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ORIGINAL STUDY

Performance and work of nasal breathing

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ABSTRACT

OBJECTIVE. To evaluate performance (Q) and work (W) of nasal breathing as potential parameters in functional diagnostic of nasal obstruction.

MATERIAL AND METHODS. We included in our study 250 patients and we measured by 4-phase-rhinomanometry with decongestion test. We calculated performance Q of the "representative breath" in inspiration and expiration and in total breath, maximal performance Q (Qmax), Work W of nasal breathing in mJ and in mJ/litre and Q in J/min.

RESULTS. The interquartile range of Win for representative breath before decongestion is 356 mJ/l, Wex 308 mJ/l, while after decongestion Win is 264 mJ/l and Wex 220 mJ/l. There is no significant difference between work before and after decongestion ($p<0.001$). Interquartile range for nasal breathing Q before decongestion is 19.2 J/min and after – 14.3 J/min. A significant correlation exists between logarithmic vertex resistance for inspiration and expiration and Qmax for inspiration and expiration ($p<0.001$). That means that the performance required by breathing depends in the first line on nasal resistance.

CONCLUSION. Inspiratory work is 1.2 times higher than expiration work. Increase in nasal airway resistance is followed by increase in maximal nasal performance.

KEYWORDS: nasal respiratory performance, nasal respiratory work, nasal resistance, four-phase rhinomanometry.

INTRODUCTION

The purpose of functional nasal diagnostic is to provide information on the quality of intranasal airflow, including the pathological function in disorders or the effect of medical or surgical treatment, as for example using intranasal decongestants or intranasal surgery[1,2]. A wide range of examinations, as well as subjective scoring systems are offered, and rhinomanometry is considered as the "golden standard". The correct measurement of the pressure difference and the flow rate in the nasal airstream allows various calculations; the introduction of logarithmic parameters for the resistance following the principles of 4-phase-rhinomanometry[3] has been accepted as the new clinical standard by the ISCOANA (*International Standardization Committee on Objective Assessment of Nasal Airway*)[1], because logarithmic resistance parameters are significantly related to the feeling of obstruction. A general review of the parameters used up to now in clinical rhinology shows that work and performance of nasal breathing have been mentioned as of possible clinical importance[4,5]. Both parameters can be calculated from flux and differential pressure as measured by rhinomanometry, but up to now, clinical studies are missing.

In a representative sample, it should be found out:

- The mode and results of calculation of performance and work at any point of the nasal breathing wave, as well as in the entire breath;
- The statistical distribution for work and performance of the nasal breathing;
- Whether a statistically significant difference exists between work parameter in inspiration and expiration and work before and after decongestion;

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- The correlation between these new parameters and already validated parameters as logarithmic vertex resistance.

MATERIAL AND METHODS

Material

The re-analysed data have been obtained anonymously from patients of the "*Park-Klinik-Berlin Weissensee*" in Berlin/Germany as a sample of 125 males and 125 females, randomly selected patients investigated by Active Anterior Rhinomanometry, with a subsequent nasal decongestion test by 2 puffs of Xylometazoline 0.1% spray and re-investigation after 10 minutes. The data are part of a comprehensive study "Four-phase rhinomanometry: a multicentric retrospective analysis of 36,563 clinical measurements" published in 2015 by Vogt et al.[6].

The measurements have been carried out by using the rhinomanometer 4RHINO (Rhinolab/Germany) with the software versions 4.31 and 5.01. The procedure of any measurement followed the standard recommendations of the ISCOANA (*International Standardization Committee on Objective Assessment of Nasal Airway*) of 1984 and the new standard of 2018[1,2].

The unified data storage of the 4RHINO-system is based on the storage of a "representative breath" as an average of the measured data for pressure difference and flow, following interpolation by splining. The data (.dat) files provide 2000 lines for every averaged measurement. This unified system allows the analysis of huge amounts of data preserved in the personal computers of the clinical units. The data export system of the 4RHINO-program to MS Excel had to be modified for the purpose of this work.

Methods

Work and performance have been calculated from the measured parameters flux and differential pressure by the following steps:

1. Performance (Q)

$$Q = 0{,}00124\,\Delta P\,\dot{V}$$

where Q means performance in milliwatt (mW), ΔP is the measured differential pressure in Pascals (Pa) and $\dot{V}$ is the measured airflow/flux in cubic centimetres per second (cm^3/s). The number 0,00124 is the specific weight of air at sea level at 20°C. First, these calculations have been done for both inspiration and expiration and then summed up for the entire "representative breath"[3].

2. Maximal performance (Q_{max}) was determined using the MAX function in *Microsoft Excel* for inspiration and expiration and the entire representative breath.

3. Calculation of the respiratory volume:

$$V = \dot{V}\,t_1$$

where V represents the volume in cubic meters (m^3), $\dot{V}$ is the airflow (cm^3/s) and t_1 represents the time for one data point in seconds (s) which differs for inspiration and expiration and was calculated separately. For every patient, 2000 data points t_1 were measured using the individual breathing frequency. In addition, negative values for expiration as generated by the rhinomanometry software had to be converted in positive values by dragging the square root from volume square.

4. Continuing, all individually calculated measurements of 250 patients for both nostrils before and after decongestion were exported into a combined *Microsoft Excel* file. The transformed parameters are: performance (Q), inspiratory and expiratory performance (Q_{in}, Q_{ex}); maximal performance (Q_{max}), maximal performance for inspiration and expiration ($Q_{max\ in}$, $Q_{max\ ex}$) and the volume of air for inspiration and expiration (V_{in}, V_{ex}).

5. From breathing frequency, we calculated the time for one data point, taking into account that, for every patient, differential pressure and airflow parameters are standardized in 2000 data points.

- Breathing frequency was transformed from breaths per minute to breaths per second.

$$\text{Freq.}(1/s) = \frac{EF_{(1/min)}}{60}$$

- Further, we calculated time for one breath by inverting freq. (1/s) value, meaning:

$$\text{Time for one breath} = \frac{1}{\text{Freq. }(1/s)}$$

- Time for one data point t_1 (s) is calculated by dividing time for one breath by 2000. This measurement was used to calculate volume for inspiration and expiration.

6. Work for one breath in millijoule (mJ):

$$W(mJ) = Q\,t_1$$

where W means work (mJ), Q is performance (mW) and t_1 is the time for one data point (s). Knowing the inspiratory and expiratory performance, the work for inspiration and expiration was calculated (W_{in}, W_{ex}).

7. To transform breathing work from mJ to mJ per litre, work in mJ was multiplied by 1000 and divided by the volume of the whole representative

Table 1. Main indicators of descriptive statistics for breathing performance (J/min) before and after decongestion.

	breathing performance (J/min) before decongestion	breathing performance (J/min) after decongestion
Number	500	500
Arithmetic mean	**33.1**	**24.8**
Standard Error of Mean	0.83	0.56
Median	**29.0**	**22.0**
Standard deviation	18.6	12.7
Variance	348.8	162.1
Minimum	**7.0**	**5.0**
Maximum	**152.0**	**84.0**
Interquartile range	**19.2**	**14.3**

breath. In addition, a formula was used to calculate work individually for inspiration and expiration in mJ per litre.

$$A(\mathrm{mJ/l}) = \frac{A(\mathrm{mJ})\ 1000}{V(\mathrm{ml})}$$

8. Breathing performance as in joules per minute (J/min) was calculated by

$$Q_{breathing} = \frac{W(\mathrm{mJ/l})\ \mathrm{Freq.}\ (\mathrm{x/min})}{1000}$$

following Ocxenski[7].

The statistical analysis of the obtained numerical data was made using *IBM SPSS Statistics Version* 22.0.

RESULTS

In Table 1, the indicators of descriptive statistics of breathing performance (J/min), before and 10 minutes after nasal decongestion with Xylometazoline 0.1% aerosol, can be seen. The arithmetic mean and median are slightly different. Mode in these cases cannot be used, because breathing performance factual values for 500 nasal cavities are different, as used results have not been rounded of, and factual data are recorded with a few decimal places. In Figure 1 and 2, breathing performance histograms in both cases – before and after decongestion – show slightly positive asymmetry, which can be caused by several relatively large data differences on the right side of the data distribution, therefore the range of minimal and maximal values is large. As noted in Skewness or asymmetry indicator, the distribution of performance values has a positive asymmetry with shift to the left side. Therefore, the interquartile range was used to describe the breathing performance parameters. Before decongestion, the interquartile range for breathing performance is 19.2 J/min, but after decongestion it is 14.3 J/min.

After statistical analysis, similarly to the parameters of breathing performance, the average value of the respiratory work and the median are slightly different (Table 2). In these cases, mode cannot be used, because breathing performance factual values for 500 nasal cavities are different, as used results have not been rounded of, and factual data are recorded with a few decimal places. The distribution of the result values is asymmetrical with a positive shift to the right, as noted in Skewness. Therefore, to describe the values of work parameter, we used the interquartile range.

A paired sample *t* test to compare average mean values of nasal breathing work, before and after decongestion, showed no significant differences for the inspiratory, expiratory or the entire breath work before and after decongestion. Also, the breathing frequency was with 30/min equal before and after decongestion.

After calculating maximal performance (Q_{max}) we compared it with the already proven rhinomanometric parameter – logarithmic vertex resistance (LogVR). LogVR is calculated as log (10VR), where VR means Vertex Resistance. Vertex resistance is the resistance (P/) at the highest point of the breathing curve in quiet breathing. At this point, the relation between differential pressure and flow is linear. The logarithmic transformation is applied in the new standard of the ISCOANA

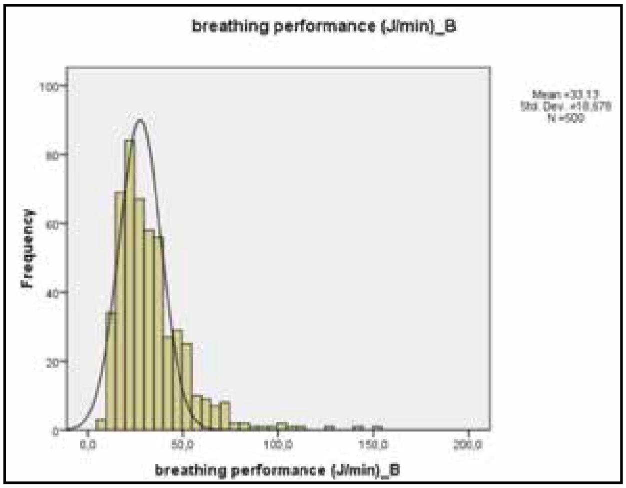

Figure 1. Breathing performance (J/min) histogram before (B) nasal decongestion.

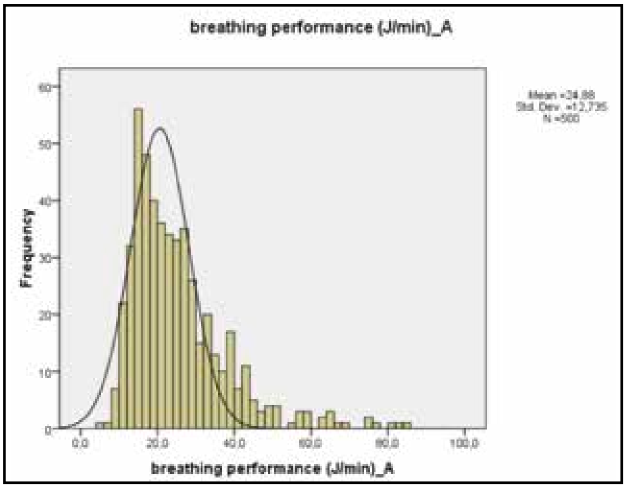

Figure 2. Breathing performance (J/min) histogram after (A) nasal decongestion.

for rhinomanometry because of the correlation with subjective sensing of obstruction by VAS scales. VR is highly correlated with the Effective Resistance (Reff), which is the Root Mean Square (RMS) of all measurements in a "representative breath". LogVR was chosen as independent variable, but Q_{max} as dependent variable. The correlation was determined individually for inspiration and expiration, before and after decongestion. We wanted to find out whether consistently increasing nasal respiratory resistance increases the maximal performance values. Therefore, Pearson correlation coefficient as well as Spearman rank order correlation coefficients have been deter-

Table 2. Main indicators of descriptive statistics for nasal breathing work (mJ/l) before and after decongestion, in inspiration (in), expiration (ex) and in the entire representative breath.

	Before decongestion			After decongestion		
	Work in (mJ/l)	**Work ex (mJ/l)**	**Work for 1 breath (mJ/l)**	**Work in (mJ/l)**	**Work ex (mJ/l)**	**Work for 1 breath (mJ/l)**
Number	500	500	500	500	500	500
Mean	613.1	515.0	1128.4	463.6	372.2	836.2
Std. Error of Mean	15.1	11.9	26.0	10.9	7.29	17.4
Median	534	453	989	404	337	743
Mode	415.0	333.0a	400.0a	243.0a	241.0a	638.0
Std. Deviation	336.7	265.7	580.1	243.2	161.3	388.8
Variance	113389	70587	337045	59125	26020	151114
Skewness	1.744	1.597	1.537	2.167	1.257	1.624
Kurtosis	4.001	3.832	3.094	7.488	2.454	4.117
Range	2102.0	1791.0	3621.0	1753.0	1156.0	2585.0
Minimum	153.0	132.0	319.0	112.0	102.0	214.0
Maximum	2255.0	1923.0	3940.0	1865.0	1258.0	2799.0
Interquartile range	**356.2**	**307.7**	**636.3**	**263.8**	**220.4**	**475.8**

a. Multiple modes exist. The smallest value is shown.

Table 3. Correlation coefficients for LogVRin and Q_{max}.

		Before decongestion		After decongestion	
N = 500		**Pearson**	**Spearman's Rho**	**Pearson**	**Spearman's Rho**
LogVRin	Q_{maxin}	0.397***	0.464***	0.578***	0.657***
LogVRex	Q_{maxex}	0.277***	0.343***	0.504***	0.579***

N = 500, Sigma 2-tailed = 0,00.

mined for the parameters as noted in Table 3, with a number of N=500 in every test. The respective diagrams are shown in Figures 3 and 4 and show the high variability of this relation in particularly in higher resistances. All correlations are statistically highly significant ($p < 0.001$).

DISCUSSIONS

The calculation of the nasal respiratory work and power in rhinomanometry is not a novelty. Already in 1988, the formula and graph for calculating work and power in the rhinomanometry was

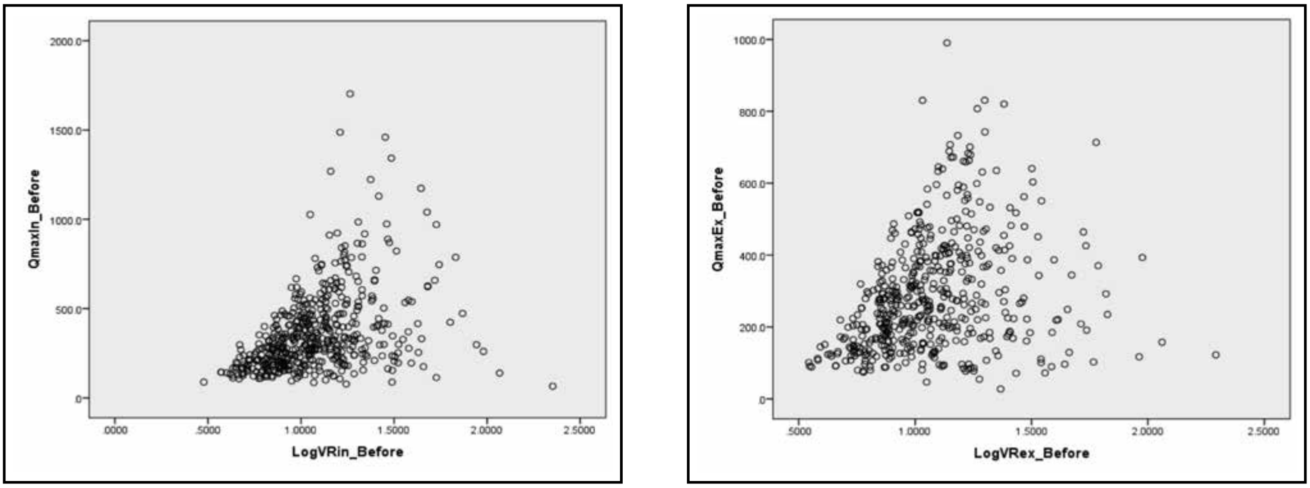

Figure 3. Correlation diagrams for LogVR and Qmax in inspiration and expiration before decongestion.

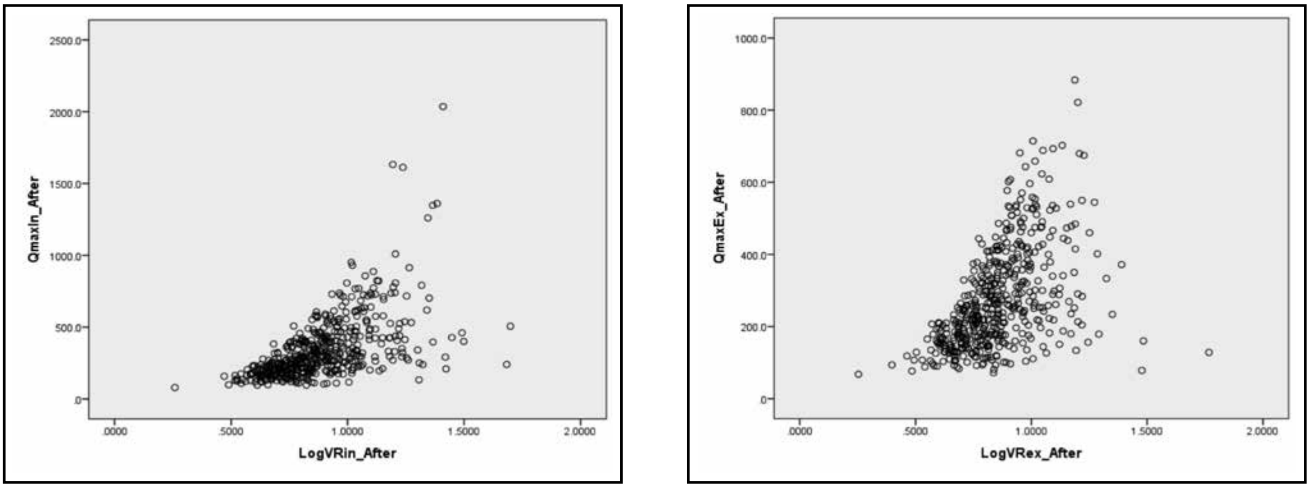

Figure 4. Correlation diagrams for LogVR and Qmax in inspiration and expiration after decongestion.

given by J. Eichler[5]. During the consensus conference on nasal function tests in Riga[1], it was proposed to re-check the feasibility and clinical information of these parameters.

Also, in 1978, Cole and colleagues published a study that determined nasal respiratory work by measuring air resistance in calm respiration. The authors note that the inhalation work was 1.6 times that of exhalation. In addition, authors describe that minor changes in respiratory rate and respiratory volume have a minor effect on respiratory work[8].

In this study, we found that the interquartile range for inspiratory work before decongestion is 356.2 mJ/l and for expiratory work 307.7 mJ/l, whereas after decongestion inspiratory work is 263.8 mJ/l and expiratory work is 220.4 mJ/l. Under all these conditions, the inspiratory work is 1.2 times greater than the expiratory work. Considering differences of results with Coles work[8], it should be taken into account that in our study an average respiratory rate was 30 breaths per minute, because the four-phase rhinomanometry measurements are recorded without an expiratory break but also in quiet breathing.

We calculated that nasal respiratory work for the representative breath before decongestion is 636.3 mJ/l and after decongestion 475.8 mJ/l. Differences of the means of work after nasal decongestion with xylometazoline 0.1% aerosol were not statistically significant ($p<0.001$). Thus, by applying this parameter, it would not be possible to effectively evaluate the intranasal decongestant effect on nasal breathing. That restricts the possibility of this parameter to be used for the evaluation of the nasal ventilation function.

When discussing the acquired work values, their comparison with the values of respiratory work described by W. Ocxenski[7] can be used. The author states that, during calm respiration, the entire respiratory work is about 0.25 J/breath and about 0.5 J/l, while, in forced breathing, respiratory work is about 1.0 J/breath and 1.0 J/l[7]. In this study, the average respiratory rate both before and after decongestion was 30 breaths per minute, corresponding to the forced respiration rate. The rounding down of the value of the work before decongestion to 0.6 J/l shows that the values are different, compared with Ocxenski[7]. Currently, it is not known whether in four-phase rhinomanometry measured nasal respiration resistance, work and performance can be used to describe the entire respiratory tract. Thus, it would be worthwhile to find out what part of the entire respiration work and performance can be calculated using rhinomanometric measurements.

In our work, we found that the interquartile range for nasal respiratory performance is 19.2 J/min, but 10 minutes after decongestion - 14.3 J/min. W. Ocxenski (2012) describes that a respiratory rate greater than 15 J/min is considered to be a critical limit, after which the patient needs a mechanical respiratory device[7]. It would follow that all patients had an excessive respiratory capacity at a given moment, which is not the case but rather an effect of the special breathing conditions during the rhinomanometric measurements. Consequently, the use of this parameter in the clinical practice of an ENT doctor would not be useful, as it does not reflect the respiratory capacity of each patient in real physiological conditions.

By studying the correlation between the inspiration and expiration LogVR and Q_{max} before and after decongestion, we found that a statistically significant correlation exists ($p<0.001$) in all cases. This means that, on average, the increase in LogVR implicates increases in Q_{max}. This is an important aspect that demonstrates that respiratory resistance has a direct impact on the body's energy consumption. Visually assessing the distribution of the parameters in graphs (Figures 3 and 4), one can notice values which differ radically from the general distribution. These *outlier* values may indicate pathological conditions, because the evaluated data are subsequently won by measurements in "normal" and pathological cases. However, statistically significant correlations are apparent by the analysis of parametric and nonparametric correlations.

Respiratory work is a product of every breath and volume that reflects the organism's energy consumption. John Hall describes three types of inspiration work in his book[9]. The first is called compliance work or elastic work, which is done by expanding the lungs against the lung and chest elastic framework. Tissue resistance work must be applied to overcome the viscosity of the lung and chest wall structures. Rhinology, on the other hand, has a greater interest in airway resistance work that occurs when the air travels to the lungs, overcoming the airway resistance. The author describes that, during normal breathing, only three to five percent of the total body energy is spent on ventilation of the lungs. On the other hand, during exercise, energy consumption can increase up to 50 times, especially if the person has increased airway resistance or reduced lung elasticity. Consequently, it should be understood that evaluating respiratory resistance work is an important aspect not only for the diagnosis of nasal obstruction, but also for the determination of athletic durability. Probably, the calculated parameters potentially could be used in sports physiology studies.

It remains questionable whether the use of the investigated parameters in clinical practice is useful. After the introduction of 4-phase-rhinomanometry[3], with the introduction of logarithmic parameters and visualisation of elastic influences, it was possible by a statistical analysis of 36.500 measurements to classify nasal obstruction in 5 classes of clinical relevance with a much higher correlation to subjective parameters (VAS-scale)[6]. Resistance as the quotient between differential pressure and flow depends only in a minor degree on breathing rate and volume.

CONCLUSIONS

There is no statistically significant difference between the mean values of nasal respiratory work parameters, before and after intranasal decongestion. Inspiratory work is 1.2 times higher than expiration work. Increase in nasal airway resistance is followed by increase in maximal nasal performance. Calculated nasal airway work and performance cannot be recommended as parameters for the clinical evaluation of the nasal airway.

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Conflict of interest: The author has no conflict of interest to declare**.**

Contribution of authors: All the authors have equally contributed to this work.

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