REVIEW ARTICLE

Measurements of nasal airflow and patency: a critical review with emphasis on the use of peak nasal inspiratory flow in daily practice

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Abstract

Objective measures can be used to assist the clinician to diagnose and treat nasal obstruction and also to quantify nasal obstruction in research. Objective measurements of nasal obstruction are as important as objective measurements of lung function. peak nasal inspiratory flow (PNIF), acoustic rhinometry (AR) and rhinomanometry (RM), with their specific peculiarity, assess different aspects of nasal obstruction. From the studies available in the literature, it seems that these methods roughly correlate with each other and that all of them can be alternatively utilized very well in research as well as in clinical practice. This review describes the various methods that can be used to measure nasal patency, airflow and resistance, mainly peak nasal inspiratory flow, rhinomanometry and acoustic rhinometry. PNIF has been demonstrated to be reproducible and as good an indication of objective nasal patency as formal rhinomanometry and has the advantage to be cheap, simple and suitable for serial measurements and for home use even in the paediatric population. PNIF normative data are available for children, adults and elderly subjects, and the availability of unilateral PNIF normal values allows evaluation of nasal sides separately. Just as in the lower airways, objective and subjective evaluation gives different information that together optimizes the diagnosis and the treatment of our patients. We argue that PNIF should be used regularly in every outpatient clinic that treats patients with nasal obstruction.

Impairment of the nasal airflow results in symptoms of nasal obstruction. The nasal valve is the narrowest part of the normal nose. Many physiologic and pathologic conditions can influence the amount of airflow or nasal airway resistance. Some of these conditions are normal such as the nasal cycle. Airflow through the nasal passages is usually asymmetrical because of spontaneous congestion and decongestion of the nasal venous sinuses at the anterior end of the inferior turbinate and nasal septum in the nasal valve region (1). The asymmetry of nasal airflow alternates over a period of 2–4 h, and this alternation of nasal airflow is usually referred to as the 'nasal cycle' (2). On top of this, pathological conditions can cause impairment of the nasal flow such as swelling of the turbinates in allergic and nonallergic rhinitis, nasal polyps (CRSwNP), secretions and crusts in the nose but also anatomical changes such as septal deviations and valve insufficiencies. Nasal patency is a measure of how open the nose is, and it is not equivalent to airflow or resistance to airflow but describes the volume or cross-sectional areas of the nasal cavity. Objective measures can be used to assist the clinician to diagnose and treat nasal obstruction and also to quantify nasal obstruction in research. This review describes the various methods that can be used to measure nasal patency, airflow and resistance.

History

An important aspect of the assessment of the nasal airway function is the history. We want to be informed about specific rhinitis symptoms such as blockage, rhinorrhea, postnasal drip, sneezing and itching, the time sequence of the symptoms, provocating factors such as allergens and irritating

factors, but also prior surgeries and the intake of prescribed or OTC medications. Some observant patients notice aspects of the nasal cycle, for example the fact that in bed the nasal airflow of the side where one is lying on is reduced. In these cases, explanation of the nasal cycle can be helpful.

Nasal examination

The nasal examination starts with the outside of the nose. A very crooked or deviated nose may point to anatomical reasons for nasal obstruction and warrant further internal evaluation. Anterior rhinoscopy enables to make a quick but limited internal inspection of the vestibulum and anterior part of the cavum nasi with the aid of an examination lamp fixed to a headband and a nose speculum. If these instruments are not available, it can also be performed with an otoscope. Even without these, the tip of the nose can simply be pushed upwards, and so, one can get a first impression of the position of the septum, the inferior meatus and of the head of the inferior turbinate. Sometimes the head of the middle turbinate can be observed. In allergic patients, the mucosa of the turbinates is pale and swollen (3).

Anterior rhinoscopy can be supplemented by the so-called mirror test. By holding a cold mirror or small metal plate under the nostrils, the airflow during nasal expiration can be assessed. A lack of fogging indicates an inadequate nasal flow.

Anterior rhinoscopy is limited in its evaluation of the entire nasal cavity. Nasal endoscopy allows inspection of the full cavum nasi, with a bigger range of view and details in comparison with anterior and posterior rhinoscopy. Nasal endoscopy can be performed by a rigid of flexible scope, which is attached to a strong light source by glass fibre. Rigid endoscopy is generally considered to be more patient friendly by nasal endoscopists (3) and supplies a better image than flexible endoscopy. In general, especially when a thin (2.7 mm) endoscope is used, local anaesthesia is not necessary (4). Nasal valve deficiency (Fig. 1) can be diagnosed by just introducing the endoscope in the vestibulum nasi and asking the patient to inhale first normally and then with more strength. When nasal valve deficiency occurs, it can nicely be observed in this way. Consecutively, the inferior meatus of the nose unto the nasopharynx can be inspected with an evaluation of the septum nasi, the lower turbinate, the choanae and the nasopharynx. Afterwards, the scope follows the edge of the middle turbinate towards the rostrum sphenoidale, with information about the middle and upper turbinates, and potential drainage from the sinuses.

Objective measurements of nasal airflow and patency

Nasal airflow is the airflow through the nose and can be recorded with or without simultaneous pressure recordings with nasal peak flow measures or rhinomanometry (RM).

Nasal patency is evaluated by measuring the cross-sectional areas of a nasal cavity or the volume of a part or the whole of a cavity which can be measured by imaging such as Computed tomography (CT) scan or Magnetic resonance imaging (MRI), acoustic rhinometry (AR), rhinosterometry or other ways to measure the volume and/or cross-sectional area.

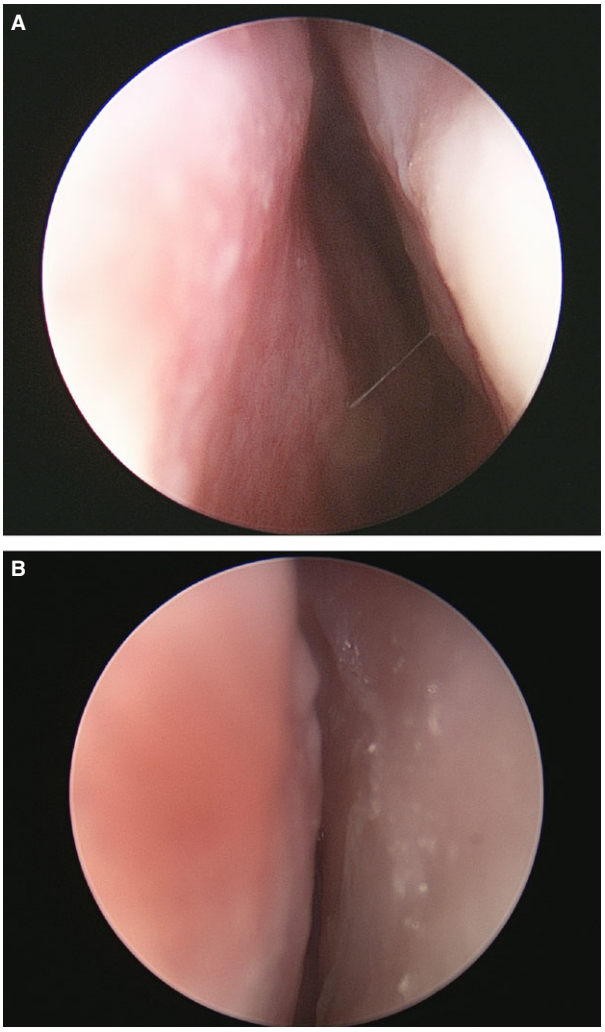

Figure 1 An endoscopic view of a left nasal valve deficiency. (A) normal nasal valve. (B) collapsed nasal valve at inspiration.

Nasal airflow measurements

Peak nasal flow measurements

Peak nasal flow has been presented since the introduction of measurement of mouth peak expiratory flow (PEF), known to be useful to monitor airway narrowing in asthma, with the purpose to assess nasal patency (5). Peak nasal flows can be measured during inspiration (PNIF) (Fig. 2), by means of a portable flow meter such as the Youlten peak flow meter (Clement Clark International), and/or expiration (PNEF), by means of a Wright's mini peak flow meter (Clement Clark International) (6, 7). PNIF and PNEF are closely correlated (7), both of them have been demonstrated to be valid for the measurement of nasal flow (5, 8), and are well tolerated by

Figure 2 Mini Wright peak nasal inspiratory flow meter (left); PNIF used on a patient (right).

patients (9). Although inspiratory manoeuvres may cause alar collapse and thus valve insufficiency, and in few cases, when the nose is totally blocked, it is not possible to obtain a measurement (7), PNIF has some undoubtable hygienic advantages over PNEF (10). Moreover, it seems that PNIF correlates better with nasal resistances than PNEF (11, 12).

PNIF

PNIF is an inexpensive, fast, portable and simple technique, which does not depend on computers to analyse the data. It has a good reproducibility (11, 13) with a correlation coefficient up to 92% (14). Furthermore, PNIF, measuring nasal flow, gives a direct measure of nasal obstruction (15). Presented by Youlten in 1980 (10), PNIF is a modification of the Wright peak flow meter (16) and consists of a face mask which the patient applies over the nose (without touching it) with the mouth closed. The patient must be encouraged to inhale as hard and fast as he can through the mask keeping the mouth closed starting from the end of a full expiration [residual volume method]. Three satisfactory maximal inspirations are usually obtained and the highest of these results is taken as the PNIF (17). PNIF should be measured standing because PNIF measures, as PEF measurements, are higher when standing than sitting PNIF especially in females (18). PNIF increases with practice, particularly after the first attempt, so it is important to allow the patient a few tries before taking the three measurements.

PNIF in adults

In adults, PNIF is higher in males than in females and increases with height, albeit with a large residual variability, and decreases with age (17) (Table 1). Square root transformation of the PNIF value reduces the residual variability (17). PNIF is correlated to PEF, and ideally in order to assess nasal obstruction by means of PNIF, PEF values should also be known, as PNIF low values may be an expression of low ventilatory activity rather than an expression of nasal obstruction (19).

Table 1 Mean PNIF values obtained by different studies in adult population

	Mean PNIF (L/min) in males	Mean PNIF (L/min) in females
Ottaviano et al. (2006) (17)	143 ± 48.6	121.9 ± 36
Blomgren et al. (2003) (20)	145	128
Bouzgarou et al. (2011) (23)	174 ± 54	126 ± 33
Klossek et al. (2009) (24)	104.6 ± 54.8	80.8 ± 33.4

PNIF, peak nasal inspiratory flow.

Although some authors did not report an association between PNIF and height and age (20), most studies do (17, 21–23). Normal PNIF values in the French population were reported to be lower than previous published reports from other countries (24). The PNIF value differences seen in the studies above mentioned most probably rely on the different ethnicity of the subjects considered. In Fig. 3, reference values for the north European caucasians are given.

Unilateral PNIF was first obtained by Larsen and coworkers in 1990 on a group of 26 patients undergoing operation for nasal obstruction, finding that PNIF gives valuable information pre- and postoperatively in patients undergoing nasal surgery and that the method is simple and easy to perform (9). Recently, unilateral PNIF normal values for adult population have been presented (25). The authors found results similar to those of previous bilateral studies (17, 19), with a positive correlation with height and sex and confirming that age was inversely associated with PNIF. But the authors concluded that, as PEF is strictly related to patients' height and pulmonary airflow and nasal airflow are strictly correlated, when measuring unilateral PNIF, the effects of age and in part of gender are largely lost and the effect of height becomes the only variable associated with PNIF itself (25).

PNIF has been successfully used for the evaluation of treatment in allergic rhinitis and its treatment both in adults (8, 26–28) and in children/adolescents (29, 30). Studies have assessed the efficacy of intranasal corticosteroids in patients with NP using PNIF (31–33), showing a significant increase in PNIF which was accompanied by subjective improvement of nasal blockage, and by an associated reduction in nasal polyp size (34, 35). It can be used to study nasal valve collapse (9, 10, 36–38), hormonal influences on the nasal mucosa (39, 40) and for the evaluation of nasal surgery outcome (41, 42), and it has been recommended by many authors as a valuable objective instrument for evaluation of subjective nasal obstruction (43). PNIF can also be used in nasal provocation testing (44–46) to evaluate nasal hyperreactivity (47) and to evaluate environmental effects on nasal patency in occupationally induced nasal obstruction (48).

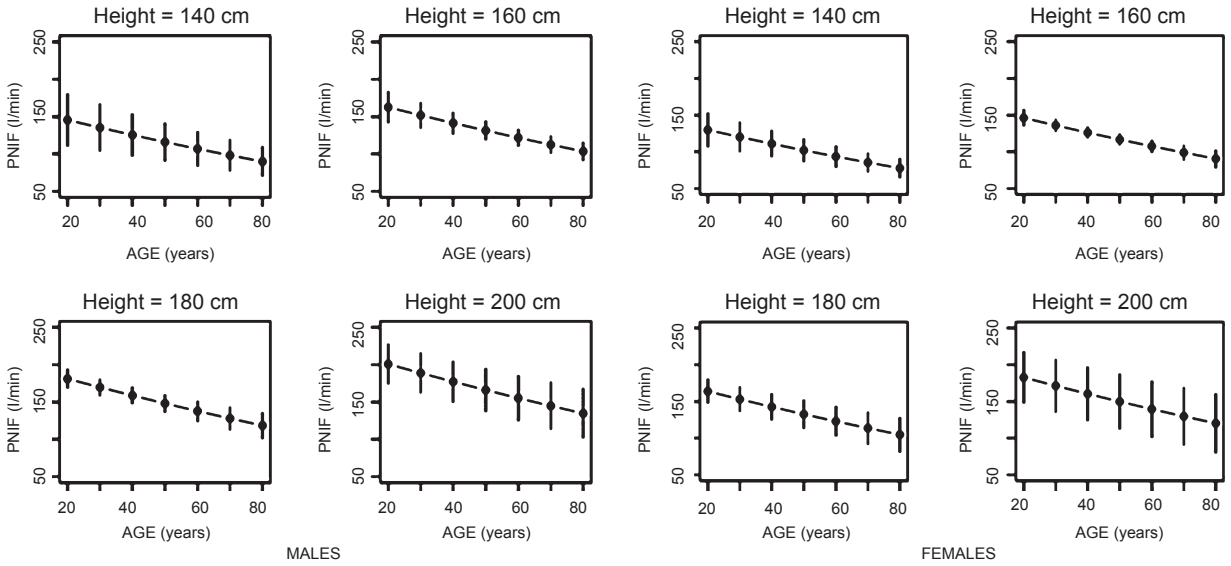

Figure 3 Mean estimates of PNIF for north European Caucasian males and females with specified age (years) and height (cm) (16, with permission).

PNIF in children

With a modified mask able to separate the oral from the nasal airway, it is possible to obtain PNIF values in a population aged from 6 months to 8 years (49) (Fig. 4). Authors found that PNIF increased in a fairly linear manner with increasing age, height and weight (49). From the age of six, and sometimes even younger, PNIF measurements can be performed with a normal PNIF mask (50). Most studies in children describe PNIF values to be higher in boys than in girls, and a continuous increase in PNIF values with age and sometimes height and/or BMI (50–52). Most important, the possibility to apply PNIF for a routine use in children has been confirmed by all these studies (22, 29, 49–52).

Rhinomanometry

Rhinomanometry (Fig. 5) provides a quantitative measure of nasal airway resistance (53). It involves measurement of nasal airflow and the pressure gradient required to achieve that flow from which nasal airway resistance can then be calculated (54). Active anterior rhinomanometry (the patient is actively breathing through one nasal cavity, while the narinochoanal pressure difference is assessed in the contralateral nasal cavity) is the most commonly used method of rhinomanometry (55). When the measurements are performed before and after the application of a nasal decongestant spray, the differences in resistance can be attributed to nasal mucosal congestion. Data obtained after nasal decongestion allow the evaluation of anatomical factors influencing resistance.

Nasal resistance is normally determined at a fixed pressure gradient of 150 Pa (55). In 2010, Vogt et al. (7) introduced another new method called 4-phase rhinomanometry where nasal resistance is calculated in the analysis of the 4 different phases of breathing (56). However, this method does not significantly differ in outcomes compared to normal rhinomanometry (54, 57).

Normal values. Reference intervals (RIs) for normal total nasal airflow resistance under congested nasal mucosal conditions were found to be at 0.25 $Pa/cm^3/s$ (95%-RI 0.10-0.40 $Pa/cm^3/s$) for adults with a slight difference between women (0.26 $Pa/cm^3/s$) and men (0.24 $Pa/cm^3/s$) (58). Lower overall mean values are found under decongested nasal mucosal conditions. No study examining children under congested nasal mucosal conditions could be found. Under decongested nasal conditions, an airflow resistance value of 0.24 $Pa/cm^3/s$ (95%-RI 0.11–0.37 $Pa/cm^3/s$) was calculated from the data of two studies involving children. This points to children having a higher level of airflow resistance than adults (58).

Rhinomanometry can be used for the evaluation of the symptoms of anatomical (59) and/or mucosal nasal obstruction (60), research in nasal physiology, allergen and aspirin challenge testing (45, 61), pre- and post-treatment assessments of surgical or medical therapy (62, 63), evaluation of adenoid hypertrophy in children (64) and evaluation of patients with sleep apnoea (65, 66). Patient selection for septal and turbinate surgery is largely undertaken around the world without any objective confirmation of genuine mechanical obstruction (67). The use of objective methods in selecting patients for septal surgery and especially the importance to measure nasal obstruction by means of at least RM before septal surgery has consistently been pointed as patients with preoperative higher nasal resistances are more likely to benefit from the surgery reporting higher satisfaction (68).

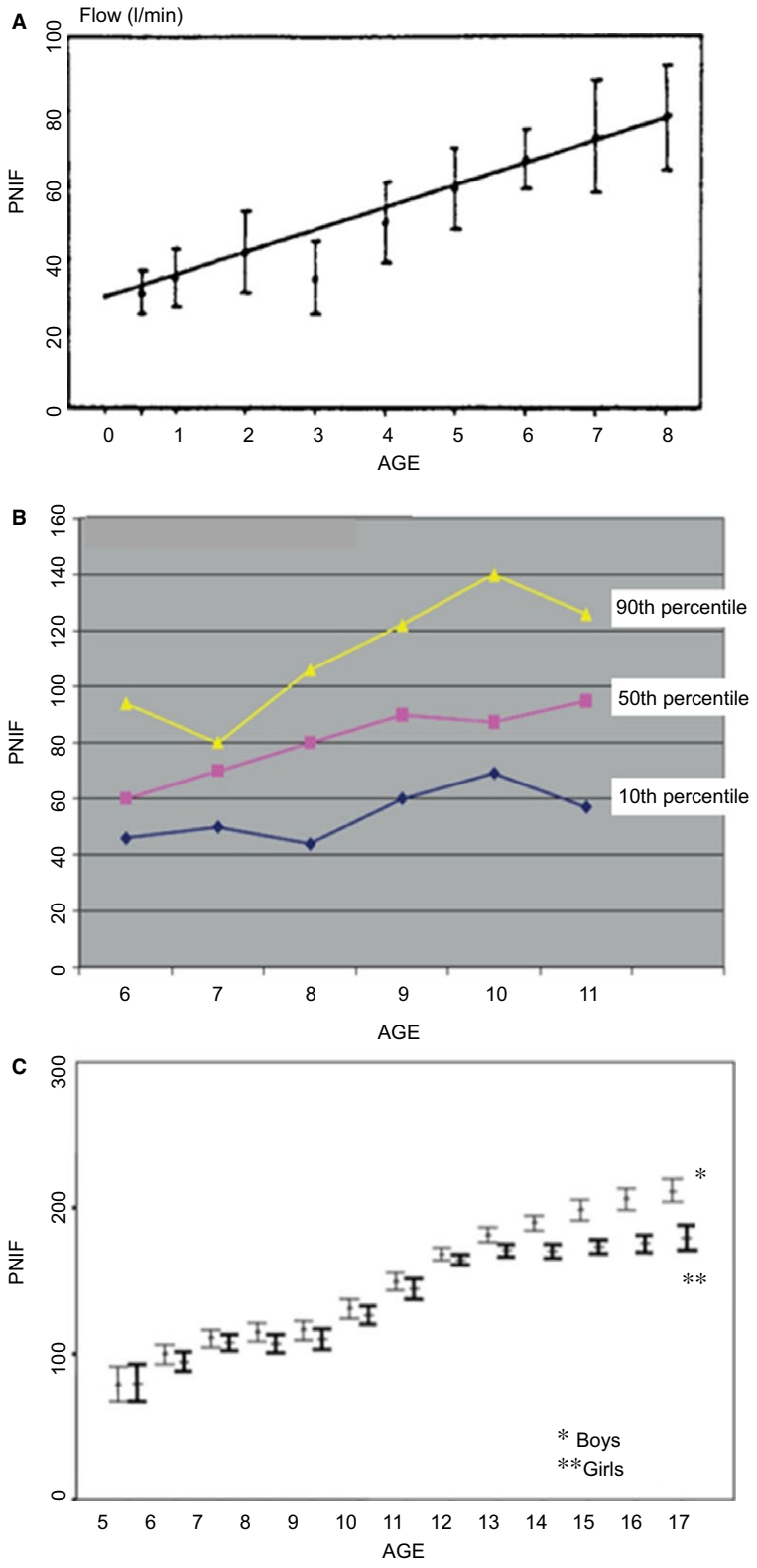

Figure 4 Mean PNIF values (L/min) obtained by different studies in children adapted from (48–50). (A) Graphical representation of PNIF *vs* age (years). (B) Normative PNIF values for children aged 6–11 years. (C) Mean and 95% confidence interval for PNIF according to the age (years) for both sexes.

Figure 5 Measuring patient's nasal resistances by means of anterior active rhinomanometry.

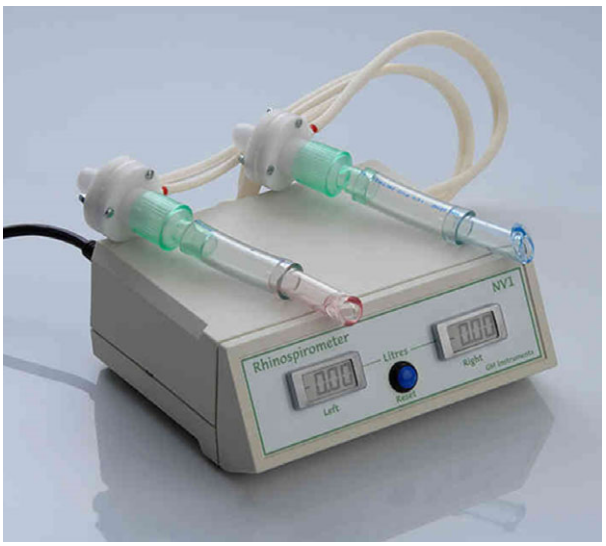

Figure 6 Example of rhinospirometer.

Nasal spirometry

Nasal spirometry is performed using a slightly modified spirometer (Fig. 6). The mouthpiece is removed from the conventional spirometer and a plastic nasal adapter, similar to that used in acoustic rhinometry, is connected. The spirometer measures the vital capacity and calculates the volume of air exhaled through the nostrils. This method, however, is seldom used. Nasal spirometry has been successfully used for the selection of patients undergoing septal surgery and for the postoperative follow-up (69).

Figure 7 Example of acoustic rhinometer.

Nasal patency measurements

Computed tomography and magnetic resonance imaging
It has already been suggested in the early days of the Computed tomography (CT) scan that this could be a valuable method to measure nasal patency (70). Measurement of the cross-sectional area of the nasal passage on CT has been used for assessing the effect of different treatment options in nasal valve surgery and for validating other nasal valve measurement methods such as AR. Modern software, however, allows using minimization procedures to automatically determine the location of the minimum cross-sectional area (MCA) of the nasal passage (71). This method can be useful in situations where other methods are not conclusive in determining the main site of obstruction. However, the method has been scarcely used because of significant disadvantages such as radiation (CT), costs (CT and MRI) and the absence of functional measurements (CT and MRI).

Volumetry
Based on CT scan images and with several image-processing techniques, the volume of the nasal cavity can be measured. As for CT and MRI, the method is seldom used to measure nasal dimensions.

Acoustic rhinometry. Acoustic rhinometry is a simple, reproducible technique for measuring the volume of the nasal cavity (72, 73) (Fig. 7). The acoustic rhinometer generates an acoustic wave, which is transmitted through a tube into one nostril. The clinical value of AR is its ability to measure the nasal cavity dimensions in terms of a curve describing the cross-sectional areas as a function of distance. This curve describes nasal airway patency and gives an impression of the degree of nasal obstruction. The area-distance curve usually shows 3 minimum notches or deflections, which represent the narrowest parts in the nasal cavity. Two of these notches are situated most anterior part of nasal cavity (up to 3 cm from the nares), representing the nasal valve and the head of the inferior turbinate (74). One of these 2 frequently is the absolute MCA, and this may vary before and after decongestion. The third notch is variable, and measurements

in the posterior part of the nose may be affected by enlarged openings to the paranasal sinuses after surgery.

The measurement is performed in each nasal cavity separately. The technique is simple and requires minimal patient cooperation, which makes the method suitable for the use in children (75, 76). Data obtained after nasal decongestion allow the evaluation of anatomical factors influencing the cross-sectional diameter of the nose (77). AR has been demonstrated to have a reproducibility correlation coefficient for both the nasal volume measurements and the MCA ranging from 0.65 (78) to more than 0.80 (79). Factors such as external noise, changes of position of the sound tube and sound leaks at the nostril may influence the reproducibility and accuracy of AR (54), leading to a possible variation of maximum 10% of the MCA among the recordings (80).

AR can be used to measure reduced nasal patency in patients with anatomical problems (81), rhinitis, and to measure the effect of challenges and treatment effects (33, 63)

Interestingly, it can show nasal obstruction in patients without nasal symptoms but with occupational asthma and rhinitis (82). AR has been shown to be useful to diagnose adenoid hypertrophy in children (83).

Normal values. The MCA is defined as the narrowest segment of the anterior part of the nasal cavities. Normal values for MCA in adults are reported to be between 1.32 and 1.51 cm^2 (SD 0.3). In normal controls, a statistically significant correlation was found between the body surface area and MCA, ranging from 1.01 (SD 0.09) with a body surface area (BSA) of 0.9 m2 (equivalent to a child age 6-7) to normal adults values with a BSA of 1.8 m2 (84). MCA equals to 0.50 cm^2, and a cross-sectional area at the piriform aperture of 0.70 cm^2 and a large effect of decongestion at MCA were found to be the best variables to separate obstructed from normal noses (85). In healthy individuals, there is poor correlation between AR data and subjective nasal obstruction scores, whereas correlations are better in congested subjects (86). The measurements are most useful to assess nasal patency before and during challenges (allergen, aspirin, methacholine, etc.) and guidelines for their use exist (87, 88).

Correlation between symptoms and objective tests

As in asthma, it has been clearly shown that symptoms and objective measurements do not always correlate well (89), and the assessment of a patient suffering of nasal obstruction should be based upon both subjective and objective measures. On the one hand, patients with objective nasal obstruction do not always have symptoms (85, 90, 91), but on the other hand, the correlation between symptoms and objective measurements is far from obvious (92). It has been suggested that objective measurements do not correlate very well with subjective measurements of nasal obstruction, because the nasal valve region primarily determines nasal resistances, while the sensation of nasal obstruction may be related to congestion in other areas of the upper airway, such as the ethmoid region Nathan et al. (93). Another possible explanation of the discrepancy between objective and subjective methods for the measurement of nasal obstruction could be the lack of validated questionnaires. The introduction in the last years of questionnaires such as SNOT-22 and NOSE has certainly increased studies reliability. The use of validated subjective scoring tools is nowadays strongly advised for future studies on this subject so as to enhance the reliability of conclusions concerning the correlation between objective and subjective outcomes (89).

For RM and AR when obstructive symptoms were present, a correlation between the patency symptoms with nasal airway resistance and MCA was found more often than in the absence of symptoms. In cases of bilateral assessment, a correlation was found almost as often as it was not between patency symptoms and total nasal airway resistance or combined minimal cross-sectional areas, while in the studies evaluating unilateral assessment patency symptoms and nasal airway resistance correlated well (89). However, anterior active RM has been demonstrated by many studies to have a significant power to discriminate pathologic from healthy subjects, similarly to PNIF (7, 10, 12, 92, 94). A study conducted upon 102 subjects affected by rhinitis, evaluating the correlation between nasal patency sensation (measured by VAS) and nasal resistances (measured by anterior active RM) before and after histamine challenge, found a significant correlation between VAS and RM at all points. (95). Controversy exists regarding the correlation between PNIF and both subjective and other objective methods for the measurement of nasal patency (15, 27, 96, 97); nevertheless, a number of studies demonstrated that PNIF is a sensitive test which correlates reasonably well with both patients' symptoms of nasal blockage (12, 34, 98, 99) and other measures of nasal function (100, 101). A number of studies have shown that the use of PNIF improves outcomes of surgical intervention and that it correlates reasonably well with patient's subjective perception of nasal passage (42, 68, 102–104). Also in patients with chronic rhinosinusitis, both PNIF and AR significantly improved after the treatment and PNIF correlated with the SNOT-22 total score at the end of the treatment protocol and showed moderate to strong correlation with nasal obstruction VAS grading during the treatment period (105). In children, PNIF was moderately but significantly correlated with allergic rhinitis, clinical scoring and with the nasal obstruction perception (106). In children treated with intranasal corticosteroids, PNIF can be utilized to evaluate treatment benefits (29). The same has been shown in children treated for nonallergic acute rhinosinusitis (107).

Correlation among objective tests (PNIF, RM and AR)

What is the best method to objectively measure nasal patency depends on the situation. Table 2 summarizes the main characteristics of the most known and used tests for the assessment of nasal obstruction (PNIF, RM and AR).

PNIF has been proposed since many years as a good solution for measuring nasal obstruction, as it can be easily learned and interpreted (22, 43). When comparing PNIF and RM in assessing nasal patency under 4 different conditions (baseline, postexercise, nasal histamine and nasal cocaine),

Table 2 Main characteristics of the most frequently used tests for the assessment of nasal patency

	PNIF	Rhinomanometry	Acoustic rhinometry	Nasal spirometry
Definition	Device with a scale to measure nasal airflow and a nasal mask	Transducers that measure nasal airflow and differences in nasal pressure	Ultrasounds	Spirometer with a nasal adaptor
Measurement	Nasal flows in litres per minute during maximal inspiration	Nasal resistance and conductance	Cross section and Volume between two points of the nasal cavity	Volume of air expired per minute through the nostrils
Patient cooperation	Yes	Yes	Minimal	Yes
Reference values	Yes	Yes	Yes	Yes, but not for children
Useful for nasal challenge test	Yes	Yes	Yes	N/A
Useful for medical treatment evaluation	Yes	Yes	Yes	Yes
Useful for surgical treatment evaluation	Yes	Yes	Yes	Yes
Strength	Portable; useful for home monitoring of patient's treatment	Still the 'golden standard' for measurement of nasal obstruction	Most used in children; guidelines for its use in nasal challenge test	Portable
Limitation	Alar collapse; not useful when nose totally blocked	Relative high cost of equipment	Relative high cost of equipment	Relative high cost of equipment

PNIF, peak nasal inspiratory flow; N/A, not available.

PNIF was found to be more sensitive to the 'decongesting' manoeuvres (108). Recently, comparing RM and PNIF in healthy and obstructed noses, Ottaviano and colleagues reported both methods to have a similar and significant power to discriminate pathologic from healthy subjects (94).

Kjaergaard et al. (101), investigating the relationship between nasal cavity dimensions by means of AR and nasal airflow by means of PNIF in a population of 2523 patients with and without nasal symptoms, found a nearly linear relationships between PNIF and nasal cavity volumes and especially MCA. PNIF and AR were shown to closely correlate in patients undergoing septo-turbinoplasty for nasal obstruction (109). AR has been found to significantly correlate with PNIF also in other studies (110). Very recently, Proimos and co-workers, studying both AR and PNIF in 78 patients affected by chronic rhinosinusitis either with or without nasal polyps before and after medical treatment, found both PNIF and AR significantly improved after the treatment (105).

Similar results have been obtained comparing AR with RM. In general, a good correlation is found between nasal cross-sectional areas (measured by means of AR), nasal resistances (measured by mean of RM) and the sensations of nasal patency, before and after topical application of a nasal decongestant in adults and children especially when unilateral measurements are performed (89, 111–114) although some authors do not find these correlations (115, 116).

A few studies compared the three methods: AR, RM and PNIF/PNEF together. Recently, a study conducted in a population of 184 subjects found a moderate to strong correlation between PNIF, AR and anterior active RM (110). Numminen et al. (117) found a statistically significant correlation between AR, RM and PNEF in 69 subjects before acute viral rhinitis and on days 3 and 10 of the infection. In a study comparing AR, RM and PNIF before and after external nasal valve surgery, a significant correlation was found only between PNIF and RM, while no significant correlations could be found neither between PNIF and AR nor between RM and AR (103). Interestingly, Wilson and colleagues found PNIF being more sensitive than the other measures (posterior active RM and AR) to evaluate the response to topical corticosteroids after histamine nasal challenge test in 22 patients affected by perennial allergic rhinitis (118)

The relation between nasal flow and patency measurements and pulmonary function

Both allergic rhinitis and CRS, especially in the presence of NP, have been clearly shown to be associated with lower airway diseases such as asthma and COPD and to be a significant and independent negative predictor of quality of life in asthmatics (119–122). Asthma diagnosis is frequently ratified by pulmonary function tests, broadly utilized in medical practice (123). On the other hand, nasal patency assessment with objective measures is still not a part of clinical routine tests although, as already mentioned, nasal obstruction is one of the main complaints in these patients. Furthermore, it has been demonstrated that more than 17% of the patients suffering of nasal blockage are unable to determine the correct side of obstruction (25), so patient's perception should be always associated with objective measures of nasal congestion to improve the clinical evaluation of nasal obstruction symptoms (25). Given the nowadays widely accept hypothesis of 'united airways' (124, 125), together with the objective study

of nasal function, the impact of the lower airways on these values should be taken into consideration (19, 77). A number of studies have tried to evaluate the relationship between upper and lower airway patency. Using AR (before and after α-agonist) and spirometry (before and after β2-agonist), performed in 221 children, a strong and consistent association between upper and lower airway patency was found (126). Another study attempted to evaluate the relation between the degree of nasal obstruction and the grade of bronchial hyper-reactivity. In this study, the authors performed a bronchoprovocation and RM with decongestion test in 57 patients with allergic rhinitis and bronchial hyper-reactivity and found that patients with a negative decongestion test showed increased bronchial hyper-reactivity (127). Studying asthmatic patients and nonasthmatic controls with PNIF, AR and spirometry, it was found that PNIF was significantly associated with asthma and forced expiratory volume in the first second (FEV1) (% predicted). Patients with asthma significantly rated their nasal obstruction by VAS more seriously than nonasthmatic controls with comparable PNIF values. Apparently the sensation of nasal obstruction in asthmatics is different from controls despite being in the same PNIF group (128). Finally, evaluating nasal resistances by means of RM in subjects with COPD, a very recent prospective study found that these patients have higher nasal resistances compared to controls also (129).

PNIF measurement has been shown to be influenced by the maximum negative pressure generated by the lower respiratory tract. Changes in either inspiratory effort or lower airways resistances can alter PNIF values independently of nasal obstruction (7). The fact that nasal flow can be influenced by lower airways status has long been considered a limitation in the use of PNIF (77). In order to account for the influence of lower airway function on PNIF and to increase the sensitivity of the PNIF test itself, in the past the blockage index (peak oral flow minus peak nasal flow divided by peak oral flow) and the nasal patency index (NPI) have been proposed (6, 130). However, a recent study has shown that PNIF is significantly correlated to peak oral inspiratory flow (POIF) and that measuring NPI instead of PNIF had no added value (131).

However, measuring PEF together with PNIF in rhinologic patients is easy and, as mentioned above, interesting because it translates the current thinking of a single airway disease in which signs of disease in one part of the respiratory tract should be considered as a disease of the whole (121, 132, 133) in an integrated fashion, allowing to have a more reliable idea of patients' airways condition. Furthermore, as a moderate correlation between PNIF and PEF has also been demonstrated in children and adolescents, and PEF is predictive and informative of PNIF also in this population, low values of PNIF should be always confirmed by PEF to exclude a reduction in lower airway patency (19, 77). In clinical practice, also realizing the different sensation of nasal obstruction in asthmatics, when confronted with a patient (children, adolescent, adult or elderly) complaining of nasal obstruction without an obvious rhinological cause, the possibility of lower airway obstruction should always be considered (93).

Conclusion

Objective measurements of nasal obstruction are as important as objective measurements of lung function. PNIF, AR and RM, with their specific peculiarity, assess different aspects of nasal obstruction. From the studies available in the literature, it seems that these methods roughly correlate with each other and that all of them can be alternatively utilized very well in research as well as in clinical practice (i.e. for nasal provocation test) (88). PNIF, being inexpensive, fast, portable and simple, should be available in every practice where 'airway' diseases are diagnosed and treated.

Author contributions

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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