The Laryngoscope
Lippincott Williams & Wilkins, Inc., Philadelphia

Value of Acoustic Rhinometry for Measuring Nasal Valve Area

Özcan Çakmak, MD; Mehmet Coşkun, MD; Hüseyin Çelik, PhD; Fuat Büyüklü, MD;
Levent Naci Özlüoğlu, MD

Objective: **To assess the validity of acoustic rhinometry for measuring nasal valve area in human subjects.** ***Study Design:*** **A comprehensive study that compared acoustic rhinometry data with computed tomography findings from scans obtained perpendicular to the acoustic axis and perpendicular to the floor of the nose.** ***Methods:*** **Fifty nasal passages of 25 healthy adults with no nasal disease were examined by acoustic rhinometry and computed tomography. In each case, the area of the nasal valve as measured by acoustic rhinometry was compared with the area calculations from computed tomography sections taken in two different coronal planes, one perpendicular to the acoustic axis and one perpendicular to the floor of the nose. Computed tomography slices perpendicular to the floor of the nose were obtained at two different locations, a specific distance from the tip of the nose and a specific distance from the anterior nasal spine.** ***Results:*** **There was a significant correlation between the nasal valve areas determined by acoustic rhinometry and computed tomography when imaging was obtained perpendicular to the acoustic axis. In contrast, when scanning was obtained perpendicular to the straight axis of the floor of the nose, the correlations between the acoustic rhinometry and computed tomography data were weak.** ***Conclusions:*** **When any type of imaging is used for comparison with nasal valve areas determined by acoustic rhinometry, the cross-sections should be perpendicular to the acoustic pathway. The results of the study show that acoustic rhinometry is a valuable method for measuring nasal valve area.** ***Key Words:*** **Acoustic rhinometry, computed tomography, nasal valve area.**

Laryngoscope, **113:295–302, 2003**

INTRODUCTION

Acoustic rhinometry (AR) is a method based on reflection of acoustic waves and is a useful tool for measuring the dimensions of the nasal cavity.[1] By comparing the incident acoustic wave with waves reflected from the walls, it is possible to determine changes in cross-sectional area within the nasal cavity. Specifically, by knowing the speed of acoustic waves and assessing the time interval from propagation of the incident wave to detection of the reflected wave, one can accurately determine the distance to a site where the cross-sectional area of a cavity changes. Acoustic rhinometry measures cross-sectional area as a function the distance from the nostril.[1,2]

Acoustic rhinometry is a quick, painless, noninvasive, reliable method that can be performed easily with minimal patient cooperation. These features explain why the technique has been widely accepted in a short time. Acoustic rhinometry has been used for characterizing the geometry of the nasal cavity, for assessing the dimensions of nasal obstructions, and for evaluating surgery results and patient response to medical treatment. However, model studies have shown that the technique has physical limitations. These cannot be eliminated completely, but technical aspects of the AR equipment can be adjusted to achieve higher accuracy.[2]

In vivo data from human subjects are needed to confirm the reliability of AR measurements. Computed tomography (CT) and magnetic resonance imaging (MRI) have been used for this purpose in clinical trials. Hilberg et al.[1] were the first to use CT to assess the accuracy of AR measurements in a single cadaver head. They found a significant correlation between CT and AR findings when the imaging was obtained perpendicular to the acoustic wave direction. Clinical studies on human subjects have documented significant correlations between cross-sectional areas in the anterior part of the nasal cavity measured by various imaging modalities and AR.[3–8] However, with the exception of the study by Terheyden et al.,[8] in all previous studies on human subjects the plane of the CT and MRI slices has been perpendicular to the floor of the nose, and the images have been obtained at various distances from the anterior nasal spine[4,5] or the tip of the nose.[3,7]

From the Departments of Otorhinolaryngology (Ö.Ç., F.B., L.N.O.) and Radiology (M.C.), Başkent University Faculty of Medicine, and the Department of Physics (H.Ç.), Hacettepe University, Ankara, Turkey.

Supported by the Başkent University Research Fund (Project KA01/93).

Editor's Note: This Manuscript was accepted for publication September 4, 2002.

Send Correspondence to Özcan Çakmak, MD, Department of Otorhinolaryngology, Başkent University Faculty of Medicine, 06490 Ankara, Turkey. E-mail: ozcakmak@hotmail.com

The aim of the present study was to assess the accuracy of AR assessment of nasal valve area in human subjects. This was performed by correlating in vivo AR and CT data obtained in similar planes and at similar locations within the nasal cavity. We also compared the nasal valve area data determined by AR with those obtained from CT slices on a plane perpendicular to the floor of the nose.

MATERIALS AND METHODS

The Institutional Review Board of Başkent University (Ankara, Turkey) approved the study protocol. Twenty-five healthy adult volunteers were examined for and questioned about nasal or paranasal sinus infection, allergy, medication, previous nasal surgery, and major structural nasal disease, such as septal deviation or conchal hypertrophy. The 50 nasal passages of the 25 subjects were assessed by AR and CT. All examinations were performed 10 to 15 minutes after decongestion with three sprays per nostril of 0.05% oxymetazoline hydrochloride nasal spray (İliadin, Santa Farma, Turkey). This was performed to eliminate mucosal variation attributable to the nasal cycle.

Initially, it was necessary to determine the location within the nasal valve and the CT plane needed in order for the imaged site to correspond to the site measured by AR. This required that we investigate issues related to the curved passageway of the human nose. The first task was to determine the acoustic axis of the curved nasal passage. A straight plastic pipe that contained a narrowed segment was used as a model. One set of AR measurements was recorded with the pipe straight. Then, without changing the location of the narrow segment, we bent the pipe into a quarter circle and repeated the AR measurements. The two sets of findings were essentially the same, and the distance from the end of the pipe to the narrow segment as determined by AR was identical in both sets, even though the passageway shape had changed (Fig. 1). These results showed that the imaginary line passing through the middle of the nasal passage was the acoustic axis, and that AR-calculated distances from the nose adapter to sites along this line would be the same regardless of passageway shape. In a previous study, we demonstrated that AR is accurate for determining the distance from the nose adapter to the narrow segment.[2] Based on these pieces of information, we were able to determine the cross-sectional plane and correct site in the nasal passage for CT so that the imaging and AR assessments would correspond.

Acoustic Rhinometry

A transient-signal acoustic rhinometer (Ecco Vision, Hood Instruments, Pembroke, MA) was used to obtain the acoustic measurements. For each subject, an external nasal adapter was selected for proper fit, and a thin layer of ointment was applied to prevent any acoustic leakage between the nostril and adapter. Special care was taken not to distort the nasal valve anatomy and to position the nose adapter so that it was only in light contact with the nostril during the assessment. All AR measurements were repeated three times to ensure that the results were reproducible. Figure 2 shows the AR measurements that were recorded and the data from one of the participants (subject 20). The places on the AR curve that correspond to the wave tube, the nose adapter, and nasal valve of this subject are marked in Fig. 2. The first minimum on the curve corresponds to the junction between the nosepiece of the rhinometer and the isthmus nasi. The second minimum corresponds to the narrowest part of the nasal cavity, which is the nasal valve.[9,10]

Acoustic rhinometry in the 25 subjects revealed cross-sectional areas of the nasal valve (*Area [AR]*) ranging from 0.46 to 1.15 cm^2. The AR-calculated distance from the nose adapter to the nasal valve (*d-AR*) ranged from 1.38 to 2.1 cm. These data for *Area* (*AR*) and *d-AR* (Table I) were used as references for CT assessment.

Computed Tomography

Computed tomography of the nasal cavity was performed using a multislice scanner (Somatom Volumezoom, Siemens, Erlangen, Germany) with tube voltage of 120 kV and current of 240

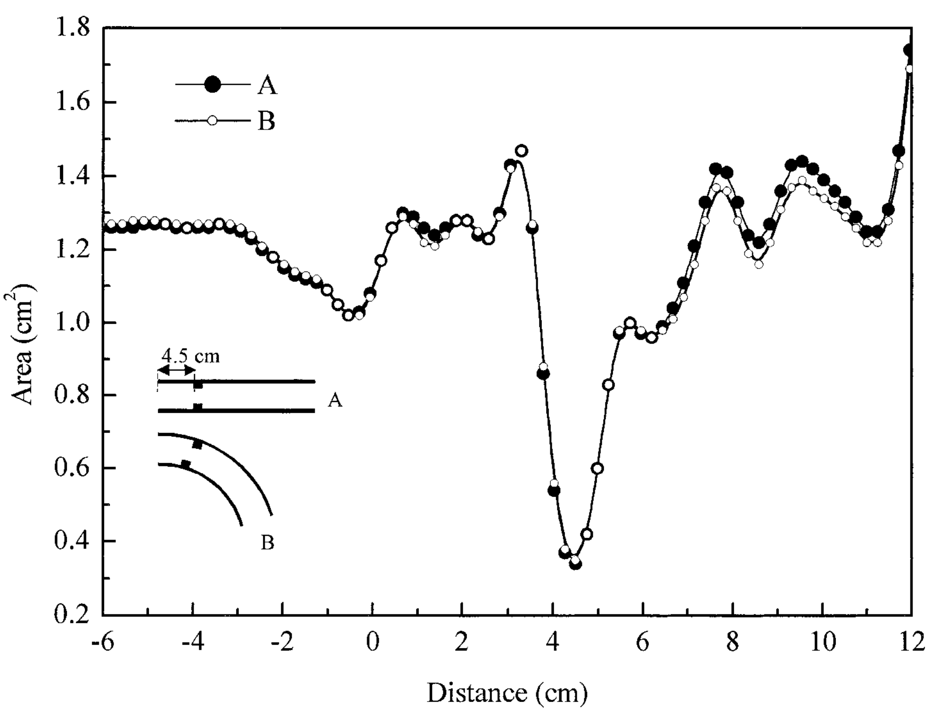

Fig. 1. Acoustic rhinometry measurements of a simple pipe model containing a narrow segment (**A**) when the pipe was straight and (**B**) after the pipe was bent.

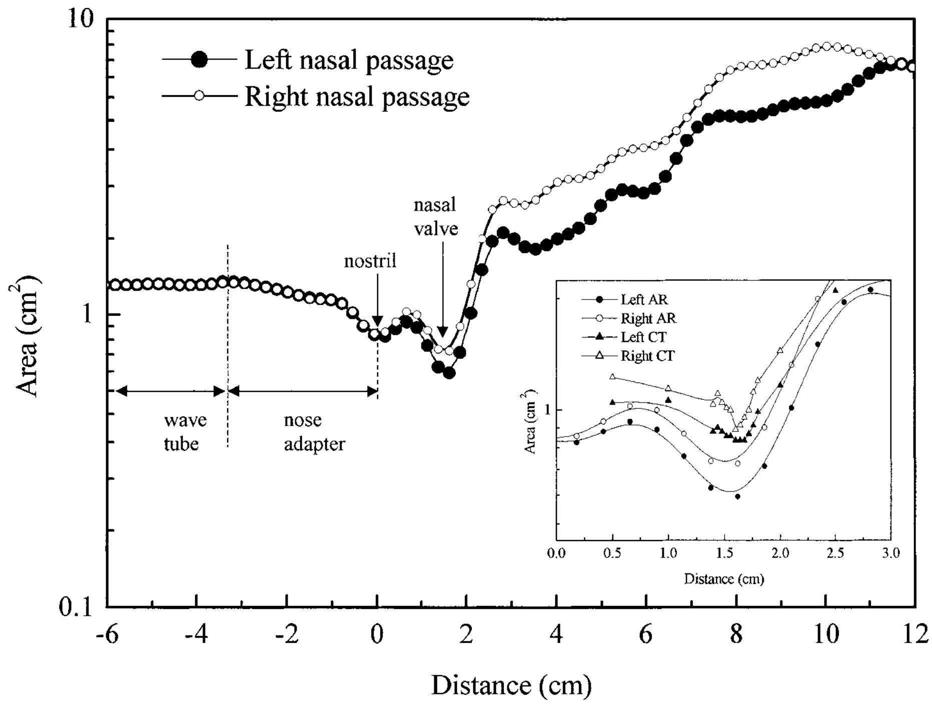

Fig. 2. Acoustic rhinometry (AR) results for one of the study subjects (subject 20 in Table I). In both nasal passages, the nasal valve was found to be located 1.62 cm from the nostril, and the AR-derived cross-sectional areas were 0.75 cm^2 and 0.63 cm^2 for the right and left sides, respectively. The inset compares the nasal valve areas measured by AR with those calculated from computed tomography images taken perpendicular to the acoustic pathway.

mA. The window width was 4000 Hounsfield units, and the window level was centered at 600 Hounsfield units. Axial CT scans parallel to the floor of the nose were obtained with 1-mm collimation, 2-mm slice thickness, and 2.6-mm table feet, and these images were reconstructed with 1-mm intervals at bone algorithm. The reconstructed image 0.5 cm from the nasal septum in the sagittal plane was obtained, and the estimated acoustic axis was drawn manually. For each individual, we calculated the angle between the hard palate and the plane we selected for the coronal section at the level of the nasal valves. Among the 25 subjects, these angles ranged from 45° to 55°. As shown in Figure 3, the angle in subject 20 was 55°.

For each individual, the distance from the nose adapter to the nasal valve area as determined by AR was marked on a sagittal CT image, as illustrated in Figure 4A. Figure 4A shows a coronal section perpendicular to the acoustic axis passing through the above-mentioned point. Ten more coronal sections located within 0.2 cm of this position were obtained as described above. The outer margin of the air passages was manually traced to calculate the cross-sectional areas (Fig. 4B), and the smallest area (*Area* $[CT_1]$) in this set of slices was recorded for each nasal passage (Table I). Figure 2 shows the AR- and CT-derived cross-sectional areas of the nasal valve in subject 20.

In addition, coronal CT slices taken perpendicular to the floor of the nose at two different locations were assessed, similar to the descriptions in previous reports.[3–7] For each subject, the slice at the same distance from the tip of the nose as determined by AR was obtained (Fig. 5A), and the cross-sectional area of each nasal passage (*Area* $[CT_2]$) was calculated as explained above (Fig. 5B). As well, the slice at same distance from the anterior nasal spine was obtained (Fig. 6A), and the cross-sectional area of each airway (*Area* $[CT_3]$) was calculated in the same way (Fig. 6B). All the calculated cross-sectional areas, including *Area* (CT_1), *Area* (CT_2), and *Area* (CT_3), for the 25 subjects are listed in Table I.

Linear Regression Analysis

Linear regression analysis was performed to test for correlations between the cross-sectional areas determined by CT and AR. This statistical method investigates the relationship between two variables, x and y. It assumes that the data are linearly related and yields the slope and the y-axis intercept of the straight line that best fits the experimental data.

A straight line can generally be written as $y = mx + b$, where m is the slope and b is the y value of the line when x equals zero. The parameters m and b are usually calculated by the method of least squares.[11] The parameter descriptions for linear regression are the intercept (b) and its standard error (SE), the slope (m) and its SE, the correlation coefficient (R), the standard deviation (SD), the P value (the probability that R is zero), and the number of data points (N). The correlation coefficient (R) is a fractional number that takes values between 0.0 and 1.0. An R value of 0.0 means that knowing x does not help to predict y. In other words, there is no relationship between x and y, and the line of best fit is a horizontal line going through the mean of all y values. If R equals 1.0, all points lie exactly on a straight line with no scatter. SD is the square root of the variance, which is a measure of the scatter of the data. Higher SD value means greater scatter. The P value gives the probability that the slope is zero, which would indicate no correlation between the two variables.

For the present study, the cross-sectional area measured by AR (*Area [AR]*) was taken as the x variable, and the cross-sectional area measured by CT (*Area* $[CT_1]$, *Area* $[CT_2]$, *and Area* $[CT_3]$ in separate plots) was taken as the y variable. The data were then analyzed using standard software (Origin, version 6.0, Microcal Software Inc., Northampton, USA).

RESULTS

The AR and CT findings for cross-sectional area of the nasal valve were compared in plots for the three different CT approaches. Figure 7A–C shows the CT results (*Area* $[CT_1]$, *Area* $[CT_2]$, and *Area* $[CT_3]$, respectively) as a function of the AR results (*Area [AR]*), as detailed above. The correlation between the AR and CT data when imaging was obtained perpendicular to the acoustic axis is illustrated in Figure 7A. The line of best

TABLE I.
The Nasal Valve Areas for 25 Subjects as Determined by Acoustic Rhinometry (AR) and Computed Tomography (CT), With Methods Detailed in the Text.

Subject No.	d-AR Right (cm)	d-AR Left (cm)	Area (AR) Right (cm^2)	Area (AR) Left (cm^2)	Area (CT_1) Right (cm^2)	Area (CT_1) Left (cm^2)	Area (CT_2) Right (cm^2)	Area (CT_2) Left (cm^2)	Area (CT_3) Right (cm^2)	Area (CT_3) Left (cm^2)
1	1.62	1.86	0.87	0.63	0.87	0.72	1.62	1.50	3.80	3.00
2	1.38	1.38	0.50	0.73	0.85	1.02	1.49	1.60	2.59	2.74
3	1.38	1.62	0.72	0.55	0.92	0.82	1.31	1.23	3.23	3.09
4	1.62	1.62	0.53	0.66	0.82	0.97	1.46	1.59	3.44	3.29
5	2.1	2.1	0.56	0.74	0.90	0.93	1.50	1.64	2.47	2.26
6	1.62	1.62	0.70	0.86	0.98	0.99	1.51	1.59	2.58	2.41
7	1.62	1.62	0.49	0.48	0.87	0.81	1.24	1.15	2.13	1.87
8	2.1	1.62	0.46	0.62	0.83	0.91	1.40	1.23	2.58	3.44
9	1.86	1.86	0.61	0.72	0.69	0.94	1.04	1.41	2.69	2.61
10	1.86	1.86	0.46	0.56	0.61	0.71	1.25	1.34	3.16	2.60
11	1.86	1.86	0.57	0.73	0.89	1.10	1.56	1.44	3.36	2.54
12	2.1	2.1	0.97	1.07	1.15	1.16	1.69	1.73	4.18	3.34
13	1.62	1.62	0.58	0.78	0.85	1.08	1.26	1.70	2.87	3.13
14	1.86	1.62	0.51	0.54	0.57	0.67	1.26	1.40	1.94	2.03
15	1.86	1.62	0.48	0.58	0.69	0.88	1.02	1.49	1.53	2.22
16	1.62	1.62	0.56	0.69	0.78	0.78	1.13	1.20	2.24	2.82
17	1.62	1.62	0.62	0.71	0.73	0.72	1.23	1.18	2.08	2.56
18	1.86	1.86	0.54	0.78	0.95	1.15	1.35	1.76	2.13	2.99
19	1.62	1.62	0.56	0.56	0.81	0.84	1.05	1.05	2.5	2.82
20	1.62	1.62	0.75	0.63	0.90	0.85	1.62	1.39	2.39	2.32
21	1.62	1.62	0.67	1.13	0.54	1.21	1.16	2.93	2.15	3.80
22	1.62	1.62	0.51	0.58	0.69	0.69	1.08	1.18	2.36	2.23
23	1.86	1.86	0.61	0.66	0.71	0.64	1.22	1.26	2.93	3.57
24	1.38	1.38	0.61	0.61	0.88	0.75	1.25	1.33	2.09	2.60
25	1.62	1.62	0.81	0.73	0.97	0.88	1.66	1.46	2.57	1.97

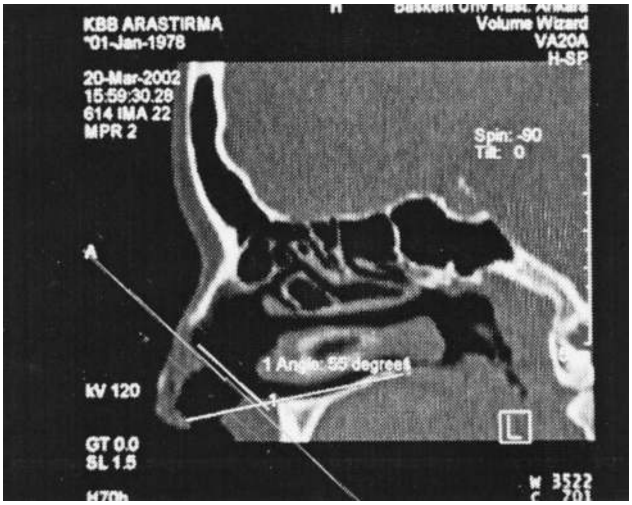

Fig. 3. The calculated angle between the selected coronal section and the floor of the nose of subject 20.

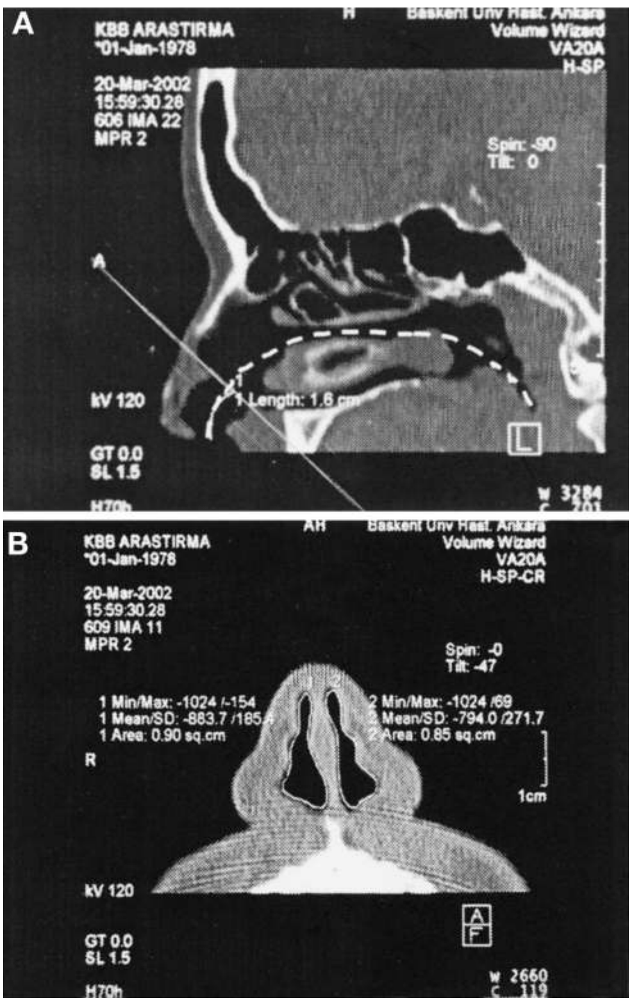

Fig. 4. (**A**) A coronal computed tomography (CT) image from a scan of subject 20. The CT section was taken perpendicular to the acoustic axis at 1.62 cm from the nostril, which is the distance determined by acoustic rhinometry examination. (**B**) The calculated nasal valve area for subject 20 based on images taken perpendicular to the acoustic axis (*Area [CT_1]*).

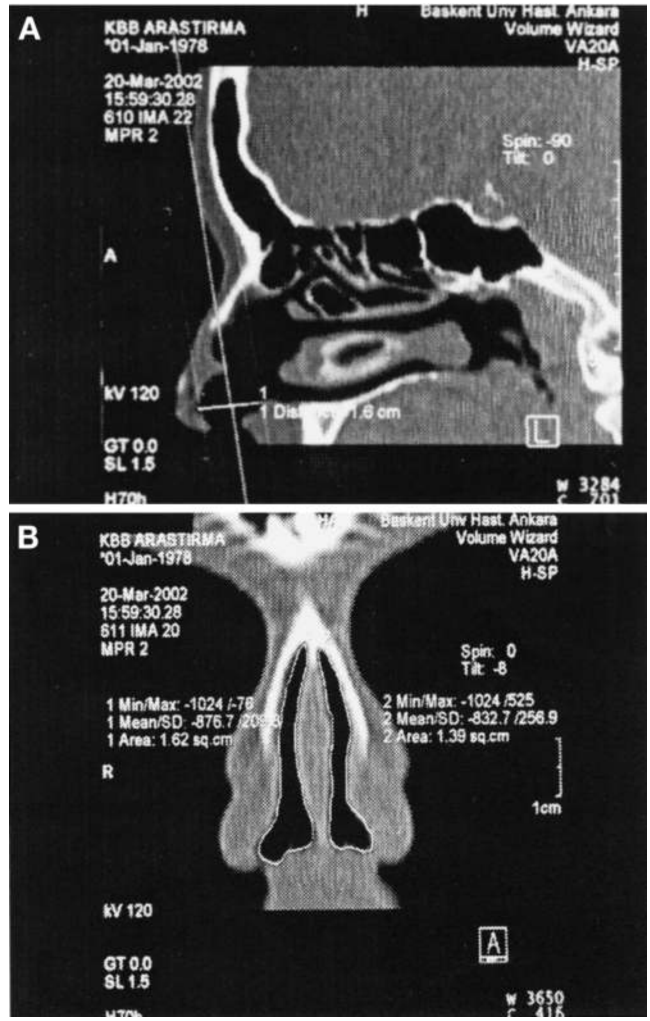

Fig. 5. (**A**) A computed tomography (CT) slice from imaging of subject 20 that was performed perpendicular to the floor of the nose at 1.62 cm from the tip of the nose. (**B**) The calculated nasal valve area for subject 20 based on images taken perpendicular to the floor of the nose (*Area [CT_2]*).

fit, as determined by the least-squares method, is given by

$$\text{Area}\ (CT_1) = 0.38 + 0.73\ \text{Area}\ (AR) \quad (1)$$

with $R = 0.69$, $SD = 0.11$, and $P < .0001$.

As described above, two sets of CT data were collected from imaging obtained perpendicular to the floor of the nose. The correlation between the AR data and the CT data with the tip of the nose as the reference point (*Area [CT_2]*) is shown in Figure 7B. The line of best fit for this plot was given by

$$\text{Area}\ (CT_2) = 0.42 + 1.50\ \text{Area}\ (AR) \quad (2)$$

with $R = 0.73$, $SD = 0.21$, and $P < .0001$.

The correlation between the AR data and the CT data with the anterior nasal spine as the reference point (*Area*

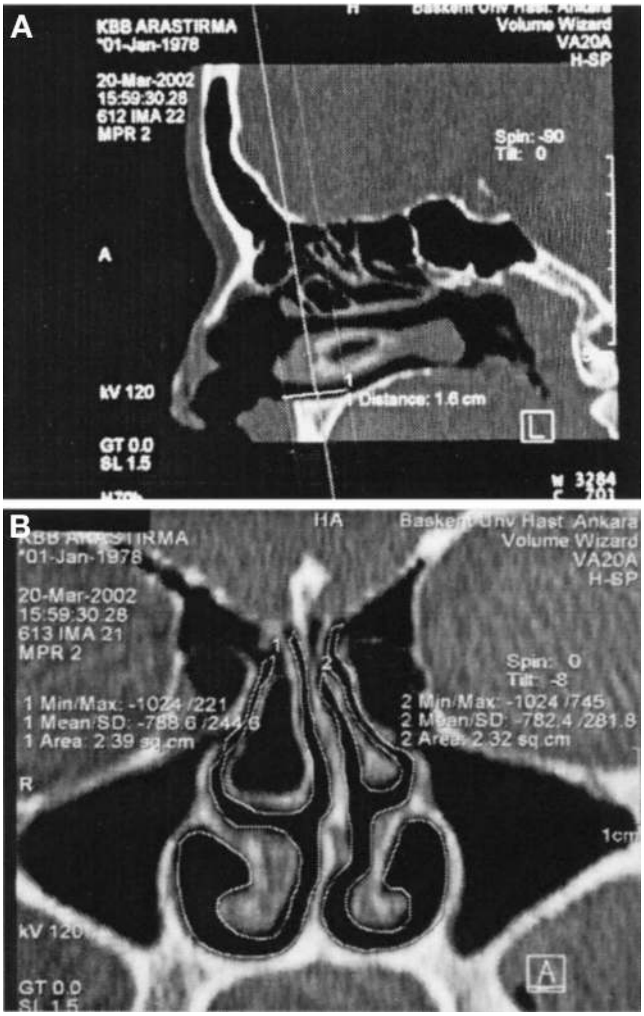

Fig. 6. (**A**) A computed tomography (CT) slice from imaging of subject 20 that was performed perpendicular to the floor of the nose at 1.62 cm from the anterior nasal spine. (**B**) The calculated nasal valve area for subject 20 based on images taken perpendicular to the floor of the nose (*Area [CT_3]*).

[CT_3]) is shown in Figure 7C. The line of best fit for this plot was given by

$$\text{Area } (CT_3) = 1.43 + 1.93 \text{ Area (AR)} \quad (3)$$

with $R = 0.50$ $SD = 0.49$, and $P < .0002$. The linear regression parameters are summarized in Table II.

If the nasal valve areas determined by AR and CT were identical, then the intercept b of the straight line would be zero and its slope m would be 1. The graph of *Area (CT_1)* versus *Area (AR)* yielded the b and m values (see Equation [1]) that were closest to these theoretical values. The b and m values of the lines in the other two plots indicate only a weak correlation between the AR and CT results (see Equations [2] and [3]). The *SD* values for the three plots corresponded with these findings. These results clearly indicate that, to determine nasal valve area by CT, it is necessary to measure cross-sections on images taken perpendicular to the acoustic path. However, most

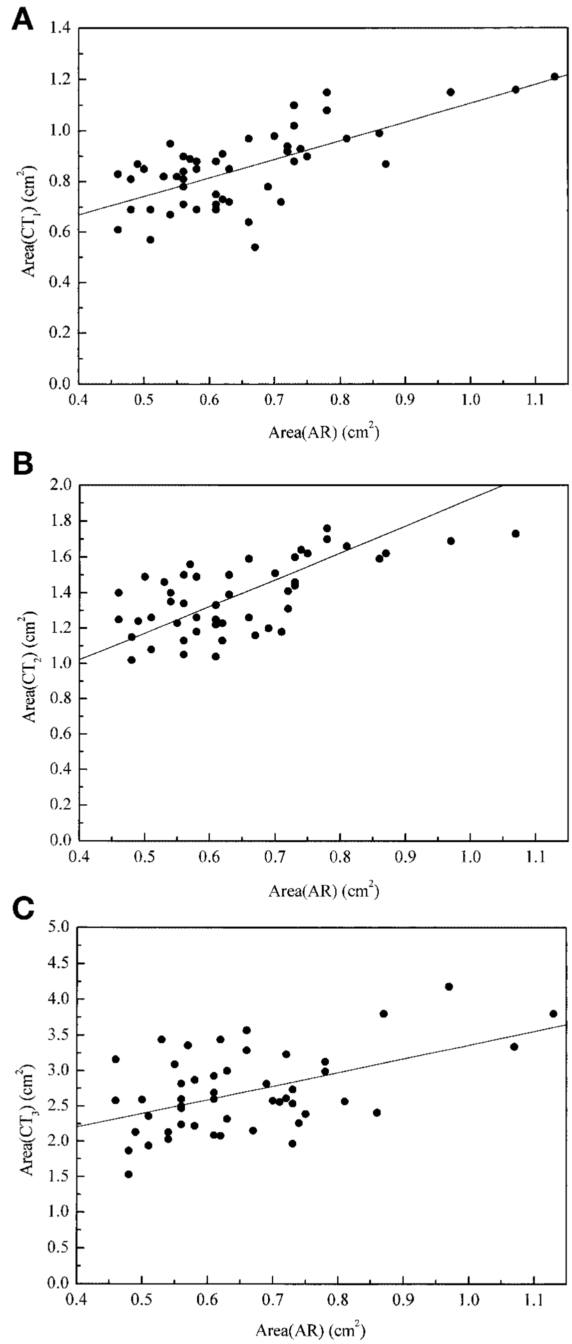

Fig. 7. Plots of cross-sectional areas determined by computed tomography (CT) as a function of the areas determined by acoustic rhinometry (AR). (**A**) *Area (CT_1)* versus *Area (AR)*, (**B**) *Area(CT_2)* versus *Area (AR)*, and (**C**) *Area(CT_3)* versus *Area (AR)*. In each case, the straight line through the experimental data points was determined by linear regression analysis.

previous studies have measured nasal valve area based on CT_2 and CT_3 cross-sections.

DISCUSSION

Several factors limit the accuracy of AR measurements.[2] The most widely recognized and longest-known problem with acoustic-pulse analysis is the inability to

TABLE II.
The Fitting Results for the Three AR Area versus CT Area Plots.

	b (cm^2)	*m*	*R*	*SD*	*P*	*N*
CT_1(area)-AR	0.38 ± 0.07	0.73 ± 0.11	0.69	0.11	<.0001	50
CT_2(area)-AR	0.42 ± 0.13	1.50 ± 0.20	0.73	0.21	<.0001	50
CT_3(area)-AR	1.43 ± 0.32	1.93 ± 0.48	0.50	0.49	<.0002	50

b = intercept valueand its standard error; *m* = slope and its standard error; *R* = correlation coefficient; *SD* =standard deviation; *P* = the probability that R is zero; *N* = number of data points of fit.

accurately measure areas beyond narrow apertures.[12,13] In addition, sound loss to the paranasal sinuses may negatively affect the accuracy of AR measurements of more distal segments, depending on the geometry of the ostium.[14,15] These issues explain why it is difficult to measure cross-sectional areas in the posterior nasal passage. The anatomy of the nose is complex, with a narrow anterior segment leading to sinus ostia. In other words, AR findings for the distal part of the nasal cavity may not be sufficiently accurate for clinical use. However, the anterior part of the nose contains its narrowest segment, the nasal valve region, which is the site of most interest for the rhinologist.[16,17] The precision of AR in the anterior part of the nose, especially for the nasal valve, makes this method valuable for rhinology.

In a previous study, we investigated factors that affect the accuracy of AR measurements, with particular focus on the nasal valve region.[2] The simple model we used consisted of a metal pipe with cylindrical inserts of various lengths and aperture diameters that were comparable to the dimensions of the human nasal valve. The results showed that there are systematic errors inherent to the physics and hardware of the AR instrument. The cross-sectional area and the length of the narrow segment are the factors that most significantly influence the accuracy of AR. The data revealed that the area of the experimental passageway was consistently overestimated. Moreover, when the cross-sectional area and the length of the narrowest part of the passage were relatively small and short, the probability of measurement error was higher.[2] In addition to flaws with models, experimental studies involving models or cadavers have also failed to reproduce the acoustic properties of the living nasal mucosa. These issues have made it essential to collect in vivo data from clinical trials to confirm the experimental results.

Various imaging modalities have been used to test the accuracy of AR in clinical trials with living subjects. Min and Jan[4] and Gilain et al.[5] compared cross-sectional areas of the nasal passages measured by AR and CT in 30 and 9 patients, respectively. In both of these studies, the CT sections were obtained in the coronal plane perpendicular to the nasal floor and hard palate, with distance calculated from the anterior nasal spine. In a more recent study, Prasun et al.[7] compared cross-sectional area measurements of the nasal passages with high-resolution CT and AR. Again, imaging was obtained in the coronal plane perpendicular to the axis of the floor of the nose, but in this work the tip of the nose was used as the reference point. Clinical studies by Hilberg et al.[3] and Corey et al. compared nasal cavity cross-sectional areas derived by AR and magnetic resonance imaging (MRI). The imaging was also obtained perpendicular to the floor of the nose in both these investigations. Hilberg et al.[3] calculated distance from the tip of the nose, but the reference point used by Corey et al.[6] was not defined. In a study conducted in 2000, Terheyden et al.[8] assessed the validity of AR in six healthy subjects who were examined by CT and AR. In the investigation, the CT-derived cross-sectional areas were calculated from slices oriented perpendicular to the axis of sound wave propagation.

All of the above reports noted significant correlations between the cross-sectional areas obtained by imaging modalities and AR, with particularly high agreement in the anterior part of the nasal cavity. However, with the exception of the study by Terheyden et al.,[8] in all of the investigations of living subjects, the CT and MR images were taken perpendicular to the axis of the floor of the nose.[3–7] Some investigations used distances from the anterior nasal spine,[4,5] whereas others used the tip of the nose as the reference point.[3,6] Clearly, it is difficult to make definitive statements about the validity of AR based on data from different imaging techniques, different imaging axes, and potentially different sites in the nasal passage, because of different reference points.

Hilberg et al.[1] stated that the major problem with comparing AR findings and data from imaging techniques is the issue of whether the acoustic axis and the CT scans are in exactly the same plane. They emphasized this in relation to the curved shape of the nasal airway. However, our pipe model shows that the acoustic axis can be considered to pass through the center of the passage and that AR-calculated distances from the nose adapter to sites along this line are the same regardless of whether the passage is straight or curved (Fig. 1). As mentioned earlier, experiments have shown that AR gives an accurate measure of the distance from the nose adapter to the narrow segment.[2] The results of the present study indicate that AR and CT findings for nasal valve area are significantly correlated when imaging is obtained perpendicular to the acoustic axis. As we had anticipated, there was only a weak correlation between the AR and CT data when imaging was obtained perpendicular to the nasal floor with the nose tip as the reference point. Further, there was no statistical correlation between the AR- and CT-derived areas when imaging was obtained perpendicular to the floor of the nose with distance calculated from the anterior nasal spine.

According to our findings, when AR data for nasal area are to be compared with calculations based on any imaging technique, the imaging cross-sections must be perpendicular to the acoustic pathway. In addition, distances represented by sites on the AR curve correspond to distances within the nasal passage, as measured on the estimated line through the center of the curved airway.

CONCLUSION

To be of significant value for rhinology, AR must give accurate measurements of nasal valve area. The finding of a significant correlation between AR data and CT data from images obtained perpendicular to the acoustic axis shows that AR is a valuable method for measuring nasal valve area. We also conclude that, to compare AR findings with data derived from any imaging technique, the cross-sections must be perpendicular to the acoustic pathway, which follows the curve of the nasal passage. Imaging studies that do not take into account the shape of the acoustic pathway lead to misinterpretation.

Acknowledgments

The authors thank Prof. Dr. Mehmet Cankurtaran, PhD, for his valuable discussion and critical reading of the manuscript.

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