Reliability of acoustic rhinometry

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Abstract
In recent years increasing evidence has been provided on frequent simultaneous coexistence of inflammatory diseases and allergies in upper and lower airways. To achieve a good standard of measurement of upper airways, an objective method should be used. A total of 48 nasal cavities with nasal stuffiness associated with chronic sinusitis were measured with acoustic rhinometry (AR) and High-resolution computer tomography volumetry (HRCTV). Comparison of volumes and minimum cross-sectional areas measured with these methods was performed. The volumes measured from the nostril with both methods were the anterior (0–10 mm), middle (11–40 mm) and posterior (41–70 mm) volumes. The AR cross-sectional area curve was analysed based on two minimal notches corresponding to local minimal areas. A series of 1-mm coronal CT images without intervening gaps were made and analysed based on two minimal voxel values, which were later converted to cross-sectional areas corresponding to local, minimum cross-sectional areas (MCA). Furthermore, the distances of these 2 MCAs from the nostril were also measured. Strong statistically significant \( P < 0.05 \) correlations were found between AR and computer tomography volumetry (CTV) volumes in the anterior \( r = 0.83 \) and middle \( r = 0.77 \) parts of the nasal cavity. In the posterior part of the nasal cavity, a statistically significant \( P < 0.05 \) correlation was also found \( r = 0.62 \). Good agreements between the AR and CTV volumes in the anterior and middle parts of the nasal cavities were confirmed with Bland–Altman plots. Correlations among the MCAs were weaker \( r = 0.59 \) and \( r = 0.55 \). Our results suggest that the reliability of AR appears sufficient for clinical and scientific use in the nasal cavities. Reliability is very good in the anterior and middle parts of the nasal cavities, while strong conclusions based on evaluation of the posterior part should be avoided due to decreasing accuracy.

Keywords acoustic rhinometry; computer tomography volumetry; nasal cavity geometry.

INTRODUCTION
In modern respiratory medicine, objective measurement of airway patency is a must. In the lower airways, objective methods are used in clinical trials and routine clinical work. In the upper airways, there is need for an equally rigorous standard of measurements, because during recent years the pathogenic view of respiratory allergies and infections has changed. The relationship between the upper and lower airways has been documented (1, 2). Measurement of nasal cavity geometry has proven to be a great challenge for researchers in modern rhinology.

The most common method used in these measurements is acoustic rhinometry (AR), which is based on analysis of reflected acoustic impulses (3,4). In clinical use AR is a non-invasive, simple, rapid and relatively cheap method. Reproducibility of AR measurements has been shown to be good if the measurement technique is favourable (5). The resolution of this method has been described to be between 3 and 7 mm, using spheres in models and living patients (3,6). AR measurements have been used for scientific and clinical purposes. The method has been used to detect normal anatomy, nasal cycle, drug actions in the nasal cavity, changes in some disorders such as nasal polyposis or septal deviations and the effects of surgical treatment.

AR results in several cross-sectional area and volume parameters in specific and changeable locations of the area distance curve. The normal curve shows two or...
three minimum cross-sectional areas (MCAs) and one to four volume areas, depending on the options selected in the software.

Computed tomography and magnetic resonance images have been earlier used as a reference in the evaluation of AR accuracy in cadavers (7) and patients (8–10). However, with the current advancement in computer technology systems, 3D high-resolution computer tomography (HRCT) images combined with segmentation methods can result in the area and volume parameters needed for analysis of nasal airways. CT volumetry (CTV) is the one of the best imaging modalities available for evaluating the nasal cavity and paranasal sinus geometry (10). This has been demonstrated with a phantom test, showing <1% error in segmented volumes when compared with actual volumes (II).

Standardization of acoustic rhinometry is a continuous process, and some official guidelines have already been published (12). The reliability of AR is still an ongoing discussion. In the present study, we compared the volumes in three different areas, MCAs, and the distance of the MCA from the nostril in the nasal cavity measured with AR and CTV. The purpose of the study was to evaluate the reliability of AR using CTV as a reference method.

PATIENTS AND METHODS

Patients

Thirteen patients (eight males and five females) with chronic sinusitis were studied. The mean age was 40.9 years ranging from 19 to 69 years. Investigations were performed preoperatively in 13 patients and 6 months after endoscopic sinus surgery in 11 patients. Two of the patients did not attend the postoperative visit., one due to acute psychiatric disorder the other could not be contacted. Some of the patients were also examined in previous studies (10,II). A total of 48 nasal cavities were evaluated. Due to endoscopic sinus surgery, these were analysed as geometrically different kinds of nasal cavities. The patients went through bilaterally uncinectomies combined with anterior ethmoidectomies during an endoscopic sinus surgery. The definition we used for chronic sinusitis was that the patients had sinusitis symptoms for at least 3 months before the study despite active therapy and that the sinusitis was at least once diagnosed with the help of X-ray images. Chronic sinusitis was diagnosed based on patient history, clinical examination including endoscopy and X-ray images. Patients with groove septal deviations, nasal polyposis and allergies were excluded from the study. All patients underwent both measurements on the same day pre- and postoperatively. CTV images were taken first and AR measurements within 15 min. The Tampere University Hospital Research Ethics Committee approved the study protocol and all subjects gave their written consent for the study.

Methods

Acoustic rhinometry

An A1/2 AR (G.M. Instr., Glasgow, U.K.) and programme version 3.02 were used for measurements. All measurements were performed after a short period of acclimatization and in a relatively quiet room at normal temperature (mean = 21.4°C) to minimize artefacts from physical stress, environmental noise and temperature changes (5,13,14). The measurements were performed during a breathing pause while patients were in a sitting position. The nosepiece used in the measurements was 5 cm in length and was anatomically sculptured. To ensure a tight connection between the nosepiece and tip of the nose, a small amount of ultrasound transmission gel was applied to the edge of the nosepiece. The angle of the incident acoustic impulse was about 45° with respect to a line joining the base of the piriform aperture of the nose to the tragus. MCAs and volumes were comprised of a mean of four repetitive measurements. The technique we used allowed us to analyse two local minimal points giving us minimum cross-sectional areas (MCA1 & MCA2) and distance (ARd1 & ARd2) to the points from the nostril. The software we used also produced three volume regions: anterior, defined as a region from nostril to 10 mm posteriorly (AVAR); middle, from 10 to 40 mm (MVAR); and posterior, from 40 to 70 mm (PVAR).

Computer tomography volumetry

Coronal HRCT images were performed on a Pro Speed PLUS scanner (General Electric, Milwaukee, Wisconsin, U.S.A.) with a tube voltage of 120 kV and tube current of 200 mA. The thickness of the processed coronal slices was 1 mm without intervening gap. Images were then processed with a semi-automatic segmentation program called Anatomic™. It utilizes several image-processing techniques, such as image filtering, amplitude segmentation, region growing, manual editing and image fusion. The segmented HRCT images are then also converted to cross-sectional areas and volumes as a function of the distance by algorithms (10,II) (Fig. 1).

Consequently, two regions were defined by CTV to be representative of two local minimal areas. The cross-sectional areas and the distance from the nostril to these regions were calculated from the segmented HRCT images and areas were labelled as CTVA1 and CTVA2 and distances labelled as CTVd1 and CTVd2. The equivalent volumes with AR were also measured with CTV, and labelled AVCTV (anterior), MVCTV (middle) and PVCTV (posterior).

Statistical analysis

To examine the geometrically difference in pre-and postoperative nasal cavities, analysis of variance (ANOVA)
for repeated measurements was used. Descriptive statistics were expressed as mean values ± SD. The strength and direction of a linear relationship between the AR and CTV data were tested by the Pearson correlation coefficient test. Values of $P < 0.05$ were considered statistically significant. Agreement between the AR and CTV volumes was also tested by Bland–Altman plots using 95% confidence intervals. All statistical analyses were performed using statistic software SPSS 10.0 for Windows.

**RESULTS**

The volumes correlated favourably in the anterior ($r = 0.83$) and middle ($r = 0.77$) regions of the nasal cavity, while highly significant correlation existed in the anterior region (Figs. 2a and b). In the posterior part of the nose, the correlation of volumes was weaker ($r = 0.62$) between AR and CTV (Fig. 2c). All the results were statistically significant ($r^2 < 0.05$) (Table I). Agreement between AR and CTV volumes in anterior, middle and
posterior parts of the nasal cavities is described in Bland–Altman plots (Figs. 3a–c). Volumes measured postoperatively were in general consistently larger than preoperative values between measurements in the same patients.

The MCAs were surprisingly poorly correlated between the AR and CTV ($r = 0.59$ and $0.55$), furthermore, the results were not statistically significant. The mean distances between the nostril and the first minimal area were $\text{ARd}1 = 2.27 \pm 0.44\text{ cm}$ and $\text{CTVd}1 = 2.18 \pm 0.52$.

### Table I. Acoustic rhinometry (AR), computer tomography volumetry (CTV), Pearson's correlation coefficient ($r$)

<table>
<thead>
<tr>
<th></th>
<th>AR (cm$^3$)</th>
<th>CTV (cm$^3$)</th>
<th>$r$</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>$1.05 \pm 0.57$</td>
<td>$1.25 \pm 0.55$</td>
<td>0.83</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Middle</td>
<td>$4.42 \pm 1.88$</td>
<td>$5.30 \pm 1.80$</td>
<td>0.77</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Posterior</td>
<td>$6.99 \pm 2.12$</td>
<td>$7.16 \pm 2.32$</td>
<td>0.62</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
The mean distances between the nostril and the second minimal area were ARd2 = 4.77 ± 0.62 cm and CTVd2 = 5.14 ± 0.73 cm. The distance from the nostril to two local MCAs measured by these methods was very similar, indicating that both methods recognize constricted areas in the nasal cavity very well (Table 2.)

**DISCUSSION**

In modern respiratory medicine, increasing numbers of researchers and clinicians interested in the upper airways have begun to use AR as a tool to measure the volumetric dimensions of the nasal cavity. The interest in reliability and usefulness of AR in clinics has also increased during recent decades. In the present study, we tried to avoid some well-known artefacts that affect the results of AR measurements. With the optimal measurement technique and a new validation method, we attempted to determine if AR is reliably used in clinics. We first tried to use a good measurement technique in which environmental aspects are optimal by minimizing the effects of temperature, noise and physical stress, which were previously reported (14,13,5) to affect these measurements. In the study, we used anatomically sculptured nosepieces with ultrasound transmission gel, and all the measurements were performed during the breathing pause to minimize errors from air leaks or pressure changes in the nasal cavity. The angle of the sound pulse was kept constant in all measurements.
(~45°) to avoid variations in acoustic impulse, which have also been reported to affect the measurements (15).

The intranasal dimensions are likely to differ significantly between the congested and decongested states. The use of decongestive medication has been reported by Flanagan and Eccles (16) to increase nasal cavity volume from 19 to 42%. Most studies in the literature have made use of some type of decongestant in measurements to avoid the "nasal cycle". Understanding of this unusual phenomenon is still very confused and there is very little evidence for any true periodicity (16). The alternating "nasal cycle" occurs only in 13% of individuals (17). In our opinion, there was only slight risk that the "nasal cycle" could affect the results.

Intranasal decongestants were not used because the aim of the present study was to examine the accuracy of AR in patients with chronic sinusitis, which is a disorder that affects mostly the nasal and paranasal mucosae. In the present study, we evaluated the effect of surgical treatment on intranasal geometry. Since the surgery was quite minor, the change in nasal geometry was expected to be due to recovery of mucosal inflammation and decrease in mucosal swelling. In the present study the use of decongestants would cause disturbances in the evaluation of nasal mucosal changes between the preoperative and postoperative nasal cavities.

CTV is a modification of ordinary CT data, which have earlier been used as a reference for validation studies of AR (9,10). CTV is more advantageous than ordinary CT in this evaluation, as reported by Dastidar et al. (11). HRCT-based volumetry is also a very good tool for evaluating volumetric measurements in clinics. CT-based analyses have some basic problems, which can be seen when this type of comparison is made. The first problem is the difference between the axis of the CT images and the acoustic pathway in the nasal cavity, which automatically leads to differences in cross-sectional areas. The difference is caused by linear cross-sections in the antero-posterior measurements used in CT and the non-linear cross-sections used in AR. The second problem is the paranasal sinuses, which may significantly contribute to the acoustically determined areas in the posterior part of the nasal cavity and epipharynx, reported by Hilberg and Pedersen (18). In our study, where about 50% of the nasal cavities measured were operated on, including the meatal ostium and anterior ethmoidal sinuses, this was significant factor, causing large errors in the results for the posterior part of the nasal cavities. The third problem is the possible leakage of acoustic pulses to a contra lateral nasal cavity or oropharynx during the measurements, which also leads to error in interpreting results. The fourth problem, which should be noted, is that the measurement of both the volume beyond a constricted area in the nasal cavity and the area of the constriction may be associated with systemic errors. This error has been calculated in models and may be as much as 10%, as reported by Hamilton et al. (19). This cannot be observed in CT-based measurements, which are more accurate in this aspect. On the other hand, the image window used in CT measurements can eventually attain some degree of significance in volumetric measurements. Wider image window levels lead to inaccurate increase and narrower image window levels to inaccurate decrease in the volume measurements.

The values of volumes measured with AR are comparable with those measured with CTV. Despite the methodological problems described above, a strong, statistically significant linear correlation and agreement between the volumes was found in the anterior and middle parts of the nasal cavity. In the posterior part, the correlation was moderate or even weak, and the deviation of these results was relatively wide. The possible reasons for this are discussed above. Comparison between the volumes before and after the operation measured with AR showed clearly the increase in volumes due to postoperative healing of the nasal mucosae. The postoperative increase in volumes was seen in all parts of the nasal cavity.

The mean distances between the nostril and the first minimal area and the second minimal area are shown Table 2. These values, especially the first (ARd1 and CTVd1) are similar to those reported by Roithmann et
The distances from the nostril to the two local MCAs measured by these methods were very similar, indicating that both methods recognize constricted areas in the nasal cavity very efficiently. The second MCA values have not been as often measured or described in the literature. One of the reasons could be the slight effect of this area on nasal function in individuals. We measured it to validate the accuracy of AR. The measurements were apparently very similar between the methods, and AR can identify the distance to the MCAs very satisfactorily.

The cross-sectional area values at these points were disappointing. Our results were not statistically significant and the values did not correlate as well as expected. The correlation coefficients were 0.59 and 0.55, suggesting that the values for AR and CTV showed only moderate linear correlation in these two MCAs. The differences in resolutions between the methods in a single measurement point can be the reason why the area results do not correlate so well.

In conclusion, AR is a clinically reliable method for measuring nasal cavity geometry in the anterior and middle parts of the nasal cavity. In scientific use the method appears also to be sufficiently reliable in the anterior and middle parts of the nasal cavity, and strong conclusions based on measurements in the posterior part of the nasal cavity should be avoided. Further research is needed before standardization of AR can be accomplished.

REFERENCES