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Acoustic rhinometry: Values from adults with subjective normal nasal patency

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SUMMARY

The nose with normal feeling of nasal patency, and no gross structural changes has been described in 82 individuals by acoustic rhinometry. Curves for one and both sides of the nasal cavity and before and after decongestion have been recorded. We have found that the minimal cross-sectional area (MCA) is located anteriorly in the nasal cavity; in some subjects it is localized at the head of the inferior turbinate and in other subjects more anteriorly at the nasal valve. After decongestion MCA moves even more anteriorly. Beyond the MCA the dimension of the nasal cavity increases, with maximal effect of decongestion at 4 cm from nostrils. Decongestion increases the total volume of the nasal cavity by 35%.

INTRODUCTION

We have earlier presented acoustic rhinometry as a new objective method to assess the geometry of the nasal cavity (Hilberg et al., 1989). The method, based on sound reflection analysis provides an estimate of the cross-sectional area of the nasal cavity as a function of the distance from the nostril (Figure 1). The method has demonstrated its applicability in the pre- and postoperative evaluation of cases of impaired nasal patency due to septal deviations and turbinate pathology (Grymer et al., 1989). The minimal cross-sectional area and more posterior areas located near the inferior turbinates as well as the total volume of the nasal cavities were found to be important measures of the nasal cavity related to impaired nasal patency.

To describe a normal nose is difficult due to racial, developmental and environmental differences, which provide a wide variety of skeletal and mucosal variations within the nasal cavity. Nevertheless, from the clinical point of view we are interested in knowing the characteristics of the nose with apparently normal function, defined as the nose where respiration happens unnoticed. It is important to have objective methods which describe the nasal cavity in an accurate, reliable and reproducible way. Rhinomanometry and nasal peak flow are objective dynamic methods expressing characteristics of airflow, but they do not provide a topical description of the nose. CT-scan is suitable in the three dimensional evaluation of the nasal cavity (Montgomery, 1979) but it provides only a static picture and gives no information about rapid changes of the nasal mucosa. Both requirements are encountered by acoustic rhinometry.

The purpose of this study has been:

1. To describe the geometry of the nasal cavity with subjective normal patency, and to determine the effect of maximal decongestion on the nasal mucosa in different parts of the nasal cavity with special regards to the effect on and the location of the minimal cross-sectional area relative to the inferior turbinate.
2. To evaluate and describe methodological details of acoustic rhinometry.

MATERIAL AND METHOD

Individuals studied rhinomanometry

A random population of 82 individuals were studied. It was chosen among a group participating in another study and was unbiased concerning nose troubles. The group was drawn randomly from the central personal register. The criteria for participation in the present study was a subjective feeling of normal nasal patency, and no gross structural changes on rhinoscopic examination. The group consisted of 48 men and 34 women (mean age 28 years; range 18 to 40 years) (Table 1).

Table 1. Age distribution, height and weight of the studied subjects.

	age groups (years)				height (cm)	weight (kg)
	18-25	26-30	31-35	36-40	mean (range)	mean(range)
women	21	9	0	4	169 (159-178)	63 (36-100)
men	5	23	17	3	182 (170-204)	78 (61-123)

Methods

Acoustic rhinometry: the equipment is shown in Figure 1 and the method has been described in a previous paper (Hilberg et al., 1989). An audible sound pulse (150-10,000 Hz) generated by a spark is propagating in a sound tube and is reflected by local changes in acoustic impedance due to changing cross-sectional area with distance. If the signal of the incident and reflected waves are measured in a time domain it is possible to determine the distance to the local impedance change and by comparing incident and reflected waves it is furthermore possible

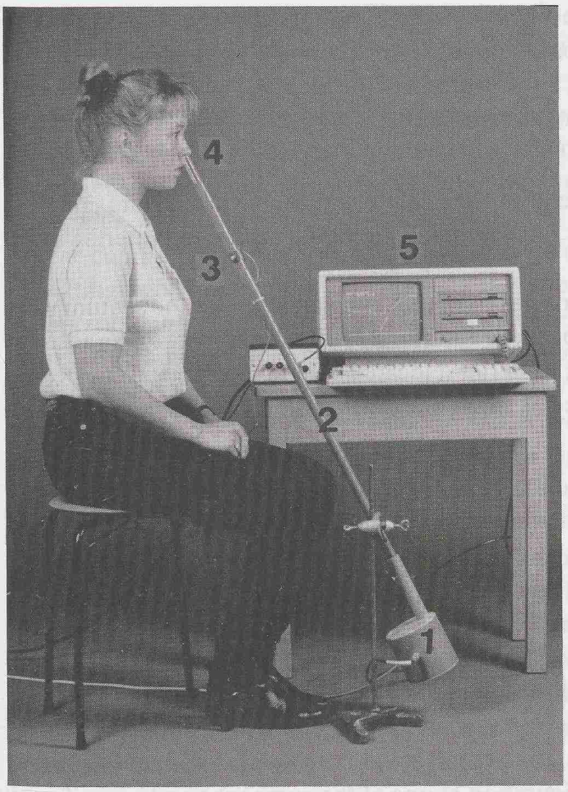

Figure 1. The set-up for acoustic rhinometry:
1. Spark source
2. Sound tube
3. Microphone
4. Nosepiece
5. Computer

to determine the size of change in the cross-sectional area. This provides an estimate of the cross-sectional area as a function of the distance from the nostril. Nosepieces with two different diameters (12 mm, 10 mm) were used for nostrils of different size. It is important that the nosepiece fits tightly and great precaution was taken to avoid deformation of the vestibulum nasi. Each measurement was repeated three times alternating between right and left sides, in order to assure the validity of each measurement. The measurements were done before and after decongestion. To obtain maximal decongestion the nasal cavities were filled with 0.12% ephedrine followed by two sprays of xylometazoline hydrochloride 0.5%, at the top and the bottom of the nose respectively. From each measurement the following parameters were calculated:

- Size and location (distance from the end of the nosepiece) of the minimal cross-sectional area (MCA).
- Cross-sectional area at 3.3 cm from the end of the nosepiece (CA3.3).
- Cross-sectional area at 4.0 cm from the end of the nosepiece (CA4.0).
- Cross-sectional area at 6.4 cm from the end of the nosepiece (CA6.4).

- Total volume of the nose (TV), by integration of the area-distance curve between the end of the nosepiece and 7 cm posteriorly.
- The rhinopharynx volume, by integration of the area-distance curve from 9 cm to 15 cm beyond the end of the nosepiece.

Anterior rhinoscopy: at the end of the trial, in the decongested state, anterior rhinoscopy provided directly the columella – inferior turbinate (anterior edge) distance (Figure 2).
The morphology of the septum was recorded, and deviations of the septum were classified according to their location: anterior if located anteriorly to the anterior edge of the inferior turbinate; posterior if located behind this region. The degree of deformity was also recorded as slight or moderate i.e. never filling more than half the lumen.

Selection of the acoustic rhinometric curve:
two methods were used:
1. A manual/visual selection and
2. An automatic/computerized selection.

In the manual selection one of the authors selected one of the three curves done for each side, according to criteria based on the appearance of the curve. The first part of the curve, describing the nosepiece with a fixed cross-sectional area, should be straight. If the configuration of one of the curves showed a significant deviation from the others it was discarded. A volume larger than 45 cm^3 of the

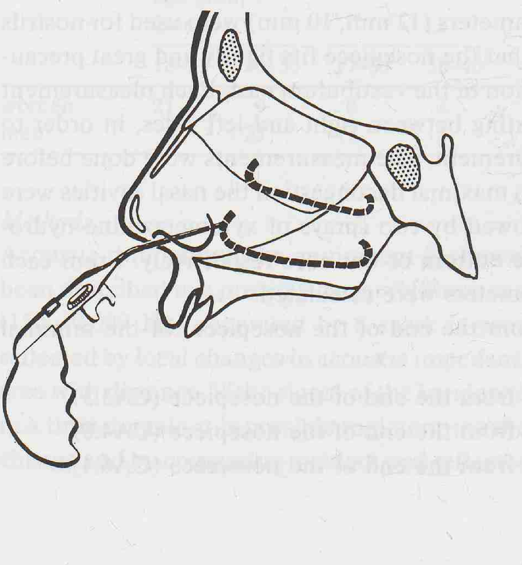

Figure 2. Method and instrument (Richards ®) applied in direct measurement from columella to anterior edge of the inferior turbinate.

cavity between 9.2 and 13 cm from the nostrils, corresponding to the rhinopharynx, might indicate a leak at the nosepiece and that also lead to rejection. If no curves were discarded the one in between the two others was chosen. If one curve was discarded then one of the two remaining curves was chosen. Finally, the volume of the rhinopharynx of the chosen curve was compared with that on the other side and the curve with the rhinopharynx volume closest to that on the other side was chosen.

By the computerized method, curves with a slope of the first part (the nosepiece) deviating significantly from zero (actual value) were discarded. Secondly, curves with a rhinopharynx volume exceeding 45 ml were discarded. A significant deviation in the rhinopharynx volume of one of the curves in relation to the others also lead to rejection.

If only one curve remained, this was selected. If two or three curves remained, the mean of these was calculated. For every eliminated curve, the computer displayed why a curve was rejected and how many curves of the three had passed the different steps in the calculation.

Less than 6% of the curves were rejected, and in no case all three curves in a series of measurements. For the first two steps no difference was seen between the manual and the automatic selection. For the following steps a difference in less than 7% between the manual and the automatic method was observed. The most common reason for rejection of a curve was a deviation of the first part of the curve, probably due to electrical noise during the measurement. In the present study the numerical values are from curves selected by the manual method.

Statistics: paired t-test, correlation and regression analysis were used. P-values less than 0.05 (two-tailed) were considered significant.

RESULTS

By anterior rhinoscopy 12 individuals (14%) were found to have anterior septal deviations, all of slight or moderate degree, rhinoscopically evaluated as normal variations of the septum and of no functional importance. Fiftyfour (65%) had posterior deviations. Acoustic rhinometry showed a difference between the deviated and the contralateral side, but the difference between smallest and largest side compared to those with a straight septum was not significant.

Acoustic rhinometry

The cross-sectional areas were calculated separately for right and left side (MCA, CA3.3, CA4.0, CA6.4). The values are shown in Table 2. Since no systematic difference was found between right and left side, the rest of the calculations were done on total cross-sectional areas, i.e. the sum of right and left side. The values of total cross-sectional areas and the total volumes (TV) are seen in Table 3.

Table 2. Minimal cross-sectional area (MCA), cross-sectional area at 3.3 cm (CA3.3), 4.0 cm (CA4.0) and 6.4 cm (CA6.4) of right and left nasal cavity before and after decongestion.

	right (cm^2)		left (cm^2)	
	mean (range)	sem	mean (range)	sem
MCA non-decongested	0.73 (0.33–1.20)	0.02	0.72 (0.29–1.27)	0.02
MCA decongested	0.92 (0.52–1.34)	0.02	0.95 (0.34–1.32)	0.02
CA3.3 non-decongested	1.31 (0.33–2.69)	0.05	1.31 (0.29–3.39)	0.06
CA3.3 decongested	2.08 (0.74–4.00)	0.06	2.20 (0.81–4.55)	0.08
CA4.0 non-decongested	1.51 (0.42–3.43)	0.05	1.56 (0.50–3.42)	0.06
CA4.0 decongested	2.51 (1.24–3.93)	0.07	2.63 (1.02–4.89)	0.08
CA6.4 non-decongested	2.27 (0.97–6.02)	0.09	2.31 (1.16–6.35)	0.10
CA6.4 decongested	2.99 (1.60–5.42)	0.08	3.19 (1.66–5.72)	0.09

sem = standard error of the mean

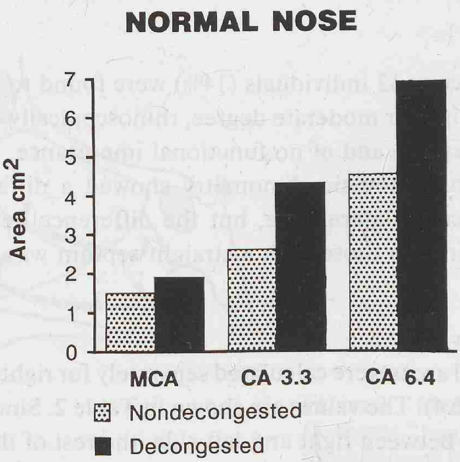

Figure 3. The dimensions of the normal nose. The minimal cross-sectional area (MCA), and cross-sectional area at 3.3 cm (CA3.3) and at 6.4 cm (CA6.4) from nostrils.

Table 3. Sum of right and left side values of minimal cross-sectional area (TMCA), cross-sectional area at 3.3 cm (TCA3.3), 4.0 (TCA4.0) and 6.4 cm (TCA6.4) and volume (TV) of the nasal cavity to 7 cm from the nostril, in males and females, before and after decongestion.

	males		females		all	
	mean (range)	sem	mean (range)	sem	mean (range)	sem
TMCA non-decongested	1.43 (0.62–2.10)	0.04	1.49 (0.91–2.29)	0.05	1.46 (0.62–2.29)	0.03
TMCA decongested	1.86 (0.86–2.52)	0.05	1.91 (1.26–2.37)	0.05	1.88 (0.86–2.52)	0.03
TCA3.3 non-decongested	2.52 (0.62–5.13)	0.12	2.97 (1.69–4.70)	0.12	2.63 (0.62–5.13)	0.09
TCA3.3 decongested	4.14 (1.83–7.38)	0.16	4.51 (2.66–7.85)	0.17	4.29 (1.83–7.85)	0.12
TCA4.0 non-decongested	2.97 (0.92–5.39)	0.11	3.23 (2.07–5.61)	0.13	3.08 (0.92–4.69)	0.09
TCA4.0 decongested	5.14 (3.32–7.52)	0.14	5.17 (2.73–8.08)	0.23	5.15 (2.73–8.08)	0.13
TCA6.4 non-decongested	4.03 (2.26–8.02)	0.21*	5.37 (2.95–9.85)	0.27*	4.58 (2.26–10.28)	0.18
TCA6.4 decongested	5.81 (3.38–10.55)	0.19	6.69 (3.73–10.66)	0.27	6.18 (3.38–10.66)	0.16
TV non-decongested	21.6 (13.5–38.9)	0.71**	24.0 (18.4–40.0)	0.81**	22.6 (13.5–40.0)	0.55
TV decongested	30.6 (19.9–48.9)	0.70	31.6 (20.7–46.5)	0.96	31.0 (19.9–48.9)	0.57

* significant difference between males and females (p=0.000)
** significant difference between TV of males and females (p=0.03)

The results show that the cross-sectional areas of the nasal cavity increased in anteroposterior direction (Figures 3 and 4). The total volume of the nasal cavity (TV) increased by 35% from 23 cm^3 to 31 cm^3 during maximal decongestion. In the non-decongested nose, the total volume was significantly larger in females (24 cm^3) than in males (22 cm^3). The effect of decongestion was more pronounced in males than in females and after maximal decongestion the TV was not different between sexes.

The same observation applies for the most posterior part of the nose. The cross-sectional area at 6.4 cm from nostrils (CA6.4) was significantly larger in females than in males (p=0.000), specially before decongestion.

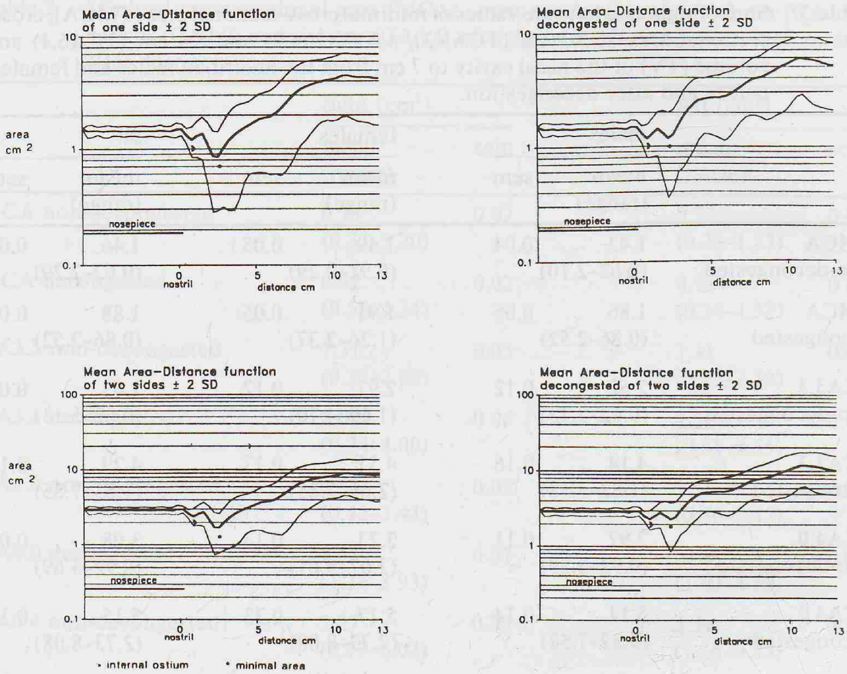

Figure 4. Acoustic rhinometric curves from 82 individuals (both sexes) without complaints of impaired nasal patency. Unilateral and bilateral values, before and after decongestion.

Up to the level of the middle turbinate (CA4.0) there was no difference between males and females neither in the size of the areas nor in the effect of decongestion. The maximal effect of decongestion was found at CA4.0 from the nostril. The cross-sectional area increased by 67% from 3.1 to 5.2 cm^2 compared with 63% at CA3.3 and 29% at the MCA.

The size of the total minimal cross-sectional area (TMCA) increased by 29% after decongestion (from 1.46 cm^2 (mean) to 1.88 cm^2, males 30% females 28%).

The minimal cross-sectional area (MCA) was located in the anterior part of the nose at a mean value of 2.23 cm from the nostril, not different between sexes. In males at 2.2 and at 2.1 in females (range 0.6–3.3). After maximal decongestion MCA moved anteriorly to 1.53 cm from the nostril (mean), (range 0.44–3.03).

Results concerning the anterior segment of the nose

The directly measured columella – inferior turbinate distance (C-C distance) was 2.7 cm (males 2.8, females 2.5). The area at this position (CCA), was calculated in addition to the other cross-sectional areas, and was significantly larger than the minimal cross-sectional area (MCA) after decongestion.

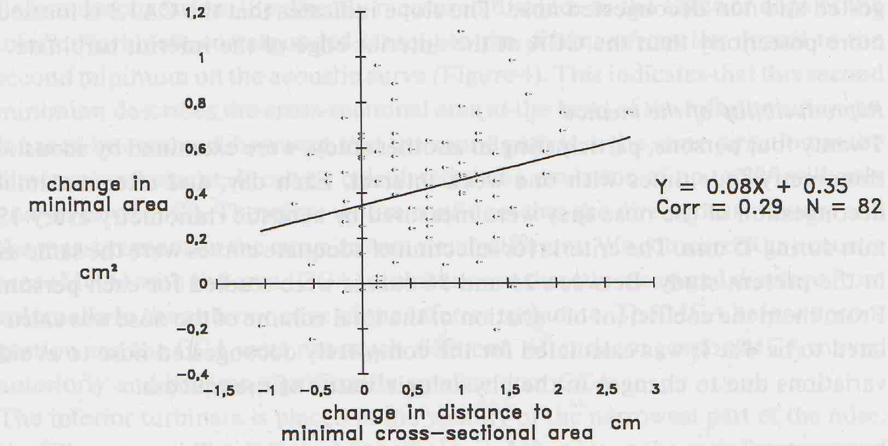

Figure 5. Correlation between the effect of decongestion on the minimal cross-sectional area (change in minimal area = MCA decongested - MCA non-decongested) and the change in distance to minimal cross-sectional area.

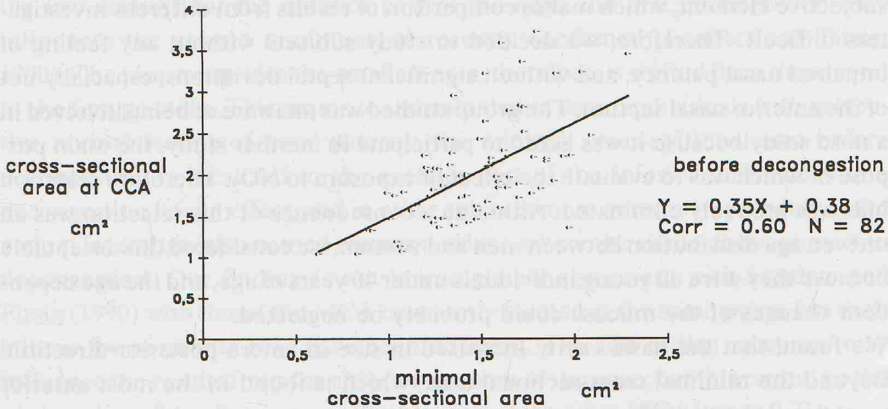

Figure 6. Correlation between the cross-sectional at the known distance from columella to inferior turbinate (CCA) and the minimal cross-sectional area before decongestion.

There was a highly positive correlation between the effect of decongestion and the distance to the minimal cross-sectional area and also the change in distance to the minimal cross-sectional area. This and the columella-inferior turbinate distance implies that the minimal cross-sectional area in some subjects is localized at the head of the inferior turbinate and in other subjects more anteriorly at the nasal valve (Figures 5 and 6).

The cross-sectional area at the C-C distance (CCA) was positively correlated to the cross-sectional area at 3.3 cm of the acoustic path (CA3.3) both in the decongested and non-decongested nose. The slope indicates that the CA3.3 is located more posteriorly than the CCA at the anterior edge of the inferior turbinate.

Reproducibility of the method

Twenty four persons, participating in another study, were examined by acoustic rhinometry four times with one week interval. Each day, and after maximal decongestion of the nose they were measured by acoustic rhinometry every 15 min during 45 min. The criteria for selection of adequate curves were the same as in the present study. Between 24 and 36 curves were studied for each person. From them the coefficient of variation of the total volume of the nose was calculated to be 4%. It was calculated for the completely decongested nose to avoid variations due to changes in the physiologic status of the mucosa.

DISCUSSION

From a clinical point of view the feeling of normal nasal patency is relevant, but not equivalent to normal nasal function. It is difficult to define the normal nose rhinoscopically. Especially concerning the size of the turbinates there is always a subjective element, which makes comparison of results from different investigators difficult. Therefore, we decided to study subjects without any feeling of impaired nasal patency, and without significant septal deviations, especially not of the anterior nasal septum. The group studied was unaware of being involved in a nose study because it was asked to participate in another study, the main purpose of which was to evaluate the effect of exposure to NO_2. Therefore selection bias was probably eliminated. Although a consequence of this selection was an uneven age distribution between men and women, we considered this acceptable because they were all young individuals under 40 years of age, and the age dependent changes of the mucosa could probably be neglected.

We found that the nasal cavity increased in size in antero-posterior direction. Beyond the minimal cross-sectional area, which is found in the most anterior part, the skeletal nasal cavity increased with distance as judged from measurements with decongested mucosa. The maximal effect of decongestion was seen at 4.0 cm from the nostrils, i.e. the region of the nose at the anterior end of the middle turbinate, where the mucosa of the inferior and middle turbinates are affected by decongestion. The cross-sectional area increased by 67% compared with 29% at the MCA.

The segment of the nose, anterior to the inferior turbinate has been demonstrated to be of great functional importance as the flow limiting segment (Bachmann and Legler, 1972; Haight and Cole, 1983). We found that the minimal cross-sectional area was located in the anterior part of the nose. However, the areas measured by acoustic rhinometry are cross-sectional areas in the sound path. Therefore we wanted to compare their positions to directly measured landmarks.

Before decongestion, the directly measured distance to the anterior edge of the inferior turbinate corresponded closely to the distance from the nostril to the second minimum on the acoustic curve (Figure 4). This indicates that this second minimum describes the cross-sectional area at the head of the inferior turbinate. It has to be assumed, however, that the sound path is in the same direction as the direct measurement. It can be calculated that a deviation of up to 20° will only give an error of 6%. Therefore we are confident that the direct measurement and the measurement on the curve are not much different. We compared the acoustic area (MCA) with the area (CCA) at the known, directly measured distance from columella to the anterior edge of the inferior turbinate. The MCA before decongestion and the CCA were not much different. After decongestion MCA moved anteriorly and became significantly smaller than CCA.

The inferior turbinate is placed in the vicinity of the narrowest part of the nose, the isthmus nasi. Physiological or pathological changes in the erectile mucosa of its anterior edge may be of special clinical interest in cases of impaired nasal patency. We found a highly positive correlation between the effect of decongestion and the distance to the minimal cross-sectional area. Figure 4 clearly shows the two minima for the anterior part of the nose and that decongestion only influences the second minimum, as recently confirmed (Lenders and Pirsig, 1990). The minimum with the smallest area, therefore, is shifted from the second to the first position. This seems to indicate that in some individuals with subjective normal feeling of nasal patency, the minimal cross-sectional area before decongestion is localized in the anterior part of the inferior turbinate where decongestion has an effect, and in other subjects more anteriorly, probably at the ostium internum (also named the nasal valve), where the tissue does not react to decongestion. Our finding is not in completely agreement with Lenders and Pirsig (1990) who found the MCA constantly located at the same point, but their criteria for normality may have been different. The size of the nosepiece may influence the results from the anterior segment of the nose, but this cannot be the explanation of the discrepancy, since we found the same MCA (mean 0.73 cm) as they did. Great precaution was taken not to distort the vestibulum when the nosepiece was introduced few millimeters. Although it is wise to have different sizes of nosepieces, we feel that, in a homogeneous adult population like the Danes, nosepieces of 10 and 12 mm were adequate. From several studies conducted by our group less than 5% will need smaller or wider nosepieces.

The size of the inferior turbinate may certainly influence the results. Deliberately we did not base the selection of noses on rhinoscopy, because we wanted to eliminate the subjective element in the rhinoscopic evaluation, especially concerning the size of the turbinate. It is unlikely, however, that our population had turbinate hypertrophy. None had vasomotor or allergic rhinitis complaints or any subjective feeling of nasal obstruction. We presume that Lenders and Pirsig only included noses with very small inferior turbinates in their study of normals. The discrepancy between their and our findings indicates a need for stricter definition of normality.

As we have pointed previously (Grymer et al., 1989) the MCA before decongestion may, at least in some individuals, represent the isthmus nasi, and the anatomical ostium internum or nasal valve may be MCA after decongestion (Figure 7).

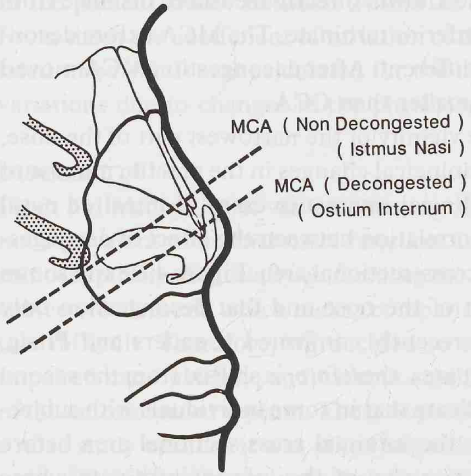

Figure 7. Location of the minimal cross-sectional area before and after decongestion.

According to our findings we may define the nasal valve as a region extending from the apertura piriformis and anterior edge of the inferior turbinate to the ostium internum anteriorly. Indications for surgery should include an evaluation of the anterior segment of the nasal cavity. Septal deviations, racial and genetic differences in the valve area, and changes in the inferior turbinates should be considered.

The role played by the posterior part of the nose in the feeling of nasal patency is far from elucidated. Some studies suggest that posterior septal deviations and turbinate variations are of genetic and developmental origin (Grymer, 1989) and only marked posterior septal deviations have importance as flow-limiting factor (Cole, 1988). The importance of that region in paranasal sinus pathology remains to be solved.

In our study we found a difference between males and females concerning the posterior part of the nose; this is not completely explained by the study. The cross-sectional area at 6.4 cm from nostrils and the total volume of the nasal cavity was significantly larger in females than in males. No correlation was found between body height or body weight and the total nasal volume. However, from cephalometric studies (Riolo et al., 1974) it is known that the antero-posterior length of the maxilla is larger in males than in females. When we determine the total volume at a fixed distance for all the subjects it is possible that in females we are including structures located more posteriorly, at the epipharynx, than in males. On the other hand, after decongestion the total volume was not significantly different in males and females which may indicate that the amount of mucosa affected by decongestion is larger in males. The clinical relevance of this should be studied further.

CONCLUSIONS

The following conclusions may be drawn from this study:

1. The cross-sectional area of the nasal cavity increases in antero-posterior direction.
2. The minimal cross-sectional area (MCA) is located in the anterior part of the nose, in some individuals probably at the head of the inferior turbinate, and after decongestion it moves anteriorly to the ostium internum.
3. The maximum effect of decongestion is found in the middle part of the nasal cavity, at the level of the middle turbinate.
4. The amount of mucosa in the posterior part of the nose seems to be more pronounced in males than in females.

REFERENCES

1. Bachmann W, Legler U. Studies on the structure and function of the anterior section of the nose by means of luminal impressions. Acta Otolaryngol (Stockh) 1972; 73: 433–442.
2. Grymer LG, Hilberg O, Pedersen OF et al. Acoustic rhinometry: Evaluation of the nasal cavity with septal deviations, before and after septoplasty. Laryngoscope 1989; 99: 1180–1187.
3. Grymer LG, Melsen B. The morphology of the nasal septum in identical twins. Laryngoscope 1989; 99: 642–646.
4. Haight JSJ, Cole P. The site and function of the nasal valve. Laryngoscope 1983; 93: 49–55.
5. Hilberg 0, Jackson AC, Swift DL et al. Acoustic rhinometry: Evaluation of nasal cavity geometry by acoustic reflections. J Appl Physiol 1989; 66: 295-303.
6. Lenders H, Pirsig W. Diagnostic values of acoustic rhinometry: Patients with allergic and vasomotor rhinitis compared with normal controls. Rhinology 1990; 28: 5–16
7. Montgomery WM, Vig PS, Staab EV et al. Computed tomography: A three dimensional study of the nasal airway. Am J Orthod 1979; 76: 363–375.
8. Riolo ML, Moyers RE, McNamara JA, Stuart Hunter W. An atlas of craniofacial growth: Cephalometric standards from the university school growth study. University of Michigan, Monograph No.2, 1974; 145.

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