

Original article

Repeatability of peak nasal inspiratory flow measurements and utility for assessing the severity of rhinitis

Background: The measurement of peak nasal inspiratory flow (PNIF) provides a simple, cheap, fast and readily available tool for determining the extent of nasal airway patency. However, there are questions regarding its repeatability when used to assess the degree of nasal obstruction in large populations. Therefore, this study aimed to evaluate the repeatability of PNIF measurements and to assess their association with the signs and symptoms of rhinitis.

Methods: The PNIF, rhinitis symptoms, judged by Meltzer questionnaire and rhinitis signs, as determined by anterior rhinoscopy, were assessed in 283 adults representative of the general population. One training and two test PNIF measurements were recorded during the same session.

Results: The PNIF was highly reproducible (ICC = 0.92; 95% limits of agreement: ± 36 l/min). The PNIF was strongly correlated with rhinitis signs, measured by anterior rhinoscopy ($r_s = -0.38$, $P < 0.0001$) but was not correlated with rhinitis symptoms, measured by questionnaire ($r_s = -0.11$, $P = 0.057$). Differences in PNIF for subjects categorized as asymptomatic, mild or moderate/severe on the basis of rhinitis signs, were highly significant ($P < 0.0001$), but less significant on the basis of rhinitis symptoms ($P = 0.04$). A PNIF cut-off of 115 l/min had moderately high specificity (72%) and sensitivity (65%) and a high negative predictive value (90%) for moderate/severe signs of rhinitis.

Conclusion: In a large general population-based sample of young adults, PNIF was highly reproducible and closely related to the signs of rhinitis, as determined by clinical examination. The PNIF provides information that is qualitatively different to that provided by symptom scores and may be useful to measure the extent of nasal obstruction.

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Nasal obstruction is a common manifestation of rhinitis. It is characterized by insufficient airflow through the nose and is often associated with inflammation of the nasal mucosa. Nasal obstruction is difficult to quantify directly by clinical examination so objective assessments such as rhinomanometry and acoustic rhinometry are commonly used. However, these methods require complex and expensive equipment and are limited to use by highly trained operators. Subjective assessments of patient symptoms, using questionnaires, are also essential for diagnostic and research purposes. However, subjective and objective measurements of nasal obstruction do not always correlate. Therefore, a simple, objective measurement of nasal airflow would be a very useful tool for assessing nasal patency. For these purposes, peak nasal inspiratory flow (PNIF) offers a simple, cheap and noninvasive method. In addition, PNIF may provide an objective index for evaluating the effects of new pharmacological therapies as well as the effect of nasal allergen challenge.

The PNIF measurements have been used in several studies to assess nasal patency (1) where they have been shown to be at least as sensitive as acoustic rhinometry (2, 3) and active anterior rhinomanometry (4, 5), the latter of which is currently considered the gold standard for measuring nasal resistance. Furthermore, several independent investigations have demonstrated strong, positive correlations between the subjective sensation of nasal obstruction, determined using patient questionnaires and PNIF (6, 7). However, not all studies have reported such strong correlations and some have actually shown little concordance between these different measurements (8).

The PNIF has previously been used to evaluate the efficacy of intranasal medications (9–11) and to assess the effects of nasal challenge with mannitol, histamine or allergen on nasal obstruction (3, 12–14). In addition, PNIF has been used pre- and postoperatively to measure the success of nasal surgery (15, 16). However, the results from some studies have raised questions about the repeatability and sensitivity of PNIF measurements

(17–19) and have suggested that they are of limited use as indices of nasal patency (20).

Most previous studies have been conducted in study populations limited to healthy subjects, without rhinitis, and/or have been conducted in a small number of subjects (21). Therefore, further studies to evaluate the repeatability of PNIF measurements and the relationships between PNIF and nasal signs and symptoms using large group of subjects, which include both rhinitic and nonrhinitic subjects, are needed to evaluate the utility of PNIF measurements for clinical and epidemiological purposes. Therefore, this study aimed to investigate the repeatability of PNIF measurements in a large group of subjects and to assess the sensitivity and specificity of PNIF for nasal signs and symptoms in a general population sample of young adults. Use of a study sample that is representative of the general population allows estimation of the positive and negative predictive value of findings, in that setting.

Materials and methods

Study population

Data from 283 randomly selected adults, aged between 28 and 30 years of age and living in Belmont, a coastal town in New South Wales, Australia, was analysed. This data was obtained during the 20-year follow up of the Belmont Cohort comprising subjects who were originally recruited in 1982 as 8–10 year olds (22). Before the study commenced, approval was obtained from the Human Research Ethics Committee of the University of Sydney and written, informed consent was obtained from each of the subjects.

Atopic status

Atopic status was determined by skin prick tests with a panel of eight aeroallergens including house dust, house dust mite (Der p 1 and Der f), rye grass, cat dander, cockroach, *Alternaria alternata* and *Cladosporium*. In addition, histamine and glycerol were used as positive and negative controls, respectively. Subjects with negative histamine tests or positive glycerol results were retested. All subjects were examined out of the peak pollen season (June–August). Wheal size was recorded after 15 min and a mean wheal diameter ≥ 4 mm was considered positive. Subjects were considered atopic if they had a positive response to one or more of the allergens tested.

Assessment of rhinitis signs and symptoms

Current symptoms of rhinitis and signs of nasal obstruction were assessed using the standardized and validated scoring system of Meltzer (23). The presence and severity of sneezing/itching, nasal congestion, rhinorrhoea and postnasal drip were measured using this doctor-administered questionnaire. Signs of nasal obstruction, including turbinate mucosal colour, turbinate swelling, nasal discharge and pharyngeal inflammation, were assessed by anterior rhinoscopy, performed by a doctor. Each sign or symptom was assigned a score, according to the Meltzer (23) criteria, using a 4-point scale from 0 to 3, where 0, represented no symptoms; 1, mild; 2, moderate and 3, severe. The severity of signs and symptoms was assessed by summing the scores for signs and symptoms

separately, where 0, represented asymptomatic; 1–4, mild signs or symptoms and 5–12, moderate/severe signs or symptoms.

A self-completed questionnaire was used to record the presence of 'hay fever' at any time in the past, or in the previous 12 months, as well as past history of lower respiratory tract symptoms such as wheeze, the use of asthma medications and smoking history.

Peak nasal inspiratory flow measurements

The PNIF was measured using an In-Check portable nasal inspiratory flow meter (Clement Clarke International, Harlow, Essex, UK). Prior to the readings being taken, all subjects received appropriate instructions on how to use the PNIF meter correctly and were supervised while readings were obtained. Three measurements were recorded for each subject. An additional manoeuvre was conducted in the event that an incorrect technique was noticed.

Histamine challenge and airway hyperresponsiveness

Lung function tests were performed during the 20-year follow up of the Belmont cohort and the methods have been previously described in detail (24). In brief, forced expiratory volume in 1 s (FEV₁) and forced vital capacity (FVC) measurements were obtained using a dry rolling seal spirometer (Mijnhardt BV, Bunnik, the Netherlands). A bronchial allergen challenge with histamine was performed by the rapid method (25) using DeVilbiss hand held nebulisers (DeVilbiss Health Care, Inc., Somerset, PA, USA) in doubling doses ranging from 0.03 to 3.9 μ mol. Subjects with a PD₂₀ FEV₁ of ≤ 4 μ mol were classified as having airway hyperresponsiveness (AHR).

Statistical analyses

Repeatability was determined by the methods of Bland–Altman (26) and reported as the intra-class correlation coefficient (ICC) and 95% limits of agreement. In general, a correlation coefficient larger than 0.80 represents high repeatability (27, 28). The associations between PNIF and severity of rhinitis signs or symptoms were determined by ANOVA using ANALYSE-IT software (Analyse-It Ltd, Leeds, England, UK). The relationships between PNIF and other variables were assessed by Spearman correlation coefficient and stepwise multiple linear regressions. The sensitivity and specificity of PNIF measurements were assessed using Receiver Operator Characteristic (ROC) curves.

Results

Subject characteristics

Satisfactory PNIF measurements were obtained from 283 subjects (136 males). Of the 275 subjects for whom skin prick test data and atopic status were available, 139 were nonatopic (56 males) and 136 were atopic (79 males). Eight subjects did not undergo skin prick tests as they had recently used antihistamine medication. In total, 121 subjects had current rhinitis symptoms with 32 from the nonatopic group and 89 from the atopic group. Of the 283 subjects, 130 reported symptoms of hay fever in the last 12 months.

Repeatability of PNIF

Three measurements of PNIF were made in each subject. The first PNIF measurement was significantly lower than both the second (mean difference $\pm$ 95% confidence interval: 4.42 ± 2.22 l/min, $P = 0.0001$) and third (6.14 ± 2.50 l/min, $P < 0.0001$) measurements, suggesting that there was a training effect. However, there was no significant difference between the second and third readings (1.73 ± 2.08 , $P = 0.10$). On this basis, only the second and third readings were used to determine the repeatability of the measurement. Figure 1 shows the differences between the second and third PNIF measurements plotted against the higher of the two measurements for the 283 subjects. The ICC was 0.92 and the 95% limits of agreement were ± 36 l/min. The higher of the second and third PNIF values was used as the measure of PNIF for each subject in subsequent analyses.

Relationship of PNIF to severity of signs and symptoms

In order to evaluate the relationship between PNIF and the signs and symptoms of rhinitis, determined by anterior rhinoscopy and questionnaire, respectively, subjects were divided into groups on the basis of the severity of their signs or symptoms. Moderate and severe groups were combined due to low numbers in the severe category. The mean maximum PNIF in subjects classified as being asymptomatic or having mild or moderate/severe rhinitis, as judged by either anterior rhinoscopy and questionnaire, are shown in Fig. 2A,B, respectively. In subjects classified according to rhinitis signs, there were highly significant differences between groups in PNIF ($P < 0.0001$, by ANOVA, Fig. 2A). However, in subjects

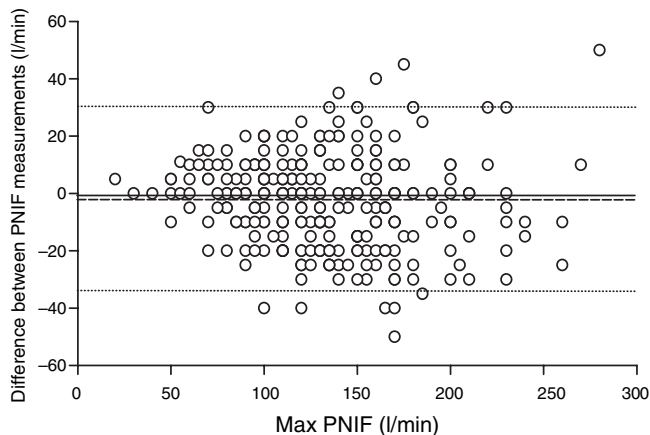


Figure 1. Repeatability of peak nasal inspiratory flow (PNIF) measurements, as the difference between the second and third PNIF measurements, plotted against the higher of the two values (Max PNIF). The dotted lines show the 95% limits of agreement.

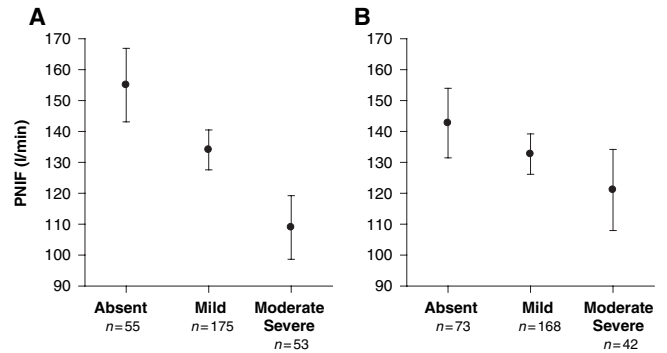


Figure 2. Mean peak nasal inspiratory flow (PNIF) values in subjects divided into groups on the basis of severity of signs, determined by anterior rhinoscopy (A), or symptoms determined by questionnaire (B). Data are presented as the mean $\pm$ 95% confidence interval (CI).

classified according to rhinitis symptoms, differences in PNIF were barely significant ($P = 0.04$, Fig. 2B). There was a highly significant, inverse correlation between PNIF and scores for rhinitis signs, determined by anterior rhinoscopy ($r_s = -0.38$, $P < 0.0001$), but not between PNIF and scores for rhinitis symptoms, determined by questionnaire ($r_s = -0.11$, $P = 0.057$).

Neither being atopic nor having hay fever in the last 12 months was associated with decreased PNIF. The mean ($\pm$ 95% confidence interval) maximum PNIF in nonatopic and atopic subjects was 130.90 ± 7.07 ($n = 139$) and 137.10 ± 7.79 ($n = 136$), respectively ($P = 0.3$). The mean maximum PNIF in subjects without and with hay fever in the last 12 months was 137.94 ± 7.51 ($n = 153$) and 128.27 ± 7.19 ($n = 130$), $P = 0.07$.

Predictors of PNIF

A normal subject group, defined as nonatopic, nonsmokers who did not report hay fever in the last 12 months, was identified ($n = 76$) and was used to determine prediction equations for PNIF. In the normal group, PNIF measurements were normally distributed, were significantly greater in men than women ($P = 0.009$), and were significantly correlated with height ($r = 0.28$, $P = 0.01$) but not weight ($r = 0.20$, $P = 0.07$). In multiple regression analyses, neither height nor weight were significant predictors of PNIF after controlling for gender. Stepwise linear regression that included gender, height, weight, as well as less routinely available variables, such as FEV₁, FVC, AHR and expired nitric oxide, revealed that only FEV₁ and FVC were independent, significant predictors of PNIF ($F = 7.84$, $P = 0.001$, adjusted $R^2 = 0.15$; Table 1). The regression equation was used to calculate a predicted PNIF value for each subject and then calculate the actual PNIF as a percentage of the predicted value.

Table 1. Predictors of PNIF in 76 normal subjects

Term	Coefficient	SE	P-value	95% CI of coefficient
Intercept	89.9	19.6	<0.0001	50.7–129.1
Absolute FVC (l)	41.2	12.7	0.0018	15.8–66.6
Absolute FEV ₁ (l)	–39.1	16.3	0.0191	–71.5 to –6.6

PNIF, peak nasal inspiratory flow; FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 s; CI, confidence interval.

The ROC curves were constructed to assess the sensitivity and specificity of PNIF, both as absolute and as percentage predicted values, for moderate/severe signs (Fig. 3A) and symptoms (Fig. 3B). There was no significant difference between absolute PNIF and percentage predicted PNIF in the area under the ROC curves for either signs or symptoms. The PNIF had highly significant discriminatory capacity for moderate/severe signs ($P < 0.001$) but had barely significant discriminatory capacity for moderate/severe symptoms ($P = 0.05$). The cut-point that maximized the sum of sensitivity and specificity for moderate/severe signs was 115 l/min. Table 2 shows the sensitivity and specificity as well as the positive and negative predictive values of a cut-point of 115 l/min for signs of moderate/severe rhinitis. A PNIF cut-off of 115 l/min had moderately high specificity

(72%) and sensitivity (65%) and a high negative predictive value (90%) for moderate/severe signs of rhinitis.

Discussion

This study examined the repeatability of PNIF measurements in a large population of young adults and assessed their utility for identifying the presence and severity of rhinitis signs and symptoms. The results showed that once the significant training effect was taken into consideration, PNIF measurements were reproducible. Furthermore, they were significantly related to the severity of physical signs of rhinitis, determined by physical examination. Although we were able to identify a normal subject group and derive prediction equations for PNIF, albeit in a very restricted age range, we found no additional advantage in using percentage predicted values to estimate the risk of signs or symptoms of rhinitis. However, an absolute PNIF of 115 l/min had moderately high specificity and sensitivity and high negative predictive value for moderate/severe signs of rhinitis.

The repeatability of the PNIF measurements in this study is similar to that reported elsewhere. In this study, the ICC was 0.92 and 95% limits of agreement were ± 36 l/min. The ICC is comparable with that obtained by Cho et al. (28) who reported a coefficient of 0.89 using a similar inhalation technique and the same brand of portable meter to measure PNIF rates in 12 healthy subjects over a period of 5 consecutive days.

The availability of normal values for PNIF might reasonably be assumed to be a prerequisite for the use of PNIF in clinical practice, however at present, no such data set has been published. In our sample of young adults, in the very narrow age range of 28–30 years, we found that in a normal group defined by the absence of allergic sensitization or self-reported hay fever, PNIF was independently related to spirometric lung volumes, but not additionally related to height, weight or gender. These findings are consistent with previous studies in adults that found that PNIF was independent of height and age (19) and was strongly correlated with a number of pulmonary parameters including FEV₁, peak expiratory flow rates and FVC (5). It seems likely that respiratory muscle strength would play a role in determining inspiratory flow and that this might be indirectly related to body size or lung size. However, we found that using a prediction equation derived from our normal subject group to calculate predicted values for PNIF for our population did not improve the sensitivity or specificity of PNIF for signs or symptoms of rhinitis. This suggests that the predictor variables identified in this study are only weakly associated with PNIF and do not account for a high proportion of the variance. A larger population study that includes a broader range of age groups would be needed to define a more robust set of normal values.

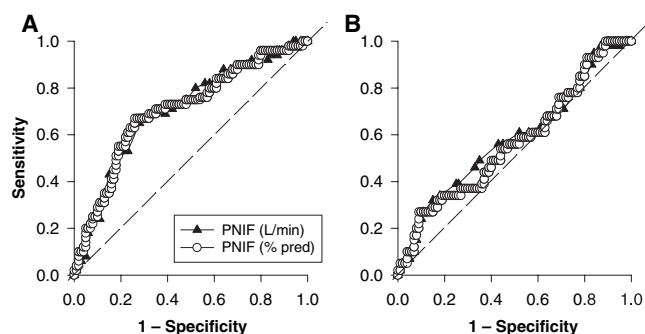


Figure 3. Receiver Operator Characteristic (ROC) curves of the discriminatory capacity of maximum peak nasal inspiratory flow (PNIF) and PNIF (percentage predicted) for moderate/severe signs of rhinitis (A) and moderate/severe symptoms of rhinitis (B). The dashed line shows the line of no discrimination.

Table 2. Maximum PNIF as a test for moderate/severe signs of rhinitis

Moderate/severe signs (l/min)	Present	Absent	Predictive value (%)
Max PNIF < 115	33	65	Positive = 34
Max PNIF > 115	18	166	Negative = 90
	Sensitivity = 65%	Specificity = 72%	

PNIF, peak nasal inspiratory flow; ROC, Receiver Operator Characteristic.

The cut-point for maximum PNIF was obtained from ROC curves as the value that maximized sensitivity and specificity.

In population studies and in many clinical settings, the diagnosis of rhinitis can be difficult because of the lack of objective diagnostic criteria that can be applied easily in these settings. In the absence of evidence from physical examination by an appropriately qualified doctor, the diagnosis and the classification of severity usually depends on a report of typical rhinitis symptoms. This study has shown that there is a highly significant, but imperfect association between the severity of current symptoms of rhinitis and physical signs of reduced nasal patency, and that PNIF measurements are more closely associated with nasal obstruction than with symptoms of rhinitis. This suggests that the information provided by PNIF is qualitatively different from that provided by information about symptoms. Since both types of information might contribute to the diagnosis, PNIF measurements are likely to have considerable utility in these settings. Information about current symptoms can be readily obtained from the patient, but objective evidence obtained from a physical examination conducted by a specialist ENT doctor may not be. The present study shows that a PNIF above 115 l/min has good specificity and a high negative predictive value for moderate/severe signs of rhinitis, suggesting that PNIF measurements could be useful to exclude nasal obstruction as a cause of current rhinitic symptoms in the setting of population screening. However, in the clinical setting, where the prior probability of rhinitis would probably be higher, the negative predictive value, and hence its utility for 'ruling out' rhinitis, would be lower. In contrast, the positive predictive value of the PNIF in this study was low, indicating that there were a high proportion of subjects with low PNIF values that

did not have evidence of moderate or severe nasal obstruction. The positive predictive value would be higher in population with a higher prevalence of rhinitis and nasal obstruction, as would expected in the clinical setting.

A measurement of PNIF is likely to reflect nasal obstruction at the time of measurement. Longitudinal studies would be needed to determine if a low PNIF can predict prognosis or response to treatment or if re-occurring episodes of rhinitis cause irreversible reduction in PNIF and/or permanent obstruction in the upper airways, a situation analogous to remodelling in the lower airways (29).

The results from this study show that PNIF measurements reflect the severity of nasal signs of rhinitis in a general population sample of young adults. The strong association between PNIF and rhinitis signs, determined by physical examination, suggests that PNIF measurements may provide useful, objective information about nasal obstruction that is additional to that provided by subjective symptom scoring. In addition, like peak expiratory flow rate it may aid in the assessment of subjects who have impaired symptom perception.

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