Objective Assessment of Nasal Patency

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Abstract

The aim to objectify nasal airflow and patency is ongoing—many methods have been suggested, often lacking clinical relevance or showing weak correlations with patients' symptoms. It is crucial to thoroughly consult our patients presenting with nasal obstruction—and to inform them about realistic possible surgical outcomes. Often, a perfect-looking internal nose with a straight septum and normal-appearing turbinates does not guarantee a happy, symptom-free "owner." A review of the literature and the current technical market is presented here to facilitate the rhinosurgeon's decision to perform pre- and postoperative objective measurements of nasal airflow. Recommendations by the societies have been included.

Keywords
- assessment of nasal airflow
- nasal function
- obstruction
- nasal ventilation
- breathing

Several clinical settings require the evaluation of nasal patency: when the presenting symptom is nasal obstruction, rhinorrhea as in allergic rhinitis, or when there is the desire to undergo rhinoplasty without any functional impairment.

Patency emanates from the Latin word "patens," which means open. In the National Library of Medicine, the medical term "vascular patency" is defined as the degree to which blood vessels are not blocked or obstructed. Malm describes nasal patency as a measure of "how open the nose is."[1] The objective methods for recording nasal patency include rhinomanometry, nasal peak flow, acoustic rhinometry, rhinostereometry, optical rhinometry, endoscopic estimates of the nasal minimal cross-sectional area (MCA), nasal sound spectral analysis, computed tomography (CT), and magnetic resonance imaging (MRI).

It is crucial to properly consult our patients presenting with nasal obstruction—and to realistically inform them about possible surgical outcomes. Anterior and posterior rhinoscopy and nasal endoscopy should always precede any nasal patency assessment for clinical evaluation of the nasal cavity and nasopharynx. A comprehensive diagnosis of the nose from the morphological and functional view-point should ideally include a detailed patho-anatomical analysis (by inspection and endoscopy), quantitative determination of the physical properties of the nasal air stream (by objective air flow measures), and the subjective complaints of the patient.

The nasal airway resistance is related to the fourth power of the cross-sectional area of the nose, so that minimal changes of the diameter cause big changes in the resistance (law of Hagen-Poiseuille). Neither can the human eye estimate the degree of impairment of the nasal patency nor do measurements of the nasal diameter sufficiently relate to the nasal airway resistance. [2] Erroneous estimations of the nasal resistance of "narrow noses" are the most frequent cause of unnecessary nasal surgery. The sensation of nasal obstruction follows a logarithmic scale (law of Weber-Fechner). This concerns the cooling effect of the mucosal surface as well as the feeling of effort needed for breathing.

Generally, 15 to 30 minutes are required for acclimatizing the patient to the indoor climate, before starting nasal patency assessments.[3,4] Also, various emotional stimuli may interfere with measurement outcome and should be avoided.[4] Finally, there is no definite data in the literature on whether patients with nasal obstruction should clean mucus from their nose before the objective assessment of nasal patency. A current task force on nasal allergen challenge/

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nasal provocation testing in allergic rhinitis by the European Academy of Allergy and Clinical Immunology (EAACI) concurred that patients should blow their nose before examination if necessary. Nasal suction could cause mechanical, iatrogenic irritation of the nasal mucosa, and should hence be avoided.

Measuring nasal airflow may serve medicolegal reasons or diagnostic purposes such as nasal allergen challenge testing. However, the measurements may not reflect the clinical results or patients' symptoms. It was thus the aim of this article to present comprehensive literature review to provide an overview of the currently available devices and to give recommendations for the use in clinical settings.

Methods

A systematic review of the literature was performed in PubMed and Web of Science databases, using the following keywords: "Nasal patency" and "measurement" or "outcomes." The search was limited to trials in human species and publication dates of the last 12 years (2004–2016). The search was performed in German and English.

Manual selection of the 250 retrieved studies identified the relevant publications. Studies were considered relevant if a clinical patency test or objective measurement were part of the outcome.

The German guidelines for functional septorhinoplasty were also considered in the present article.[5] Further information was gained from manufacturer manuals of the introduced scientific instruments.

Results

Overview of the Various Methods to Assess Nasal Patency

Active Anterior Rhinomanometry

Active anterior rhinomanometry measures the transnasal pressure differences or pressure drops (Pa) and the resulting values of airflow (cm^3/s) during respiration for each nostril separately. The characteristic of these variables is nonlinear and depicted in a typically curved graph (►**Fig. 1**) that comprises an entire breathing cycle. Clinical decisions are traditionally based on the consideration of the flow at a pressure difference of 150 Pa. The total resistance ($Pa/cm^3/s$) of each nasal cavity is defined by the quotient of the driving pressure difference and the resulting airflow. Thus, the total nasal resistance varies according to the characteristics of the values pressure drop and airflow during inspiration and expiration. Consequently, comparison of noses' resistances requires information about the respective flow.

In their meta-analysis, Merkle et al presented reference intervals (RIs) for nasal airflow resistance with respect to different conditions (e.g., gender, ethnicity, age). In total, they found a value of 0.25 $Pa/cm^3/s$ (95% RI: 0.10–0.40 $Pa/cm^3/s$).[6]

Active anterior rhinomanometry is a sensitive, highly specific method that is currently accepted as an international standard method for nasal patency measurement.[7–10]

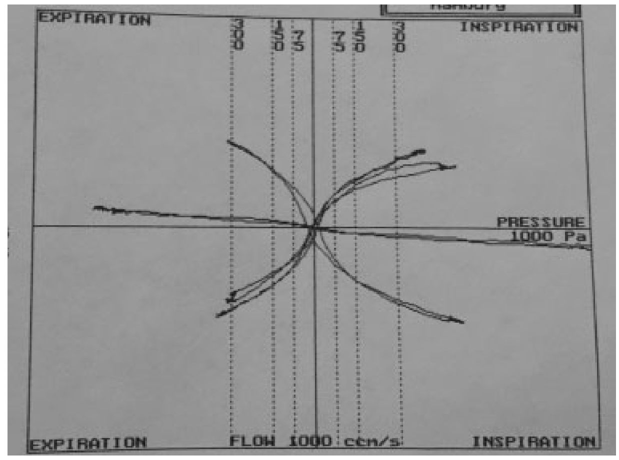

Fig. 1 Active anterior rhinomanometry before and after decongestion with xylomethazoline.

This relatively easy[9] method correlates with symptom scores.[11] The chance of correlation between subjective and objective measurement is greater when nasal passages are measured separately.[12] Using a full-scale or anesthesia mask prevents distortion of soft facial tissue.

Although rhinomanometry is a well-established method, the device is rather expensive and requires both patients' cooperation and experienced investigators.[13,14] Formerly, it also had the disadvantage of not being easily transportable.[9] In several conditions, it is impossible to perform active anterior rhinomanometry (AAR) measurements, for instance with one completely obstructed nostril, a perforated septum, or intense rhinorrhea.[9] Moreover, it interferes with the nasal cycle under certain conditions using decongestants. Correlations of AAR values to subjective measurements for nasal congestion are not always significant.[9] In fact, it was recently shown that rhinomanometry measurements do not correlate with subjective outcome measures in special conditions, such as septoplasty or radiofrequency ablation of the inferior turbinate.[15,16] Depending on the measurement protocol used, the method is prone to errors in retesting,[17] revealing a low test–retest reliability. In their study from 2000, Carney et al. state that a coefficient of variation $< 15\%$ is acceptable, as lower values can hardly be reached in unilateral testing.[18] Also, a negative test outcome of the method does not exclude a functionally relevant nasal stenosis.[19]

Peak Nasal Inspiratory Flow

The peak nasal inspiratory flow (PNIF, ►**Fig. 2**) has been proposed as a noninvasive method that measures nasal airflow during maximal forced nasal inspiration. Usual peak flow meters can be attached to an anesthesia mask that is applied over the nose with holding the mouth closed. The position of the body while measuring has an important influence on the outcome in peak nasal expiratory flow but not in PNIF. In peak nasal expiratory flow (PNEF), an upright position significantly increases the flow compared with a seated position. In PNIF, a tendency to a higher flow is observed.[20] Measurements in an upright position for both modalities are recommended.[21]

Fig. 2 Peak nasal flow meter (Reprinted with permission from Clement Clarke International, Essex United Kingdom, available at: http://www.clement-clarke.com; http://www.peakflow.com.).

Peak nasal inspiratory flow is a rapid, reliable, and reproducible method that is inexpensive, portable, and easy to handle.[9,13,22,23] It does not need complex trained personnel[13,14] and correlates well with subjective symptoms[10,22,24,25] as well as with rhinomanometry.[13,26,27] PNIF is said to be the best-validated technique for evaluating nasal flow through the nose[10] and should be available in every practice.[21]

Ottaviano et al point out that normal values are difficult to define since they are always as representative as the related group of volunteers. For the cohort used in his study in 2006, he investigated normal values taking variables of height, age, and gender into account.[28] Starling-Schwanz et al have found a normal value of 115 L/min,[29] which is comparable to the normal values Teixeira et al found comparing normal values with those in allergic rhinitis patients. They showed a range in airflow between 114 and 154.31 L/min.[22] Normal values also exist for children.[30,31]

A difference of 20 L/min has been shown to be the minimum clinically important difference.[32] This is an important value given the high intra- and inter-individual variability of PNIF results.

Peak nasal inspiratory flow is strongly dependent on pulmonary/lower airway function and also relies on patients' cooperation.[9,33] Its dependence on lung capacity[34] has enormous effects on reproducibility.[35] It has been shown that there is a significant correlation between peak flow (lung function) and peak nasal flow.[9,36] The idea of calculating differences between peak flow and peak nasal flow came up with Kirtsreesakul et al who investigated the ratio between both methods to assess nasal patency.[37] Further, Bermüller et al concluded that a negative test outcome of this method does not exclude a functionally relevant nasal stenosis.[19]

Blomgren et al reported that PNIF results of some volunteers measuring nasal patency daily at the same hours varied over 50% and therefore PNIF cannot be seen as a reliable technique.[35] Moreover, there are turbulences with maximal inspiration due to nasal valve collapse (Bernoulli's effect).[9] An interference of nasal valve in forced inspiration would lead to distorted results. Barnes et al investigated the effect of two different kinds of stents on nasal valve collapse during PNIF where repeatability improved marginally compared with PNIF without stents.[38]

Peak nasal inspiratory flow has been shown to be comparative to rhinomanometry[13,26,27,39] but was less exact than active anterior rhinomanometry.[23] The low reproducibility and high variability are shortcomings of this technique. Peak nasal inspiratory flow was strongly recommended to objectify nasal congestion; however, the quantification of nasal obstruction is weak with a moderate quality of evidence.[40]

It has been observed that there is a significant correlation between peak nasal expiratory flow (PNEF, lung function) and PNIF.[9,36] The idea of calculating differences between peak flow and peak nasal flow comes from Kirtsreesakul et al who investigated the ratio between both methods to assess nasal patency.[37]

Differences between first and second PNIF recordings show the effect of learning.[28] Therefore, we recommend to perform three measurements in a row and to execute a test run with specific instructions. The best results from three consecutive measurements counts.

Peak nasal inspiratory flow measures bilateral nasal flow simultaneously.[9,39,41] This disadvantage could be avoided easily by occluding one nostril, for example, with a band-aid strip. This has not been validated.[40]

Several studies observed that PNIF correlates well with subjective symptoms.[10,22,24,25,42–44] On the other hand, there are also studies pointing out the miscorrelation between PNIF and subjective symptoms.[27,29,45–48] Martins de Oliveira et al explain this matter with complex subjective perceptions and possible over- or underestimation of the patient. They often do not have a comparative standard for their chronic symptoms.[48] Asthma and allergic rhinitis are manifestations that often occur conjointly[49] and make it difficult to evaluate low PNIF results.

Measuring PNEF and PNIF together would lead to a more precise assessment of airflow eliminating the factor of lung capacity.[50] PNEF would also solve the problem of alar collapse in deep inspiration, and it even has a good correlation with PNIF,[48] but it is harder to measure due to the drawback of potential contamination by secretions[35,36,51] and air leakage.[35]

Barnes et al reported that the use of nasal stents or sinus cones could improve PNIF values significantly and therefore be a possible solution for the problem of alar collapses in forceful inhalations.[38]

Bermüller et al investigated that PNIF and AAR do not differ significantly and are both helpful in diagnosing nasal deformities, but approximately 25% of patients with an obstructed nose remain undetected by PNIF and rhinomanometry.[19]

Four-Phase Rhinomanometry

Four-phase rhinomanometry (4PR, ►Fig. 3), earlier known as high-resolution rhinomanometry, was first introduced by Vogt and Hoffrichter in 1994. The introduction of the four breathing phases (ascending and descending curve part in inspiration and expiration) led to the development of 4PR. The differences between classic rhinomanometry and 4PR originate from the data acquisition process. Classic computerized rhinomanometers collect alternative values for flow and pressure and place the obtained data points in an x-y-Cartesian system. 4PR separately and visually controls the uptake of the flow and pressure data. Then, a representative

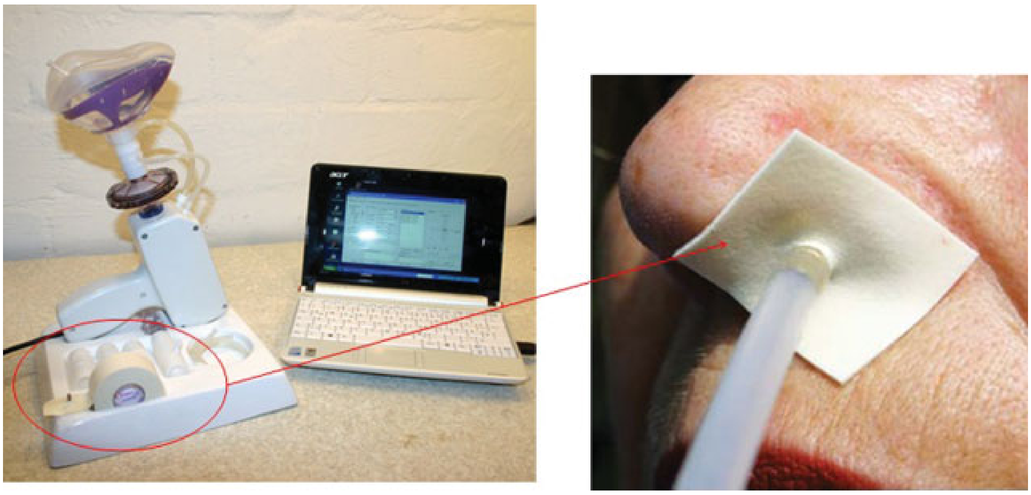

Fig. 3 Careful occlusion of one nostril without distortion of the septum and nasal valve area with 4-phase rhinometry.

breath is constructed as a real-time procedure. Two additional new parameters were also introduced in 4PR: Vertex resistance, which is the resistance at the point of maximum flow during inspiration or expiration in a normal breath; and effective resistance, which is equivalent to the average of all the resistances during either inspiratory flow, expiratory flow, or the entire breath.[52,53] The advantages of 4PR as described by Vogt et al.[52] include the acquisition of better diagnostic information due to the representation of the entire work of breathing. Moreover, the better correlation of the logarithmic transformation of resistance values with the subjective feeling of obstruction in the visual analog scale (VAS) and the consideration of valve problems and Bernoulli's effect in breathing have been discussed.[54]

However, Wong et al concluded that there is a high degree of conformity between resistances measured by the classic rhinomanometry and 4PR. Thus, applying the principle of "lex parsimoniae," which implies that the simpler the method or hypothesis, the better, the complexity of 4PR does not provide any benefit over the simpler standard measurements.[55] A newer version of the 4PR hardware and software has made it easily accessible, and the handling is akin to the AAR. The occlusion of one nostril by tape makes it a better representation of natural structures.

Acoustic Rhinometry

The fundamentals of acoustic rhinometry (►**Figs. 4** and **5**) were developed in 1977 by Jackson et al.[56] Acoustic

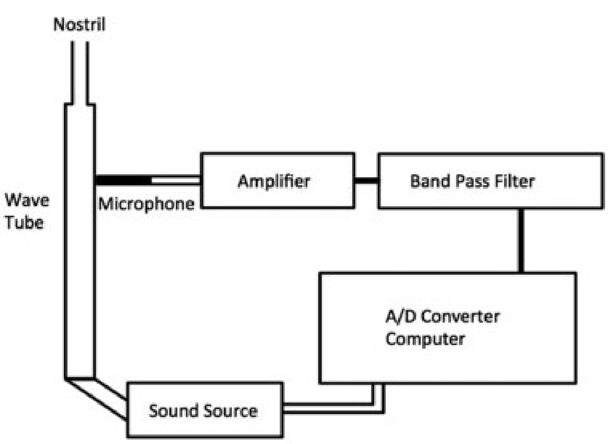

Fig. 4 Apparatus for acoustic reflections measurements. The apparatus includes (**A**) a computer with an analog-to-digital converter for data acquisition and processing; (**B**) a module, which produces the sound waves; (**C**) a wave tube, which is connected to nasal cavity; (**D**) a microphone; (**E**) an amplifier; and (**F**) a band pass filter.

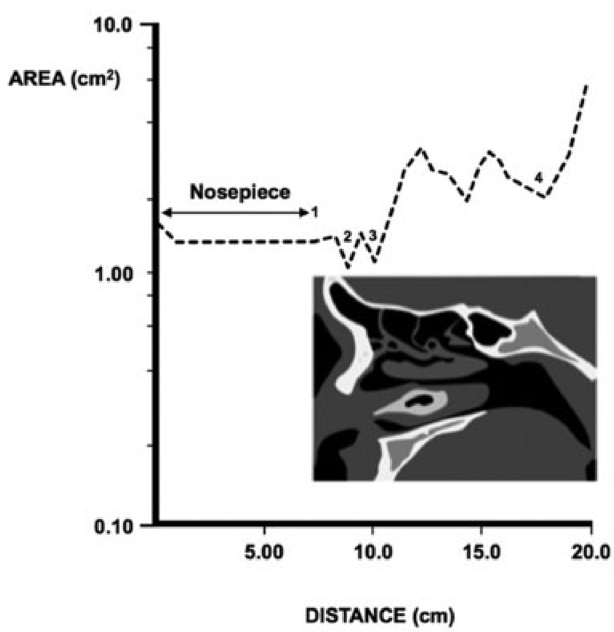

Fig. 5 Diagram of model and area–distance function obtained by acoustic reflection. y-axis: logarithm of cross-sectional area in cm^2; x-axis: distance in cm; (**1**) nostril; (**2**) minimal cross-sectional area—nasal valve; (**3**) head of inferior turbinate; and (**4**) posterior end of the nasal cavity.

resistance of a segment of a cavity is related to the segment's cross-sectional area. Changes of the cross-sectional area will therefore, cause a reflection of an incident sound wave delivered into a cavity. The main and necessary simplification is that the cavity is considered a round tube without frictional sound losses. Acoustic pulse response measurements were established by Hilberg et al in 1989 as a means of measuring the geometry of the nasal cavity (►**Fig. 1**).[57] Acoustic rhinometry allows measurements of cross-sectional areas of the nasal cavity as a function of distance from the nozzle (►**Fig. 2**).[57–59] The distance from the nozzle is calculated by the running time of the incident and reflected sound waves. Derived parameters include nasal cavity volume, MCA, and cross-sectional area at the nasal isthmus and the anterior end of the inferior nasal turbinate. Acoustic rhinometry was standardized in 2005 by the Standardization Committee on Objective Assessment of the Nasal Airway of the European Rhinology Society.[60]

Acoustic rhinometry is most accurate at the anterior portion of the nasal cavity from the nostril to the anterior end of the inferior turbinate. This region covers the most resistive segment of the nasal cavity.[61] Septal perforation influences the results of acoustic rhinometry. Mishima et al studied this effect before and after closing a septal perforation by thin cotton patches. The authors reported a decrease in cross-sectional areas and volumes after closure.[62] Acoustic rhinometry is less time consuming compared to active anterior rhinomanometry. It is noninvasive, easy to perform, and requires relatively little patient cooperation.[9,24,63] This makes it suitable to assess children,[64–66] also in preschool age.[67] The method requires no airflow through the nose and can be performed in patients with congested nasal airways.[63] Acoustic rhinometry values are supposed to be less variable than active anterior rhinometry values.[68] However, several authors reported that subjective obstruction correlates better with resistance or airflow than with anatomic structures of the nasal cavity.[40,69,70] Also, acoustic rhinometry is not suitable for home monitoring.[71] Furthermore, an operator and expensive equipment are required for this procedure.

Acoustic rhinometry has been used for nasal allergen provocation tests. Kim et al reported that VAS and acoustic rhinometry in nasal provocation tests could be a valuable tool in diagnosing allergic rhinitis with high sensitivity and specificity. They proposed a series of diagnostic criteria (more than 24.5% change of total nasal volume and more than 20% of MCA after nasal allergen provocation) to diagnose allergic rhinitis.[72] The Spanish Society of Allergy and Clinical Immunology Rhinoconjunctivitis Committee suggested likewise.[23] They recommended that nasal provocation should be considered positive if one of the following symptom scores increased by three or more points and acoustic rhinometry reveals a 10% or more reduction in MCA, nasal cavity volume between 2 and 6 cm from the nostril or both.[73,74] Ganslmayer et al investigated the nasal response to allergen provocation with cross-sectional changes of the nasal mucosa measured with acoustic rhinometry. After allergen challenge, mean deviation of MCA in nonatopics was $-0.4 \pm 14.3\%$, compared with baseline. This allowed the determination of a threshold of -29% of MCA. All but one of the 30 atopic patients reached this threshold.[24] In a review, Uzzaman et al reported that with acoustic rhinometry, the cross-sectional area at the anterior end of the inferior turbinate is most sensitive in monitoring the response to nasal allergen provocation.[75] Also, bilateral nasal provocation and the summation of right and left cross-sectional area at the anterior end of the inferior turbinate have been shown to be more sensitive and specific than unilateral measurements of the more obstructed nasal cavity.[75,76] Kim et al. observed that only the amplitude of the nasal cycle is influenced after allergen provocation, whereas the overall duration and reciprocity of the nasal cycle remain unchanged.[77]

On the other hand, Keck et al observed that active anterior rhinomanometry is superior to acoustic rhinometry in the diagnosis of perennial allergic rhinitis. The authors investigated 30 patients and reported that there was no significant decrease in MCA1 and MCA2 after allergen provocation with house dust mite. In active anterior rhinomanometry, the median flow on the tested side before allergen provocation was 243 cm^3/s and after the provocation, it was 136 cm^3/s (range: 129–472 cm^3/s), which was a significant flow decrease. Likewise, a significant flow decrease was observed on the nontested side.[78]

Rhinostereometry

Rhinostereometry was developed by Juto and Lundberg in 1982 to detect changes in nasal mucosa swelling.[79] This method is based on an optical system whereby the optical axis and a narrow plane of focus are used to establish a three-dimensional coordinate system. A surgical microscope is used. The patient is exactly and reproducibly attached to the microscope by an individually adapted tooth splint. The nasal cavity is viewed through the microscope. The position of the nasal mucosa surface in the plane of focus is determined by the calculation of the distance between the mucosal surface and the optical axis.[79]

Rhinoresistometry

The unilateral measurement of inspiratory nasal resistance at a flow velocity of 250 cm^3/s can differentiate between patients with symptom-free septal deviation (so termed, patients with physiological endonasal resistance ≤ 0.35 $Pa/cm^3/s$)—classified as having a physiological septal deviation—and those with increased resistances > 0.35 $Pa/cm^3/s$ as suffering from a pathological and symptom-causing septal deviation.[80] This potential tool to assess nasal airflow resistance has, however, no clinical significance and is questionably superior to symptom-assessment by VAS or simple history taking.

Optical Rhinometry

This method assesses mucosal edema by changes of blood flow and light absorption. Light crosses the nasal tissue, and more light will be absorbed by increased blood flow due to the light absorbing character of hemoglobin.[81] Optical rhinometry has been shown to be able to assess changes in nasal patency comparable to acoustic rhinometry and subjective scores,[82] as well as compared to active anterior rhinomanometry.[83] All patients can be assessed because it is also possible to evaluate patients with polyps or septal perforation. This method is more comfortable since patients can breathe normally and no mask has to be fitted to the face. Some studies support the use of optical rhinometry in allergen provocation challenges.[84,85] Specifically, Luong et al reported that this method can assess changes in nasal patency during challenges with histamine.[85] Also, Krzych-Fałta et al performed optical rhinometry in 30 patients with allergic rhinitis and 30 healthy subjects. They reported that the level of light extinction in patients with allergic rhinitis returned to baseline after 28.15 minutes. These objective changes were strongly correlated with subjective VAS scores.[84]

Glatzel Mirror

The so-called Glatzel-mirror is named after his inventor Ernst Glatzel, who first published this method of assessing nasal ventilation in 1905.[86] A cold steel plate is placed under both nostrils, and the amount of steam condensing on the plate is assessed and noted at the maximum extension in millimeters. The method of rhinohygrometry was further developed in 1925 by Zwaardemaker and in 1938 by Jochims who suggested fixing the steam with a rubber and ink coating of the steel plate.[87] Nevertheless, this is the easiest, fastest, and cheapest method to date to assess nasal patency. It is ideal, for example, to help diagnose choanal atresia in a newborn. However, it does not correlate well with patients' symptoms and does not take the nasal cycle or mucosal swelling into consideration.

Endoscopy-Minimal Cross-Sectional Area

Lang et al have investigated another method of calculating MCA by calculating MCA from digitalized images recorded by nasal endoscopy. Results appeared to be poorly correlated to VAS scale of nasal breathing and acoustic rhinometry. This two-dimensional measurement cannot be correctly transformed to a three-dimensional anatomy. The authors consider that it is unlikely that this method will be in use anytime soon.[88]

Nasal Sound Spectral Analysis and Magnetic Resonance Imaging

Nasal sound spectral analysis (NSSA) is another method for the evaluation of nasal obstruction.[89–91] This method, developed by Seren,[91] converts the frequency of sound generated by nasal airflow within a cross-sectional area with the help of a microphone by spontaneous breathing through one nose, while the other nostril is occluded.[89] Choi et al. concluded that combined PNIF and NSSA could be used for assessment of nasal obstruction in allergic rhinitis as they provide clinical relevance by allowing a fair degree of reliability. Furthermore, such combined testing can be performed as a surrogate for rhinomanometry.[92]

Leaker et al determined that inflammatory changes following nasal allergen challenges can be quantified by MRI and thus provide an objective measure of the response to nasal allergen challenge. Limitations include costs, imaging time, and the potential stress of patients, for example, suffering from claustrophobia.[93] This applies to the perioperative setting too.

More experimental methods try to calculate nasal airflow from CT scans. Hildebrandt et al reported that numerical flow simulation has the potential to analyze the nasal airstream of an individual patient using CT scans of the nose and paranasal sinuses. Specifically, detailed information about the nasal flow, such as pressure and velocity in specific areas of the nasal cavity in different phases of the inspiration and expiration can be calculated.[94]

Guidelines and Recommendations

The guidelines for functional (septo-) rhinoplasty recommend the following objective measurements to be performed before rhinosurgery:

- active anterior rhinomanometry (pre- and postdecongestion of the nasal mucosa with α-mimetic drops to exclude the nasal cycle)
- Rhinoresistometry (pre- and postdecongestion)
- 4PR
- Acoustic rhinometry (pre- and postdecongestion)

The guidelines for functional testing of allergic rhinitis suggest performing:

- PNIF (Food and Drug Administration recommendation)[95]
- Acoustic rhinometry or active anterior rhinomanometry (Spanish recommendation)[23,96]
- AAR (German recommendation)[5]

Discussion

Various technical methods to assess and objectify nasal airflow and ventilation have been developed. Many are laborious or costly, and often do not represent patients' subjective symptoms. It is thus a key necessity to evaluate and even predict nasal ventilation—especially when planning rhinosurgery.

There are local and political customs having led to asserting different assessments of nasal patency among the nations. The technical possibilities also vary regarding commercial possibilities. ►**Table 1** sums up the advantages and disadvantages of the various available technical measurements of nasal patency and airflow.

PNIF is the easiest and cheapest method to measure nasal airflow, but it is strongly dependent on patients' collaboration and lung function. Thus intermeasurement variations can be significant, and a measurement depicts only a momentary inspiration or expiration.

Acoustic rhinometry is quick and easy to perform, without the need of patient collaboration. It was standardized in 2011 by the Standardization Committee on Objective Assessment of the Nasal Airway of the European Academy of Allergy and Clinical Immunology (EAACI).[9] However, the equipment is expensive, and the correlation to subjective symptoms has been shown to be weak.

Active anterior rhinometry is a sensitive, highly specific method, and currently accepted as an international standard method for objective nasal patency measurements. However, it is prone to errors and requires an experienced examiner and patients' collaboration.

Table 1 Devices for objective measurement of nasal ventilation

Device	Advantages	Disadvantages
AAR	• Sensitive, highly specific method • Currently accepted as international standard method for objective nasal patency measurement	• Expensive • Requires both patients' cooperation and experienced investigators • Prone to errors (poor test-retest reliability)
4PR	• Acquisition of better diagnostic information due to representation of entire work of breathing • The better correlation of the logarithmic transformation of the resistance values with subjective feeling of obstruction in the VAS • Consideration of nasal valve	• Small benefit over the simpler classic AAR • Conduction akin to AAR • Expensive
PNIF and PNEF	• Relatively cheap • Easy, rapid • Upright standing position • Reliable and reproducible • Best validated technique	• Varying normative values • Low reproducibility • High variability (3 consecutive measures recommended) • Measures bilateral nasal flow simultaneously • Dependent on collaboration of patient and lung function
Acoustic rhinometry	• Standardized in 2005 by the Standardization Committee on Objective Assessment of the Nasal Airway of the European Academy of Allergy and Clinical Immunology (EAACI).[9] • Most accurate at the anterior portion of the nasal cavity from the nostril to the anterior end of the inferior turbinate • Quicker than AAR • Easy to perform • No patient cooperation required • Good for children • More stable values	• Not possible in septal perforation • Subjective obstruction correlates better with resistance or airflow than with anatomic structures of the nasal cavity • Expensive
Rhinostereometry	• Detect changes in nasal mucosa swelling	• Surgical microscope and equipment to attach patient are needed • Poor validation
Optical rhinometry	• Assesses changes in nasal patency • Comfortable	• Not yet standardized
Endoscopy-MCA	• Time consuming • Digitalized images recorded by nasal endoscopy needed	• Poor validation • Poor correlation to nasal breathing in VAS
NSSA	• Uses microphone to assess obstruction	• Requires combined evaluation with PNIF data
MRI	• Assessment of mucosal swelling	• Expensive • Time consuming • Possible exclusion of patients due to claustrophobia
CT and CFD	• Simulation and calculation of air flow and turbulences	• Radiation (CT) • Obligatory software • Expertise in calculating needed

Abbreviations: 4PR, four-phase rhinomanometry; AAR, active anterior rhinomanometry; CFD, computational fluid dynamics; CT, computed tomography; MCA, minimal cross-sectional area; MRI, magnetic resonance imaging; NSSA, nasal sound spectral analysis; PNEF, peak nasal expiratory flow; PNIF, peak nasal inspiratory flow; VAS, visual analog scale.

Overall, it has to be considered that nasal patency is very difficult to assess objectively, so a VAS of patient symptoms should be added to the pre- and postoperative routine along with the objective assessment of nasal patency. The severity of symptom rating still seems to be best assessed with self-assessment by a VAS (0 mm no symptoms, 100 mm maximum symptoms)—without the possibility to predict surgical outcomes, but to document the burden of nasal ventilation.

Future investigations will demonstrate which method is the most feasible in daily clinical practice.

Conclusion

There is a variety of technical equipment to assess nasal ventilation. However, it seems questionable to find a device that reliably depicts subjective symptoms. The international standard of AAR seems feasible, and PNIF is cheap and easy and ubiquitously accessible. 4PR is reported to be the most reliable method to assess nasal valve function.[97]

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