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Nasal resistance to respiratory airflow: a plethysmographic alternative to the face mask

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SUMMARY

Nasal airflow resistances were measured simultaneously by face mask and "head-out" body plethysmograph and compared. Computer averaging of transnasal pressure and flow signals digitized at 50Hz during 5 breath sequences was employed to determine a ratio of pressure to flow as an index of nasal resistance to breathing. The mean value of ten plethysmograph measurements differed by only 2.0% from that of ten face mask measurements which were made simultaneously. Coefficients of variation of plethysmograph resistance measurements averaged < 6% in twenty subjects (ten measurements/subject) aged 7–68 years over an intersubject resistance range of 1 to 7 cms H_2O/l/sec (0.1–0.7 Pa/cm^3/sec). Voluntarily altered minute ventilations from 8–28 l/min in a subject at rest increased this variation to 10%. The "head-out" body plethysmograph is a versatile and reliable instrument for assessment of nasal respiratory airflow resistance.

INTRODUCTION

This presentation is concerned with comparisons between results obtained by different techniques for measurement of transnasal respiratory airflow resistances.

Rhinomanometric assessment has emerged from the research laboratory and is increasingly recognized as a valuable objective clinical measure. It is of particular value in documentation and diagnosis and in monitoring therapy of obstructive nasal disease. A commonly used method for measurement of respiratory airflow employing a Scuba type face mask which incorporated a Fleish #2 pneumotach (Hamilton and Christman, 1977; Hamilton, 1979) was compared with a "head out" volume displacement body plethysmograph which incorporated a 6" diameter laminar flow element (Niinimaa et al., 1979; Griffin and Zamel, 1979). The magnitude and variation of resistance values obtained by these two methods and by both per oral and per nasal technique for measurement of transnasal pressures were compared.

The Scuba mask and plethysmograph are examples of the many methods which are employed for assessment of nasal airflow – methods vary from insertion of nozzles into the nose (Georgitis, 1985; McCaffrey and Kern, 1979a) to encasing the head in a plastic box (Gurley and Vig, 1982). Between these extremes we find small anesthesia masks which form a seal around the nose, custom fitted masks (Solow and Greve, 1980; Kastner et al., 1985), modified masks of Scuba divers (Hamilton and Christman, 1977; Hamilton, 1979), aviators and firemen which seal against the face more remotely from the nose (Kern, 1973), and even deep sea divers' helmets which seal around the neck (Georgitis, 1985). Insertion of a nozzle into the nose is invasive, it deranges the vestibular component of nasal resistance (Haight and Cole, 1983). A pressure seal close to the nose also risks alteration of resistance of the compliant vestibule (Cole and Havas, 1986). Vestibular resistance normally constitutes almost half of the total nasal resistance (Haight and Cole, 1983).

On the other hand, large masks which minimize risks of facial distortion increase respiratory dead space and require a bias airflow to remove CO_2. CO_2 accumulation alters not only breathing pattern but also nasal airflow resistance (McCaffrey and Kern, 1979b) and it promotes further changes in resistance by alar muscle dilation of the vestibule (Strohl et al., 1982). A "head out" body plethysmograph as used for nasal airflow measurement is not invasive; it avoids problems associated with facial masking, and the common options for transnasal pressure measurement are open. Furthermore, it leaves the face, mouth and nasal vestibules free for observation and experimental studies. Validation of the plethysmographic method is described below.

METHODS

Subjects. Volunteer members of laboratory staff and patients in the course of diagnostic studies of nasal respiratory function.

Nasal resistance is a ratio between transnasal pressure and airflow. Transnasal pressure was detected by:

1. Traditional posterior rhinomanometry. The subject's lips were closed firmly around a per oral tube which was placed between tongue and palate to sense oropharyngeal pressure (Clement and Hirsch, 1984).
2. A fine plastic catheter (Infant feeding tube 8F) lubricated with lidocaine gel (Cole and Haight, 1985) was introduced along the floor of the nose to the nasopharynx.

Transnasal airflow was detected by means of:

1. A Scuba type diving mask which incorporated a Fleisch #2 pneumotach.
2. A "head-out" displacement type body plethysmograph which incorporated a 6″ diam. laminar flow element (Niinimaa et al., 1979; Griffin and Zamel, 1979) (Figure 1).

Pressure and flow signals were sensed by transducers (Validyne MP 45 and DP 103) and their electrical analogues were digitized at 50 Hz by the A/D converter

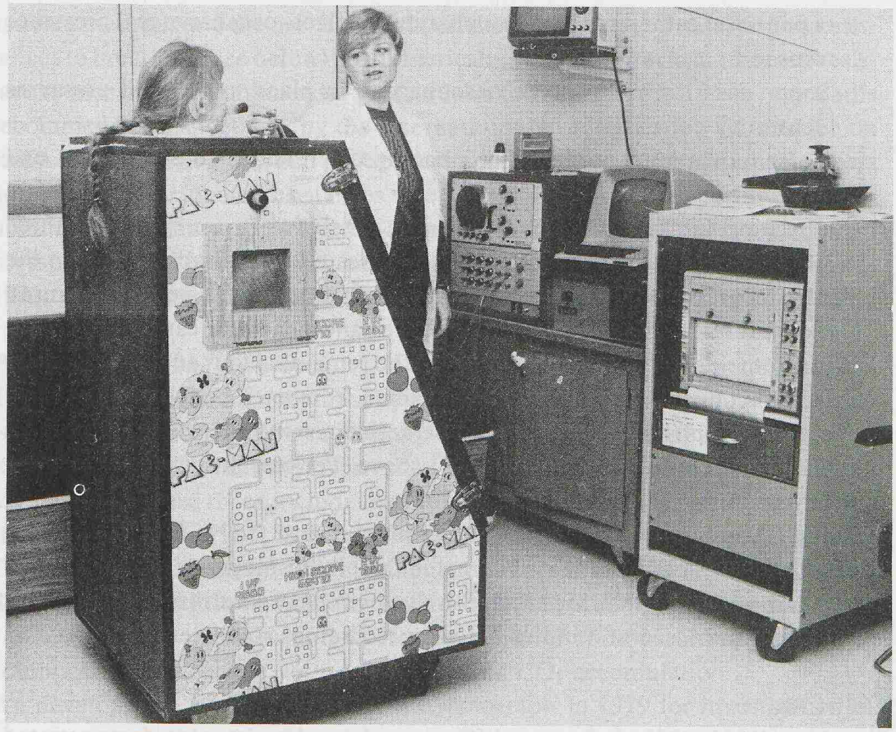

Figure 1. Head out displacement type body plethysmograph.

of a programmed IBM/PC microprocessor. Digitized values were stored in the computer memory and several respiratory variables, which included resistances, were computed on completion of chosen sequences of breaths (Cole et al., 1980)

Experiments

1. Simultaneous plethysmograph versus mask measurements of nasal resistance – A subject with a face mask in place was seated in a "head out" body plethysmograph. Respiratory airflow signals from the mask and the plethysmograph were conducted to separate programmed microprocessors and the same posterior rhinomanometric pressure signal was conducted to each microprocessor. With the subject breathing comfortably at rest both microprocessors were activated simultaneously and ten consecutive recordings of nasal resistance were computed, displayed and printed at 60 sec intervals by each microprocessor.
2. Plethysmograph measurements of nasal resistance with per nasal versus per oral rhinomanometry – Subjects were seated at rest in the plethysmograph. Ten recordings of resistance were obtained in each of the following situations:

a. a per nasal catheter to the nasopharynx in place, oropharyngeal pressures sensed by per oral tube.
b. a per nasal catheter to the nasopharynx in place, post nasal pressures sensed by per nasal catheter.
c. per nasal catheter removed oropharyngeal pressures sensed by per oral tube.

3. Plethysmograph measurements of nasal resistance in ten patients (three children, seven adults) – Each patient was seated comfortably at rest in the plethysmograph. Per oral posterior rhinomanometry was performed in all three children and three adults (2c above) and per nasal catheter pressure measurements (2b above) were made in the remaining four adults. Ten determinations of nasal resistance were obtained from each patient.
4. Plethysmograph measurements of nasal resistance from ten selected patients with differing nasal patencies – As 3) above. Per oral posterior rhinomanometry was used in each case.
5. Plethysmograph measurement of nasal resistance at twelve different minute ventilations – A subject seated at rest in the plethysmograph altered ventilation rate voluntarily during each of twelve periods of recording. Spontaneous ventilation for several minutes between recordings stabilized blood gases.

RESULTS

Simultaneous recording of computer averaged nasal resistances demonstrated almost identical magnitude of mask and plethysmograph measurements, and the coefficient of variation was $<8\%$ in each case. The results demonstrate also the similarity in variation from the mean of synchronous pairs of nasal resistances obtained by the two techniques, which suggests that a portion of the variation originates from the subject. In the absence of a face mask, plethysmograph recordings are less variable. It appears that use of a Scuba face mask is a source of subject variation (Haight and Cole, 1983; Cole and Havas, 1986; Dvoracek et al., 1985). The plethysmograph method of resistance measurement which employed rhinomanometry via per oral or per nasal routes produced results of similar magnitude in each case and the coefficients of variation of ten consecutive recordings at 60 secs intervals in twenty subjects with difffering nasal patencies averaged approximately 6%. Children varied no more than adults and wide voluntary alterations in resting breathing pattern increased the coefficient of variation of nasal resistance to only 10%.

DISCUSSION

This paper is concerned with comparisons between techniques employed in different centres for nasal airflow resistance measurement.

In a previous paper (Cole and Havas, 1986) we have shown by means of computer assisted methods and the use of a face mask that time averaged nasal airflow resistances to breathing (see below) are numerically equivalent to instantaneous resistances measured at a transnasal pressures in the range of 75–100 Pa, standards recommended respectively by the International Standardization Committee on Rhinomanometry (1985), and by Japanese rhinometrists. This relationship holds good for a wide range of resistances when transnasal respiratory airflow is measured with a Scuba type face mask incorporating a Fleish #2 pneumotach and pressure by a per oral tube to the pharynx, i.e. posterior rhinomanometry (Kern, 1973; Clement and Hirsch, 1984).

Plethysmograph and face mask

The small volume of air contained by a face mask favours its response characteristics for respiratory airflow recording, closed loops are readily obtainable with X–Y plots against transnasal pressure. However, facial masking may entail several difficulties, these include distortion of facial and nasal vestibular tissues (Haight and Cole, 1983; Cole and Havas, 1986; International Standardization Committee on Rhinology, 1985), sealing problems (Solow and Greve, 1980), and discomfort, in addition concealment and isolation of airway orifices are disadvantages. Large masks which overcome some of these problems introduce complications associated with dead space and CO_2 accumulation.

We developed a "head-out" body plethysmograph in 1979 for investigation of nose/mouth partitioning of respiratory air (Niinimaa et al., 1979; 1981) and have continued to use the plethysmograph method for measurement of airflow in most of our clinical and experimental nasal resistance investigations, but when ease of transportation is of consequence we use a face mask (Broder et al., 1984). The plethysmograph is of particular value in paediatric studies, the neck airseal is independent of facial size or shape and children usually find the experience to be fun.

In addition to child and adult "head-out" body plethysmographs with adjustable seats, suitable for clinical and research purposes we employ several modifications for different applications, e.g. a small transparent plastic box for infants, an exercise box with pedals connected to an external ergometer (Niinimaa et al., 1981) and a box suitably shaped for posture and recumbency studies (Cole and Haight, 1984).

Time averaged nasal resistance measurements (see below) obtained by these plethysmograph techniques accurately match those obtained by face mask without the disadvantages of the latter.

Posterior and anterior rhinomanometry

We have found per oral posterior rhinomanometry (Clement and Hirsch, 1984) to be successful in almost all of >3,000 subjects and patients ranging in age from 4

to 90 years, patience and persistence improve the success rate (Solow and Greve, 1980), which we found to be 98.6% in 1,000 consecutive paediatric patients.
Anterior rhinomanometry (Clement and Hirsch, 1984) demands less effort and time from subject and investigator but our experience of resistance measurements in the combined and separate nasal cavities of >1,000 subjects supports the findings of Dvoracek, Hillis and Rossing, (1985) that the posterior method is more precise and the simple mathematical relationship between electrical resistors in parallel provides only an approximation when it is applied to nasal airflow resistances.

Per nasal and per oral rhinomanometry

Per nasal insertion of a catheter to the nasopharynx for measurement of transnasal pressure avoids the coaching required for success of the per oral method. We use a 40 cm 7F infant feeding tube lubricated with lidocaine gel (Cole and Haight, 1985) for this purpose. Entry of nasal secretion is prevented by a slow airstream through the catheter, it is generated by a small peristaltic pump adjusted so as not to affect pressure measurements.
Results obtained by per nasal and per oral techniques show little difference. We use the per nasal technique for adult patients and the per oral technique for children in whom assessment of adenoid obstruction may be of importance.
The per nasal catheter ceases to irritate immediately if it is fixed in position by adhesive taping to the upper lip and it is used successfully not only for short duration clinical tests but also for lengthy periods of investigation in awake and sleeping subjects.
In addition to transnasal measurements we employ similar pressure detection techniques for measurement of resistances to breathing across other segments of the upper airways, e.g. transoral, transglottic, transpalatal etc.

Averaged and instantaneous resistance

Nasal patency may be quantified in many forms; its reciprocal resistance is one form which has become firmly established by tradition. It is determined by calculation of a transnasal pressure: flow ratio (Hamilton and Christman, 1977; Hamilton, 1979), or in the Brom's method (1980), it is described in terms of polar coordinates. The ISCR recommends determination of the ratio at transnasal pressures of 75, 150 and 300 Pa, and Japanese rhinologists make their measurements at 100 Pa.
We have made use of computer assisted calculations of resistance and other respiratory parameters from digitized signals for several years (Cole et al., 1980) and this approach is receiving attention in an increasing number of centres. The method readily produces both instantaneous and time averaged resistance values. The time averaging method is independent of pressure and flow limita-

tions and it is particularly well suited for the plethysmograph technique where the phase angle between transnasal respiratory airflow and pressure signals is less favourable for the calculation of instantaneous pressure/flow ratios than with the face mask technique. The latter does not constitute a serious problem since the pressure signal can be easily delayed by longer tubing or electronic means. Simultaneous recordings provide good agreement between mask and plethysmograph when the computer assisted averaging method is used for nasal airflow resistance assessment, and the results are less variable and numerically equivalent to instantaneous resistances measured at the ISCR recommended transnasal pressure of 75 Pa (Cole and Havas, 1986).

CONCLUSIONS

The "head-out" body plethysmograph has an important place in nasal airflow resistance assessment and offers advantages over the face mask when mobility and space requirements are not limiting factors. Computer assisted digitized signal processing produces good agreement between the two methods and time averaged resistance values are numerically equivalent to the ISCR and Japanese recommended resistances in the 75–100 Pa range of transnasal pressure.
The computer-plethysmograph combination provides a reliable, labour saving and versatile apparatus for recording airflow resistances and other respiratory variables in several segments of the respiratory passages in addition to the nose.

ZUSAMMENFASSUNG

Nasal Luftstromwiderstände wurden gleichzeitig durch Gesichtsmaske und "Head-out" (Kopf über dem Behälter) Körperplethysmograph gemessen und verglichen. Computer Durchschnitte von transnasal Druck- und Flussanzeigen in aufeinander folgenden Intervallen von 20 msec während 5 Atmungsfolgen wurden verwendet um das Verhältnis von Druck zu Fluss als einen Index von nasal Widerstand für Atmung zu ermitteln. Der Mittelwert von 10 Plethysmograph-Messungen unterschied sich nur bei 2% von 10 Gesichtsmasken-Messungen, welche gleichzeitig vorgenommen wurden. Variationskoeffiziente von 10 Plethysmograph-Widerstandsmessungen betrugen durchschnittlich < 6% bei 20 Personen (10 Messungen pro Person) im Alter von 7–68 Jahren bei einem Widerstandsbereich untereinander von 1–7 cms H_2O/l/sec (0.1–0.7 Pa/cm^3/sec). Freiwillige veränderte minutliche Ventilationen (Atemzüge) von 8–28 l/min bei einem ruhenden Person erhöhten diese Variation auf 10%. Das "Head-out" (Kopf über dem Behälter) Plethysmograph ist ein vielseitiger und zuverlässiger Instrument für die Wertung von nasal Atmungs-Luftstromwiderstand.

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