The influence of flowmeters on rhinomanometry results and detection of nasal airflow asymmetry

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ABSTRACT: Introduction: Rhinomanometry is an otolaryngological diagnostic method used to determine airflow as a function of the pressure drop through the left and right nasal cavities. Airflow is measured using orifice flowmeters that attenuate the flow.

Aim: This paper describes the results of a study into the effects of flowmeter design on rhinomanometry results and detection of nasal airflow asymmetry.

Material and methods: Four flowmeters were examined using a 3D printed model of a human nose.

Conclusions: Each flowmeter interfered with the rhinomanometry results.

KEYWORDS: flowmeters, RMM

INTRODUCTION

Rhinomanometers for anterior rhinomanometry

Rhinomanometry is used in research on nasal physiology and in clinical practice. It helps to quantify the effects of conservative or surgical treatment of nasal obstruction. It is also utilized to measure the increase of nasal resistance after nasal allergen challenge. The results of rhinomanometry may aid the selection of patients for septoplasty. However, clinical examination and the patient’s subjective assessment have to be taken into consideration as well due to the lack of standard reference values for rhinomanometry [1–3].

Rhinomanometry is also used in biomedical engineering, for example in the verification of computational fluid dynamics results of the airflow in the human nasal cavities [4–6].

Anterior rhinomanometry [7] involves determining the relationship between the airflow through the nasal cavities and the pressure difference between the nasopharynx and the atmosphere surrounding the patient’s face (Fig. 1.). Flow measurements are performed using a differential pressure sensor (differential pressure sensor no. 2) and a flow sensor, mounted on a mask placed tightly on the patient’s face. When measuring the pressure difference in the nasal cavity, it is assumed that the pressure in the nasopharynx is the same as in the front of the nasal cavity, on the side opposite to where the flow measurement is being performed. This pressure is measured relative to the atmospheric pressure (differential pressure sensor no. 1). By analysing the rhinomanometry results, it is possible, among other things, to compare the airflow through the left and right nasal cavities and, in the case of significant differences or low values of air flow, to perform rhinoscopy, endoscopy, and imaging to find the cause, which may be, for example, septum deviation.

An alternative rhinomanometer design is the use of nose plugs (olives) instead of face mask (Fig. 1.–2.).

The main part of a rhinomanometer is a flow sensor with an orifice. The pressure drop on the orifice is measured and airflow is calculated using the Bernoulli principle. The accuracy of orifice flowmeters in respiratory monitoring is described by Tardi et al. [8].

A review of the literature shows that rhinomanometry is a method of otolaryngological diagnosis that has been used over the past few decades. Airflow is measured using orifice flowmeters which
paranasal sinuses. The model was smoothed (3DSlicer – smoothing factor: 0.5) and saved in the STL format.

The nose model was fabricated using the Fused Filament Fabrication (FFF) method [10], on a specially prepared 2-head 3D printer (Fig. 3.).

The 3D model has low accuracy and lower air flow resistance than a real patient which means that the airflow asymmetry in the model will be lower than in a real patient (65% : 35%).

**MATERIALS AND METHODS**

**A model of the nose and nasal sinuses**

A model of the nose and paranasal sinuses was created based on the CT examination of a patient with significant airflow asymmetry, diagnosed during rhinomanometry (left nasal cavity air flow 99%; right 1%).

CT scanner: Toshiba Aquilion. CT protocol: sinuses. Pixel Spacing (DICOM Tag): 0.366 mm; 0.366 mm. Slice Thickness (DICOM Tag): 0.500 mm. Reconstruction kernel: bones.

Segmentation was performed in 3D Slicer [9] in the interval [-1024, -200] HU (Hounsfield units), corresponding to the radiological density of air. The result was a virtual model of the cavities and paranasal sinuses. The model was smoothed (3DSlicer – smoothing factor: 0.5) and saved in the STL format.

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**Reference flow meter**

SpiroQuant-H [11] was used as the reference flow meter (Fig. 4.).

The flow meter documentation includes flow vs. pressure characteristics equation [11].

In addition, the SpiroQuant-H flow meter readings were checked in a laboratory using an Almemo digital precision vane anemometer [12] (Fig. 5.).

Pressure measurements were made using the Sensirion SDP810 digital pressure sensors [13].
The measurement equipment shown makes it possible to test the influence of flow meters on the results of rhinomanometry.

The volume buffer has a volume similar to that of the air inside the face mask.

The attenuation of the reference flow meter does not affect the results of rhinomanometry.

The measurement equipment has been assembled ensuring the airtightness of the system.

Reference rhinomanometry

Rhinomanometry of the model has been performed without the tested flow sensor being connected. The measurement results (Reference RMM) show the airflow characteristics without attenuation caused by the rhinomanometer.

Airflow asymmetry

The percentage of airflow through the left ($L$) and right ($R$) nasal cavities was calculated:
\[ L = \left( \frac{Q_{\text{left}}}{Q_{\text{left}} + Q_{\text{right}}} \right) \cdot 100\% \quad \text{Eq. 1} \]

\[ R = \left( \frac{Q_{\text{right}}}{Q_{\text{left}} + Q_{\text{right}}} \right) \cdot 100\% \]

\( Q_{\text{left}} \) – left nasal cavity flow [cm³/s],
\( Q_{\text{right}} \) – right nasal cavity flow [cm³/s].

RESULTS

Flowmeter from Rhinotest 1000 rhinomanometer

Fig. 10. shows the airflow measurement results of the model without connecting the flow meter (“Reference RMM”) and with a connected flow meter (“RMM – flowmeter from Rhinotest”).

Flowmeter from Mertz Rhino rhinomanometer

This rhinomanometer uses the SpiroQuant-H flowmeter. Fig. 11. shows the measurement results.

Flowmeter from Homoth Rhino 4000M rhinomanometer with face mask

Fig. 12 shows the measurement results.

Flowmeter from Homoth Rhino 4000M rhinomanometer with olives

This rhinomanometer has an unusual design (Fig. 1c.–2.). The pipe with olive is an additional element which attenuates the airflow.
Measurements have been performed in the same way as for the other flowmeters (Fig. 13. – “RMM – olives from Homoth Rhino”). During the measurement, an RMM examination of the model was performed with the Homoth Rhino 4000M rhinomanometer (Fig. 13. – “RMM report from Homoth Rhino”).

Furthermore, inspiration airflow was calculated using Computational Fluid Dynamics (CFD) software Ansys Fluent [17]. In order to simulate the flow, numerical finite volume models were prepared for this purpose in Ansys Fluent. Parameters of the numerical mesh were chosen empirically after a mesh independence and sensitivity study for different geometric models. The quality of generated meshes remained at the level of Minimum Orthogonal Quality > 0.3. The flow volume was discretized into a hybrid polyhexacore mesh with prismatic boundary layer elements growing according to the local area. The kω-SST turbulence model was adopted in the series of analyses performed. Stationary airflow was defined by assuming pressure type boundary conditions at the inlet to the nose and at the outlet to the throat. Assuming a pressure-induced airflow with pressure drop of 25 Pa, 50 Pa, 75 Pa, 150 Pa, and 300 Pa respectively, with a reference pressure equal to atmospheric pressure, the velocity distribution field and volumetric flow rate of the air were solved in the numerical simulation. Flow characteristics were calculated for the model without (Fig. 13. – “CFD – Reference RMM”) and with the pipe and olive (Fig. 13. – “CFD – RMM – olives from Homoth Rhino”).

**Final results**

Rhinomanometry results show quantitative airflows as a function of the pressure drop, as well as the magnitude of flow asymmetry, the cause of which may be nasal septum deviation.

To aid the analysis of flow asymmetry, a Flow Ratio Indicator (FRI) was defined:

\[
FRI = \frac{(R - L)}{100} \quad \text{Eq. 2}
\]

Thus, FRI = 0 indicates symmetrical airflow; FRI>0 – greater airflow through the right nasal cavity; FRI<0 – greater airflow through the left nasal cavity.

Air flows for pressure of 50 Pa are presented in Tab. I., Fig. 14. and Fig. 15.

**DISCUSSION**

Reference airflow shows the “breathing” of the model without a connected rhinomanometer – i.e., natural breathing. The reference airflows are compared with those of the model with connected rhinomanometers.

The attenuation of airflow by flowmeters used in rhinomanometers is clearly visible (Fig. 14.). This is caused by attaching additional flow elements to the reference model which increase the airflow resistance, thus throttling the airflow. Such throttling manifests itself in a reduction of the flow rate at a given pressure difference. Flow throttling is caused by increasing the length of the flow channels, reducing the characteristic dimension and disturbing the flow velocity field, resulting in flow separation.

The throttling effect is particularly noticeable with the flowmeter from Homoth Rhino 4000M with pipes and olives, for which rhinomanometry was performed with various methods (Fig. 13.). Measurements were made using the equipment from Fig. 8. (Fig. 13. – “RMM – olives from Homoth Rhino”), to which the measuring apparatus of the rhinomanometer was connected (Fig. 13. – “RMM – report from Homoth Rhino”). In addition, a CFD simulation of airflow through the model was carried out, with and without connecting the pipe and olive. The measurement results and CFD simulations show very high pressure drops and a reduction of airflow. This is due to the use of a flowmeter with small orifice and pipe diameters. Flow through the flow channel of such a design generates flow resistance values several times greater than the flow resistance in the examined nasal cavities. This is confirmed by the measured airflow values. In the case of the Homoth Rhino 4000M with pipes and olives, at a reference pressure of 50 Pa, a flow reduction of up to 75% is observed compared to the reference flow for Left Expiration and a flow reduction of 54% compared to the reference flow for Right Expiration. A similar situation is observed for Inspiration (Tab. I. and Fig. 14.). Such a large change in airflow negatively affects the assessment of the effect of nasal septum deviation on the respiratory function of the nose.
Rhinomanometers use orifice flowmeters which attenuate the airflow. The effect of flowmeters on rhinomanometry results is non-negligible. This is evident in both airflow values and airflow asymmetry.

In rhinomanometers using a face mask with orifice flowmeters, the influence of flowmeters on rhinomanometry results can be considered acceptable. In contrast, the rhinomanometer using pipes and olives greatly disturbs the airflow. Because of this, the test results (particularly with regard to airflow asymmetry) do not reflect the actual conditions of airflow through the nasal cavities.

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### CONCLUSIONS

Rhinomanometry is one of the diagnostic methods in otolaryngology to determine the amount of airflow as a function of the pressure drop for left and right nasal cavities, as well as flow asymmetry.

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