Acoustic rhinometry and computed tomography scans for the diagnosis of nasal septal deviation, with clinical correlation

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OBJECTIVE: **The aim in this study was to analyze the efficiency and reliability of acoustic rhinometry (AR) readings in recognition of nasal septal deviation.**
METHOD: **We compared 24 patients' AR readings with their sinus CT scans. The patient data were analyzed by comparison with normative data, area, and percentage differences between the two sides. Additionally, the data further analyzed by receiver operating characteristic curve and Spearman correlation of CT and AR in determining nasal septal deviation.**
RESULTS: **The sensitivity of AR in detecting anterior septal deviations was found to be 54%, with a specificity of 70%. A very highly significant correlation ($P \leq 0.001$) was found between minimal cross-sectional area (CSA) 1 values and CT results.**
DISCUSSION: **In the interpretation of AR readings, comparison of each CSA value should be included, in addition to use of the total absolute CSA values.**
CONCLUSION: **According to our findings the diagnosis of nasal septal deviation can be supported by AR readings.** (Otolaryngol Head Neck Surg 2000; 123:61-8.)

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Deviation of the nasal septum (DNS) is one of the most common diagnoses in otolaryngology practice. The diagnosis usually is based on patient symptoms and anterior rhinoscopic findings. For more than 30 years, physicians have attempted to use different diagnostic methods to demonstrate nasal septal deviation objectively.

Patients with DNS usually have nasal congestion. However, these patients rarely have only anatomic deformities. They also have other problems that affect their nasal mucosa, including vasomotor diseases, infections, and autoimmune diseases. In each case, the physician must use his or her judgment to understand the contribution of any of these diseases to patient symptoms. Consequently, any nasal function test that will be used for evaluation of these patients should give information about reversible mucosal congestion as well as bony and septal deviations.

CT of the sinuses and acoustic rhinometry (AR) are two diagnostic tools that can be used to demonstrate DNS. Although CT will show bony and cartilaginous anatomic abnormalities of the septum very reliably, this method should be used only rarely for the diagnosis of DNS. The main purpose of obtaining a CT scan is to evaluate the paranasal sinuses. It is an expensive method for evaluating septal deformity and will expose patients to unnecessary radiation. CT scans and AR measurements of the nasal airway have been shown to correlate well with each other, especially in the anterior portion of the nose.[1,2]

AR is a relatively new method based on analysis of sound waves reflected from the nasal cavity. It is a noninvasive and rapid technique. In this method, measurements are taken separately at baseline and after appropriate decongestion or shrinking of the mucosa by α-sympathomimetic agents such as oxymetazoline or phenylephrine (Neo-Synephrine).[3] The postdecongestant acoustic rhinometry analysis provides data predominantly about the fixed anatomic status of the nasal cavity. The predecongestant and postdecongestant analyses can be compared to provide information about the reversible mucosal component that is effecting the patient's symptoms. Hence, AR may provide the clinician with objective data beyond that of a physical examination. A computer draws a graph plotting the distance from the nostril relative to the cross-sectional area (CSA); thus the 3-dimensional nasal cavity is projected into a 2-dimensional graph. In this graph, the y-axis represents the distance into the nasal cavity, and the x-axis represents the 2-dimensional area relative to distance. Most subjects demonstrate a sudden decrease, which looks like a valley on the graph, at around 2 cm; this corresponds to the anterior portion of the inferior turbinate. This site is referred to as minimal CSA 1. At about 4 cm, another valley usually appears, which is termed minimal CSA 2 and which corresponds to the anterior portion of the middle turbinate. The valley that appears at about 6 cm is termed the minimal CSA 3 and roughly corresponds to the middle portion of the middle turbinate and the natural maxillary ostium.[4]

In previous publications, Grymer et al[5] compared objectively measured CSA values to patients' subjective feelings of nasal obstruction. They showed that a minimal CSA below 0.4 cm^2 is a critical value that corresponds to a feeling of nasal obstruction. Grymer et al also found a correlation between the subjective sensation of nasal patency and CSA values. Additionally, Roithmann et al[6] demonstrated a significant relationship between the minimal CSA and a visual analog scale in a group of patients reporting nasal obstruction. On the other hand, Tomkinson and Eccles[7] did not see any correlation between the minimal CSA and visual analog scale in non-DNS patients. Milqvist and Bende,[8] Corey et al, [4] and Grymer et al[9] have published normative values for CSA and volume in non-DNS patients to be used clinically and in research studies.

In this retrospective study, we investigated the use of AR and CT in diagnosing DNS. We conducted 5 different tests that could give information to be used in diagnosis. We checked to determine the usefulness of AR data, including published normative standards, area differences between sides, and percentage differences in area before and after decongestion between sides. We hypothesized the following: (1) that most of the CSA values of non-DNS patients would fall within the range of normative values[4]; (2) that DNS patients would have larger area differences than non-DNS patients; (3) that DNS patients would have larger percentage differences in area than non-DNS patients on comparison of the change in area before and after decongestant; and (4) that AR and CT would have similar accuracy compared with clinical diagnosis and compared with each other.

METHODS AND MATERIAL

Twenty-four patients were randomly selected for our retrospective study. These patients were fully evaluated by nasal endoscopy, CT, and allergy testing and were followed up for at least 6 months by one of us (J.P.C.). Our initial physical examination (anterior rhinoscopy and endoscopy) allowed us to designate a patient's septum as having no deviation or being mildly, moderately, severely, or markedly severely deviated. All CT studies were done for evaluation of each patient's sinus problems. The CT scans and AR graphs were usually obtained between the patient's initial visit and first follow-up visit. The ages of the patients ranged from 14 to 67 years (median 36 years). Written consent is not regularly required by our local institutional review board for retrospective chart reviews, which contain aggregate information and which lack patient identification. All of the interventions were based on clinical criteria; no changes in patient care were undertaken for the purposes of this study.

A blinded gradation, ranging from 1 to 4, was assigned on the basis of the coronal CT views at the following locations: at the anterior end of the inferior turbinate, at the anterior end of the middle turbinate, and around the middle portion of the middle turbinate. As previously noted, these 3 locations correspond roughly to CSA 1, 2, and 3, respectively. A minimal deviation was represented by the number 1, moderate deviation represented by 2, severe deviation represented by 3, and markedly severe deviation represented by 4. Deviations to the left were labeled with negative values, deviations to the right were labeled with positive values, and no deviation was labeled with the number 0. In reading of the CT scans, only shift of the septum from the midline was taken into account; no notice was taken of turbinate or sinus pathology for this study.

The AR graphs were obtained with a 2-microphone acoustic rhinometer (Hood Laboratories, Pembroke, MA). Each AR study was performed by an experienced technician in a standard fashion that has been described previously.[4]

Minimal CSAs 1, 2, and 3 were measured after application of topical decongestants. The first 3 valleys were identified and noted for their respective locations. These were labeled CSA 1, 2, and 3 according to their distance from the tip of the nosepiece, as described above. The distance of the CSAs may differ from side to side; this shift was accepted as normal if it was equal to or less than 0.50 cm. However, if it was greater than 0.50 cm, the measurements were taken directly at 2 cm for CSA 1, at 4 cm for CSA 2, and at 6 cm for CSA 3. The percentage difference in area before and after decongestant administration for each CSA was calculated as follows:

$$\%\text{Difference} = \frac{(\text{After CSA} - \text{Before CSA})}{\text{Before CSA}}$$

Next, the percentage difference in area between the right and left sides after decongestant was calculated as follows:

$$\%\text{Difference} = \frac{(\text{Larger CSA} - \text{Smaller CSA})}{\text{Smaller CSA}}$$

Table 1. Patient data

Patients	CSA 1		CSA 2		CSA 3	
	CT 1	AR 1	CT 2	AR 2	CT 3	AR 3
Non-DNS patients						
1	0	18 (L)	0	2.9 (L)	0	2.5 (L)
2	1	47	1	5 (L)	0	38.9 (L)
3	1 (L)	21.8 (L)	1 (L)	13.8 (L)	1 (L)	15.4
4	2	46	0	9.7	0	7.1
5	1 (L)	85 (L)	1 (L)	23.6 (L)	0	3.8
6	1	2.7	2	2 (L)	2	31.2 (L)
7	0	48.5 (L)	2 (L)	63.3 (L)	3 (L)	46.2 (L)
8	0	10	1 (L)	6.7	0	16.4
9	0	52 (L)	0	2.2 (L)	0	77
10	1	34.4	1 (L)	19.1 (L)	2 (L)	25.5 (L)
11	0	26 (L)	0	37 (L)	1 (L)	40 (L)
DNS patients						
1	1	20.4	1	16.8 (L)	1	44.8 (L)
2	1	21.7	0	4.1	1	20
3	2 (L)	30.6	1 (L)	36.6	0	20.4
4	0	61	0	46.6	0	7.1
5	1	32	1	11 (L)	2	29 (L)
6	2 (L)	82 (L)	3 (L)	67.8 (L)	3 (L)	87.6 (L)
7	2 (L)	11 (L)	4	12	3	28
8	1	55	3	10	3	13
9	0	20.8	2	47.4	2	17.7
10	0	4.8	2	8.4 (L)	2	53.7
11	3	20	2	9.4	0	20 (L)
12	0	18.6	0	19	0	38
13	0	2.8 (L)	0	38.5 (L)	0	39.1 (L)

These data were used in the ROC analysis and the Spearman correlations. All deviations were to the right, except those marked with *(L)*, which indicates that they were to the left. The AR readings were the absolute percentage difference in area after decongestant between the two sides. The formula is shown in the Methods section. In the AR readings, anything below 26% was taken to indicate no deviation for purposes of ROC analysis. A grading of 0 for the CT scans denotes no deviation.

The patient data (Table 1) were analyzed in 5 ways. The first test was applied to determine the usefulness of normative values in determining DNS. The values we used were those established by the senior author (J.P.C.) in a previous study.[4] These are a range of CSA values that were obtained from non-DNS patients. Patients were divided into groups with and without DNS, as determined by the clinical diagnosis. For each set of patients, we evaluated how many patients fell within the range of normative values for each CSA on both the right and left sides. We hypothesized that most of the CSA values for non-DNS patients would fall within the range of normative values. The patients with DNS were hypothesized to have one nostril of larger area and one of smaller as a result of the deviation. Most of these patients were expected to be either above or below the normative-values range.

In the next test, we subtracted the area of the smaller side from that of the larger one after administering decongestant to each patient. We expected there to be a larger average difference in area in the DNS and non-DNS patients. We also hoped to find a critical value for the difference in area between the two sides that could perhaps be used as a standard in the diagnosis of DNS.

In the third test, we subtracted the percentage difference in area before and after decongestant (Equation 1) for the smaller side from that of the larger side for each CSA. We expected that there would be a larger percentage difference before and after decongestant in the larger side than in the smaller one and that this would be more visible in the DNS patients and non-DNS patients because the former have one larger side as a result of septal deviation.

We used ROC analysis to compare the accuracy of AR and of CT scans in determining DNS relative to clinical diagnosis. The CT readings were compared with the percentage difference values in area between the right and left sides after decongestant, as obtained from AR (Equation 2). ROC analysis assesses the accuracy of a diagnostic tool by calculating sensitivity and specificity. Correlation data are not sufficient for assessing the utility of a diagnostic tool in clinical practice. Sensitivity and specificity are affected by a threshold level that sets the critical point from which results are considered positive or negative. This threshold point can be chosen arbitrarily. However, on the basis of normative data from the senior author's previous article,[4] we chose a 26% difference

Table 2. Percentage of CSA values that fall into the normative-values range

CSA	DNS patients		Non-DNS patients	
1	36	36	38	46
2	54	18	23	46
3	18	9	54	54
MEAN	36	21	38	49

Table 3. Side-to-side differences in area between larger and smaller side after decongestant

	Mean difference (cm^2)		
	CSA 1	CSA 2	CSA 3
DNS patients	0.15	0.29	0.61
Non-DNS patients	0.25	0.38	0.76
Difference (DNS – Non-DNS)	–0.1	–0.09	–0.15

between each side as the threshold value. This was based on the average percentage difference in non-DNS patients. A difference in area between the two sides of 0% to 26% and a zero reading from the CT grading were both taken to indicate no DNS. ROC analysis provides us with predicted specificity values as the sensitivity values change. These can be discerned from the ROC curve and the scales on the y-axis (true-positive fraction, or sensitivity) and the x-axis (false-positive fraction, or 1 – Specificity). The AR measurements and CT scans were compared for each CSA, with the clinical diagnosis used as the standard. The *Az* values on each graph are equivalent to the sensitivity for the particular comparison.

Lastly, Spearman correlation coefficients and *P* values were determined between the CT values and the percentage differences in area (obtained from AR) between the right and left sides after decongestant administration. In this statistical test, *P* values below 0.05 indicate a significant probability that the data are not random.

RESULTS

According to the CT readings, 14 patients showed DNS at the level of the anterior end of the inferior turbinate; 9 of these had minimal, 4 had moderate, and 1 had severe DNS. Sixteen patients showed DNS at the level of the anterior end of the middle turbinate; in 8 it was minimal, in 5 moderate, in 2 severe, and in 1 markedly severe. At the level of the middle portion of the middle turbinate, which corresponds to CSA 3, 13 patients had DNS; in 4 it was minimal, in 5 moderate, and in 4 severe. Nine of the patients had DNS at all 3 levels; 5 of them had DNS at the level of anterior end of both the inferior and middle turbinates.

Table 4. Percentage difference in area before and after decongestant between larger and smaller sides

	Mean difference (%)		
	CSA 1	CSA 2	CSA 3
DNS patients	24.15	109.31	86.46
Non-DNS patients	30.45	87.91	72.09
Difference (DNS – Non-DNS)	–6.3	21.4	13.56

These are the results for the 5 tests that we conducted. First, similar percentages of CSA values for all CSAs were within the normative-values range for patients with and without deviations on the left side. There was no significant difference as to which group fell within the normative-values range at a higher rate on the left side. However, on the right side, there was an increase in the percentage of non-DNS patients that fell into the normative-values range for all CSAs over the percentage of DNS patients. Table 2 lists the percentage of CSA values for each CSA, for both the left and right sides, that fell into the normative-values range.

Second, the non-DNS patients had larger differences in area than did the DNS patients. We expected a larger average difference in area in the DNS patients than in the non-DNS patients. The non-DNS patients actually had larger differences in area than did the DNS patients (Table 3).

Third, the difference between the percentage change in area before and after decongestant values of the two sides in the DNS patients for CSAs 2 and 3 was much larger than that for the non-DNS patients. The average percentage difference for CSA 2 between the two sets of patients was 21%, and for CSA 3 it was 14% (Table 4).

Fourth, the CT scans and AR readings were compared by means of ROC analysis. When compared with clinical diagnosis as the gold standard, both the CT and the AR readings were reasonably close to the clinical diagnoses in terms of sensitivity and specificity. The CT results were correlated with the clinical diagnosis somewhat better than the AR readings, but this difference was not significant (Figs 1-3).

Fifth, The correlation between CT scan readings and percentage difference values between the two sides was determined for all CSAs. The Spearman correlation test gave an *r* value of 0.73 ($P < 0.001$). The *r* value of CSA 2 was 0.58 ($P < 0.01$). The *r* value of CSA 3 was 0.44 ($P < 0.05$). The overall sensitivity and specificity of AR readings in detection of anterior septal deviations according to CT findings were found to be 57.14% and 70%, respectively.

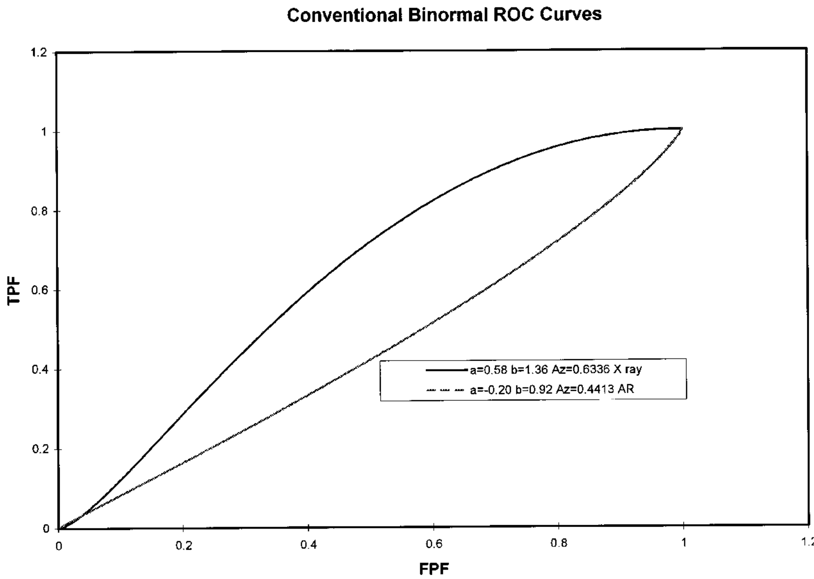

Fig 1. CT versus AR for CSA 1.

DISCUSSION

Although the reasons for nasal obstruction are complex and varied, the causes can be simplified as reversible factors, such as mucosal edema and congestion, and nonreversible factors, such as anatomic deformities. An ideal nasal function test would give objective information on both types of factors.

In a number of studies, the reliability and reproducibility of AR readings has been demonstrated, and a good correlation with both CT and MRI findings has been demonstrated.[1,2,10] The accuracy of AR decreases as the distance into the nose increases; consequently, measurements beyond 6 cm are not often advised. In a previous study,[10] the AR was noted to be more accurate in detecting deviations located more anteriorly in the nose. In this study, the correlation of AR readings and MRI results was very highly significant at the CSA 1 level (about 2 cm from the nostril). This correlation gradually decreased but remained significant at CSA 2 and CSA 3 (at about 4 and 6 cm, respectively).

Comparison with normative values may be an indicator of DNS. Both DNS and non-DNS patients fell within the normative-values range at the same rates for all CSAs for the left side, but not for the right. The fact that the results for the two sides were not consistent suggests that there is too much variation in the nasal area and structure to allow diagnosis of deviations simply by use of the normative standards as critical values that "draw the line" for determining deviations. The normative values are useful as references for average area but are not completely reliable to be used alone in determining deviations.

We also concluded that the differences in area are misleading in the diagnosis of DNS. Our results were the opposite of what we expected. There were some outliers among the non-DNS patients, but even if these patients are excluded, there is still a large difference in area between the DNS and non-DNS patients. Area may not be the best way to look for septal abnormalities in the nose. It may be wrong to assume that one side should be larger than the other simply because of a deviation. A minimal CSA at any particular level may be due to septal deflection alone or to nonreversible turbinate hypertrophy. Other physiologic factors, such as the shape of the lateral nasal wall, as well as physical differences resulting from surgery and physical damage, may cause the side that we assume should be smaller, because the septum is caving in toward it, actually to be larger. In other words, we may have been wrong in assuming that the nose is divided perfectly enough so that each side normally has roughly an equal area under all conditions.

Percentage differences are valuable in the determination of DNS. The percentage difference in area before and after decongestion of the two sides in the DNS patients for CSAs 2 and 3 was much larger than that for non-DNS patients. Little difference in CSA 1 would be expected because of the amount of erectile tissue in that area.[12] Even though the percentage difference in non-DNS patients was greater at CSA 1 than in DNS patients, it was only 6.3%. The degree of congestion, perhaps resulting from turbinate hypertrophy, may be a better guide to DNS. It may be that greater congestion with or without turbinate hypertrophy occurs on the side

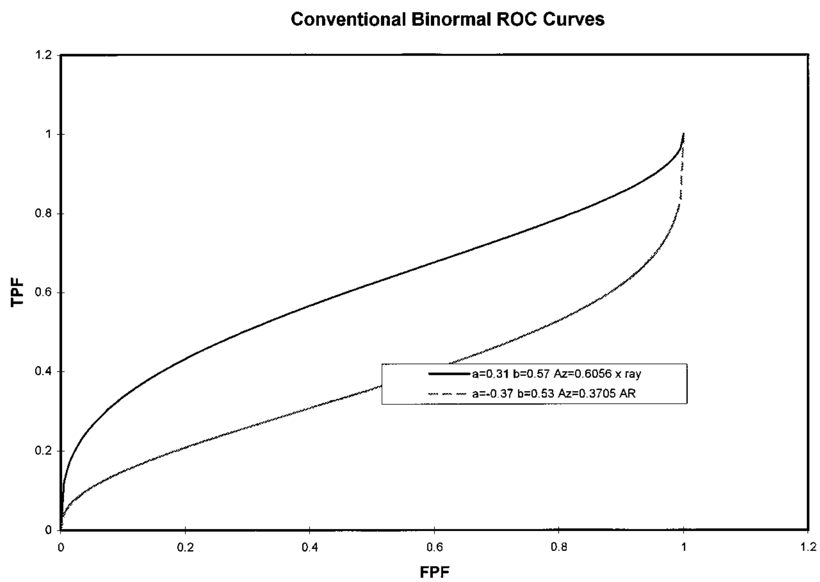

Fig 2. CT versus AR for CSA 2.

that is deviated, regardless of the overall area of that nostril. Clinically, it is often related that there can be a compensatory turbinate hypertrophy leaving the larger side functionally smaller. These findings agree with that clinical observation.

The AR is capable of detecting fluid accumulations that may be confused with structural or mucosal changes. It is possible that the deviation itself creates a shape or niche, on the side toward which it caves in, that is conducive to mucus accumulation. However, obstructions such as an S-shaped deviation should also be taken into account. These deviations would not necessarily induce mucosal accumulation on one side rather than on the other. In general, percentage differences can be used as better guidelines for inferring possible DNS (or turbinate hypertrophy).

From ROC analysis, we were able to conclude that CT scans and AR readings compared reasonably well with the clinical diagnosis for each CSA. Although the CT scans outperformed the AR readings slightly, one is about as reliable the other.

We used only postdecongestant values at each CSA when comparing the AR readings and CT scans in both ROC analysis and the Spearman test, to decrease the contribution of erectile tissue on the AR graphs. The anatomy of the nose becomes increasingly complex deeper inside the nasal cavity. At CSA 1 (at the 2-cm mark inside the nose), the floor of the nose, the septum, and the anterior part of the inferior turbinate contribute to the structure and area as displayed on the AR graphs. However, farther inside the nose, the middle turbinate and lateral nasal wall, made up of the agger nasi cell, uncinate, medial wall of the maxillary sinus, and ethmoid bulla, contribute to the structure and area of the CSAs on the AR graphs as well. In this study, the correlation of AR readings and CT results was significant for CSA 1. This correlation gradually decreased for CSAs 2 and 3. The increasing complexity of the intranasal anatomy, leading to increased scatter of acoustic energy, may have contributed to the decline in correlation at farther distances into the nose.

We studied a limited number (24) of patients, and most of them had minimal DNS; thus we did not have an adequate population of patients with severe DNS. These factors affected the sensitivity and specificity calculations. Most of the previous correlation studies done with AR were based on patients with severe DNS. Szücs and Clement[11] found that AR was sufficiently sensitive to reveal severe deviations in the anterior nasal cavity. If we had ignored the minimal septal deviations seen on CT scan and had noted only the more severe deviations, our sensitivity and specificity would likely have been higher than 57.14% and 70%, respectively. On the other hand, this study confirms that AR can detect even minimal anterior deviations with reasonable sensitivity and specificity.

Gilain et al[1] found reasonable agreement between AR and CT assessment of the nose. Their volume findings were statistically significant within the anterior part of the nose. Our studies differed regarding which CT or MRI scan frames representing the minimal cross-sectional areas (MCAs) were selected. Gilain et al stated that CSAs 1, 2, and 3 were represented by the piriform aperture, by a site lying between the head of the inferi-

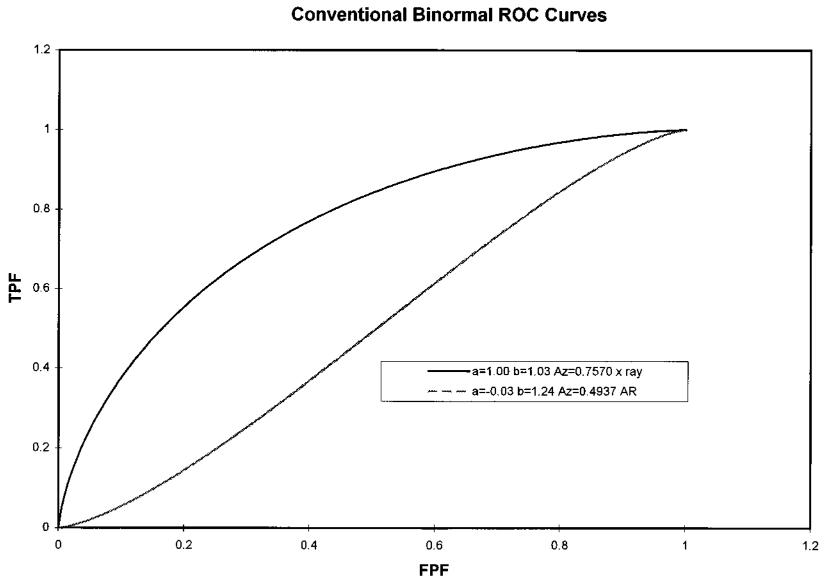

Fig 3. CT versus AR for CSA 3.

or and middle turbinates, and by the choana, respectively. The MRI scan frames we chose were not too divergent from those of Gilain et al for CSAs 1 and 2, but our third site was the middle portion of the middle turbinate, as determined by Grymer et al[5] and by our previous studies.[10] If our MRI scan frame representing CSA 3 is a more accurate localization, this may explain why Gilain et al found no correlation between AR and CT at CSA 3, but we did in previous studies using MRI and AR. Gilain et al concluded that CSA 3 does not match the third narrowest portion of the CT; the results may have shown some correlation had they used the CT scan at the level of the anterior ends of the inferior and middle turbinates and at the center of the middle turbinate, as our studies did.[1,10]

Although both CT and AR graphs provided CSAs, there is actually a 30° to 40° difference in the axial plane between these areas. A coronal CT scan is oriented perpendicular to the skull base, whereas the AR is oriented perpendicular to the plane of the nostril. This issue might be a cause of error in the reading of CT scan results, especially in S-shaped deviations with the septum deviated to the left at the top and to the right at the bottom, or vice versa.

Our study suggests that AR is a reasonable approach to an objective demonstration of anterior nasal deviation. However, although refinements in technology and/or interpretation may be necessary for improvement of the sensitivity and specificity of AR, it can be used as a routine clinical tool. In the current state of AR, this means that if the results are abnormal, AR can objectively document DNS about as well as CT scans; a clinical diagnosis of DNS is not ruled out by a normal AR or CT.

A further refinement of our work would be to compare the patients' subjective nasal symptoms, including nasal obstruction, to the objective findings of physical examination, CT, and AR. The patients' subjective symptoms were recorded through a standardized survey format after their initial visit; we intend to perform such a correlation with the objective data presented in this article.

CONCLUSION

This study demonstrates the utility of AR in assessing DNS. Percentage differences between sides at each CSA are better indicators of deviation than are absolute area or normative values. This study also showed that CT scans are a reliable method for diagnosing DNS, but the AR is better to use because it is quicker and does not involve radiation. Rather than relying on subjective interpretation, AR offers a simple objective measure of DNS. With our present medical climate demanding ever more objective proof of a disability before surgical intervention, AR offers a possible solution to this dilemma.

AR and CT are correlated to each other, but their accuracy is limited compared with that of the clinical diagnosis. They offer objective documentation, however, and are particularly useful in abnormal cases.

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