A functional tool to differentiate nasal valve collapse from other causes of nasal obstruction: the FRIED test

Ramzi Maalouf,1,2,3,4* Emilie Bequignon,1,2,3,4* Marie Devars du Mayne,4 Françoise Zerah-Lancner,1,2,3,5 Daniel Isabey,1,2,3 André Coste,1,2,3,4 Bruno Louis,1,2,3 and Jean-François Papon1,2,3,6,7

1Institut National de la Santé et de la Recherche Médicale, U955, Créteil, France; 2Université Paris-Est, Faculté de Médecine, Créteil, France; 3Centre National de la Recherche Scientifique, ERL 7240, Créteil, France; 4Assistance publique-Hôpitaux de Paris, Hôpital Henri-Mondor–A-Chenevier et Hôpital intercommunal, service d’ORL et de chirurgie cervico-faciale, Créteil, France; 5Assistance publique-Hôpitaux de Paris, Hôpital Henri-Mondor–A-Chenevier, service de physiologie et d’explorations fonctionnelles, Créteil, France; 6Assistance publique-Hôpitaux de Paris, Hôpital Bicêtre, service d’ORL et de chirurgie cervico-faciale, Le Kremlin-Bicêtre, France; and 7Université Paris-Sud, Faculté de Médecine, Le Kremlin-Bicêtre, France

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Maalouf R, Bequignon E, Devars du Mayne M, Zerah-Lancner F, Isabey D, Coste A, Louis B, Papon JF. A functional tool to differentiate nasal valve collapse from other causes of nasal obstruction: the FRIED test. J Appl Physiol 121: 343–347, 2016. First published June 9, 2016; doi:10.1152/japplphysiol.00779.2015.—Nasal valve collapse is a dynamic abnormality that is currently diagnosed purely on the basis of clinical features and thus subject to certain interpretation. The aim of this study was to develop a new and reliable functional test to objectively characterize nasal valve collapse. This was an observational prospective study including consecutive patients referred to our center for exploration of chronic nasal congestion. The patients were classified into two groups according to their symptoms and clinical abnormalities: the nasal valve collapse (NV+) group when nasal valve collapse was clinically detected during moderate forced inspiration and/or when the feeling of nasal congestion improved during passive lateral cartilage abduction (n = 32); and the no-nasal valve collapse (NV−) group for the others (n = 23). All patients underwent nasal functional tests (posterior rhinomanometry and acoustic rhinometry) before and after topical nasal decongestion. We compared the difference between the pressure flow of the inspiratory and expiratory phases during posterior rhinomanometry [flow rate inspiratory-expiratory difference (FRIED) test] between the two groups. The difference between the absolute value of inspiratory and expiratory flow was significantly higher in the NV+ group than in the NV− group both before and after topical decongestion. The cutoff value for the FRIED test was −0.008 l/s with a good sensitivity (82%) and a specificity of 59%. We suggest that the FRIED test constitutes an objective and easy-to-apply technique to diagnose nasal valve collapse in daily practice.

CHRONIC NASAL CONGESTION is a common issue that affects up to 15% of the population in developed countries (1). It can arise from various conditions such as chronic rhinitis or rhinosinusitis, and nasal bone or cartilage deformations. For the clinician, confirming nasal congestion remains a challenge because it is a subjective feeling that is not always in accordance with nasal clinical examination or functional testing. Another problem is to characterize the origin of the obstruction so as to administer appropriate treatment. Septal deviation, turbinate hypertrophy, chronic rhinosinusitis, and even tumors are relatively easy to diagnose by rhinoscopy, endoscopy, imaging, and nasal functional tests such as rhinomanometry and acoustic rhinometry. Nevertheless, the diagnosis of nasal valve collapse, a dynamic abnormality that can also be a cause of nasal congestion, relies on clinical features alone and is subject to certain interpretation.

The nasal valve is the first narrowing of the nasal airway that represents the main site of nasal resistance to airflow (3). Anatomically, it includes various joined and juxtaposed segments: the external valve between the lateral inferior cartilage and anterior rim of the nasal septum, and the internal valve between the lateral superior cartilage and nasal septum (4, 15). To detect a valve dysfunction leading to nasal congestion, the clinician may inspect the shape of the nose, apply the Cottle and Brackman maneuvers, and observe nasal valve collapse during moderate inspiration (2). However, to date, no objective gold standard is available to evaluate nasal valve collapse. In this study, we set out to develop a new and reliable functional test to objectively characterize nasal valve collapse in patients complaining of nasal congestion.

METHODS

Patients and Study Design

We conducted a 3-mo, open, prospective longitudinal study in consecutive adult (≥18 yr) patients who were referred to our Ear, Nose, and Throat Department for exploration of chronic nasal congestion. Patients with chronic sinusitis, nasal polyps, and nasal tumors were excluded from the study on the basis of nasal endoscopy and computed tomography scan. All data were collected during routine clinical care of our patients with no additional intervention. Formal ethics approval was not required according to the Declaration of Helsinki. The data were anonymized and processed in compliance with the French Information Technology and Privacy Law. All patients were provided with full information about the study in writing.
Septal deviation, atopy, tobacco use, and atopy. The nasal clinical examination included the research purposes.

For each patient, we recorded age, sex, body mass index (BMI), and gave their written informed consent for the use of their data for research purposes.

**Clinical Evaluation**

For each patient, we recorded age, sex, body mass index (BMI), tobacco use, and atopy. The nasal clinical examination included the following: 1) inspection of the external shape of the nose and rhinoscopy (paying special attention to the nasal cartilages and the isthmus); 2) dynamic nasal valve evaluation [lateral cartilage collapse during moderate forced inspiration, modification of nasal respiration sensation when passive abduction is applied to the nasal valve cartilages (using a thin cotton swab)]; 3) flexible nasal endoscopy. For each patient we recorded the presence or absence of septal deviation, inferior turbinate hypertrophy, nasal valve collapse during moderate forced inspiration, and any modification of nasal respiration sensation on application of passive abduction to the nasal valve cartilages.

Patients were diagnosed with nasal valve collapse if there was presence of nasal valve collapse during moderate forced inspiration and/or improvement of nasal respiration sensation when passive abduction was applied to the nasal valve cartilages. These patients formed the nasal valve collapse (NV+) group. Patients in whom no nasal valve collapse was observed and for whom no improvement during nasal cartilage support was detected formed the no-nasal valve collapse (NV−) group.

**Nasal Explorations**

After the clinical examination, nasal patency was measured by posterior rhinomanometry and acoustic rhinometry. Nasal obstruction was also evaluated by a visual analog scale (VAS) scoring from 0 (no obstruction) to 10 (total obstruction).

Each subject was evaluated in a comfortable upright seated position before and after topical nasal mucosa decongestion as previously recommended (0.05% oxymetazoline, 2 sprays of 50 μg each nostril; repeated after 5 min with a single spray; measurements obtained at 15 min) (7). All measurements with rhinomanometry and acoustic rhinometry were performed by a single experienced person while data analysis was performed by another person (physicist) blinded to the diagnosis.

Both uninasal and binasal resistances were determined for each patient by posterior rhinomanometry according to international recommendations (6, 8). For the unilateral measurements, the contralateral nostril was tightly closed using surgical tape. A differential pressure transducer (Validyne MP 45, Northridge, CA; ±2 cm H2O) connected to a catheter inserted through a hole drilled into a stopcock obstructing the cylindrical part of a modified mouthpiece and connected to nasal face mask fitted with a Fleisch no. 1 pneumotachograph (Lausanne, Switzerland) was used to measure transnasal pressure and flow during breathing. Nasal resistance was defined as the ratio between transnasal pressure and flow when the transnasal pressure reached 100 Pa.

The flow rate inspiratory-expiratory difference (FRIED) test consisted of establishing a score (FRIED score) evaluating the difference in pressure-flow relationship between inspiratory and expiratory phases using the pressure-flow curve of the rhinomanometry during uninal measurement. The difference between the absolute value of inspiratory and expiratory flow was calculated (see Appendix I) at the maximum common absolute value of pressure (P_{max}) recorded during rhinomanometry and 2) at a single pressure value of 100 Pa (P100).

Longitudinal area profiles of the nasal cavity, A(x), were determined for each patient by the two-microphone acoustic reflection method (13, 14). The setup used was derived from a device provided by Benson Hood Laboratories (Pembroke, MA) consisting of two microphones and a horn driver mounted on a homemade wave tube (inner diameter 12 mm, overall length 220 mm). Nasal compliance was estimated as previously described (5, 10, 12) from the measurements of A(x) when different steady pressures were applied to the distal end of the wave tube connected to the nostril, i.e., atmospheric pressure (P_{atm}), P_{atm} – 2, P_{atm} – 4, P_{atm} – 6, P_{atm} – 8, and P_{atm} – 10 cm H2O. Compliance per unit length was defined as the ratio between the variation of area [ΔA(x)] and the variation of steady pressure (ΔP) applied to the nasal cavity. Compliance was computed as the slope of the line [ΔA(x) = C(x)ΔP, where C is the compliance]. To facilitate interpretation of compliance and area, we divided the nasal cavity into three distinct physiological segments, as previously described by our group: the valve segment, the inferior turbinate segment, and the middle meatus segment (5, 10, 16).

**Statistical Analysis**

Comparison of the NV+ and NV− groups was performed with a statistical software package (Statistica v7.1; Stat Soft, France) using a nonparametric test (Mann-Whitney U-test) and the chi-square test for the qualitative variables. To compare the rhinomanometry and acoustic rhinometry results from the two groups, data from nostrils without nasal valve collapse in the NV+ group (unilateral nasal valve collapse) were excluded (i.e., only the data from the sides with nasal valve collapse were selected in the NV+ group). A P value <0.05 was considered significant. The estimated sensitivity and specificity for the diagnosis of nasal valve collapse of each parameter that was found significantly different between NV+ and NV− groups were evaluated using the receiver operator characteristics (ROC) curve. The optimal cutoff value for the FRIED test was determined with the Youden’s index on the ROC curve as the best value for both sensitivity and specificity.

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![Fig. 1. Visual analogic scale (VAS) evaluation of nasal congestion, from 0 (no congestion) to 10 (total congestion), by the patients with (NV+) and without (NV−) nasal valve collapse. Results are plotted as means ± SE (error bars). Variation due to nasal decongestion is computed for each patient as the value before minus after decongestion.](http://jap.physiology.org/)
RESULTS

Study Population

Fifty-five patients presenting for exploration of chronic nasal congestion were enrolled. Patients were clinically considered as either having valve collapse (NV+, group, n = 32) or not (NV−, group, n = 23). General and nasal clinical characteristics of the patients in each group are reported in Table 1.

In the NV+ group, we identified 19 patients with bilateral nasal valve collapse (i.e., 38 nostrils) and 13 with unilateral nasal valve collapse (i.e., 13 nostrils).

Nasal obstruction evaluation with VAS. The VAS score was significantly higher in the NV+ group than in the NV− group, both before and after topical decongestion (Fig. 1).

Rhinomanometry. Unilateral nasal resistance was not different between the NV+ and NV− groups before topical decongestion, but was significantly higher in the NV+ group than in the NV− group after topical decongestion (Fig. 2).

FRIED test. The difference between the absolute value of inspiratory and expiratory flow at Pmcav was significantly higher in the NV+ group than in the NV− group, both before and after topical decongestion (Fig. 3). The cutoff value of the FRIED score at Pmcav, determined with Youden’s index, was −0.008 l/s with a sensitivity of 82% and a specificity of 59% for the FRIED test (Fig. 4). This Youden’s index was the best compared with the Youden’s index obtained for other parameters significantly different between NV+ and NV− groups [i.e., unilateral resistance after topical decongestion, minimal cross-sectional area (MCA) after topical decongestion, and nasal valve segment compliance after topical decongestion].

The difference between the absolute value of inspiratory and expiratory flow at P100 was significantly higher in the NV+ group than in the NV− group, both before and after topical decongestion (Fig. 3). The cutoff value of the FRIED score determined at P100 was −0.009 l/s with a sensitivity of 71% and a specificity of 70% for the FRIED test (Fig. 4). Nevertheless, in this latter case, two patients were excluded from the analysis because they were unable to reach P100 at the expiration during spontaneous quiet breathing.

Acoustic rhinometry. The MCA was not different between the NV+ and NV− groups before topical decongestion, but was significantly higher in the NV− group than in the NV+ group after topical decongestion (Fig. 5). Nasal compliance was not different between the two groups, except in the nasal...
Fig. 6. Compliance of the three nasal segments (the valve segment, the inferior turbinate segment, and the middle meatus segment) before and after nasal decongestion in patients with (NV+) and without (NV−) nasal valve collapse. Results are plotted as means ± SE (error bars).

valve segment before topical decongestion, where the compliance was higher in the NV− group (Fig. 6).

DISCUSSION

We present here an objective and easy-to-use tool, the FRIED test, to diagnose nasal valve collapse from rhinomanometry measurements in patients with nasal congestion. In the present study, we demonstrate a “proof of principle” that the FRIED test provides significantly different values in patients with nasal valve collapse compared with patients with nasal obstruction but no clinical valve collapse. The test was evaluated using the clinical gold standard for nasal valve collapse (2, 11, 17), which is subject to variations depending on both the physician and patient. It was found to have a high sensitivity and reasonable specificity indicating that it could be useful in daily practice, especially when taking into account that until now the only way to assess valve collapse is by clinical examination. Moreover, the FRIED test is based on specific treatment of routinely acquired rhinomanometry data and does not require any supplementary measurements. It seems therefore that the FRIED test is easy to perform and helpful in daily practice for the clinician to detect and confirm objectively a nasal valve collapse in patients complaining of chronic nasal obstruction.

We developed the test on the basis of the hypothesis that inspiratory and expiratory resistance should be different because of the potential different collapsibility of the nose during the two phases of respiration. The pressure drop in a rigid duct does not depend on flow direction, considering that entry effect and singular loss are negligible. This assumption seems to be in agreement with previous observations obtained in a plastinated, and thus rigid, nose model (9). In contrast, when the duct is not rigid, such as in a patient’s nasal cavity, the pressure differences across the inlet and outlet cross sections of the duct modify the duct geometry and the pressure drop (18). We would expect, therefore, an increase of the resistance on inspiration compared with expiration and that this difference is accentuated in patients with nasal valve collapse.

The FRIED test differentiates between fixed and dynamic collapse and does not specify the localization of the collapse. Nevertheless, the most deformable and resistive segment of the nose is certainly the nasal valve. So, it is reasonable to think that positive FRIED test is associated with nasal valve collapse. However, a certain amount of collapse may occur in other segments of the nose. This might be detected by the FRIED test, thus explaining the specificity of 59% of this test for nasal valve collapse diagnosis.

FRIED score was inferred with unilateral resistance measurement while the contralateral nostril was tightly closed using surgical tape. Surgical tape sealing of one nostril presents the advantage of having no effect on the shape or the dynamic of the studied nostril. The choice to infer FRIED score on separate nostril was made in order to be able to detect unilateral nasal valve collapse.

FRIED tests at Pmcav and at P100 provide the same level of performance in terms of Youden’s index (0.4104 at Pmcav and 0.4099 at P100). Nevertheless, at the optimal point of the ROC curves, FRIED test at Pmcav is more specific but less sensitive than FRIED test at P100 in detecting nasal valve collapse. Additionally, FRIED test at P100 is not always achievable in some patients that cannot reach P100 during expiration, while FRIED test at Pmcav is performed during usual breathing conditions of each single patient. For all these reasons, it seems interesting to present both modalities of FRIED test, one that allows interindividual comparisons (P100) while the other (Pmcav) allows evaluation of the patient at the patient’s own level of breathing corresponding to the patient’s true needs.

The clinical characteristics of each group in our study were similar apart from turbinate hypertrophy, which was more frequent in the NV− group. This difference was more or less expected as turbinate hypertrophy is in itself a distinct and frequent cause of nasal obstruction. The sensation of nasal obstruction evaluated with the VAS before nasal decongestion was significantly higher in the NV+ group, while both the resistance and MCA before nasal decongestion did not differ
between the two groups. While it is difficult to determine the exact reason of this finding, we may speculate that the dynamic nature of the obstruction in nasal valve collapse generates greater discomfort than an obstruction resulting from a static component (e.g., septal deviation). After nasal decongestion, the sensation of nasal obstruction was still higher in the NV+ group. This was not surprising, as we would expect greater improvement of nasal obstruction sensation in the NV− group with more common turbinate hypertrophy, which is more sensitive to oxymetazoline. This assumption is supported by the results obtained with both rhinomanometry (higher resistance in the NV+ group, Fig. 2) and acoustic rhinometry (higher MCA in the NV− group, Fig. 5).

Surprisingly, compliance was higher in the nasal valve segment in the NV− group. This result can be explained by considering that 1) the head of the inferior turbinate is part of the septoturbinal valve, 2) turbinate hypertrophy is more frequent in the NV− group, and 3) nasal compliance is proportional to the amount of erectile tissue (5). Moreover, acoustic rhinometry (used for compliance measurement) requires a quasi-rigid nosepiece applied to the nasal aperture, which increases its rigidity. This undoubtedly affects the measurement of nasal valve segment compliance by minimizing the component due to the lateral cartilages (those that are involved in nasal valve collapse). Clearly, measuring nasal compliance with acoustic rhinometry is not a reliable way to characterize nasal valve collapse. Nevertheless, compliance measurements are of great interest when exploring nasal obstruction and could detect any potential dysfunction posterior to the valve (e.g., turbinate dysfunction) (16).

In conclusion, this study provides the first proof of principle of a useful, reliable, and easy-to-perform test to objectively and quantitatively characterize nasal valve collapse in patients complaining of nasal obstruction. In the future, the FRIED test could also be used to evaluate the efficacy of nasal valve treatments, both prosthetic and surgical.

APPENDIX

The FRIED test consists of evaluating the symmetry of the pressure-flow relationship between inspiratory and expiration phases by comparing the absolute value of flow between these two phases at the same absolute value of pressure variation. For this, from the pressure-flow curve obtained by rhinomanometry (see example in Fig. 7), we determine the maximum absolute of pressure both during the inspiratory phase ([P\text{inspi}]) and the expiratory phase ([P\text{exp}]). The maximum common absolute value of pressure ([P\text{max}]) is defined as the smallest value between [P\text{inspi}] and [P\text{exp}]. Flow rates during both inspiratory phase ([V\text{inspi}]) and expiratory phase ([V\text{exp}]) are inferred at [P\text{max}] in order to compute the difference between the absolute value of inspiratory and expiratory flow: [V\text{inspi}] and [V\text{exp}].

For this, the absolute values of inspiratory flow and expiratory flow are separately interpolated as pressure function with equations of fourth degree using classical least squares method:

\[ V_{\text{inspi}} = a_p p^4 + b_p p^3 + c_p p^2 + d_p p = f_p(p) \]
\[ V_{\text{exp}} = a_p p^4 + b_p p^3 + c_p p^2 + d_p p = f_p(p) \]

Then, the difference between the absolute value of inspiratory and expiratory at the maximum common absolute value of pressure ([P\text{max}]) recorded during rhinomanometry is given by

\[ |V_{\text{mcav.inspi}}| - |V_{\text{mcav.expi}}| = f_p([P\text{max}]) - f_p([P\text{max}]) \]

This difference was also computed at a single pressure value of 100 Pa:

\[ |V_{100.inspi}| - |V_{100.expi}| = f_p(100) - f_p(100) \]

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS


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