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Peak nasal inspiratory flow – the plateau effect

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Abstract
To study the efficacy of peak nasal inspiration flow (PNIF) as a means of recording change in nasal patency 20 subjects were given increasing doses of intranasal xylometazoline. Nasal resistance (NR) and peak nasal inspiratory flow (PNIF) were measured in the resting state and after each xylometazoline administration. Successive increases in dose caused a progressive decrease in nasal resistance and an increase in PNIF but the change in peak nasal inspiratory flow (PNIF) was much less. Peak nasal inspiratory flow shows a plateau effect as nasal resistance decreases. The reasons for this plateau are discussed in terms of respiratory flow mechanics.

Key words: Nose; Airway resistance; Flow meters

Introduction

The measurement of nasal patency has interested rhinologists and respiration physiologists for over a century. Zwaardemaker's method of placing a cold mirror under the patient's nose and studying the resultant condensed water vapour pattern (Zwaardemaker, 1889) was followed decades later by attempts to describe the nasal airway numerically (Stocksted, 1953) and by the development in the 1950s of modern rhinomanometry (Aschen *et al.*, 1958). These techniques have since been refined and remain the benchmark in modern respiratory physiological research for the measurement of nasal airway resistance (Jones *et al.*, 1987).

Because the rhinomanometer is bulky, expensive and time-consuming in use alternative methods of nasal airway measurement have been sought. Benson (1971) described a method for assessing nasal patency by measuring the peak nasal inspiratory flow rate and a variety of other techniques have been described including the use of a Vitalograph spirometer. More recently Youlten (1980) has described a modification to the Wright peak flow meter (Wright and McKerrow, 1959) which can be used to measure peak nasal inspiratory flow. The device consists of a face mask which the patient applies over the nose and closed mouth forming an airtight seal on the face. The patient now sniffs air through the nose and the maximum flow rate is recorded by a cursor.

Some recent work has shown that nasal peak inspiratory flow rates correlate well – although inversely – with nasal resistance measured by rhinomanometry (Jones *et al.*, 1991).

Xylometazoline is a potent nasal vasoconstrictor and causes a dose-related shrinkage of the nasal mucosa which is reflected in a decrease in nasal resistance (Hoffman and Lefkowitz, 1990). In this study we look at how faithfully the peak nasal inspiratory flow meter reflects these changes in nasal resistance.

Patients and methods

Twenty healthy volunteers were recruited from among the students and staff of the Royal Liverpool University Hospital. There were 14 women and six men with a mean age of 29 years. All had been free of coryzal illness for at least one month prior to the study and had normal nasal cavities on anterior rhinoscopy. Each subject was given 20 minutes to acclimatize to laboratory conditions and resting nasal resistance and peak nasal inspiration flow were then measured.

Nasal resistance measurements were made using the NR6 rhinomanometer (Mercury Electronics, Glasgow, UK) by the posterior method described by Jones *et al.* (1987). Peak nasal inspiratory flow was measured using the Youlten meter (Clement Clarke International, London, UK). The patient was asked to apply the mask to the face to obtain an airtight seal and then sniff air through the nose. The maximum flow rate was then read from the cursor. As some instruction is required to ensure correct use of the instrument, the highest of three readings was recorded. For the present study the device was fitted with a clear plastic face mask so that the nasal vestibule could be seen during use.

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TABLE I

NASAL PATENCY VALUES MEASURED BY PEAK INSPIRATORY FLOW AND RHINOMANOMETRY FOR DIFFERENT DEGREES OF NASAL VASOCONSTRICTION INDUCED BY TOPICAL XYLOMETAZOLINE

	PNIF (Median l min^{-1})	NR (Median $Kpal^{-1}s$)
'Resting'	155 (127–173)	0.48 (0.38–0.67)
Post-xylometazoline		
Dose 1 ml	175 (160–192)	0.32 (0.25–0.46)
2 ml	200 (188–218)	0.16 (0.25–0.46)
4 ml	190 (184–216)	0.09 (0.70–0.11)

n = 20; 95% Confidence Intervals in parentheses.

Intranasal xylometazoline was now administered in successively increasing doses. Aliquots of 1, 2 and 4 ml of a 0.1 per cent solution were used and to facilitate even distribution throughout the nasal mucosa the solutions were nebulized and administered via an air brush (De Vilbiss Airbrush, Letraset, London, UK) using a 'Rotring' mains air compressor (Rotring Conopois 777 air compressor, Sagola, Spain) after the method described for the intranasal histamine challenge (Corrado *et al.*, 1986).

Ten minutes after each administration readings were repeated for nasal resistance and peak nasal inspiratory flow – highest of three – and the next aliquot was given.

Statistical analysis was carried out using Friedman analysis of variance and the Mann-Whitney U-test.

Results

The results are shown in Table I and in Figures 1 and 2.

The Friedman analysis of variance showed a highly significant difference between all sets of NR values ($p<0.0001$). The Mann-Whitney *U*-test showed a highly significant difference between all pairs of PNIF values ($p<0.0001$) except between the 2 ml and the 4 ml dose of xylometazoline where PNIF values showed no significant change ($p = 0.17$).

Despite a stepped decrease in nasal resistance the peak inspiratory flow rate levels off at high flow rates i.e. there is a 'plateau' effect with increasing intranasal vasoconstriction. This 'plateau' is observed to coincide with collapse of the alar cartilages.

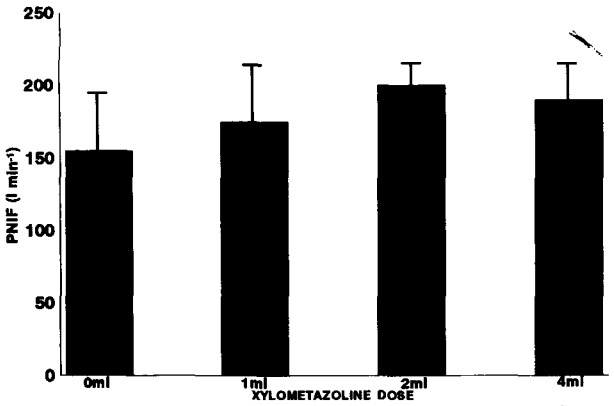

FIG. 1

Variation in nasal peak flow inspiratory flow (PNIF) for increasing doses of xylometazoline. Upper and lower quartiles are shown.

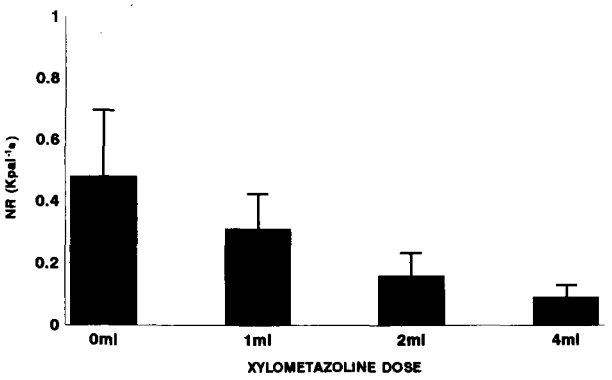

FIG. 2

Variation in nasal resistance (NR) for increasing doses of xylometazoline. Upper and lower quartiles are shown.

Discussion

The results confirm that high transmural pressure generated by forced inspiration in the presence of a low nasal resistance causes collapse of the alar cartilages. This physiological phenomenon makes inspiratory flow measurements in the presence of low nasal resistance of little use when assessing nasal mucosal swelling.

The five-fold reduction in nasal resistance following 4 ml of xylometazoline is associated with only a 23 per cent increase in peak nasal inspiratory flow i.e. peak nasal inspiratory flow lags behind rhinomanometry in its capacity to detect changes in nasal patency. This is in keeping with our earlier findings on the effect of the histamine challenge on peak nasal inspiratory flow (Clarke and Jones, 1994) and is probably related to various physiological properties of the airways. A part of the respiratory tract resistance which limits peak nasal inspiratory flow is located not in the nose but 'downstream' in the small intrapulmonary airways which are of course unaffected by intranasal xylometazoline. Another factor which almost certainly limits the maximum nasal inspiratory flow rate is the indrawing of the soft tissues at the entrance to the nares induced by the 'Venturi' effect at high flow rates ('alar collapse'). This is the probable explanation for the phase variation in nasal resistance which occurs at high flow rates with inspiratory resistance being greater than expiratory – an observation made as early as 1920 by Mink (Uddstromer, 1940). Clearly the alar collapse seen at high flow rates is not physiological as in the normal patient a shift from nasal to oral breathing usually occurs at an average flow rate of 35 l/minute. It may be that expiratory flow rates are a better physiological measurement.

Nasal resistance and peak nasal inspiratory flow are of course very different entities in terms of fluid mechanics. Resistance is the ratio between the pressure gradient across the nose and the flow rate through the nose at that pressure (P/V). For this

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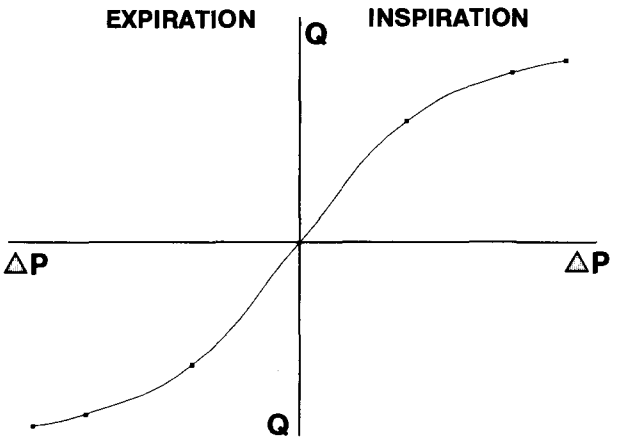

FIG. 3

The pressure flow relationship for airflow through the nose as measured by rhinomanometry. A typical curve is depicted. ▲ P = pressure gradient; Q = flow rate.

calculation nasal airflow is assumed to be laminar but this of course is only the case at low flow rates (which do not register on the Youlten meter). Laminar and turbulent flow coexist as flow rate increases but flow is exclusively turbulent at high rates.

In this case resistance would be equal to the quotient of pressure gradient and the square of the flow rate. The pressure/flow relationship for airflow through the nose may be expressed diagrammatically (Figure 3) and is sigmoidal in shape. At low flow rates it is a straight line indicating laminar flow. As the airflow increases the relation becomes increasingly curved indicating an increasing amount of turbulent flow. This relationship has been described mathematically by Röhrer (1915):

$$P = K_1V + K_2V^2$$

where V = flow rate at a pressure gradiant of P across the nose (driving pressure);
K_1 is a constant representing the contribution of laminar flow to the total energy loss;
K_2 is a constant representing the contribution of turbulent flow to the total energy loss.

Unfortunately the formula is useless in practice as the values of K_1 and K_2 are not known and in any event their relationships are continuously variable. In an attempt to provide a practical solution various compromise formulae have been suggested including:

$$Rn = P/V^{1.85}$$

where Rn is the nasal resistance to airflow.

In the committee report on the standardization of rhinomanometry Clement (1984) suggested that a biological definition of nasal resistance was made. This is simply the quotient of the pressure gradient and the flow rate at that pressure. In quiet respiration with sample points taken at low pressure gradients this is probably a reasonable approximation in terms of fluid mechanics.

Unlike nasal resistance to airflow, peak flow is measured directly and not derived. When the nasal pressure/flow diagram is referred to (Figure 3) it is seen that the curve forms a plateau at high flow rates which tends to become parallel to the X-axis (pressure) at the extremes of respiration. The cause of this plateau is the increasing energy loss due to an increasing proportion of turbulent compared to laminar flow. Thus at high flow rates the energy supplied to the system in the form of driving pressure (pressure gradient across the nose) is lost by the flow pattern becoming disorganized. The plateau represents a situation where an increase in pressure gradient is not accompanied by a corresponding increase in flow rate. In rhinomanometry flow rates are typically measured in the range 20–45 l/minute. Peak inspiratory flow rates on the other hand are in the range 100–250 l/minute but it seems the levelling off or 'plateau' occurs at lower flow rates.

It is a basic principle of rhinomanometry that nasal resistance is the quotient of driving pressure across the nose and the flow rate at that pressure. It is essential that the pressure gradient and flow rate are measured simultaneously otherwise flow and pressure will be sampled at different points on the pressure/flow curve. This would produce a nonsensical value for resistance. With this in mind a random sampling of flow values along the curve would also have no meaning. In view of this it is at first sight surprising that peak inspiratory flow values are so highly correlated with nasal resistance values at low flow rates. However, a peak inspiratory flow value is not the same as a random flow estimation; it occurs at a specific point on the pressure/flow curve where a condition of constant flow exists. Thus, after the plateau has been attained, sampling on any point on the curve will give the same flow rate albeit with an associated rising pressure gradient.

Conclusions

Peak nasal inspiratory flow may be useful as a static measure of nasal patency but is inferior to rhinomanometry in its capacity to detect change. The limitations of peak nasal inspiratory flow are especially evident at comparatively low resistance levels, probably because of the combined effects of alar collapse and 'downstream' airway resistance, both of which limit nasal inspiratory airflow. We would caution against reliance on peak nasal inspiratory flow measurements in experimental rhinology.

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