medications for 3 days.

The preoperative and postoperative air conditioning data for the patients were compared with data from the controls (Table 2). The nasal heat increase was significantly lower before surgery in the patients compared with the controls but was not significantly different after surgery. The preoperative and postoperative water gradient was significantly lower in the patients compared with the controls.

NASAL-AIR CONDITIONING BEFORE AND AFTER ENDONASAL SURGERY

After endonasal surgery, the ability of the nose to warm air was better than before surgery. The postoperative end-inspiratory heat increase was significantly higher than the preoperative heat increase (P=.006; Table 2). The water gradient did not increase postoperatively (P=.72; Table 2).

RELATION OF NASAL PATENCY AND NASAL GEOMETRIC DATA TO NASAL-AIR CONDITIONING

Values for both preoperative and postoperative measurements were used to calculate the relation of nasal airflow and nasal geometry with nasal-air conditioning. High nasal volumes, measured using acoustic rhinometry, and high nasal airflow, measured using rhinomanometry, showed a significant positive correlation with higher temperature gradients than small nasal volumes and low nasal airflow. There was a statistically significant negative correlation between the nasal volume, detected using acoustic rhinometry, and the water gradient, whereas the nasal airflow, detected using rhinomanometry, only showed a trend toward a negative correlation with the water gradient (Table 3).

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SUBGROUP ANALYSIS IN PATIENTS AFTER ESS ONLY AND ESS PLUS SEPTOPLASTY

In 11 patients (5 women and 6 men), only ESS without septoplasty or turbinoplasty was performed. In 2 patients, ESS was unilateral. Therefore, measurement values of 20 nasal sides could be used for data analysis. In 14 patients (5 women and 9 men), ESS was combined with septoplasty. In the patients with ESS plus septoplasty, measurement values of 28 nasal sides could be used for data analysis.

The preoperative and postoperative nasal airflow and nasal geometry did not differ between the 2 patient groups. Before and after endonasal surgery, the ability to warm and moisten air was not significantly different between the 2 subgroups. Comparing changes in rhinometric and rhinomanometric values with changes in the nasal-air conditioning values before and after endonasal surgery revealed no differences between the subgroups, analogous to the correlation results of the entire patient group (T.K., unpublished data, 2006).

COMMENT

The capacity of the nasal airways to heat and moisten air is affected by surgical interventions inside the nasal airways. This has been shown in surgery of nasal septal perforations, unilateral sinus surgery with resection of the turbinates with inverted papillomas, septoplasty and inferior turbinate, and septorhinoplasty and inferior turbinate. In this study of patients with CRSNP+ who underwent ESS with or without septoplasty and turbinoplasty, a significant improvement in the heating capacity of the nasal airways 4 to 6 weeks after endonasal surgery was demonstrated. In 14 of 25 patients, ESS was combined with functional septoplasty. Anterior turbinoplasty was performed in 5 patients. Thus, it is our opinion that nasal heating may also be improved 4 to 6 weeks after endonasal surgery when the surgical steps of both the anterior turbinate and the correction of the nasal septum are properly carried out when ESS is performed. In all study patients, the temperature gradient across the nasal cavity was higher postoperatively than preoperatively. Both nasal patency, measured using active anterior rhinomanometry, and intranasal volume, assessed using acoustic rhinometry, were significantly elevated after ESS.

We hypothesize that nasal heating after endonasal surgery increased because of improved airflow within the wider nasal airways after ESS with or without septoplasty, which leads to a closer contact of the inhaled air with the bordering nasal mucosa. A significant improvement of the moisturizing capacity of the nasal airways 4 to 6 weeks after ESS could not be shown. Both nasal patency and intranasal volume showed a negative correlation with nasal humidification. We conclude that widening of the nasal airways 4 to 6 weeks after ESS neither improves nor worsens nasal humidification. Thus, we believe that there must be other factors that influence the capability of the nasal airways to condition inspired air.

A primary goal of ESS is removal of pathologically altered respiratory mucosa from the nasal cavity and the paranasal sinuses to open the ostia of the sinuses to the nasal cavity. To measure the postoperative outcome after sinus surgery, the preoperative and postoperative evaluation of nasomucociliary function by heat frequency, olfaction by qualitative olfactometry, and nasal airway resistance by acoustic rhinometry and anterior rhinomanometry have been performed. In these studies, nasal function was improved after ESS. A possible explanation is that physiologic functions are reestablished inside the nose, in particular, at the junction between the nasal airways and the sinuses.

Aust and Drettner postulated that the paranasal sinuses have a minor role in nasal-air conditioning. In a pre-
vious study, no changes in the endonasal temperature profile after endonasal surgery in patients with CRSNP− could be demonstrated. We believe that the increase in nasal heating is associated with restoration of the anatomy of the nasal airways by ablation of sinonasal polyps and reopening of the sinusal ostia rather than with regeneration of the sinuses. Widening of the nasal passages might restore the nasal airflow, leading to closer contact of the inhaled air with the sinonasal mucosa and a subsequently increased exchange of heat. However, that nasal humidification was not improved postoperatively may indicate that restoration and regeneration of the mucosal lining of the osseometal complex and sinuses was not complete 4 to 6 weeks after surgery. Thus, nasal moisturizing capability may be primarily dependent on intact sinonasal mucosa. Furthermore, enlargement of the nasal airways negatively correlated with nasal humidification, indicating that altered airflow in wider nasal airways might reduce the contact of the inspired air with surrounding nasal respiratory mucosa. To our knowledge, this issue has not been intensively investigated to date, and only scant data indicate that complex regulatory mechanisms participate in the modulation of nasal-air conditioning to various conditions.

In patients, simultaneous reduction of the anterior or lateral part of the inferior turbinate was performed. Nevertheless, heating of inhaled air was sufficient in these patients, indicating that this surgical step does not disturb the nasal capability to warm inhaled air.

**Conclusion**

In 5 patients, simultaneous reduction of the anterior or lateral part of the inferior turbinate was performed. Nevertheless, heating of inhaled air was sufficient in these patients, indicating that this surgical step does not disturb the nasal capability to warm inhaled air.

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**Author Contributions:** Dr Kappe had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. **Study concept and design:** Papp, Keck, Rozsasi, and Kappe. **Acquisition of data:** Papp, Leiacker, and Kappe. **Analysis and interpretation of data:** Papp, Keck, and Kappe. **Drafting of the manuscript:** Papp and Leiacker. **Critical revision of the manuscript for important intellectual content:** Keck, Rozsasi, and Kappe. **Statistical analysis:** Papp, Keck, Rozsasi, and Kappe. **Administrative, technical, and material support:** Papp, Leiacker, Rozsasi, and Kappe. **Study supervision:** Leiacker and Keck.

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**REFERENCES**