



Nasal valve elastography: quantitative determination of the mobility of the nasal valve*

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Abstract

Background: The nasal valve area is the narrowest region of the entire upper airway. Numerous procedures and spreader devices are published to widen the nasal valve or to stabilize it, but the indications are based only on the surgeon's experience.

Methods: In 30 healthy volunteers the deflection of elastic steel elements touching the lower nasal side at its deepest point was precisely measured by means of strain gauges. The deflection was calibrated by standard calibration devices. A special 4-phase-rhinomanometer (4RHINO/ Rhinolab/Germany) with a protective face mask allowed simultaneous measurements of the airflow and differential pressure. All signals were recorded simultaneously on both sides. The measurements have been carried out as unilateral measurements according to anterior rhinomanometry.

Results: Surprisingly the lateral nasal wall is already moving during quiet breathing. The airflow and its acceleration as well as the pressure difference generating a complete closure of the nose can be determined and has expectedly a high variance between individuals.

Conclusions: The elastography confirms the loops in 4-phase-rhinomanometry as symptomatic for the nasal valve elongation and will after developing as medical product allow the systematic quantitative measurement of the influence of the nasal valve on the nasal air stream.

Key words: lateral nasal wall, nasal valve, elastography, rhinoplasty, surgical indication

Introduction

Valves are mobile structures controlling the flow of a fluid, air or any other material through a passage, pipe, duct etc. Within the nose various anatomic structures are acting as valve regulating the air flow. However, till today there is no complete agreement about the nasal valve terminology and correct usage of the term valve. A review of the literature shows different terminology like – nasal valve area, internal nasal valve and external nasal valve, or just nasal valve each defining their topic of interest ⁽¹⁻⁴⁾. From the physiological aspect the nasal valve is a singular structure, but a complex three-dimensional entity or area consisting of several morphological structures. It is a functional unit that, acting as "flow limiting segment" at the place of maximum flow resistance, which allows air flow regulation ⁽⁵⁾ in particular in higher flow rates.

Difficult nasal breathing is one of the most common complaints in the clinical practice of otorhinolaryngology. Disorders of the nasal valve are frequently overlooked and/or not included in a systematic examination thus resulting in false diagnoses and unsuccessful surgical treatments of impaired nasal breathing⁽⁶⁾.

The main content of the work was presented at the conference of the European Rhinologic Society, London, April 2018 and awarded by a Travel Grant of the Society

Due to the complexity of nasal valve physiology the patient's sensation of this impairment is different. Objective quantitative measurements of the valve movement insufficiency are missing in the clinical practice. The classic routine investigation of the nose with a speculum already prohibits any information about the function of the nasal entrance.

The detailed analysis of the ascending and descending parts of the breathing wave by "4-phase rhinomanometry" (4PR) ^{(2,} ⁷⁾, allows an estimation of the influence of the nasal valve by the size of inspiratory loops within the graphs ⁽⁸⁾. If there is any suspicion of a valve problem, additional tests should be made as for instance Cottle 's manoeuvre or a retraction test. In most publications related to nasal valve insufficiency and its possible causes, authors mostly observe anatomical variations of the nasal cavity or the structures belonging to the nasal valve area: e.g. malposition of the cartilages, septal deviation, scarring due to previous surgery etc. and suborder all the possible causes either as static or dynamic ^(4, 9-12).

To this day there are no publications about objective diagnostic methods that would be capable to evaluate mechanical properties of the elastic structures of the nasal valve, in other words, of quantitative determination of the mobility of the nasal side wall, which would allow to diagnose too mobile nasal valve or conversely overly rigid. Everybody can close his nose by forced inspiration. It is not defined, when the term "collapse" for a pathological behaviour is justified.

New technical preconditions have been published by Vogt and Prill ⁽¹⁴⁾ including strain gauge technology as a possibly feasible technique in practice. Strain gauges (also named as "strain gages") are sensors whose resistance varies in proportion to the amount of applied forces. Strain gauge technology is one of the most important electrical measurement techniques that can determine the mechanical quantities of an object by converting different types of forces into variable electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as object's internal resisting forces, in turn, strain is amount of deformation of material that occur. Strain can be positive (tensile), due to elongation, or negative (compressive), due to contraction. Similarly, we could assimilate created forces to the lateral nasal wall by nasal breathing - during inspiration and expiration. Thus, in certain conditions, the value of the influencing quantity can be derived from the measured strain value. This method is widely used in experimental stress analysis. Such stress analysis by measuring the strain values that are determined in some material allows to determine the stress in the material, thus to predict its safety and durability (see: http:// www.ni.com/white-paper/3642/en/#toc1. and https://www. omegaeng.cz/prodinfo/StrainGages.html#nav). The aim of the study was to quantify the mobility of the lateral

nasal wall under the influence of breathing to improve the in-



Figure 1. Scheme of nasal valve elastography (from Vogt and Prill 2018 [13]). Border between soft and hard tissue of the nose (3); Fixating element attached to a headband (7); Mechanical connection piece (6); Feather strip on which (5); Strain gauges on both sides (4); Connection to the electric measurement bridge (8).

dication for surgical or prosthetic procedures with influence on the nasal valve, also to verify loops in 4-phase-rhinomanometry.

Methods

The study was approved by the Ethics Committee for Clinical Research at the University of Latvia. 30 volunteers were enrolled into the study, 11 males and 19 females between age of 20 and 61 with no previous history of nasal pathology or absence of acute respiratory tract infection in the preceding 2 weeks. All volunteers were introduced to the study and were informed about the course, purpose, and non-invasiveness of the approach. Regular 4-phase-rhinomanometry was carried out before in resting conditions and the subjects have been classified in class 1 or 2 ⁽¹³⁾. Written informed consent was obtained from all volunteers.

Technique of elastography

The technical equipment was the first practical realisation of the applied patent by Vogt and Prill ⁽¹⁴⁾. The constructive elements and the realisation of the measurement device are shown in Figures 1, 2 and 3. The device was set up at the laboratory of



Figure 2. Device in situ fixed on a head-band.

MedTecResearch / Krakow am See I (Germany), which is affiliated to the Centre of the Experimental Surgery of the Faculty of Medicine University of Latvia. The realization was following the principles of prototyping of a medical device following regulations of the European Union.

Stainless steel strips of 11 cm length and 5 mm width have been equipped with wired strain gauges of 3x7 mm size (MICRO-MEASUREMENTS Inc.). The steel strip was fixed via a bendable metal unit to the headband. The electrical realisation was first following the principles of a quarter-bridge resistance measurement, after an additional attachment of strain gauges on the lower side of the steel strip half-bridge measurements with a higher signal have been carried out. The amplifier was built as an additional unit into the rhinomanometer 4RHINO (Rhinolab GmbH, Germany).

At the distal end of the metal strip a 3 mm metal ball was fixed, which is following the inwards directed movement of the nasal wall by the minimal elastic force of the feather strip. For data recording, a special measurement program Rhino DSM was set up based on the free program LABVIEW (National

Instruments). This program is processing the signals for nasal flow and differential pressure separately as depicted in channels 1-2. Channels 3-4 show the time related valve movement for both sides.

The deflection of elastic steel elements touching the lower nasal side at its deepest point was calibrated by commercial calibration devices. The modified 4RHINO rhinomanometer was used with a full-face protective mask allowing simultaneously to measure air flow, differential pressure, and deflection signals. The measurements have been carried out as unilateral measurements according to anterior rhinomanometry during quiet and forced breathing.

Statistics

Microsoft Excel 2016 was used for a descriptive analysis of the data.



Figure 3. Measurement device under a full-face mask with rhinomanometer 4RHINO.

Results

Figure 4 shows a typical 3-channel record of pressure, flow, and deflection in quiet breathing, during sniffing and slightly elevated breathing.

Unilateral measurements from the entire study population from right and left side of the nose were stratified according to the parameters of flow (\dot{V}), pressure (Δ P) and deflection (D) in quiet breathing (Table 1). The distribution of means of the deflection is depicted in Figure 5.

We noticed first, that there was not any measurement with no deflection at all. In 31 measurements high deflection (> 2 mm) was already seen in ΔP > 200 Pa or in 21 cases at a flow rate of \dot{V} < 200 cm³/s. The deflection in higher pressure or flow rates have been expected. Three measurements could not be evaluated by technical reasons.



Figure 4. 3-channel-recording of flow, pressure, and relative deflection of the lateral nasal wall. QB quiet breathing, SN sniffing, EB elevated breathing.

Table 1. Simultaneous measurements of flow, differential pressure, and deflection of the lateral nasal wall.

Deflection	Pressure < 200 Pa	Flow < 200 cm³/s	Pressure > 200 Pa	Flow > 200 cm ³ /s
No deflection (n, %)	0	0	0	0
Clear deflection < 2 mm (n, %)	13 (22.8)	10 (17.5)	5 (8.8)	8 (14.0)
High deflection > 2 mm (n, %)	8 (14.0)	21 (36.8)	31 (54.4)	18 (31.6)

Discussion

The primary intention of this work was the development of a complete new technique for the evaluation of the movement of the lateral nasal wall including a pilot study in healthy volunteers. Principally, different quantitative measurement techniques can be used such as distance measurements by changing induction ⁽¹³⁾, determining the changes of the cross-section area by a micro camera, laser or infra-red distance measurements. Good estimations are possible by the determination of the inspiratory loop area in 4-phase-rhinomanometry.

Because the strain gauge technology is highly developed, we decided to test first the application of this technique, looked for the best suitable strain gauges, and tested two basic techni-

ques for the electronic evaluation, which is the quarter bridge technique and later the half bridge technique. During the basic experiments we found out that the half bridge technique as expected is superior to the quarter bridge technique because of the better signal and higher distance between the signal and noise. Therefore, the next task for the development of the present strain gauge technology is the design of the fixation elements following the demands for a Medical Product and the validation against the other techniques as mentioned above. A bilateral measurement of the valve elongation is possible by applying posterior rhinomanometry for the determination of the entire air-stream through both nasal sides. The importance of the quality of the measurement is highly rated, because the



Figure 5. Deflection (D) in mm of the lateral nasal wall in quiet breathing and forced breathing.

simultaneous depiction of the standard rhinomanometric result and of the time related variations of flow, pressure, and deflection will inform about the time relations between deflection and rhinomanometric standard parameters.

The results of the pilot study show clearly that the onset of the movement of the lateral nasal wall starts already in quiet breathing, where it has obviously a minor influence on the regulation of the nasal airstream, but it is very likely that even this minor movement in a range of two millimetres in both directions contributes to the feeling of the nasal breathing. Also, initial results suggest that there is no nasal breathing without movement of the nasal wing and the onset of deflection starts already before the sensation of valve activity.

From the initial analysis of the curves in forced breathing, it is also clearly visible in most of them that as the flow increases, deflection is also increasing releasing collapsing forces on the nasal valve, and that clearly confirms the effectivity of Bernoulli's principle. In our pilot study the intended valve effect for sniffing starts in a range between 3 to 4 mm movement of the lateral nasal wall (D < 2 mm = 5%; D > 2 < 4 mm = 67 %; D > 4 mm = 28%). For a precise quantification the measurement system has to be improved.

From our first experiments it is not yet clear if the pressure or flow are the leading parameters to determine the elongation. The analysis of the timeline differences between the signals are under progress. The ongoing experiments must answer the question if flow or the acceleration of the flow are determining the Bernoulli's effect which leads to the narrowing of the nasal channel.

However, it can be shown that the strain gauge technique applied is fast enough to follow the movement of the nasal wall, and a hysteresis if observed is a physiological phenomenon corresponding to the type C (elastic type) of rhinomanometric patterns as given by Vogt et al. ⁽²⁾. Such a hysteresis was also confirmed by O'Neill and Tolley during the recent meeting of the SCONA Society in London (April 2018). The elaboration of a clinical protocol showing the rhinomanometric figure as well

the time-line of elastography is in progress.

It is likely but not proved that the feeling of a movable lateral nasal wall determines in part the general feeling of normal nasal breathing in human being. This statement must be investigated by myography to determine the muscle activity or similar methods.

Overall, our pilot study demonstrates, that the nasal valve is not only a passive instrument to close the nasal airway for generating an under-pressure to remove mucous or to produce vortices in "sniffing" but that it also is involved in the entire regulation of the human airway.

Conclusion

The elastography of the lateral nasal wall delivers important information about the influence of motile structures of the nasal entrance onto the nasal airway resistance, and should be developed as quantitative and statistically verified method determining the indication and success of surgery in this area. Also, in consent with the beginning introduction of CFD -methods into the clinical routine, it is important that the narrowest structure within the entire airway is also in low flow rates an inconstant element depending on the influence of Bernouilli-effects. The mutual validation of the methods mentioned above is mandatory before the introduction of the elastography as clinical method and was already started.

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Authorship contribution

All authors contributed equally to this work and publication.

Conflict of interest

All authors declare that they have no conflict of interest.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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