Comparison of Optical Rhinometry and Active Anterior Rhinomanometry Using Nasal Provocation Testing

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Objective: To investigate whether there is a correlation between active anterior rhinomanometry (RMM) and optical rhinometry (ORM) data in the detection of changes in nasal congestion.

Design: In 70 subjects both ORM and RMM were performed. Changes in nasal congestion were induced by nasal provocation with histamine, allergens, solvent, and xylometazoline hydrochloride, 0.1%. Using visual analog scales, subjects rated the degree of nasal congestion and how comfortable each of the 2 measures was. In total, 136 measurements were evaluated.

Subjects: Seventy subjects were included in the study. All had a normal otorhinolaryngologic status with no acute or chronic infections.

Interventions: Nasal provocation tests with allergens, histamine, control solution, or xylometazoline were performed.

Main Outcome Measures: Congestion or decongestion of the nasal mucosa was measured via nasal resistance (RMM), changes in light absorption of the nasal tissue (ORM), and visual analog scale.

Results: When comparing the relative change in light extinction in ORM with nasal airflow in RMM, we found correlation coefficients up to $r = -0.69$. Results from RMM were correlated with the subjects' ratings of nasal congestion ($r = -0.63$). In comparison, the correlation coefficient between these ratings and ORM was $r = 0.84$. In addition, ORM was rated to be more comfortable than RMM.

Conclusions: The subjects' ratings of nasal congestion correlated to a higher degree with the results from ORM than with those from RMM. In addition, ORM was rated as more comfortable than RMM. Overall, ORM appeared to be a valid technique for the assessment of changes in nasal congestion.

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THE NASAL PROVOCATION test is a standardized method to diagnose suspected allergies. In this test, reactions are observed in response to potential allergens or histamine being placed in the nasal cavity. Among other symptoms like sneezing, nasal secretion, itchiness, and lacrimation, swelling of the nasal mucosa is considered to indicate an allergic reaction.

Several methods are used to measure changes in nasal congestion during nasal provocation. Active anterior rhinomanometry (RMM) is routinely used for the assessment of the effects of nasal provocation. It allows the measurement of respiratory resistance in the nasal passage, a parameter that reflects the degree of obstruction due to swelling of the mucosa or other anatomic changes. However, its application in nasal provocation tests faces problems. First of all, measurements cannot be performed continuously, meaning that measurements have to be interrupted to present allergens and/or drugs to the nasal epithelium. This interruption changes conditions of measurement, which may lead to more variance in the obtained measures. Artifacts are produced if the patient mistakenly breathes through the mouth or if the face mask does not fit tightly. Measurements via RMM are not possible in cases of septal perforation or in totally obstructed noses (e.g., if the provocation produces major congestion or if obstructing polyps are present). In addition, swelling of the nasal mucosa is only detected indirectly via nasal airway resistance. Real-time measurements are not possible. Furthermore, correlations between the subjects' ratings and RMM results have not been proven, and so the clinical value of RMM is controversial.
In addition, patients find RMM to be uncomfortable, especially when they have to breathe through an obstructed nose with their mouths closed.

Other techniques for the assessment of nasal congestion include acoustic rhinometry, in which the geometry of the nasal cavity is calculated by the reflection of a sound applied to the nose. However, this technique, while elegant, does not allow for continuous measurements; it produces reliable results for the anterior portion of the nasal cavity but not for the posterior parts. Ultrasound also allows objective measurements of changes in nasal congestion, and it allows continuous measurements. In combination with the Doppler effect, it provides insights into nasal blood flow. A problem here is the discomfort of the patient, whose nose has to be filled with ultrasound gel or water.

These problems inherent to RMM or other methods for measuring changes in nasal obstruction sparked the development of optical rhinometry (ORM), a new approach for the continuous measurement of changes in nasal swelling. It was first evaluated using nasal provocation tests. As opposed to RMM, ORM allows continuous and direct measurement of nasal congestion while the nasal passages remain open. This is possible because the sensor sits on the nose, and no face masks are needed. Using this technique, patients can breathe freely while measurements are performed. The measurement is possible in cases of nasal polyps or septal perforations. Swelling is directly detected by measuring changes of blood volume in the nasal mucosa (not indirectly, as occurs in the measurement of via nasal resistance). A major disadvantage of ORM is that only relative changes in the blood volume in the field of view can be detected.

While ORM appears to have some advantages over other techniques, no data, to our knowledge, exist concerning the comparison of ORM with RMM. Therefore, the aim of this study was to compare results from RMM and ORM in terms of the detection of changes in nasal congestion.

**METHODS**

**OPTICAL RHINOMETRY**

The principle behind ORM (transmission spectroscopy) is to measure nasal swelling optically by placing an emitter and a detector at opposite sides of the nose and continuously recording the time course of the extinction of the light that passes through the nasal tissue (Figure 1). If there is an increase of blood volume in the nasal tissue, a larger portion of the light will be absorbed by the nasal tissue and so less light can be detected by the detector. Because the nose is continuously transilluminated with the light, and the light at the other side of the nose is continuously detected, the continuous measurement of changes of nasal congestion is possible.

The principle behind ORM is closely related to that of tissue spectroscopy, a generic term for optical measurement techniques used to quantify certain physiologic tissue parameters by measuring the absorption of visible and near-infrared light in tissue. Most optical spectroscopy methods rely on the fact that hemoglobin is a dominant absorber in the near-infrared part of the spectrum and aim at monitoring circulatory parameters such as local blood volume and hemoglobin oxygen saturation. It is known from pulse oximetry and other optical diagnostic methods that light in the red and near-infrared range (ie, with a wavelength between 600 and 1000 nm) can penetrate soft tissue to depths of a few centimeters. Endonasal swelling is characterized by an increase in blood volume, and this volume change can be measured as an increase in the absorption of light in the mucosa. The 800-nm wavelength of the light used in optical rhinometry corresponds to the isobestic point of hemoglobin (same absorption coefficient of oxygen-saturated and -desaturated hemoglobin). Therefore the blood volume in the nasal tissue is measured directly by measuring the changes in hemoglobin volume. By using the isobestic point of hemoglobin, ORM measurement does not have to rely on the oxygen saturation of hemoglobin.

The ORM sensor is placed on the subject’s nose in a frame of lensless glasses designed to keep the optical elements accurately in position (Figure 2). This is necessary because of possible movements of the subject’s head or movements of facial muscles due to sneezing or sniffing (virtually unavoidable) during nasal provocation. Endoscopic examination of the light field inside the nasal passage has shown that in this position the anterior portions of the inferior and middle turbinates as well as the septal intumescence are transilluminated.

**STUDY DESIGN**

Changes in nasal swelling were assessed following nasal provocation with histamine or allergens (congestion expected) and xylometazoline hydrochloride (decongestion expected). In a total of 70 subjects, 136 measurements with ORM and RMM were performed to measure changes in light extinction (ΔE) and nasal resistance. A total of 43 histamine provocations, 20 positive allergen provocations, 15 provocations with control solution (solvent), 15 negative allergen provocations, and 43 decongestions with xylometazoline were performed. Subjects were asked to rate nasal airflow using visual analog scales. They rated (1) whether and to what degree the nasal airflow was better or worse following application of the provocation agent and (2) which technique for assessment of nasal swelling was more comfortable. With regard to the second rating, subjects were also asked to provide an explanation why this should be so. The visual analog scales ranged from −10 (airflow after provocation was much better; ORM compared with RMM was extremely uncomfortable) to +10 (airflow after provocation was extremely low; ORM compared with RMM was extremely comfortable). A rating of 0 indicated no change of nasal airflow after provocation and that both methods were similarly comfortable.
Another RMM was performed immediately. In RMM, the permeability with the maximum dE in ORM, ORM was stopped, and pregnant women were excluded from the study.

Figure 3. Graphic representation of a typical course of light extinction in optical rhinometry in a nasal provocation test: After 2 minutes, the allergen (stinging nettle pollen) is applied into the nose. T1 indicates the onset of swelling; T2, the time when maximum swelling is reached; ΔE, the change in light extinction after provocation compared with the light extinction before provocation. MIE indicates the mean of the initial changes of light absorption. The relative change of light extinction [rE] can be calculated as ΔE/MIE. In this case it is 0.52/0.05 OD=10.4. OD indicates optical density.

INCLUSION AND EXCLUSION CRITERIA

All patients had a normal otorhinolaryngologic status. None of the patients had signs of acute or chronic nasal infections. If any subject had taken antihistamines or corticosteroids, treatment with these medications was discontinued according to the study criteria of the German Association for Allergy and Clinical Immunology. Subjects with acute or chronic infections (including asthma), patients with perforations of the septum, and pregnant women were excluded from the study.

PROVOCATIONS

Subjects provoked with histamine, xylometazoline, negative allergen, or control solution had no history of allergic diseases, had negative results on a pinprick test, and normal total IgE levels. In subjects undergoing allergen provocation, sensitization to the tested allergen was excluded by the findings of a detailed history, specific IgE test, and specific pinprick test. In those patients tested with allergens, a diagnosis of “allergy” was established on the basis of the patient history, radioallergosorbent test, and pinprick test.

Active anterior rhinomanometry was performed with a Rhinomanometer (Fa Hortmann, Tuttingen, Germany) after the subjects had adjusted to room temperature. Following this, the optical rhinometer (Rhinolux; Rhios GmbH, Grosserkmannsdorf, Germany) was placed on the subjects' nose and ORM was started. After baseline measurements were taken over a period of 2 minutes, xylometazoline hydrochloride, 0.1%; histamine, 2 mg/mL; allergen solution (stock solution diluted 1:10); or solvent was administered using a pump spray to 1 of the nostrils. The applied volume was constant (0.14 mL) in all conditions.

A result from a typical nasal provocation test documented with ORM is shown in Figure 3. After reaching a stable plateau with the maximum dE in ORM, ORM was stopped, and another RMM was performed immediately. In RMM, the percentage change in nasal airflow after application of the drug (histamine, allergen, control solution, xylometazoline) at 150 Pa was evaluated vs the initial airflow before provocation. The provoked side, the nonprovoked side, and the airflow in both nasal cavities were evaluated. In ORM, the dE measured in optical densities and, in addition, the dE divided through the mean dE before provocation (MIE) (Figure 3) were evaluated after drug administration. This parameter was termed relative dE (rE).

In addition, in ORM the time course of the swelling (T1 indicating the beginning of the swelling and T2 the maximum swelling) was evaluated (Figure 3).

A total of 70 healthy subjects were included in the study (31 men and 39 women; mean±SD age, 27.3±11.9 years). All subjects received RMM and ORM. The results of the correlational analysis performed across all measurements are summarized in the Table.

RESULTS

A result from a typical nasal provocation test documented with ORM is shown in Figure 3. After reaching a stable plateau with the maximum dE in ORM, ORM was stopped, and another RMM was performed immediately. In RMM, the percentage change in nasal airflow after application of the drug (histamine, allergen, control solution, xylometazoline) at 150 Pa was evaluated vs the initial airflow before provocation. The provoked side, the nonprovoked side, and the airflow in both nasal cavities were evaluated. In ORM, the dE measured in optical densities and, in addition, the dE divided through the mean dE before provocation (MIE) (Figure 3) were evaluated after drug administration. This parameter was termed relative dE (rE). In addition, in ORM the time course of the swelling (T1 indicating the beginning of the swelling and T2 the maximum swelling) was evaluated (Figure 3).

SPSS software, version 12.0 (SPSS Inc, Chicago, Ill) was used for statistical analyses. For group comparisons, t tests were used; Pearson statistics were applied for correlational analyses. The chosen level of significance was .05. Results are reported as means±SDs. The study was approved by the institutional review board of the Technical University of Dresden.

COMPARISON BETWEEN RMM AND ORM, ALL MEASUREMENTS

In ORM, the dE was evaluated. When ORM was compared with the changes of nasal airflow at the provoked side of the nose, the correlation coefficient was r = −0.62 (P < .001); it was r = −0.26 (P = .003) at the nonprovoked side. When ORM was compared with the change in nasal airflow at both nasal sides, the correlation coefficient was r = −0.65 (P < .001). When rE was used as a measure from ORM, results from ORM and RMM exhibited similar correlations: provoked side r = −0.60 (P < .001) (Figure 4); nonprovoked side r = −0.23 (P = .004); and both nasal sides r = −0.69 (P < .001).
RESULTS FROM RMM AND SUBJECT RATINGS OF NASAL CONGESTION, ALL MEASUREMENTS

When the subject ratings of nasal congestion were compared with the airflow of the provoked nasal side, the correlation was \( r = -0.56 \) (\( P < .001 \)). With regard to the airflow of the nonprovoked side, the correlation coefficient was \( r = -0.16 \) (\( P = .06 \)), and it was \( r = -0.63 \) (\( P < .001 \)) with regard to both nasal sides (Figure 5).

RESULTS FROM ORM AND SUBJECT RATINGS OF NASAL CONGESTION, ALL MEASUREMENTS

The correlation coefficient between the \( dE \) and the subject ratings of congestion was \( r = 0.81 \) (\( P < .001 \)); for the \( rE \), it was \( r = 0.84 \) (\( P < .001 \)) (Figure 6).

In each group (histamine, positive allergen, negative allergen, control solution, and xylometazoline), significant correlations were found in the histamine group between \( rE \) in ORM and RMM (both nasal sides) \( r = -0.38; P = .01 \). Analysis revealed no significant correlation between both objective measuring methods and the subjects’ ratings of nasal swelling. In the xylometazoline group a significant correlation could be found between ORM and RMM as well as between the ratings of nasal congestion and ORM and RMM. Looking at \( dE \) in ORM, we found that the correlation coefficient to RMM at the provoked side was \( r = -0.47 \) (\( P = .002 \)); to both nasal sides it was \( r = 0.41 \) (\( P = .006 \)); and for the ratings of nasal decongestion it was \( r = 0.62 \) (\( P < .001 \)). Looking at \( rE \) in ORM, we found that the correlations were \( r = -0.52 \) (\( P < .001 \)) to the provoked side in RMM; to both nasal sides, it was \( r = -0.60 \) (\( P < .001 \)); and to the ratings of nasal congestion it was \( r = 0.68 \) (\( P < .001 \)). The correlation of RMM on the provoked side between the subjective impression was \( r = -0.31 \) (\( P = .04 \)), and for both nasal sides it was \( r = -0.41 \) (\( P = .006 \)).

For positive allergen provocations, a significant correlation of ORM (\( dE \)) and RMM was found only for the provoked side in RMM \( r = -0.49 \); \( P = .03 \). For \( rE \) in ORM, a significant correlation was found with ratings of nasal congestion \( r = 0.75 \); \( P < .001 \). All other groups revealed no significant correlation.

SUBJECT COMFORT RATINGS OF RMM VS ORM

Subjects rated ORM to be more comfortable than RMM during situations of nasal congestion (nasal histamine provocation) (mean ± SD visual analog score, 4.12 ± 2.75; \( P < .001 \)), in decongestions both methods were rated as

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**Table. Results From Correlational Analysis Performed Across All Measurements**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>( rE )</th>
<th>RMM, Proved Side</th>
<th>Subject Congestion</th>
<th>dE</th>
<th>RMM, Nonprovoked Side</th>
<th>RMM, Both Sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORM, ( rE )</td>
<td>NA</td>
<td>-0.60 (&lt;.001)</td>
<td>0.84 (&lt;.001)</td>
<td>0.86 (&lt;.001)</td>
<td>-0.25 (.004)</td>
<td>-0.69 (&lt;.001)</td>
</tr>
<tr>
<td>Subject congestion</td>
<td>0.84 (&lt;.001)</td>
<td>-0.56 (&lt;.001)</td>
<td>NA</td>
<td>0.81 (&lt;.001)</td>
<td>-0.16 (.056)</td>
<td>-0.63 (&lt;.001)</td>
</tr>
<tr>
<td>ORM, dE</td>
<td>0.86 (&lt;.001)</td>
<td>-0.62 (&lt;.001)</td>
<td>0.81 (&lt;.001)</td>
<td>NA</td>
<td>-0.26 (.003)</td>
<td>-0.65 (&lt;.001)</td>
</tr>
</tbody>
</table>

Abbreviations: \( dE \), change in light extinction; NA, not applicable; ORM, optical rhinometry; \( rE \), relative \( dE \); RMM, active anterior rhinomanometry.

\( *N = 136. \)
The higher correlation coefficient between ORM and nonlateralized vs lateralized RMM measures can be explained by the measurement principle of ORM. In transmission spectroscopy, both nasal sides are transilluminated. Therefore, the measurement of both nasal sides in RMM should provide the best correlative results, which was the case.

Following nasal provocation, there was a good correlation between the subjects’ ratings of nasal congestion and RMM. Again, the correlation was best with RMM results from nonlateralized measures. This correlation is controversial. Some authors report no correlation between RMM measures and the subjects’ ratings, while others report good correlations. In contrast, correlations between results from ORM and the subjects’ ratings of nasal congestion are higher than those obtained for RMM. This discrepancy may be explained by the fact that RMM measurements in a strongly obstructed nose are impossible.

With regard to results obtained for individual subgroups, significant correlations could be found between ORM and RMM only for provocations with histamine or xylometazoline. These spurious correlations for individual subgroups are best explained by (1) the small sample size in these groups and (2) the relative lack of variability of the results in these subgroups.

Most interestingly, ORM was rated to be more comfortable than RMM. This may be explained by the fact that ORM allows the subjects to breathe freely during measurements.

When comparing RMM and ORM, we found that ORM allows investigation of the time course of changes in nasal congestion. For example, nasal application of histamine produced a faster reaction than nasal application of allergens. This appears to be due to the immunologic reaction following allergen provocation, which ultimately leads to the liberation of histamine from mast cells. When histamine is deposited directly on the nasal mucosa, congestion is induced instantly, without an intermediate immunologic reaction.

In conclusion, major differences between the ORM and RMM include the following: (1) Unlike RMM, ORM provides only relative values; therefore a long-term follow-up is not possible. (2) In addition, lateralized measurements are not possible using nasal transmission spectroscopy. Having said this, we found that (3) the subjects’ ratings of nasal congestion exhibited a higher correlation with the results from ORM than with those from RMM. In addition, (4) ORM was rated as being more comfortable than RMM. (5) As opposed to RMM, ORM does not require a face mask. The optical sensor is just placed like spectacles on the nose of the patient. (6) Because it relies on direct measurement of changes of the blood volume in the field of view, ORM is also possible in cases of septal perforations, nasal polyps, or choanal atresia. (7) Most importantly, ORM allows the real-time documentation of mucosal changes during nasal congestion. Other studies will need to be done to determine the use of this technique to achieve clinical improvement.
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Author Contributions: Dr Wustenberg had full access to all 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: Wustenberg, Zahnert, and Huttenbrink. Acquisition of data: Wustenberg. Analysis and interpretation of data: Wustenberg, Huttenbrink, and Hummel. Drafting of the manuscript: Wustenberg, Huttenbrink, and Hummel. Critical revision of the manuscript for important intellectual content: Wustenberg, Zahnert, Huttenbrink, and Hummel. Statistical analysis: Wustenberg and Hummel. Obtained funding: Huttenbrink. Administrative, technical, and material support: Wustenberg, Zahnert, Huttenbrink. Study supervision: Wustenberg, Zahnert, Huttenbrink.

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