Rhinology, 31, 57–61, 1993

The role of acoustic rhinometry in studying the nasal cycle*

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SUMMARY

The nasal cycle has been demonstrated in man using several techniques, including magnetic resonance imaging, anterior rhinoscopy, rhinomanometry, all of which have limitations due to expense, discomfort, limited scope or poor reproducibility. Acoustic rhinometry is a new technique which analyses nasal geometry throughout the nasal cavity, not just at the flow-limiting segment. Six adult volunteers were examined at 15-to 30-min intervals using acoustic rhinometry. The classical alternating cycle was seen in three subjects, a non-classical cycle was seen in two, and no cycle seen in one subject. Changes occurred throughout the nasal cavity and corresponded with fluctuations in subjective scores of obstruction and, in one case, with nasal resistance measurements. Acoustic rhinometry is a rapid, reproducible and non-invasive technique. This pilot study demonstrates that it has potential for studying in detail the physiology of the nasal cycle.

Key words: acoustic rhinometry, nasal cycle, chronobiology

INTRODUCTION

The human nasal mucosa undergoes cyclical fluctuations in congestion which occurs in a rhythmic alternating, reciprocal fashion in up to 80% adults (Heetderks, 1927). This was first convincingly demonstrated using calibrated bellows by Kayser in 1895, and since then a variety of methods have been employed to characterize this physiological phenomenon (Lund, 1989). These include simple anterior rhinoscopy (Heetderks, 1927), rhinomanometry (Stoksted, 1952), elaborate optical devices (Juto and Lundberg, 1982), a forced random-noise technique (Fullton et al., 1984), thermography (Canter, 1986) and, most recently, magnetic resonance imaging (Kennedy et al., 1988). However, each of these techniques has its drawbacks in terms of time, expense, reproducibility, requirement for cooperation by the patient, extent of information obtained or a need for airflow to occur during the assessment.

Acoustic rhinometry is a new, non-invasive technique in which nasal geometry is assessed by means of reflected sound. The method is rapid, reproducible, requires minimal patient cooperation, and gives information about the whole nasal cavity and nasopharynx (Hilberg et al., 1989). This pilot study applies the technique to a small series of subjects to assess its potential as a tool for investigating the physiology of the nasal cycle.

* Accepted January 20, 1992

MATERIALS AND METHODS

Subjects

Six healthy non-smoking adults (four males and two females) with subjectively normal nasal patency, no history of nasal disease or recent infection, and normal appearances at rhinoscopy were assessed. Their ages ranged from 19-54 years (mean 33 years). Minor septal deviations or spurs were present in two subjects.

Methods

Subjects were seated for testing, and allowed to continue light activities and normal eating and drinking during the test period. Each subject was assessed for 6–8 h, measurements taking place every 15–30 min for at least 2 h until a pattern emerged and, subsequently, every 30-60 min. Subjective nasal patency was assessed by a visual analogue scale and nasal geometry was measured using acoustic rhinometry in all subjects. One subject with a well-defined nasal cycle as shown by these methods was concurrently assessed by rhinomanometry at 20-min intervals over a period of 6 h.

Visual analogue scale for nasal obstruction (VAS)

Each subject indicated at each time point his or her subjective sensation of blockage for each nostril by making a mark on a 100-mm linear scale (Aitken, 1969). This gave a percentage figure for each nostril.

Figure 1. Acoustic rhinometer shown during testing. Arrows indicate: (1) nosepiece; (2) wave tube; and (3) spark generator.

Acoustic rhinometry

A plot of nasal cross-sectional area against distance from the nostril was generated using acoustic equipment and computer software developed by workers in Aarhus, Denmark. This is well-described in a recent publication (Hilberg et al., 1989). The essential principles are that an audible sound (150 to 10,000 Hz) is generated in a spark generator and introduced into the nasal cavity via a perspex nostrilpiece (Figure 1). The reflections of this sound from the nasal cavity are received in a microphone and analysed by computer software to generate a plot of nasal cross-sectional area as a function of distance from the nosepiece (Grymer et al., 1991). This in turn can give rise to volume estimates and minimum nasal cross-sectional area (MCA). Two measurements were taken from each nostril at each assessment, and the mean values of technically satisfactory traces were calculated. The MCA was chosen as the principal parameter when compared with subjective patency. The total duration of each test (four measurements) was 3.5 min.

Rhinomanometry

Active anterior rhinomanometry was performed in one subject using the Mercury Rhinomanometer NR6D (Mercury Electronics Scotland Ltd). Nasal resistance for each nostril was measured by four sweeps with the reference

Table 1. Visual analogue scores (VAS) and ranges of minimal nasal cross-sectional areas (MCA) of the six volunteers.

subject	age	sex	observation period (hr)	observation interval (min)	visual analogue score range (%)		MCA range (cm^2)	
					left	right	left	right
A	19	F	7.5	30	1–4	2–6	0.44–0.61	0.45–0.62
B	28	M	8	30	3–73	7–77	0.33–1.2	0.26–1.1
C	29	M	7.5	30	2–50	0–68	0.53–1.03	0.32–0.97
D	38	M	8	30	2–28	3–34	0.66–1.07	0.45–0.96
E	54	F	6	30	1–9	6–23	0.4–0.68	0.38–0.68
F_1	32	M	7	15	3–40	34–73	0.47–0.93	0.3–0.72
F_2	32	M	6	20	8–26	26–28	0.52–0.97	0.32–0.68

Table 2. VAS (peak-trough), MCA ratio (peak-trough), resistance ratio (peak-trough), and cycle periodicity and pattern in the six volunteers.

subject	VAS (peak-trough) left (%)	right	MCA ratio (peak-trough) left	right	resistance ratio (peak-trough) left	right	cycle periodicity (hours)	cycle pattern
A	3	4	1.36	1.37	–	–		minor non-alterating fluctuations
B	70	70	3.63	4.23	–	–	3.25	classical alternating reciprocal cycle
C	48	68	1.94	3.03	–	–	3	classical alternating reciprocal cycle
D	26	31	1.62	2.13	–	–	2–3	irregular cycle
E	8	17	1.70	1.78	–	–	2–3	irregular cycle
F_1	37	39	1.98	2.10	–	–	3	classical alternating reciprocal cycle
F_2	18	42	1.87	2.13	2.8	3.3	4	classical alternating reciprocal cycle

pressure at 150 Pa, and the mean inspiratory resistance values recorded. The results for left and right nostrils for each parameter were plotted graphically in order to assess whether a true alternating cycle existed for each subject.

RESULTS

The principal findings are expressed in Tables 1 and 2. Three subjects (50%) had a classical alternating nasal cycle which was demonstrable using acoustic rhinometry. One subject had minor variations but no demonstrable cycle, and two subjects showed marked, but not classical, fluctuations subjectively and objectively. A graphical demonstration of the cyclical changes in minimal nasal cross-sectional area and the corresponding subjective scores for obstruction are shown in Figure 2 (subject C). The corresponding changes in resistance as measured by active anterior rhinomanometry are displayed for subject F2 in Figure 3, and are seen to be at their peak when nasal cross-sectional area is at a minimum. The variation in nasal cross-sectional area in the three subjects showing a classical cycle ranged from a peak/trough ratio of 1.94 to 4.23, hence the cross-sectional area can vary over 400% as a result of the physiological cycle. This is several orders of magnitude greater than the mean fluctuation between successive readings in any pair, which was less than 10%. The acoustic rhinometry curves of subject B at the peak and trough of one cycle are shown superimposed in Figure 4. This plot demonstrates that changes in nasal geometry

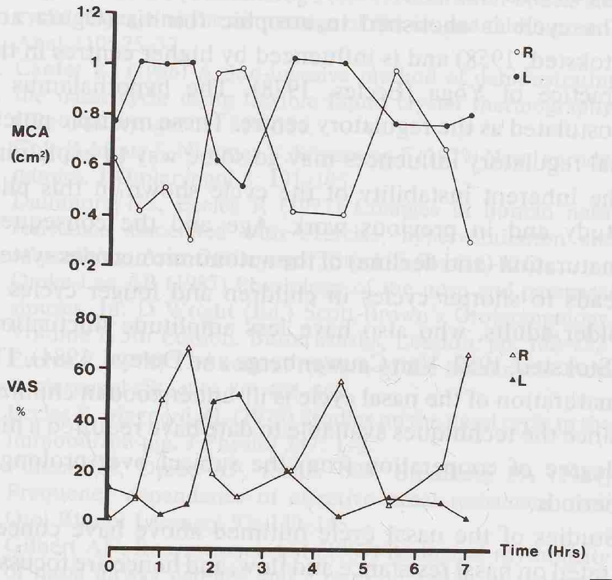

Figure 2. Graphical display of visual analogue scores (VAS) and minimal nasal cross-sectional area (MCA) as a function of time (subject B).

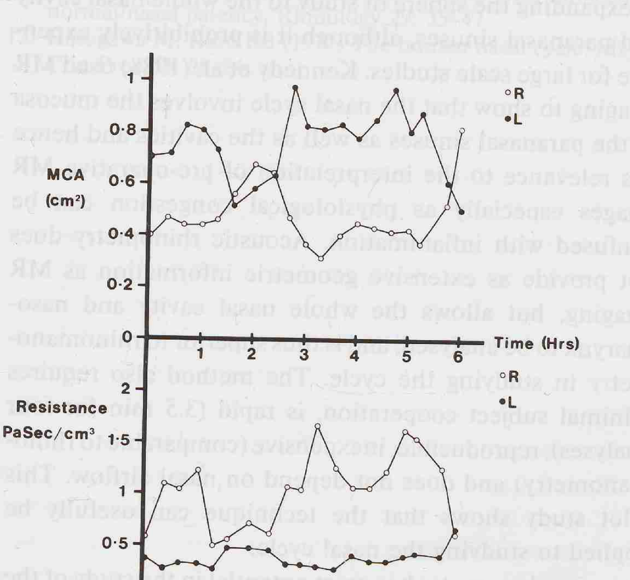

Figure 3. Graphical display of minimal nasal cross-sectional area (MCA) and nasal resistance (NR) as a function of time (subject F).

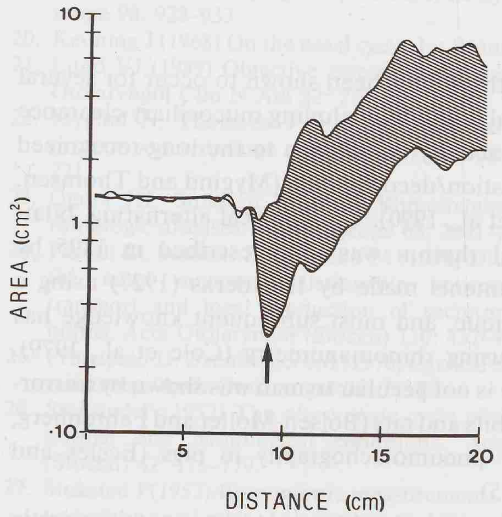

Figure 4. Superimposed acoustic rhinometry traces for subject C at the peak and trough of the cycle (left nostril). The shaded area indicates the extent of mucosal volume change as a function of distance from the nostril. The arrow indicates the 'nasal valve' at the anterior end of the inferior turbinate.

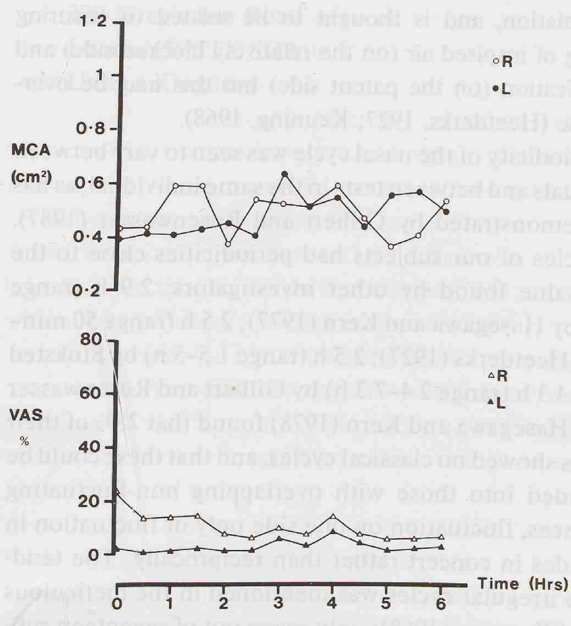

Figure 5. Graphical display of visual analogue scale (VAS) and minimal nasal cross-sectional area (MCA) of subject E, demonstrating an irregular pattern of cycling.

are spread throughout the nasal cavity and are not isolated to the region of the anterior portion of the inferior turbinate (the "nasal valve").

The periodicity of the nasal cycle varied from 2.5 to 4 h, the modal value being 3 h. A definite periodicity was difficult to calculate in the two subjects with irregular non-classical cycles. These cases did not show alternating cycles with 180° of phase difference, but rather showed fluctuation which at times was in concert for both sides, and at other times was alternating. Subjective scoring was likewise irregular in fluctuation. One such irregular pattern is shown in Figure 5. In general, the fluctuations in objective parameters (MCA and nasal resistance) were greater than subjective sensation of airflow.

DISCUSSION

Biological rhythms have been shown to occur for several aspects of nasal function, including mucociliary clearance and secretory activity in addition to the long-recognized cycle of congestion/decongestion (Mygind and Thomsen, 1976; Passàli et al., 1990). The classical alternating, bilateral reciprocal rhythm was first described in 1895 by Kayser, refinements made by Heetderks (1927) using a misting technique, and most subsequent knowledge has been gained using rhinomanometry (Cole et al., 1979). That the cycle is not peculiar to man was shown by mirror-misting in rabbits and rats (Bojsen-Moller and Fahrenberg, 1971) and by pneumotachography in pigs (Eccles and Maynard, 1975).

Despite changes in nasal resistance which may achieve a ratio of up to 4:1 (Cole et al., 1979) the subject may be unaware of any change in nasal patency (Drake-Lee, 1987) since total resistance tends to remain constant. Nasal resistance may change by up to 53% in one nostril over 15 min (Hasegawa and Kern, 1979). The function of the cycle remains a subject of speculation, and is thought to be related to ensuring warming of inspired air (on the relatively blocked side) and humidification (on the patent side) but this may be over-simplistic (Heetderks, 1927; Keuning, 1968).

The periodicity of the nasal cycle was seen to vary between individuals and between tests in the same individual, as has been demonstrated by Gilbert and Rosenwasser (1987). The cycles of our subjects had periodicities close to the mean value found by other investigators: 2.9 h (range 1–6 h) by Hasegawa and Kern (1977); 2.5 h (range 50 min–4 h) by Heetderks (1927); 2.5 h (range 1.5–5 h) by Stoksted (1953); 4.3 h (range 2.4–7.3 h) by Gilbert and Rosenwasser (1987). Hasegawa and Kern (1978) found that 28% of their subjects showed no classical cycles, and that these could be subdivided into those with overlapping non-fluctuating resistances, fluctuation on one side only or fluctuation in both sides in concert rather than reciprocally. The tendency to irregular cycles was mentioned in the meticulous study of Keuning (1968): only seven out of seventeen subjects had a classical cycle, four had irregular non-classical cycles, and four had no resistance reversals.

Gilbert and Rosenwasser (1987) rigorously analysed their rhinomanometric data by autocorrelation analysis and concluded that the classical reciprocal alternating cycle is an altogether rarer event that previous work had suggested – 13% by their most stringent criteria. Our small series supports this, but obviously requires amplification to be statistically valid.

The control of the nasal cycle is known to be centrally located, with autonomic influences predominating (Eccles, 1978): the pupil changes size in phase with ipsilateral nasal resistance. Parasympathetic or sympathetic blockade affects the cycle of the side treated, but leaves the contralateral cycle intact (Principato and Ozenberger, 1970; Dallimore and Eccles, 1977). Emotion, exercise, allergy, infection, sexual arousal, posture and nasal pathology all exert an effect on the nasal cycle (Drake-Lee, 1987). The cycle is abolished in atrophic rhinitis (Ogura and Stoksted, 1958) and is influenced by higher centres in the practice of Yoga (Eccles, 1978). The hypothalamus is postulated as the regulatory centre. These multiple potential regulatory influences may go some way to explaining the inherent instability of the cycle shown in this pilot study and in previous work. Age and the consequent maturation (and decline) of the autonomic nervous system leads to shorter cycles in children and longer cycles in older adults, who also have less amplitude fluctuations (Stoksted, 1952; Van Cauwenberge and Deleye, 1984). The maturation of the nasal cycle is ill-understood in children, since the techniques available to date have required a high degree of cooperation from the subject over prolonged periods.

Studies of the nasal cycle outlined above have concentrated on nasal resistance and flow, and hence are focussed on the nasal valve region, or flow-limiting segment (Cole et al., 1979). Magnetic resonance (MR) imaging is one way of expanding the sphere of study to the whole nasal cavity and paranasal sinuses, although it is prohibitively expensive for large scale studies. Kennedy et al. (1988) used MR imaging to show that the nasal cycle involves the mucosa of the paranasal sinuses as well as the cavities and hence has relevance to the interpretation of pre-operative MR images especially as physiological congestion can be confused with inflammation. Acoustic rhinometry does not provide as extensive geometric information as MR imaging, but allows the whole nasal cavity and nasopharynx to be analysed, and is thus superior to rhinomanometry in studying the cycle. The method also requires minimal subject cooperation, is rapid (3.5 min for four analyses), reproducible, inexpensive (comparable to rhinomanometry) and does not depend on nasal airflow. This pilot study shows that the technique can usefully be applied to studying the nasal cycle.

Acoustic rhinometry has great potential in the study of the human nasal cycle, and should be extended to children in whom the phenomenon is ill-understood. This, and further studies on adults currently in progress, will help to establish normal ranges for the parameters involved, and allow studies of clinical application to be placed in proper physiological context.

ACKNOWLEDGEMENTS

Our thanks to the staff of Aarhus University Institute of Environmental and Occupational Medicine (Denmark) for their help in establishing an acoustic rhinometer in our laboratory, to the Department of Medical Illustration of the Institute of Laryngology and Otology, and to Mr Jack Arnett of Medical Physics.

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