Practical aspects of acoustic rhinometry: Problems and solutions*†

Edward W. Fisher[1, 2], David P. Morris[1], Johannes M. A. Biemans[1], Christopher R. Palmer[3], Valerie J. Lund[1]

[1] Department of Otorhinolaryngology, Addenbrooke's Hospital, Cambridge, United Kingdom
[2] The Royal National Throat, Nose and Ear Hospital, London, United Kingdom
[3] Department of Community Medicine, University of Cambridge, United Kingdom

SUMMARY *Acoustic rhinometry now has an established place in the rhinology laboratory as a measure of nasal geometry. We aimed to investigate several aspects of technique in order to offer some guidance on preferred procedures. We studied the effects of nosepiece seal quality, nosepiece aperture diameter, angle of inclination of the wave tube (in two planes), palate position and inter-observer variation on the nasal area-distance function. One hundred nasal cavities in adults and children were examined: 50 normal and 50 pathological. Each factor was examined intensively in 20 cavities, and reproducibility data obtained on all 100 cavities. The baseline mean coefficient of variation for nasal cavity volume (V_1) was 6% and for minimum cross-sectional area (MCA) was 8%. Altering the angle of incidence of the wave tube in the axial and coronal planes caused considerable change in the traces from the anterior nasal cavity, including the I- and C-notches, and affected the MCA significantly ($p < 0.01$, Wilcoxon signed rank test). Using a small nosepiece aperture accentuated the I-notch, and the nosepiece in some cases became the site of the minimal area. Addition of a silicone-based sealant to the standard nosepiece caused a mean reduction of 14.3% in nasal volume, if the seal quality was suspected to be suboptimal. Nasopharyngeal volume decreased by a mean of 28.6 % when the palate is raised by the modified Valsalva manoeuvre, and no difference was found between quiet oral respiration and cessation of nasal respiration. Acoustic rhinometry is sensitive to minor changes in the details of technique. We recommend using an intermediate range of angles in both planes, the addition of a sealant where the nosepiece seal is suspect, use of newer improved nosepieces and synchronizing readings with either cessation of nasal respiration or with quiet oral respiration. There is a pressing need for international agreement on such details if collaboration and clinical application of acoustic rhinometry is to flourish.*

Key words: acoustic rhinometry, nasal cavity, nose, diagnosis

INTRODUCTION

Acoustic rhinometry has been steadily gaining popularity as a laboratory and potential clinical tool since its advent in 1989 (Hilberg et al., 1989). Rhinomanometry, previously the standard laboratory test of nasal patency, has failed to enter routine clinical practice. This is despite the existence of a large volume of research over decades dedicated to propagating the technique. Will acoustic rhinometry be confined to the laboratory in a similar fashion? A heterogeneity of instruments may hamper universal application of this tool, as will failure to agree on the details of a recommended technique. We must learn from the successes (Clement, 1984) as well as the failures of rhinomanometry.

Surprisingly, the literature contains little reference to the minutiae of technique, although it is agreed that a "good seal" at the nosepiece (Grymer et al., 1991), consistency between a series of records, avoidance of deformity of the nostril (Hansen, 1991; Lenders et al., 1992), regulation of penetration of the nosepiece and some consideration of the angle of the nosepiece is needed (O'Flynn, 1992). The possibility of spurious changes in apparently "satisfactory" serial recordings (or differences in single readings of two individuals) has not been adequately investi-

* Received for publication March 14, 1994; accepted August 1, 1994
† Presented at the 15th Congress of the European Rhinologic Society, Copenhagen, June 19-23, 1994

gated. We have examined a series of factors which could add confusion to traces, and evaluated their effects on acoustic rhinometry results in a variety of subjects in order to estimate the order of magnitude of the "problem."

MATERIAL AND METHODS

Patients

One hundred nasal cavities were analyzed, 50 from adults (aged 17-77 years; mean: 40 years) and 50 from children (aged 4-14 years; mean: 7.6 years). These were composed of four groups: (1) healthy adults with no history symptoms, or endoscopic signs of nasal disease (n=25 cavities); (2) adults with nasal pathology (n=25 cavities); (3) healthy children by the same criteria (n=25 cavities); and (4) children with signs of nasal disease (n=25 cavities). All were examined in an environment free from wide fluctuations in temperature and humidity. Subjects were tested after a period of acclimatization in the test room and time was devoted to explaining the technique and performing atest run. "All subjects underwent testing to determine the mean coefficient of variation for each parameter. Additionally, representatives from each category underwent a detailed examination of factors which may influence the results, with 20 cavities examined in relation to each factor.

Acoustic rhinometry

Equipment designed in the Department of Environmental and Occupational Medicine of Aarhus University, and marketed by GM Instruments Ltd., was used. The equipment is well described elsewhere (Hilberg et al., 1989), and uses a nosepiece of a tapered tip design. The NADAP (Version 1) software was used for analysis. The parameters chosen (from the large number available) were: (1) minimum cross-sectional area (MCA); (2) volume of the anterior nasal cavity (V_1); (3) volume of the nasopharynx (V_3); (4) the area at 1.3 cm from the tip (A_1); and (5) the area at 6.4 cm from the tip (A_4). For each of the variables investigated, 20 nasal cavities were studied in great detail. To limit variation due to the nasal cycle, readings were taken 15 min after decongestion with xylometazoline (0.1%) drops. Each reading consisted of the mean of three traces.

Angle of approach of the rhinometry probe

Angles in two planes were considered: in the sagittal plane readings were taken at the extremes compatible with patient comfort and with satisfactory seals at the nosepiece (20° and 75°) and at an intermediate position (45°). The angle was measured at the rhinometer base and refers to the angle of the wave tube in relation to the horizontal plane. The subject's head was kept in a comfortable neutral position (and observed for constancy). In the axial plane, readings were taken in three positions: sagittal (or para-sagittal, if true sagittal was anatomically impossible or uncomfortable), lateral (mid-position) and far lateral positions (limited by comfort and practicability rather than an arbitrary angle).

Seal quality of the conical nosepiece

Readings were taken with the standard perspex nosepieces with and without additional sealing around the nostril with a small doughnut-shaped piece of a silicone-based compound (polydimethylsiloxane: Steramould; A&M Hearing Limited, Crawley, Surrey, UK). This is illustrated in Figure 1.

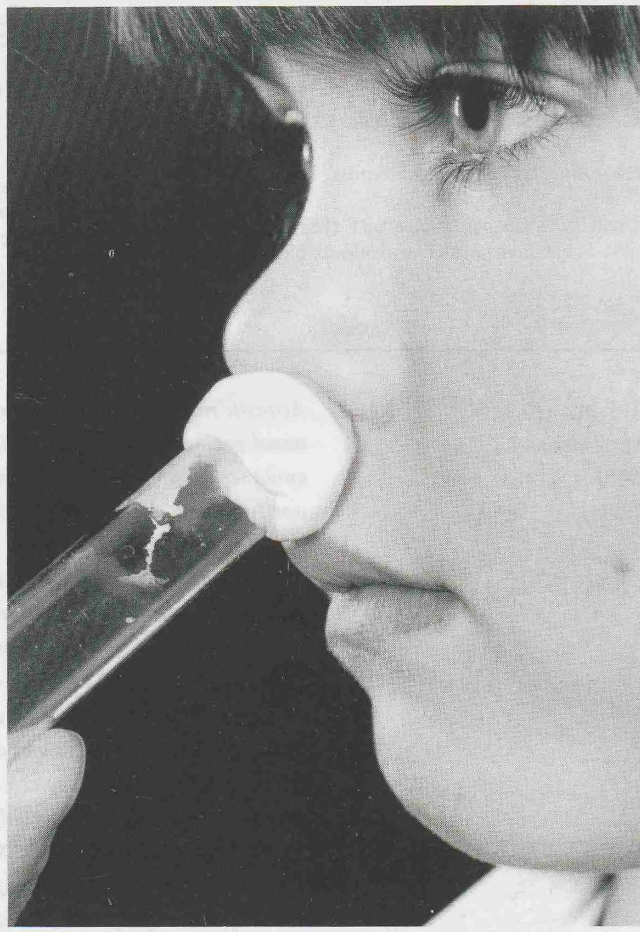

Figure 1. The nosepiece is shown *in situ* after application of a sealant composed of a soft silicone-based compound. This can increase seal quality in cases where this is in doubt.

Diameter of nosepiece aperture

Three sizes of aperture were used: small (8-mm inner diameter, after the taper), medium (10-mm diameter), and large (12-mm diameter). In some nostrils only two sizes could be comfortably accommodated.

Inter-observer variation

Two observers took independent readings from the same subject at the same sitting (in random sequence), having agreed on uniform technical parameters.

Phase of respiration and palate position

Readings were taken in quiet inspiration (nasal), expiration (nasal), during brief cessation of nasal respiration (mouth closed), on quiet oral respiration (the only choice in severe nasal obstruction) and on palate raising (gentle "puffing out" of the cheeks). The readings were taken in random sequence.

Analysis

In each instance care was taken to vary one factor only, with minimal interference with the other factors involved in generating error. Statistical analysis employed a non-parametric test for paired comparisons (Wilcoxon signed rank test; Statview®, Abacus concepts). The error for each factor and for each acoustic rhinometry parameter was calculated for each nasal cavity as shown:

$$100 \times (Xa - Xb) : 0.5 \times (Xa + Xb) = \text{percentage error}$$

in which Xa: mean value with investigated factor at one extreme (e.g., 20°); and Xb: mean value with investigated factor at other extreme (e.g., 75°) The mean and standard deviation of these errors were calculated (n=20 cavities), and entered into Table 1.

RESULTS

Overall reproducibility

The mean coefficient of variation (standard deviation in brackets) for each acoustic rhinometry parameter (n=100 cavities) was: V_1: 0.06 (±0.05); V_3: 0.13 (±0.12); A_1: 0.07 (±0.05); A_4: 0.08 (±0.08); MCA: 0.08 (±0.07).

Angle of incidence of the acoustic wave: sagittal plane

The general trend in area estimates (especially anteriorly) was to increase with increasing angle in the sagittal plane, despite preservation of the quality of seal. Volume estimates were more resistant to change in sagittal angle, with no statistically significant change demonstrable. Extremes of angle (as expected) caused more deformity of the nostril than intermediate angles, although the comfortable range of angles causing least deformity differed between individuals. At the anterior cavity, the "I-notch" and "C-notch" (Lenders and Pirsig, 1990) were both diminished and shifted anteriorly with increasing angle (Figure 2).

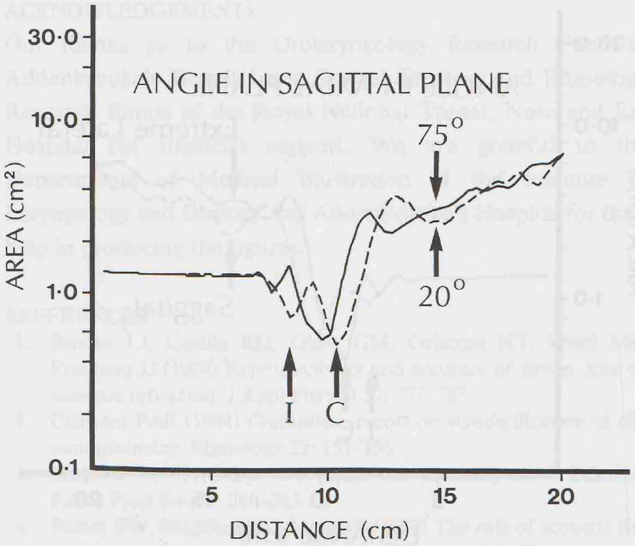

Figure 2. This shows two superimposed area-distance function traces from the same nostril. The angle of the wave tube in the sagittal plane was varied between 20° and 75°. Changes in magnitude and location of the "I" (isthmus) and "C" (concha) notches are shown.

Angle of incidence of the acoustic wave: axial plane

The principal effects seen were the shift forward in position of both the I- and C-notches, an increase in magnitude of the C-notch, and a decrease in magnitude of the I-notch with increasing lateral position of the wave tube. The undulating pattern of the deeper nasal cavity also differed in the detail of its shape (Figure 3).

Seal quality of the nosepiece

In subjects with a clearly "good" seal the addition of additional sealant had a negligible effect. In subjects whose nostril shape

Table 1. Effect of six different factors on five acoustic rhinometry parameters. Table shows the mean percentage error (and standard deviation) for each acoustic rhinometry parameter associated with the two extremes of each factor (n=20 cavities).

factor	parameter estimated by acoustic rhinometry				
	anterior cavity volume (V_1)	posterior cavity volume (V_3)	anterior cross-sectional area (A_1)	posterior cross-sectional area (A_4)	minimum cross-sectional area (MCA)
angle in the sagittal plane (20–75°)	1.5 (16.8)	1.8 (17.4)	15.1** (26.2)	1.5 (23.2)	17.2* (26.9)
angle in the axial plane (sagittal to far lateral)	11.9* (18.9)	12.7* (27.6)	13.9 (32.1)	12.7 (26.5)	-22.4** (26.9)
seal quality (no sealant to sealant)	-7.8* (12.5)	-9.5 (26.2)	-4.0 (14.4)	-7.8 (26)	-15** (25.1)
diameter of aperture (small to large)	1.5 (6.8)	1.3 (11.4)	9.6** (19.5)	1.7 (15.8)	24.3*** (24.1)
respiration & palate position (nasal to Valsalva)	-1.3 (5.4)	-28.6*** (22.2)	-3 (10)	-0.4 (10.9)	-0.3 (12.9)
interobserver error (observer 1-observer 2)	-2 (13.3)	-0.4 (27.1)	4.4 (13.5)	-8.3 (26.9)	5.6 (15.6)

*: p <0.05; **: p <0.01; ***: p <0.001 (Wilcoxon signed rank test)

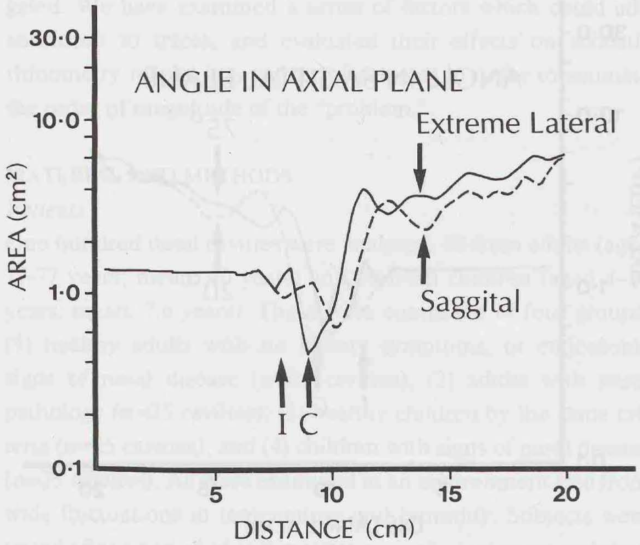

Figure 3. This shows two superimposed area-distance function traces from the same nostril. The angle of the wave tube in the axial plane was varied between the parasagittal and the extreme lateral position. Changes in magnitude and location of the "I" (isthmus) and "C" (concha) notches are shown.

allowed a seal with some difficulty (particularly subjects with long, thin nostrils in whom a nosepiece of circular cross-section is awkward), the addition of a sealant reduced the V_1 estimates by an average of 14.3%. The conical nosepiece produced a degree of deformity of the nasal valve in many subjects, although in the case of children, nostril pliability and shape tended to minimize this deformity.

Diameter of nosepiece aperture

This caused a deepening of the I-notch with reduction in aperture size. If a small nosepiece tip was used in an adult, this tip would become the new (spurious) site of the minimum cross-sectional area, rather than the true more deeply situated physiological site. Significant underestimation of A_1 and MCA resulted from the use of the 8-mm aperture nosepiece.

Inter-observer variation

This caused a surprisingly marked effect on all parameters. On subsequent analysis this was found to be in part due to one observer accepting for analysis a proportion of traces of sub-optimal quality. Stringent rules on acceptability of traces and technical parameters, together with subsequent increased experience of the second observer has reduced this effect.

Phase of respiration and palate position

The only significant effect was on the nasopharyngeal volume, which was reduced by an average of 28.6% on palatal elevation with the modified Valsalva manoeuvre. The practice of taking readings during nasal expiration and inspiration led to an unacceptably high rate of artefactual traces (over 60%), presumably due to interference by airway noises.

DISCUSSION

In order to make the transition from laboratory to clinic, a new test of nasal patency must be reproducible and meaningful as well as rapid, comfortable and low cost in medical time and equipment (Maran et al., 1971). We have shown that several technical factors need a great deal of attention if acoustic rhinometry is to fulfil its promise. Several points are worth further discussion:

(1) Angle of incidence (in two planes of orientation)

This must be comfortable for the patient and produce minimal distortion. Since each individual has his own range of comfortable angles, no one pair of figures can be universally applied. Our current work confirms and extends the work of one of our colleagues (O'Flynn, 1992). The influence of changing angle on the anterior nasal cavity trace is noteworthy, if diagnostic information is to be expected from the morphology as well as the magnitude of the I- and C-notch (Lenders and Pirsig, 1990).

(2) Mode of breathing and palate position

Nasal respiration seems logical for a test of the nasal airway, but airway sounds can interfere with the trace. Workers in the USA have suggested testing during oral respiration at end-expiration (Fouke and Jackson, 1992), but we find that cessation of nasal respiration produces traces of similar quality. Testing during oral respiration is the only choice in patients with severe blockage.

(3) Nosepiece seal and deformity

The use of silicone is an alternative to the rubber "O"-ring or petroleum jelly advised by other workers (Hansen, 1991; Fouke and Jackson, 1992). The disadvantage of using any sealant is that obscuring the nostril margin may allow the nosepiece tip to change position in the nose relatively undetected, and thereby deform the nasal valve region (Figure 1). Recently, nosepieces have been designed which limit the deformity of the nasal valve by conforming to the shape of the nostril and avoiding the need to enter the vestibule (Hansen et al., 1991; Lenders et al., 1992). These nosepieces have considerable advantages over the conical design, and we now consider these to be the most acceptable design. However, even with improved nosepieces, children in particular tend to vary involuntarily the pressure exerted on the nosepiece, and thereby cause some degree of deformity or acoustic leakage. Fixing the head in a frame (similar to that used in slit lamp examination) has been suggested to reduce movement of the nosepiece tip (Passali et al., 1994), but our population of children would find such devices unduly frightening.

(4) Palate position

We are interested in the difference between the nasopharyngeal volume before and after the modified Valsalva. In children this may give some indication of the adequacy of the nasopharyngeal airway, and offset the confounding effect of involuntary palatal movements.

The reproducibility of the data in this series of heterogeneous subjects is somewhat less than reported by others (<0.02), working in trained normal adult subjects, cadavers and models (Hilberg et al., 1989). However, it is comparable with other studies using similar techniques (Brooks et al., 1984; Marshall et al., 1993) and particularly with values from children, where a greater within-run variability (2.618% for volume estimates) is acknowledged (Riechelmann et al., 1993). Data from cadavers and models cannot be extrapolated in an unqualified fashion to living subjects, since confounding factors such as movement of the palate (Eccles, 1990), airway noises, nasal mucosal fluctuations, and variation in co-operation all may influence the quality and validity of the trace. We have used three traces per nostril in our tests, although we are aware that the literature has examples of 2-8 traces being averaged per nostril (Riechelmann et al., 1993), and the present system may be adapted to increase the number of traces averaged. There has recently been a proliferation of machines and techniques which use repetitive clicks or white noise rather than spark-generated clicks (for example, the Rhin 2000; S.R. Electronics ApS, Denmark). We aim to settle on a technique which can be considered for application in the clinic for both children and adults. Where comparison between populations is required, such as pre-operative versus post-operative (Grymer et al., 1993) or nasal cycle studies (Fisher et al., 1993), great care must be taken to ensure that each of these technical variables are constant. Where comparison between populations is required the need to control for technical variables is even more important if spurious and misleading results are to be avoided. Since this study was completed an international committee of standardization of acoustic rhinometry has been formed, and we hope that the remaining difficulties of technique will soon be resolved.

CONCLUSIONS

Acoustic rhinometry can generate a bewildering array of parameters, whose magnitude is dependent on a large number of technical variables. These variables are in part dependent upon one another, and when altered can lead to significant shifts in the magnitudes of rhinometry parameters. This is a potential obstacle to more widespread clinical application of acoustic rhinometry.

We recommend that:

(1) Readings be taken in the mid-range of angles compatible with the individual subjects' comfort and minimum nostril deformity.

(2) The nostril-nosepiece interface is sealed with an additional inert material when the quality of the seal is in doubt.

(3) The subject is asked to transiently suspend respiration for the instant of the test sound.

(4) Improved nosepieces are used which do not enter the nasal valve.

(5) There is a need for further international agreement on approved techniques of acoustic rhinometry if rhinologists are to compare each another's data meaningfully.

ACKNOWLEDGEMENTS

Our thanks go to the Otolaryngology Research Fund of Addenbrooke's Hospital, the Special Trustees and Rhinology Research Funds of the Royal National Throat, Nose and Ear Hospital for financial support. We are grateful to the Departments of Medical Illustration of the Institute of Laryngology and Otology and Addenbrooke's Hospital for their help in producing the figures.

REFERENCES

1. Brooks LJ, Castile RG, Glass GM, Griscom NT, Wohl ME, Fredberg JJ (1984) Reproducibility and accuracy of airway area by acoustic reflection. J Appl Physiol 57: 777–787.
2. Clement PAR (1984) Committee report on standardization of rhinomanometry. Rhinology 22: 151–155.
3. Eccles R (1990) Other techniques for assessing nasal function. Facial Plast Surg 7: 260–265.
4. Fisher EW, Scadding GK, Lund VJ (1993) The role of acoustic rhinometry in studying the nasal cycle. Rhinology 31: 57–61.
5. Fouke JM, Jackson AC (1992) Acoustic rhinometry: Effects of decongestants and posture on nasal patency. J Lab Clin Med 19: 371–376.
6. Grymer EF, Hilberg O, Pedersen OF, Rasmussen TK (1991) Acoustic rhinometry: Values from adults with normal nasal patency. Rhinology 29: 35–47.
7. Grymer LF, Illum P, Hilberg O (1993) Septoplasty and compensatory inferior turbinate hypertrophy: A randomized study evaluated by acoustic rhinometry. J Laryngol Otol 107: 413–417.
8. Hansen BJ (1991) The nosepiece in acoustic rhinometry. Jpn J Rhinol 30: 124.
9. Hansen BJ, Christiansen NB, Osterhammel PAA (1991) Morphometric evaluations of nosecasts compared to acoustic rhinometry. Jpn J Rhinol 30: 124.
10. Hilberg O, Jackson AC, Swift DL, Pedersen OF (1989) Acoustic rhinometry: Evaluation of nasal cavity geometry by acoustic reflection. J Appl Physiol 66: 295–303.
11. Lenders H, Pirsig W (1990) Diagnostic value of acoustic rhinometry: Patients with allergic and vasomotor rhinitis compared to normal controls. Rhinology 28: 5–16.
12. Lenders H, Scholl R, Brunner M (1992) Akustische Rhinometrie: Das Fledermausprinzip in der Nase. HNO 40: 239-247.
13. Maran AGD, Walker FS, Rimmer AR, Gibb AG (1971) A method for the measurement of nasal airway resistance. J Laryngol Otol 85: 803–810.
14. Marshall I, Maran NJ, Martin S, Jan MA, Rimmington JE, Best JJK, Drummond GB, Douglas NJ (1993) Acoustic reflectometry for airway measurements in man: Implementation and validation. Physiological Measurement 14: 157–169.
15. O'Flynn P (1992). Acoustic rhinometry: The influence of the incident wave on apparent airway geometry. Abstract Book XIV Congress of the European Rhinologic Society, Rome, p. 40.
16. Passali D, Bellusi L, Biagini C, DiGirolamo S (1994). Positional Acoustic Rhinometry. Abstract Book XV Congress of European Rhinologic Society and XIII International Symposium on Infection and Allergy of the Nose, Copenhagen, p. 233.
17. Riechelmann H, Rheinheimer MC, Wolfensberger M (1993) Acoustic rhinometry in pre-school children. Clin Otolaryngol 18: 272–277.

Edward W. Fisher, MA, FRCS
Birmingham Heartlands Hospital
Bordesley Green East
Birmingham B9 5SS
United Kingdom