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Manometric rhinometry: A new method of measuring nasal volume*

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SUMMARY *A new method of measuring the volume of the air space in the nose and sinuses is presented. We have called this method "manometric rhinometry." By closing off the nose anteriorly and posteriorly a closed space is created. A volume of air is then removed and the resultant pressure change is recorded. The original volume is calculated from the pressure change. Twenty adults have been investigated using this method. The volume recorded ranged from 78 to 198 ml (average: 138 ml). Test-retest analysis showed a correlation coefficient of 0.98. In addition, 24 children aged 4 to 12 years were examined. Their volumes were 43 to 198 ml. Test-retest analysis gave a correlation coefficient of 0.94. The significance of these findings is discussed.*

Key words: nasal volume measurement, nasal pressure, manometric rhinometry

INTRODUCTION

Rhinology has lagged behind otology as a science for many years. This is partly due to the difficulty in making objective measurements to describe the function of the nose in both health and disease. It is only relatively recently that rhinomanometry (Cole et al., 1980), peak flow (Benson, 1971), and acoustic rhinometry (Hilberg et al., 1989) have objectively defined the physical characteristics of the nasal airway. Each of these methods has its uses and limitations. Their principal limitation is that they are influenced predominantly by the internal configuration at the point where flow is rate limited. A method of assessing the volume of the nose and nasal sinuses and their degree of congestion is required. This would allow us to monitor the nose and sinus system, both of which may be involved in disease. It would also help us monitor our treatments, both medically and surgically. We have experimented with a new device which we have labelled a "manometric rhinometer". The principle on which the method is based is Boyle's Law of Gases:

$$\text{Pressure} \times \text{Volume} = \text{constant} \times \text{Temperature}$$

If one assumes constant temperature, then within a closed system a change in volume will result in a measurable and consistent change in pressure. We have used this method to measure the volume of the nose, paranasal sinuses, and the nasopharynx.

CALIBRATION METHOD

In order to calibrate the device it is necessary to measure the pressure change in a closed system of known volume. Figure 1 illustrates the apparatus. The air is removed via one plastic tube whilst a second tube records the pressure change. The machine is set to extract a known volume of air (1.3 ml). Collection of baseline data takes place in the 600 ms before the air extraction, then the maximum pressure change in the subsequent 40 ms is recorded. The whole measurement is complete in 1 s. The maximum change in pressure is displayed on the screen in arbitrary units.

For calibration the rigid container is filled with water and then the water is extracted by a pipette, 10 ml at a time. Ten readings are taken at each volume and the average reading plotted against volume. This calibration curve can be transformed into a straight line by plotting the log [reading] against log [volume]. A regression line which describes the relationship mathematically is given by the following equation:

$$\text{Volume} = \exp\,(12.104 - 1.468 \ln [\text{reading}])$$

Using this formula readings can be converted directly into volumes in a computer spread-sheet.

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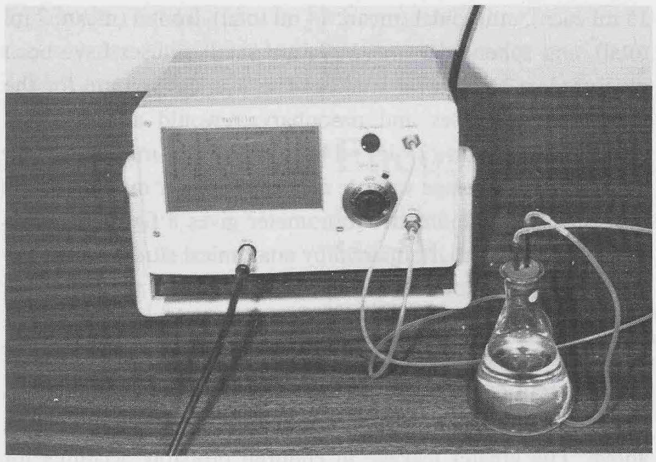

Figure 1. The manometric rhinometer connected to calibration flask.

RESULTS

Normal adults

To determine the volumes in adults a series of 20 volunteers were examined (aged 18–64 years). To achieve closure of the nasal cavity posteriorly the subjects blew a manometer up to 40-mbar pressure to elevate the soft palate against the posterior pharyngeal wall. Anterior closure was obtained by making individual nasal moulds out of silicone rubber (Steramould; A+M Hearing Ltd.). Two plastic tubes were drilled through the moulds, one into each nostril, and these tubes were connected to the manometric rhinometer. Ten readings were taken for each subject, and the average was calculated. Using the formula (*vide supra*) the apparent volumes were derived. The range of results was 78–198 ml with an average of 138 ml (Figure 2). This procedure was repeated on a second occasion at least 24 h later in eight subjects. Figure 3 shows the test-retest analysis for each of these subjects. There is a very good correlation between the two readings for each subject (r=0.98).

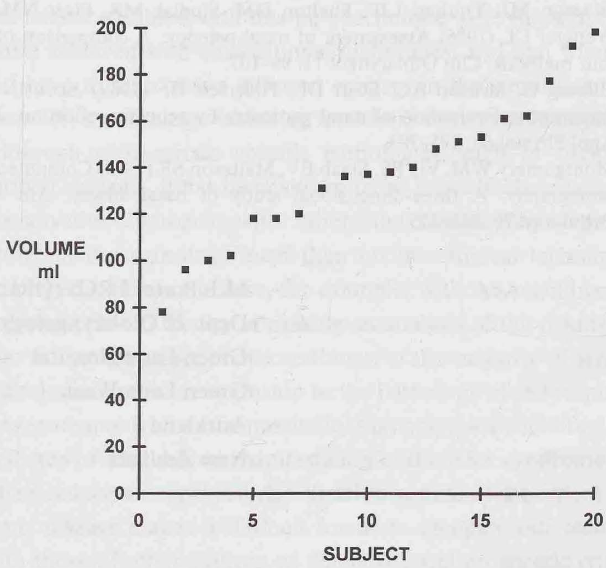

Figure 2. Nasal volume of 20 adults in ascending order.

Children

Twenty-four children (aged 4–12 years) were also examined. In order to obtain velopharyngeal closure they were asked to inflate a party blower (Figure 4). The anterior nasal seal was obtained by inserting a foam eartip (Nicolet) into each nostril. The results for nasal volume gave a range of values of 43-198 ml. There was an obvious correlation between increasing age and increasing volume (Figure 5). Test-retest analysis also showed a good reproducibility with a correlation coefficient r=0.94.

DISCUSSION

Nasal volume is a relatively neglected topic. Textbooks quote figures for the volume of individual sinuses based on anatomical studies (Ballenger, 1991). Gleeson et al. (1986) measured the volume in the nasal cavity by filing the nose with saline and tipping it out again. Montgomery et al. (1979) used CT scans to look at the cross-sectional area and volume of the nasal cavity in cadavers and compared this to post-mortem casts, but there is little information on the volume of the total air-space within the nose and sinuses during life. There is a need for a safe, non-invasive method to monitor this volume, which would be another objective measure of nasal physiology, disease, and its treatment.

Manometric rhinometry would appear to have a place in the investigation of the nose, both in health and disease. It has the advantage of being relatively quick to perform, well tolerated even in children, and reproducible. Correlation coefficients of >0.94 are very encouraging, especially in children where the pressure exerted in using the party blower is not as strictly controlled as blowing into a manometer.

The major technical difficulty when taking measurements is leakage of air. It is important to ensure that there is a good seal anteriorly and posteriorly. The manometric rhinometer displays the pressure change as a function of time and any leakage of air is represented by a decay in the curve away from its maximum displacement. At present, we have no way of quantifying this

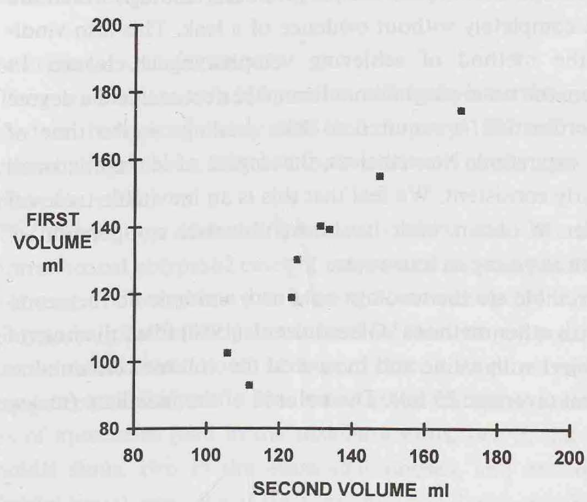

Figure 3. Test-retest analysis in adults (r=0.98).

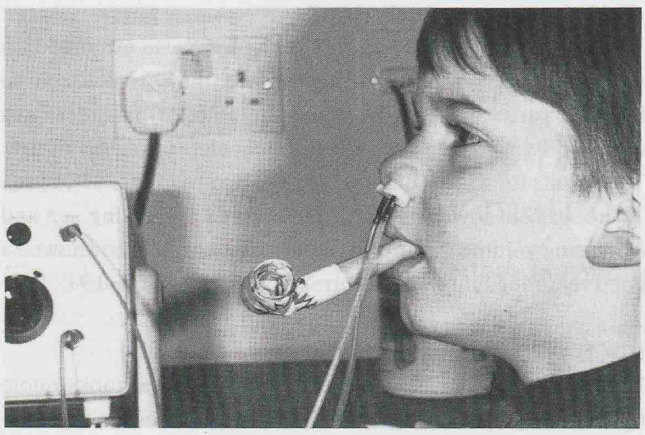

Figure 4. Four-year old demonstrating method of obtaining velopharyngeal closure.

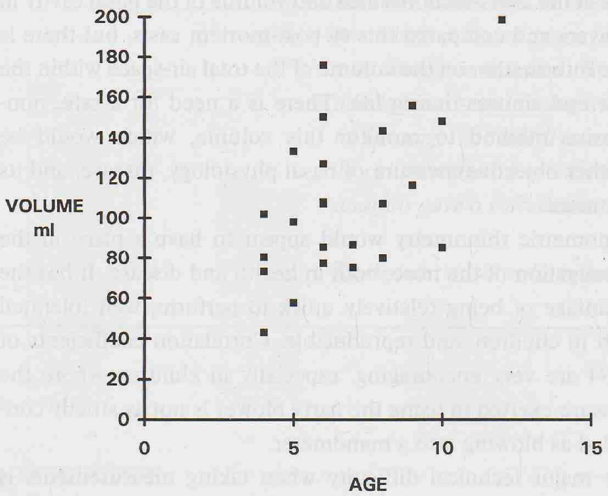

Figure 5. Nasal volume in children aged 4 to 12 years.

rate of decay and must exercise a subjective judgement as to whether the reading should be disregarded on the basis of a leak, which will tend to give an artificially small pressure change and thus an apparent volume which is too high.

In adults the customized mould produces readings which are almost completely without evidence of a leak. This also vindicates the method of achieving velopharyngeal closure. In children, the nasal plugs do not form a perfect seal and a degree of co-ordination is required to take readings at the time of forced expiration. Nevertheless, the degree of leakage is small and fairly consistent. We feel that this is an inevitable trade-off in order to obtain what is almost universal co-operation of children as young as four years.

How credible are the readings obtained, and how do they compare with other methods? Gleeson et al. (1986) filled the nose of his subject with saline and measured the volume contained as 12-34 ml (average: 25 ml). The volume of the maxillary (mean: 15 ml each), ethmoidal (mean: 14 ml total), frontal (mean: 7 ml total), and sphenoidal (mean: 7.5 ml total) sinuses have been measured in anatomical studies. The average volume for the nasal cavity, sinuses and nasopharynx would appear to be approximately: $25+(2\times15)+14+7+7.5=83.5$ ml. This compares with the average volume derived from our method of 138 ml. Thus, the manometric rhinometer gives a figure which is 65% greater than that obtained by anatomical studies. This calculation assumes that all the sinuses are open to the nasal cavity and are measured by the rhinometer.

There are two main reasons which we believe are the cause of this apparent overestimate of the total volume. Firstly, there is the question of leakage of air during measurements as discussed above. The greater leakage in children probably accounts for relatively higher values obtained. The second reason is that the calibration and mathematical model assume a rigid system and, of course, the nose is not rigid. The mucosa of the nose and sinuses are compliant and any degree of compliance during air extraction will result in a smaller pressure change and, hence, a larger apparent volume.

The volume of nasopharynx measured is another variable. In the method of manometric rhinometry palatal closure is achieved by blowing at a known pressure. Gleeson's displacement method used reflex closure to prevent fluid leaking from the nose into the mouth. Whether the position of the soft palate is the same in each case is not established.

Manometric rhinometry is still at a very early stage in its development. Further technical refinements are required. However, we believe that it will prove to have a place in the investigation of nasal physiology and pathophysiology.

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