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Rhinomanometry in clinical use

A tool in the septoplasty decision making process

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The defence of this doctor's thesis in medical science will be held at Grubbsalen, BMC section I, Lund, on Friday 4th May at 1:00 pm

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Abstract

Subjective nasal obstruction is a common chronic complaint caused by mucosal disease, skeletal abnormality or a combination of both. The challenge is to determine the main cause and to decide whether the intervention should be medical or surgical. Diagnosis is done by a combination of rhinoscopy, subjective and objective assessments of nasal obstruction. Rhinomanometry measures the nasal airway resistance (NAR) for each nasal cavity. Septal deviations are common with prevalences of up to 58% with the majority having no nasal complaints. Septoplasty can straighten the septum. In Sweden on average 24% of patients are dissatisfied 6 months after their septoplasty. The principal aim of this thesis was to investigate the clinical use of rhinomanometry in the septoplasty decision making process. This resulted in a checklist to increase the patients' satisfaction with the operation.
We found that higher age and allergic rhinitis were factors giving significant odds for a spontaneous long term improvement of the nasal obstruction without septoplasty. That was in spite of septal deviation and pathological NAR.
In a study of 1000 patients with nasal obstruction we found that there has to be a certain NAR side difference between the nasal cavities before the patient could significantly assess it on a Visual Analogue Scale.
When rhinomanometry was performed in 9 participants every two weeks during 5 months, we found a high variability of the NAR, where tested subjects could move from pathological to normal. Intervention with topical budesonide treatment during a new five month period reduced both NAR and it's variability significantly.

Key words

Rhinomanometry, nasal obstruction, nasal airway resistance, septoplasty, VAS, xylometazoline, budesonide, topical nasal glucocorticosteroid

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Helle Lundgaard Thulesius

Faculty of Medicine

Lund University, Faculty of Medicine, Doctoral Dissertation Series 2012:29

Front cover: “Peaceful breathing”

….in memory of my father

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And the Lord God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul.
Genesis 2:7

To Hans
Jacob, Sara and Daniel

Table of Content

List of papers

This thesis is based on the following papers referred to in the text by their Roman numerals.

I. Thulesius HL, Thulesius HO, Jessen M. What happens to patients with nasal stuffiness and pathological rhinomanometry left without surgery? Rhinology 2009 Mar;47(1):24-27

II. Thulesius HL, Cervin A, Jessen M. The importance of side difference in nasal obstruction and rhinomanometry. Clinical Otolaryngology 2012 Mar;37(1):17-22

III. Thulesius HL, Cervin A, Jessen M. Can we always trust rhinomanometry? Rhinology 2011 Mar;49(1):46-52

IV. Thulesius HL, Cervin A, Jessen M. Treatment with a topical glucocorticosteroid, budesonide, reduced the variability of rhinomanometric nasal airway resistance. Submitted March 2012

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Abbreviations

AAR	Active anterior rhinomanometry
AR	Acoustic rhinometry
CI	Confidence interval
CV	Coefficient of variation
Δp	Pressure difference in Pascal
ISCR	International Standardization Committee on Rhinomanometry
MCA	Minimal cross-sectional area
NAR	Nasal Airway Resistance
NOSE	Nasal Obstruction Symptom Evaluation
OR	Odds ratio
Pa	Pascal (1 kPa = 10.2 cm H_2O)
PNIF	Peak Nasal Inspiratory Flow
R_2	NAR at 200 Pa-200cm^3/sec- circle
R_{150}	NAR at Δp = 150 Pa
SNOT	Sino-Nasal Outcome Test
SD	Standard deviation
SPT	Skin prick test
VAS	Visual Analogue Scale
V°	Nasal flow rate in cm^3/sec
v_2	Angle in Broms' algorithm ($R_2 = \tan v_2$)

Thesis at a glance

The following issues were addressed in this thesis:

Could the partly obstructed nasal cavity get better without surgical intervention? Paper I	→	Yes
↓		
Are the side differences of NAR and VAS between the nasal cavities of importance? Paper II	→	Yes
↓		
Can we always trust rhinomanometry? Paper III	→	No
↓		
Can treatment with topical budesonide reduce the variability of rhinomanometric NAR? Paper IV	→	Yes

Background

Introduction

The nose acts as the entrance to the airway and has multiple functions as a passageway for airflow, a chemo sensor, an air conditioner, and the first line of defence against infections. In humans and mammals the nose is divided into two anatomically distinct passageways, each of which has its own separate blood supply and nerve pathways. The nasal septum divides the nose into the two cavities and is composed of a bony and a cartilaginous part. The lateral wall of each cavity consists of three bony turbinates hanging into the cavity (Figure 1).

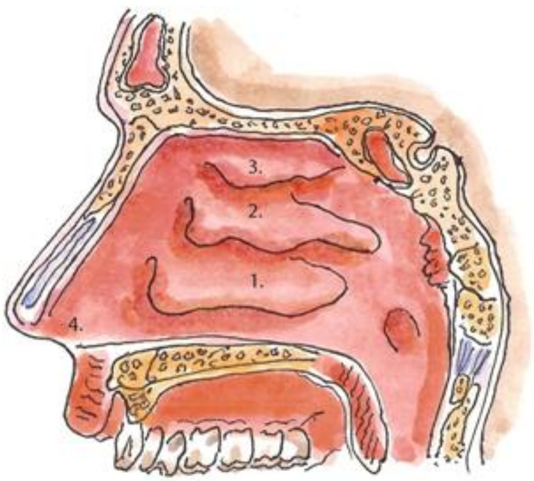


Figure 1. The anatomy of the lateral wall of the right nasal cavity. 1. inferior turbinate, 2. middle turbinate, 3. superior turbinate, 4. vestibulum. *Illustration*: Olav Thulesius.

The nasal mucosa surrounds all the bony and cartilaginous structures, and has a very complex and characteristic vasculature. Two types of vessels may be distinguished: a rich capillary network in the subepithelial zone and around the seromucous glands and a cavernous plexus, the venous sinusoids deep within the submucosa (Kayser 1895). The capillaries are called resistance vessels and the plexus of venous sinusoids are called capacitance vessels (Widdicombe 1986). The latter are particularly found in the anterior half of the inferior turbinates and on the anterior part of the septum.

With a standard resting tidal volume of 0.5 litres and a respiratory rate of 12 breaths per minute the combined volume of inspiratory and expiratory air passing through the nose is ≈ 12 litres/min. (≈ 200 cm^3/sec) (Eccles 2000). The inspiratory air, ≈ 6 litres/min has to be warmed up mainly by the nasal mucosa to body temperature and moistened to nearly 100% humidity (Ingelstedt 1956). At ambient temperatures above zero the nose has the capacity to warm the inhaled air to 32-35˚C (Ingelstedt et al 1951). The nasal airconditioning capacity is lower at night than in the daytime (Drettner et al 1981).

Nasal obstruction is a common condition in the population (Jessen et al 1997). It is defined as discomfort manifested as a feeling of insufficient airflow through the nose. The sensation of obstruction of airflow through the nose may be one of the most distressing of all symptoms of nasal disease. The degree to which nasal obstruction causes symptoms is determined not only by the severity of the obstruction but also by the subjective perception of obstruction to nasal airflow.

Because the severity of obstructive nasal symptoms is not well correlated with measured airway obstruction, it is important to be able to accurately assess the degree of physiological obstruction (Andre et al 2009; Thulesius et al 2012). Methods used to objectively measure nasal patency and resistance include rhinomanometry and acoustic rhinometry. These two methods provide complementary and important objective information concerning the nasal airway. In general, rhinomanometry provides information about nasal airway flow and resistance, while acoustic rhinometry shows the anatomic cross-sectional area, the geometry of the nasal cavity. Other methods used are the four-phases-rhinomanometry (Vogt et al 2010 ; Vogt et al 2011), Ron Eccles' rhinospirometer (Hanif et al 2001) which measures the nasal partitioning of airflow ratio (NPR), and peak nasal inspiratory flow, (PNIF) (Youlten 1983; Klossek et al 2009).

Historic perspective

The first attempt at objectively measure nasal airflow was probably performed by Zwaardemaker in the Netherlands in 1889. He placed a cold mirror beneath the nose and measured the size of the resultant condensation spots (Zwaardemaker 1889).

In 1895 Kayser started scientific studies on nasal airflow. “Only the demonstration of a functional insufficiency of the nose can give our therapeutic intervention greater accuracy, and only in this way can we demonstrate any effects of this intervention in an objective manner” (Kayser 1895).

Glatzel improved Zwaardemakers method in 1901 by using a metal plate instead of a mirror (Glatzel 1901). These hygrometric methods were physiologically perfect because there was no deformation of the nostrils, and no artificial airstream was used. But, they had numerous disadvantages in clinical use since they were dependent on environmental factors such as temperature and humidity etc. Further modifications of these methods were described by Jochims in 1938 by the fixation of the condensed pattern with Gummi Arabicum (Jochims 1938).

Later the hygrometric methods were replaced by methods characterizing the nasal airflow by its physical parameters of flow and pressure; thus rhinology as well as pneumology were following methods based on physics and general fluid dynamics. Methods of estimation were replaced by measurements and calculations. The first rhinomanometric procedures in 1958 were of the passive types (Seebohm & Hamilton). But it was difficult for patients to hold their breath and not to swallow when air was being blown through their nose. These methods have rarely been applied clinically. Sometimes they have even required general anesthesia.

Active rhinomanometry was first used for research purposes (Aschan et al 1958), but later also for routine clinical use. Since then, numerous and important developments have been made like the flow regulator (Ingelstedt et al 1969). Active rhinomanometry can be anterior with the pressure measured at the nostrils (Stoksted et al 1958), or posterior with the pressure measured in the nasopharynx at the base of the tongue (e.g. Kumlien et al 1979).

Since most rhinologists had their own type of equipment and their own examination methods, a standardization was urgently needed. Kern started the standardization procedure in 1977-1981 (Kern 1977, 1981). In 1984 came the first report from the International Standardization Committee of Rhinomanometry (ISCR) lead by Clement from Belgium (Clement 1984). In this the method of measurement in active anterior rhinomanometry (AAR) was standardized. All agreed that AAR was the most common and the most physiological technique of rhinomanometry.

Acoustic rhinometry was added in the early 1990s as a method to measure the cross-sectional area and volume of the nasal cavity (Hilberg et al 2000). A new report from ISCR came in 2005 to try to resolve all controversies to achieve a mutual understanding of clinicians, surgeons, scientists and manufacturers (Clement et al 2005).This report included recommendations for acoustic rhinometry and four phases rhinomanometry

Basic principles of nasal airflow and resistance

Nasal airflow

For a better understanding of the different aspects of rhinomanometry it is useful to have some elementary knowledge of the ventilation mechanisms of the nose. Air moves through the nose due to the work performed by the respiratory muscles such as the diaphragm which contracts to expand the lungs on inspiration. During normal breathing, the expansion of the lungs on inspiration moves air through the nose into the lungs. Nasal airflow always occurs along a pressure gradient from a high pressure area to a low pressure area of the airway. On expiration, the respiratory muscles relax and the elastic lungs recoil to create a pressure in the lungs that is greater than the atmospheric pressure at the nostrils.

The majority of adults are nose breathers, and only resort to an oral or oronasal route under demanding situations such as exercise (Niinimaa et al 1980). Patterns of airflow are difficult to determine in a dynamic situation, but it would seem that on inspiration at rest, air passes nearly vertically up through the anterior nares at a velocity of 2-3 m/s. The flow converges to become laminar and achieves a velocity of 12-18 m/s at the narrowest point, the valve area of the nose, with the direction becoming horizontal. Laminar flow disrupts to a variable extent, depending on flow, after passing through the valve area, which is important for cleaning and conditioning the air. Most of the air then continues along the middle meatus and to a lesser extent the inferior nasal passage. Finally the airstream curves downwards towards the choana and reaches the nasopharynx and continues in a vertical direction. The inspiratory airstream takes a higher curved course while the expiratory airstream follows the lower nasal passage (Cole 2000; Mlynski et al 2001) (Figures 2-3).

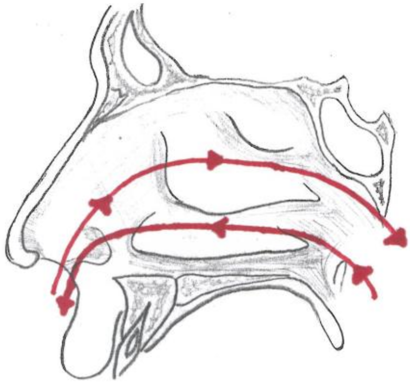


Figure 2. Route of inspiratory and expiratory airstream during normal breathing. *Illustration*: Daniel Thulesius.

Expiration is more turbulent with air flowing throughout the cavity, sweeping inspired air out of the olfactory region. Sniffing creates greater eddies of inspired air in the olfactory niche, but if it is too vigorous, the vestibule collapses due to Bernoulli's principle (increased velocity produces decreased pressure) (Berg et al 1956).

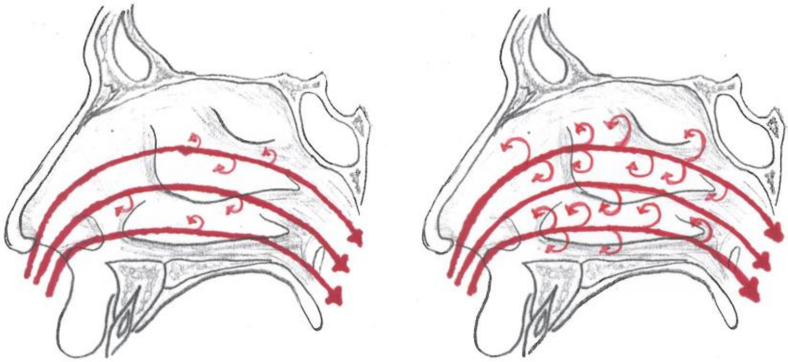


Figure 3. Patterns of the airstream at different flows. At a flow of 10 ml/s (left) the airstream is laminar at the anterior segment and somewhat turbulent in the middle segment of the nose. At a flow of 300 ml/s (right) the airstream is still laminar in the anterior segment but turbulent in the nasal cavity. *Illustration*: Daniel Thulesius.

Nasal resistance

Poiseuille's law ($Q = (\pi\Delta P/8\eta L)r^4$, and $R = 8\eta L/\pi r^4$, where Q = the flow, ΔP = pressure gradient, L = length of the tube, η = dynamic viscosity, r = radius and R = resistance to flow) describes the laminar flow of a gas or fluid through a tube according to the radius of the tube (Roos 1962). And this is applicable to the nose as a "tube" and the airflow as "the gas" flowing through the "tube". From this formula we can see that even a small decrease of the radius have a major influence and gives a great increase (r^4) in the nasal airway resistance.

An adaptation of Ohm's law (in the nose Δp is the pressure drop across the nasal cavity, V° is the nasal airflow and R is the nasal airway resistance) states that in laminar flow:

$$R = \Delta p/ V^\circ$$

But to express complete turbulence:

$$R = \Delta p/ V^{\circ 2}$$

However, we know that airflow through the nose is neither completely turbulent nor laminar. Hence the relationship between pressure and flow varies with flow rate; a defined point is taken on a pressure-flow curve. Thus resistance there is expressed as:

$$R = \Delta p/ V^\circ$$

And by standardizing the resistance at a fixed pressure of 150 Pa (R_{150}) or using Broms' algorithm $R_{2=}$ tan v_2 (see page 25) according to ISCR in 1984 and 2005, it was made possible to compare the results from different studies (Broms et al 1982b; Clement et al 2005; Clement et al 1984).

Anatomical aspects of the nasal airway

External nasal anatomy can be considered in structural thirds (Figure 4). The upper third includes the paired nasal bones. The middle third is composed of the stiff paired lateral cartilages fused to the septal cartilage in the midline. The lower third of the nose consists of softer lower lateral cartilages. From a functional standpoint, the lower and middle thirds of the nose play an important role in the nasal valve. The external valve is defined laterally by the lateral cartilage and medially by the septum, whereas the internal valve is defined by the attachment of the upper lateral cartilage to the septum which forms an angle of approximately *15°*.

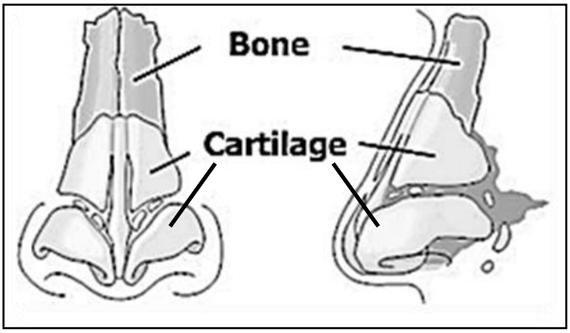


Figure 4. The anatomy of the bone and cartilage of the external nose. The cartilage consists of the upper lateral and the lower lateral (alar) cartilage. *Illustration:* Daniel Thulesius

The internal nose, i.e. the nasal cavity, can also be divided into three areas when considering changes in nasal airway resistance: 1. the vestibule 2. the valve region 3. the erectile tissue on the septum and the lateral turbinated nasal wall. The vestibule contributes to about one-third of the airway resistance, and acts as the flow-limiting segment of inspiration. It is normally stented by the alar cartilages, but will collapse on forced inspiration at a flow of about 30 litres/min (= 500 cm^3/sec) or greater. The valve area lies at the anterior end of the inferior turbinate just within the first few millimetres of the bony pyriform aperture. This area contributes to most of the remaining two-thirds of the resistance. Posterior to this, the lateral turbinated wall contributes very little to the nasal airway resistance.

Nasal cycle

The existence of a cycle of spontaneous reciprocating nasal congestion and decongestion has been well established (Hasegawa 1997; Eccles 1996; Hanif 2000). But, it was accidentally discovered by Kayser already in 1895 (Kayser 1895). One nasal cavity is in a “working phase” while the opposite cavity is in a “resting phase”. This is found in 20-80% of the population, though it largely goes unnoticed, as the total resistance remains constant throughout (Heetderks 1927; Flanagan et al 1997). It results from changes in sympathetic tone, probably controlled by respiratory areas in the brain stem closely associated with respiratory activity. The duration of the cycle varies from 2-7 hours, normally 3-5 hours and is found in the standing, seated and supine positions. The amplitude of the cycle is greatest in subjects lying down and lowest in the standing position. It persists after topical anaesthesia, nostril occlusion and during mouth breathing. It is absent in laryngectomised and tracheotomised patients, though it returns in the latter when the normal airway is restored (Deniz et al 2006; Havas et al 1987; Maurizi et al 1986). The nasal cycle is temporarily abolished by vasoactive substances, exercise and hyperventilation.

Control of nasal resistance

Changes of nasal resistance are primarily the result of a vascular response. This is principally mediated via the sympathetic system, which determines the state of engorgement of the capacitance vessels in the venous erectile tissue on the inferior and middle turbinates and the septum. Stimulation of the adrenergic sympathetic supply leads to vasoconstriction and decrease in blood volume. There appears to be a continuous level of sympathetic tone which, when removed, as in cervical sympathectomy, leads to an increase in nasal congestion and resistance. Parasympathetic supply is mainly to the glands, and stimulation results in an increased watery secretion. Its effect on the erectile tissue is small.

A normal nasal airway resistance of 0.15–0.5 Pa/(cm^3/sec) ($v_2 \approx 8$–26°) is generally accepted after decongestion using the Broms' technique. Broms published his length-adjusted normal data in 1982 (Broms 1982). Since then other authors have presented their normal materials (Gordon et al 1989; Jessen et al 1988; Sipilä et al 1992; Suzina et al 2003). The resistance seems to alter inversely with body height and age but not with gender (Thulesius et al 2009; Zapletal et al 2002). It is important to have reference values for NAR for the technique that is used. Otherwise it is not possible to distinguish between skeletal stenosis and mucosal swelling. Unfortunately, generally usable validated normal data for NAR is still lacking and that is a major problem (Holmström 2010).

Exercise decreases NAR, probably due to an increase in sympathetic tone in the erectile tissue. The onset is rapid, within 30 seconds, and the subject is not usually aware of this change. NAR returns to normal 20-30 minutes after exercise (Cole et al 1983; Forsyth et al 1983) and drops in proportion to exertion, with a 39% reduction at a workload of 75 watts and 49% after 100 watts. Sympathetic vasoconstriction of nasal vessels is part of a general sympathetic effect to maintain the flow of oxygenated blood to the muscles (Olson et al 1987).

Marked changes in NAR result from changes in posture, probably associated with alterations in jugular vein pressure, in addition to the reflex changes in the sympathetic tone (Rundcrantz 1969). Not only does NAR increase in the supine position, but on lying on one side an increase occurs on the dependent side with a reciprocal NAR reduction on the uppermost side (Haight et al 1984; Singh et al 2000). Increase of temperature of the skin in the axilla and lateral chest wall can lead to alterations in nasal mucosal blood flow with increased NAR ipsilateral to the warmth (Preece et al 1993). These changes are believed to be due to corpora-nasal reflexes mediated by pressure and warmth applied to the skin.

The intertwining of sexual arousal, genitalia, and the nose has long been intimately linked (Mackenzie 1884). Foreplay and coitus lead to increased sympathetic reflexes with nasal constriction. But postcoital nasal congestion will then take over (Shah et al 1991). Emotional stress increases sympathetic stimulation and decreases resistance in anticipation of a “flight” (Malcolmson 1959).

Subjective sensation of airflow can be altered by a number of odours. Inhaling the vapour of menthol, camphor, eucalyptus or vanilla, has shown to cause a perceived increase in nasal airway patency, but the NAR remains unchanged (Burrow et al 1983; Eccles et al 1983; Lindemann et al 2008).

Rhinomanometry

The word rhinomanometry means “rhino” for nose and “manometry” for measurement of pressure. The goal of rhinomanometry was in the beginning either to measure how much pressure was required to move a given volume of air through the nose during respiration, or to determine the airflow that could pass through the nose at a given pressure.

Rhinomanometry may be performed by active or passive techniques, and anterior or posterior approaches. In passive rhinomanometry, a fixed amount of air (250 cm^3/sec) is blown through one or both nostrils via an external nozzle, while the subject is holding his/her breath and the amount of pressure needed is measured. The method does not represent normal breathing, and differences between inspiration and expiration are not established.

During the transition from graphical to computerized rhinomanometry it became apparent that the most important parameter is neither the pressure nor the airflow velocity, but the relation between these two parameters. This allows us to better describe the physics of the nasal air stream. The basis of these relations became the accepted standard for evaluating the degree of nasal obstruction in the field of rhinology in 1984 (Clement 1984). Active anterior rhinomanometry is today the most commonly used method of rhinomanometry.

In active posterior rhinomanometry pressure measurements are made with a tube posterior to the base of the tongue with the mouth closed, while the subject breathes through the nose. The airflow is measured for both nasal cavities simultaneously. Since many patients do not tolerate a tube in the back of their mouths, this is not advised as a standard method. It is limited to assessment of the nasal patency in the presence of septal perforations, or if one nasal cavity is completely obstructed (Guyette et al 1997; Naito et al 1992).

Many years ago rhinomanometry equipment was so complicated that the use was limited to research projects. Today, many ENT-departments, especially those where nasal operations are common, have rhinomanometric equipment (Figure 5).

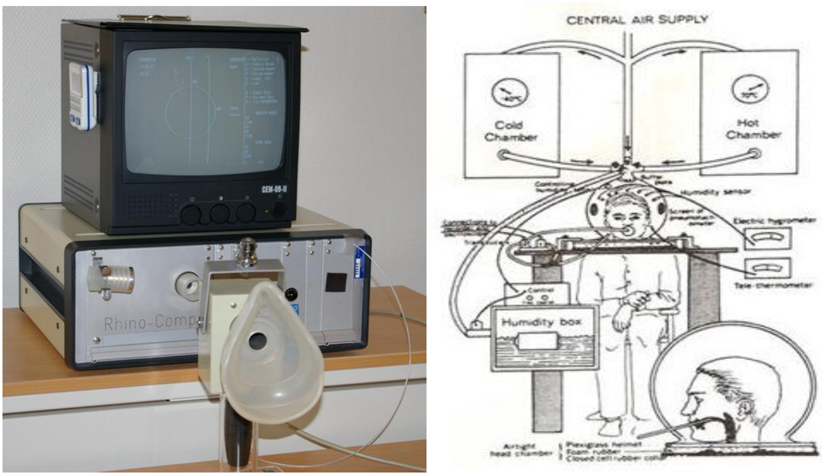


Figure 5. Left: Rhino-Comp®, Sweden. Our active anterior rhinomanometry equipment in Växjö. Right: An earlier complicated rhinomanometric equipment.

In active anterior rhinomanometry the measurement is done during spontaneous breathing with the patient in a sitting position. Anterior means that the pressure difference is measured at the nostrils (Figure 6) (Broms et al 1982a). It was first used only for research purposes, but later also for clinical use. A disadvantage of this method is that any disturbance of spontaneous breathing causes the mucosa to react with either congestion or decongestion as a result. And that is why standardization is important.

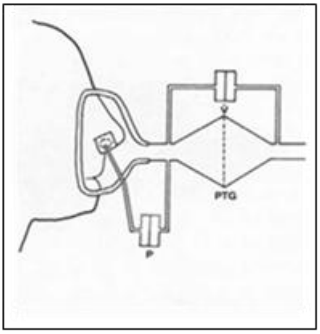


Figure 6. Active anterior rhinomanometry. The subject tested in a sitting position. The pressure-flow relationship during quiet breathing is measured independently for both nasal cavities. An airtight mask is fitted over the nose and connected to a pneumotachograph to measure flow through the side to be tested. A tube is sealed to the nostril of the opposite side to measure the pressure gradient between the nostril and the nasopharynx of the tested side.

At the rhinolab in Växjö we use a transparent airtight facemask with one nostril sealed off with adhesive tape (Figure 7). A hard plastic tube is passed through the tape to measure the nasopharyngeal pressure. This is a dynamic test that studies nasal ventilation, and shows the nature of the air stream. Pressure is recorded in one nostril while the patient breathes through the other (Figure 8).

Figure 7. Sealing of one nostril with adhesive tape. *"Patient":* Sara Thulesius.

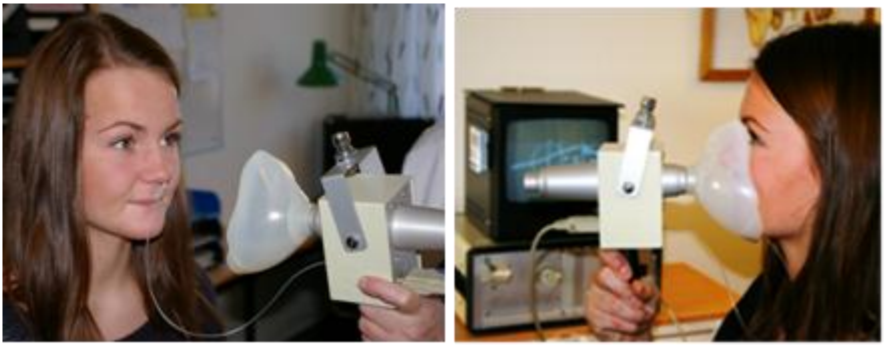


Figure 8. A transparent face mask, similar to that used for administering general anaesthesia is used, incorporating a pneumotachograph and connected to an amplifier and a recorder. *"Patient":* Sara Thulesius.

Rhinomanometry measures the pressure difference (Δp) and airflow (V°) between the posterior and the anterior of the nose during inspiration and expiration. Nasal resistance is calculated according to Ohm's law ($R = \Delta P/V^{\circ}$) and is given at a designated point of the pressure-flow curve. According to the ISCR (Clement et al 2005) the resistance should be given at a fixed pressure of 150 Pa (R_{150}) or as in Broms' model as v_2 (see below). One problem is that the rhinomanometric pressure-flow curve may not reach 150 Pa (Kern 1981; Sipila et al 1992). Yet, nearly every curve will reach a circle with the radius of "2" (200 Pa and 200 cm^3/sec) (Broms et al 1982b).

Nasal airway resistance = pressure across the nose / the nasal airflow

$$R = \Delta p / V^{\circ}$$

In a normal nose and with the resistance given at 150 Pa according to the ISCR, the median value for unilateral inspiratory nasal resistance in the undecongested nose is 0.36 Pa/(cm^3/sec) (range 0.34-0.40), and for the decongested nose during inspiration 0.26 Pa/(cm^3/sec) (range 0.25-0.30). Total nasal resistance may be calculated according to the formula:

$$R_{tot} = R_l \text{ x } R_r / R_l + R_r$$

The nasal pressures are usually measured in Pascal (Pa). The Pascal is a standard international unit (S.I) and is a very small unit. A pressure of 100 Pa equals the pressure created by a 1 cm high column of water. Nasal airflow is usually measured in units of cubic centimetres per second (cm^3/sec). The units of nasal resistance are expressed as a combination of pressure and flow calculated from the formula above and are expressed as Pascal per cubic centimetres per second (Pa/cm^3/sec).

The relationship between nasal pressure and nasal airflow is usually plotted on a computer screen and a diagram of a typical pressure flow is shown in figure 9.

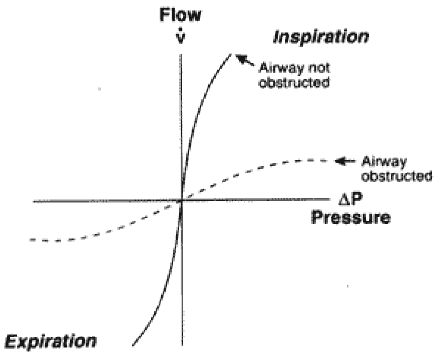


Figure 9. Rhinomanometric recording of transnasal pressure against flow during breathing at rest through an unremarkable nose and through an obstructed nose.

During quiet breathing at low pressures and flows the relationship between pressure and flow is almost a straight line. But at high pressures and flows the relationship becomes more curved. This means that the relationship between pressure and flow is not constant but differs according to where on the pressure flow curve the resistance is measured. With a curvilinear relationship of nasal pressure and airflow it is important to standardize the point on the line at which resistance is calculated so that resistance measurements can be standardized between research centres (Clement 1984; Clement et al 2005).

The relationship between nasal pressure and flow is disturbed at higher pressures and flows, because the airflow becomes turbulent. The nose is a complicated airway with constrictions and changes in airflow direction and this creates turbulent airflow. The turbulent airflow is good for mixing the nasal airflow, and ensuring maximal air conditioning with efficient warming and humidification of the air, as it passes through the nose to the lungs.

Indications for rhinomanometry:

- Rhinomanometry can be used to differentiate if the nasal obstruction is structurally mucosal in nature by conducting the test before and after topical decongestion.

- Objective testing is useful in the quantitative assessment of the benefit of medical and surgical therapy. It can be used to assess the effectiveness of septoplasty and/or turbinoplasty in alleviating nasal obstruction.

- In nasal physiology research it provides quantitative information on the response of the nasal mucosa to intranasal challenges with allergens and other types of physical and chemical stimuli (Malm 2000).

There are two occasions when anterior active rhinomanometry is not possible to use: 1. If the nasal cavity that transmits the pressure from the nasopharynx is totally obstructed no measurement is possible. 2. In septal perforation the flows and pressures recorded are not representative of the nasal cavity being studied.

Decongestants in rhinomanometry

The nasal mucosa covers a 100-200 cm^2 surface area and is highly vascularized with the extensive network of large capacitance vessels present deep within the mucosa. When this network of venous sinusoids is engorged with blood, the swollen mucosa reduces the size of the airway lumen and congestion ensues. The vasculature tone is strongly influenced by the sympathetic nervous system and the only drugs approved specifically to relieve vascular nasal obstruction are α-adrenoceptor sympathomimetic agents. Due to their vasoconstrictor action, the sympathomimetic decongestants oppose vasodilatation. This reduces nasal airway resistance and thus facilitates nose breathing (Bende 1983; Corboz et al 2008). The sympathomimetic agents act even on the resistance vessels with vasoconstriction.

For decongestion in the rhinomanometric procedure we use the selective α_2-adrenoceptor agonists (e.g. xylometazoline or oxymetazoline) which act preferentially on nasal venous capacitance vessel, the sinusoids. Broms used physical exercise on a bicycle ergometer to decongest the nasal mucosa

(Broms 1982). He showed that maximal decongestion was achieved at a heart rate of 150/minute that occurred at a load of 150–250 watts.

In 1988 Jessen and Malm showed that decongestion was best achieved by 0.1% xylometazoline hydrochloride nasal spray twice, 7–8 minutes apart. (Jessen et al 1996; Jessen et al 1988). They compared the decongestion effectiveness of exercise on a bicycle ergometer, nose drops and nasal spray. In our Växjö rhinolaboratory we use their method for decongestion with xylometazoline hydrochloride 1 mg/ml (Otrivin®, Novartis) two puffs of 0.14 ml in each nasal cavity followed by one puff of 0.14 ml extra in each nasal cavity after 7-8 minutes, thus a total of 0.42 ml (420μg) of xylometazoline hydrochloride in each nasal cavity.

The ISCR stated in 1984 that the decongestion of the nasal mucosa was in the hands of the rhinologists (Clement 1984). But in 2005 the committee report update recommended standardized decongestion with a α_2-mimetic administered in two steps (e.g. oxymetazoline or xylometazoline; 2 sprays of 50 μg in each nostril; repeated after 5 minutes with a single spray; thus a total of 150 μg in each cavity) (Clement et al 2005). Measurements should then be obtained at approximately 15-30 minutes after the full effect of the drug is achieved.

International Standardization Committee on Objective Assessment of the Nasal Airway

1977–1981 Kern started a standardizing procedure on rhinomanometry (Kern 1977). This work was followed up in 1983 by Clement and many other investigators from different countries around the world (Clement 1984). All members agreed that the most common and physiological technique of rhinomanometry was active anterior rhinomanometry. They made a consensus report covering nearly every detail of the rhinomanometric procedure like type of mask, patient position, fixation of the pressure measuring tube, type of pneumotachograph, calibration of the equipment, the recording, and the elaboration of results. But the decongestion of the nasal mucosa was initially in the hands of the rhinologists.

Later in 2004 at a follow-up committee meeting, the decongestion was standardized (Clement et al 2005).

The following demands for standardization were listed:

- Daily calibration of the equipment according to the manufacturer's requirements.
- Pressure given in Pa, flow in cm^3/sec (SI units).
- Room temperature and humidity range that allows correct measurements should be specified.
- Adaptation and resting period of 20-30 minutes before measurement.
- The patient is measured in a sitting position.
- Both nasal cavities must be tested separately before and after decongestion.
- Decongestion of the mucosa with an α-mimetic topical spray in two steps (e.g. oxymetazoline or xylometazoline; 2 sprays of 50μg in each nostril; repeated after 5 minutes with a single spray in each nostril).
- Averaging should include 3-5 breaths.
- A transparent airtight mask that do not result in deformation of the nose/nostrils or any displacement of facial tissue and gives no leaks or kinking of the tube.

- Fixation of the pressure tube with adhesive tape without any influence on the nostril.
- The mask is connected to a pneumotachograph which measures airflow through the tested side.
- Synchronous recording of flow and pressure difference.
- Graphic representation with flow on the ordinate, the pressure gradient on the abscissa, inspiration on the right, and expiration on the left.
- The algorithm for calculation of derived data must be mentioned.
- The resistance is calculated according to the formula $R = \Delta p/V^{\circ}$ or according to Broms' model R_2 (resistance at "radius 2").

And in this consensus report, even acoustic rhinomanometry and the four phases rhinomanometry were standardized in the same way for the whole procedure.

Broms' algorithm

When the laminar flow predominates, the resistance is almost inversely proportional to the flow rate (Courtiss et al 1983). When turbulent flow dominates, the resistance can be expressed as

$$R = \Delta P/V^n$$

n=2 when the airflow is turbulent and n=1 when the airflow is laminar. Broms et al proposed a mathematical representation of the pressure-flow curve in a polar coordinate system (Broms et al 1982b). The equation they presented was

$$v_r = v_0 + c\ r$$

v_r is an angle between the flow axis and a line from origin to the point where the pressure-flow curve intersects a circle with the radius r (Figure 10). v_0 is the angle between the flow axis and the pressure-flow curve at origin, r is the radius of a circle and c is a measure of the linearity.

Any curve will reach a circle with a radius of "2" (200 Pa and 200 cm^3/s) which means, that we can get data from nearly all patients. However, data for resistance and conductance are as a rule far from normally distributed. Logarithmic transformation of primary data has often been applied. This is not applicable to a nasal cavity that is totally occluded.

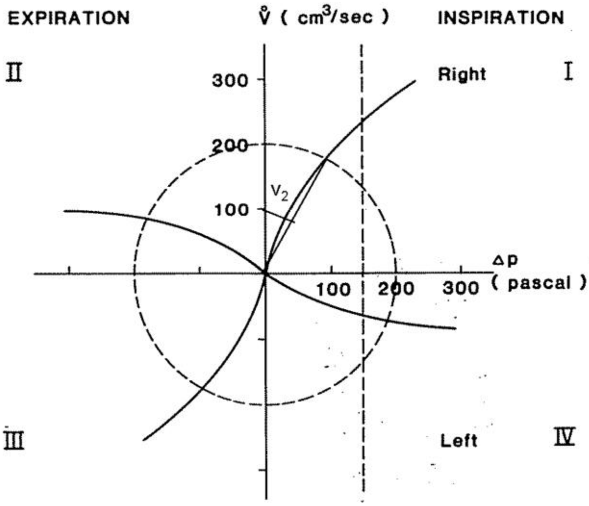


Figure 10. Broms' mathematical model. The v_2 is the angle between the flow axis and a line through the origin to the point where the $\Delta P/V^{\circ}$-curve intersects a circle with a radius of 2 (200 Pa or 200 cm^3/sec). Then $R_2 = \tan v_2$. The vertical dotted line represents the other approach to express the NAR according to ISCR, at the fixed pressure difference of 150 Pa (R_{150}).

With the pressure-flow curve at the standardized condition, the NAR can be defined as the angle v_2 (0-90°), and has been found to be close to normally distributed under normal and pathological conditions. The v_2 and R_2 are convertible. The v_2 represents the statistical mode of the system. But R_2 is used as the comprehensible NAR variable

$$R_2 = \tan v_2$$

The classical way to describe the pressure-flow curve is by using Röhrer's formula: ($P = K_1 \times V + K_2 \times V^2$) where P is pressure, V is nasal flow and K_1 and K_2 are constants which must be determined in an experimental way (Clement et al 1984; Naito et al 1998). But this is not fully applicable to the nasal airways.

Other objective methods

Four Phases Rhinomanometry (4PR)

This is active anterior rhinomanometry using the 4-phase-rhinomanometry software of Vogt and his co-workers (Vogt et al 2010; Vogt et al 2011). The key parameters are not only intranasal pressure and flow, but also time. Resistance is determined for phase 1 (ascending inspiratory phase) and phase 4 (descending expiratory phase) of the four loop rhinomanometry by using the “highest possible flow” at a pressure of 150 Pa.

Acoustic rhinometry

Acoustic rhinometry (AR) is a method to objectively measure the nasal geometry. It is easier to perform than rhinomanometry, but has several pitfalls concerning technique and requires trained staff. AR determinates the cross-sectional area of the nasal cavity as a function of the distance into the nasal cavity. The narrowest part of the nasal cavity is usually situated within a distance of 3 cm from the nares. Two minima have been described here. One reflects the nasal valve and the other the anterior end of the inferior turbinate. The minimal cross-sectional area in cm^2 (MCA) is the interesting point. There is a significant correlation between the AR and the doctor’s evaluation of septal deviation (Szucs et al 1998). And it has been shown that preoperative AR had a significant impact in predicting the postoperative satisfaction after septoplasty (Pirila et al 2009).

Peak Nasal Inspiratory Flow (PNIF)

This is also an objective method to measure the nasal air flow (litres/min), but here both sides are tested together. It is therefore not useful for selecting patients for septal surgery, but could be used for follow-up after septoplasty. It is easy, cheap, and does not require trained staff (Holmström et al 1990; Wihl et al 1988).

Nasal spirometry/rhinospirometry

This is a small hand held device with a nasal adaptor placed to cover the nostrils completely. The expired volume is recorded. The ratio of expired air from each side of the nasal cavity is calculated as nasal partitioning ratio (NPR). The NPR ranges from -1 to +1, with a value of -1 indicating complete obstruction of the left nasal passage, and a value of +1 indicating complete obstruction of the right nasal passage. When NPR equals zero, there is complete symmetry of nasal airflow (Cuddihy et al 2003; Roblin et al 2003).

Radiology

Plain X-ray, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are also objective methods for visualizing the nasal passages. They only picture the anatomy of the nasal cavity but are not useful in diagnosing the cause of nasal congestion.

Subjective assessments of nasal obstruction

Many validated questionnaires are developed to evaluate subjective nasal complaints and their impact on quality of life. But there are no specific questionnaires for skeletal nasal disease. Therapeutic intervention is always aimed at relieving subjective complaints and therefore subjective parameters are necessary and should be used more often.

Visual Analogue Scale, VAS

The degree of subjective nasal obstruction can be estimated by using a visual analogue scale, VAS. The VAS is a psychometric response scale usually represented by a horizontal line, 100 mm in length, anchored by word descriptors at each end. It ranges from 0 (no obstruction) to 100 (complete obstruction). The patients indicate with a cross on the line corresponding to their own perception of nasal obstruction (Ciprandi et al 2009; Marseglia et al 2009). The right and left sides are assessed separately. The VAS is not a symptom-specific instrument for assessment of nasal obstruction. It was introduced in the late 1960s, has great impact, and is easy to understand for the patient. It is frequently used today to assess many different phenomena including pain, nausea and nasal congestion. But there exist some scepticism about VAS being an overly instrumental way of assessing subjective phenomena.

Nasal Obstruction Symptom Evaluation, NOSE

This is a validated disease-specific health status instrument for use in patients with nasal obstruction (Stewart et al 2004). It contains 5 questions on nasal obstruction. The patients score from 0 (not a problem) to 4 (severe problem), total range 0-20 points. The questions are: nasal congestion or stuffiness, nasal blockage or obstruction, trouble breathing through the nose, trouble sleeping, unable to get enough air through the nose during exercise or exertion. NOSE was originally designed for groups, not for individual patients.

Sino-Nasal Outcome Test, SNOT-22

This “health-related quality of life” questionnaire (HRQoL) was originally designed for rhinosinusitis (SNOT-16) (Anderson et al 1999) (SNOT-22) (Hopkins et al 2009), but authors have shown that it is a useful tool for nasal septal surgery too (Buckland et al 2003). The patients rate 22 different symptoms related to both nasal and general health with a score of 0 (no problem) to 5 (problem as bad as it can be), total score range 0-110. The parameters are: need to blow nose, sneezing, runny nose, blockage/ congestion of nose, sense of taste/smell, cough, post nasal discharge, thick nasal discharge, ear fullness, dizziness, ear pain, facial pain/pressure, difficulty falling asleep, waking up at night, lack of a good night’s sleep, waking up tired, fatigue, reduced productivity, reduced concentration, frustrated/restless/irritable, sad, embarrassed. The score can be broken down to 8 “nasal” and 14 “general” health questions, which can be analyzed individually or together.

Aims

The overall aim of this thesis was to investigate the clinical usefulness of active anterior rhinomanometry: as a tool in the septoplasty decision-making process and as a reproducible objective measurement of nasal airway resistance (NAR).

Paper I	An 8-year follow-up to investigate the long term natural course of rhinomanometric pathological nasal resistance and septal deviations in patients without septoplasty.
Paper II	To investigate if it is possible for patients to assess the side difference in nasal airway resistance.
Paper III	To investigate the long term reproducibility of active anterior rhinomanometry.
Paper IV	To investigate if it is possible to reduce the long term variability of nasal airway resistance (NAR) by treatment with topical budesonide.

Designs, statistics and results

Study I

Thulesius HL, Thulesius HO, Jessen M. What happens to patients with nasal stuffiness and pathological rhinomanometry left without surgery? Rhinology 2009;Mar; 47(1):24-27

Materials and methods

Forty-four adult patients with septal deviation not operated upon due to patients' lack of time, fear of surgery, or other treatments, were investigated with active anterior rhinomanometry 7-9 years after their initial and pathological rhinomanometry. Measurements were made according to the ISCR recommendations (Clement 1984; Clement et al 2005). Statistical evaluation was based on v_2 from Broms' algorithm (Broms et al 1982b). As a limit for normal NAR we used Broms' upper 95% CI (Broms 1982).

Statistics

Statistical analysis was carried out using Student's t-test for independent samples to compare the v_2-means from the two measurements (baseline and 7-9 years follow up). Logistic regression models were applied to get Odds ratios (95% CI). A p-value of <0.05 was considered statistically significant.

Results

In a patient survey prior to the rhinomanometric measurements we focused on one question with four alternative answers about the nasal obstruction at follow-up compared to baseline: no nasal obstruction, decreased, unchanged or increased nasal obstruction. We merged "disappeared" and "reduced" subjective nasal obstruction into one group called "improved".

At follow-up 7–9 years later we found that:

16 (36%) had no or reduced nasal obstruction
22 (50%) had unchanged nasal obstruction
6 (14 %) had increased nasal obstruction

At follow-up patients were offered different treatments:

13 (30%) were offered septal surgery again
13 (30%) were offered topical corticosteroids
18 (40%) were no longer in need of any treatment.

These results were compared to a study by Jessen and Malm from 1989 (Jessen et al 1989a) where they did similar follow-up both 9 month and 9 years after septal surgery on 35 patients with pathological NAR who answered the same survey as in our study:

Jessen & Malm, 1989:	
After 9 month:	- 26 (74%) were satisfied with the operation
	- 18 (51%) were free from subjective nasal obstruction
After 9 years:	- 24 (69%) were satisfied with the operation
	- 9 (26%) were free from subjective nasal obstruction

In our study the mean NAR (v_2) from baseline to 8 years follow-up was reduced by:

- 31% in the whole group of 44 non-operated patients
- 29% in the subgroup (n=16) with improved nasal obstruction
- 33% in the subgroup (n=28) with unchanged or worse nasal obstruction

But 48% (n=21) of the non-operated patients still had pathological NAR at 8 years follow-up.

In the follow-up study on septum-operated patients by Jessen and Malm they found a:

- 65 % reduction in mean NAR at 9 years follow-up (narrow side)
- 7 (20%) of 35 patients had pathological NAR 9 years postoperatively

In our study we made a logistic regression analysis and found that the improvement of subjective obstruction at the 8 year follow-up was significantly associated with age and history of allergy at baseline (Table 1). No other variables correlated to improvement in subjective nasal obstruction. Not in univariate regression or in multiple logistic regression models. A history of allergy gave a nine fold increased odds for being in the group that was improved spontaneously without operation. And for every year a patient was older at baseline, the odds increased with 10 % for an improvement at 8 years follow-up. So statistically, a patient 7.25 years older than another patient at baseline, had a 100% increased odds to be improved at follow-up compared to the 7.25 years younger patient.

Table 1. Variables associated with improved subjective nasal obstruction at 8 years (range 7-9 years) follow-up in 44 patients with baseline nasal obstruction without nasal surgery. Odds ratios with 95% confidence intervals. NAR- values after decongestion. * p<0.05, ** p<0.01.

Tested variables	Univariate analysis OR (95% CI)	Multiple regression model OR (95% CI)
Age (years)	1.1 (1.02 – 1.2)*	**1.1 (1.01 –1.14)***
Allergy prevalence	21 (2 – 196)**	**9.0 (1.5 – 52.5)***
Follow-up time (years)	0.4 (0.1 –1.5)	
Baseline NAR, narrower side (v_2)	1.03 (0.97 – 1.09)	
Follow-up NAR, narrower side (v_2)	1.02 (0.97 – 1.08)	
Baseline NAR, wider side (v_2)	1.06 (0.92 – 1.21)	
Follow-up NAR, wider side (v_2)	0.98 (0.85 – 1.14)	
Woman gender	0.3 (0.03 – 2.8)	

Conclusion

In this study we found that 36 % of the non-operated patients were spontaneously improved of their nasal obstruction, and history of nasal allergy or higher age at baseline gave higher odds for improvement at follow-up after 7-9 years.

Study II

Thulesius HL, Cervin A, Jessen M. The importance of side difference in nasal obstruction and rhinomanometry. Clinical Otolaryngology 2012; 37(1)17-22

Material and methods

This is a retrospective study on 1000 anterior active rhinomanometry and VAS results from patients with nasal obstruction. Thus, we had 1000 pairs of NAR measurements and the corresponding VAS assessments. We wanted to study the side difference between the two nasal cavities. The rhinomanometries were performed according to the ISCR. NAR was represented in v_2 values as according to Broms' mathematical model (Broms et al 1982b).

Statistics

We used linear regression analysis models, Spearman's rank correlation test for non-parametric data, and assessed determination coefficients. A p-value <0.05 was considered statistically significant.

Results

When the NAR side difference in v_2 was >20˚ ,R_2 >0.36 Pa/(cm^3/sec), we observed a significant correlation to the VAS side difference (Figure 11). The Spearman's rank correlation coefficient r_s was 0.72, p<0.01, indicating that 52% (r^2=coefficient of determination) of the variation in the VAS side difference could be explained by the NAR side difference.

From the piece-wise linear regression line, we found that in measurements with a v_2 side difference larger than 20˚, the VAS assessment difference increased by 0.9 cm on average for every 20˚ v_2 side difference increment of NAR. Gender or age subgroup analyses did not significantly change these results.

We found that 18% of the 1000 patients had a paradoxical sensation of the nasal obstruction, that means that they experienced more obstruction on the low NAR side (=the highest flow side) (Figure 12).

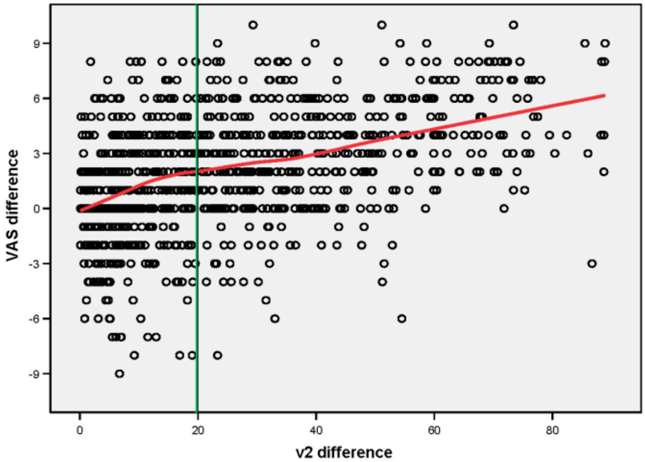


Figure 11. A scatter diagram of the relationship between the side difference in Visual Analogue Scale (VAS) and the side difference in v_2. Piece-wise linear regression (red line) with break point at v_2 difference of 20˚ (green line). N=1000. On the part of the regression line with v_2 side difference >20˚, an additional 20˚ corresponded to an additional VAS side difference of 0.9 cm. On the part of the regression line with v_2 difference <20˚, the corresponding VAS difference change was 2.2 cm. Regression analysis showed significant correlation when v_2 side difference was >20˚. Spearman's r_s=0.72**, p<0.01, r^2=52%.

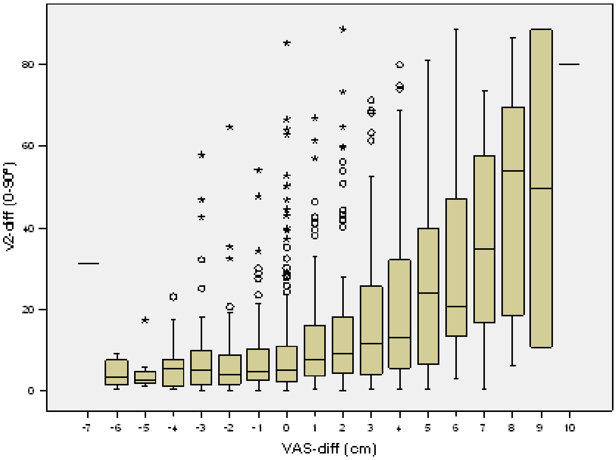


Figure 12. This figure shows a box plot of the side differences in Visual Analogue Scale (VAS) and v_2, n=1000. All the negative VAS-differences (18%) were found in the group with paradoxical sensation of nasal obstruction: they were subjectively more obstructed on the high flow side of the nasal cavity. Outliers=˚, most extreme outliers=*.

Conclusion

A significant correlation between the side difference of NAR and VAS was found when the v_2 side difference was >20˚ ,R_2>0.36 Pa/(cm^3/sec). And we found that 18% of the 1000 patients had a paradoxical sensation of the nasal obstruction.

Study III

Thulesius HL, Cervin A, Jessen M. Can we always trust rhinomanometry? Rhinology 2011 Mar; 49(1):46-52

Materials and methods

We performed active anterior rhinomanometry in 9 healthy participants every two weeks during 5 months (November-March) to test the reproducibility of NAR measured according to Broms' algorithm as v_2 (R_2 = tan v_2) (Broms 1982; Broms et al 1982b). The participants evaluated their nasal obstruction on a Visual Analogue Scale (VAS) immediately prior to the rhinomanometric measurement. The mean age for the 3 men and 6 women participants was 45 years (range 32-59 years). Four reported subjective nasal obstruction. Three had a rhinoscopic septal deviation. None had any subjective allergies, but one had a slight positive STP (skin prick test) for grass (timothy). No one used nasal topical medication during the test period.

The rhinomanometric measurements were performed according to the ISCR standards (Clement 1984; Clement et al 2005). Five of the participants did 10 test-retests the same day, right after each other, to test the short time reproducibility. The decongestion was performed with xylomethazoline hydrochloride spray 1 mg/ml, 2 puffs (0.28 ml) in each cavity and after 7 minutes 1 puff (0.14 ml) in each cavity. The measurements were performed 7 minutes after the last puff of topical decongestants.

Statistics

The Spearman's rank order correlation coefficient and coefficient of variation were used to test the reproducibility.

Results

The rhinomanometric NAR from the decongested nasal cavity is shown in figure 13. Five participants did 10 and 4 participants did 15 rhinomanometric measurements.

Fig.13. The decongested NAR from all the rhinomanometries for the 9 participants during a 5 month period (v_2 on the y-axis and measurement number on the x-axis). The horizontal line is the upper 95% CI limit according to Broms (Broms 1982).

From the 10 test-retests within 60 minutes in 5 participants we found a co-efficient of variation (CV) 8–17% which is within acceptable limits for an investigation method. But long-term we found a relatively high variability with a mean CV of the NAR for the whole group being 27% with the range 8–53%. For the 3 participants with septal deviations CV range was 13–53% and for the 6 participants with straight septums CV was 8–41%. We found NAR values that could move between pathological and normal over time. We found no significant correlation between NAR and VAS. And in 15% of the measurements the participants had difficulties estimating their nasal obstruction on the VAS.

Conclusion

We found a high NAR variation over a period of five months and the NAR could move from pathological to normal and vice versa. This implies low long-term reproducibility of the rhinomanometric NAR.

Study IV

Thulesius HL, Cervin A, Jessen M. Treatment with a topical glucocorticosteroid, budesonide, reduced the variability of rhinomanometric nasal airway resistance. Submitted March 2012.

Material and methods

In this study 8 of the 9 volunteers from study III participated (Thulesius et al 2011). None of the participants had any subjective allergies but one had a slight positive reaction for grass (timothy) in his STP. One participant was a cigarette smoker. Two had septal deviations and 6 had rather straight septums.

The participants were treated with the topical nasal glucocorticosteroid budesonide for a five month period from November to March. During this time they had rhinomanometric measurements done every two weeks, in total 10 times for each participant. The participants assessed their subjective nasal obstruction on a 10 cm VAS immediately prior to the rhinomanometric measurement.

The decongestion and the rhinomanometry were performed as in study III. We then compared the rhinomanometric measurements in the same 8 participants from the two five month periods, with and without treatment with topical budesonide.

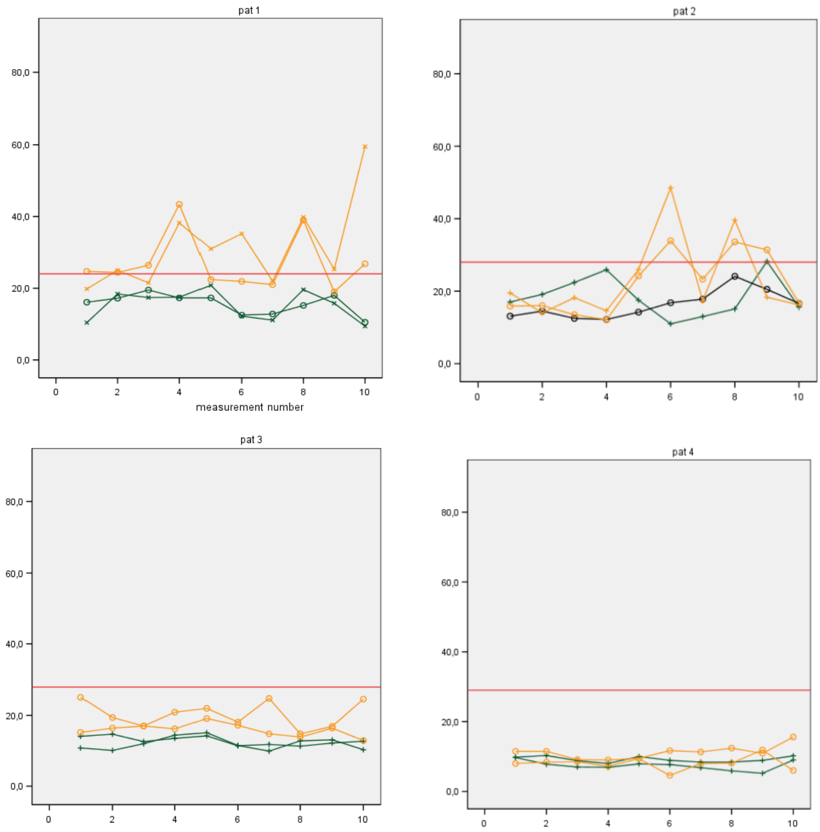
Statistics

Statistical analysis was carried out using Student's t-test to compare the v_2-means, and the F-test to compare their variances (SD^2). Differences in v_2 and VAS between the two five month periods were tested with the Mann-Whitney test. A p-value of <0.05 was considered statistically significant. The coefficient of variation (CV) was used to test the reproducibility of the rhinomanometric NAR.

Results

This study was a controlled before and after intervention. Participants from study III served as their own controls comparing results from rhinomanometries before and after treatment with nasal budesonide. The budesonide treatment started one week prior to the first rhinomanometric measurement.

The mean reduction in NAR was 40% for the decongested nasal cavity when comparing the five month periods with and without treatment with topical budesonide (Figure 14). The mean v_2 value decreased significantly ($p<0.05$) for 6 of the 8 participants during the budesonide treatment period. The coefficient of variation was still relatively high, 8-50%, owing to the fact that both the mean-v_2 and the standard deviation (SD) of the mean had decreased (CV=100 x SD/mean-v_2).



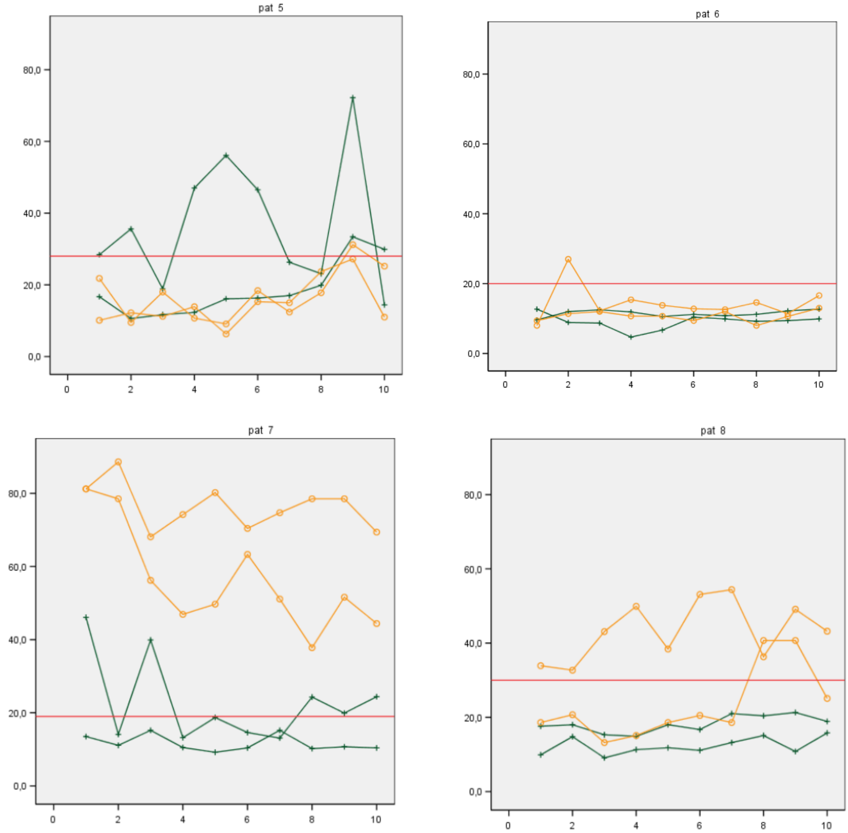


Fig.14. The decongested NAR (v_2 on the y-axis and measurement number on the x-axis) from the 8 participants. The horizontal red line is the limit (upper 95% CI) for normal values according to Broms. The green lines are NAR during treatment with topical budesonide, and the yellow lines are NAR without budesonide treatment.

Conclusion

The long-term variability of the rhinomanometric NAR was significantly reduced by treatment with topical budesonide.

Discussion

Nasal obstruction is one of the most common chronic complaints presenting to the otorhinolaryngologist. The subjective feeling of nasal obstruction may be unilateral or bilateral and can be caused by mucosal disease, a skeletal abnormality, or a combination of both. The challenge to the clinician is to determine the main cause of the obstruction, because this will dictate whether surgical or medical intervention is indicated.

In Sweden we have a quality register on septoplasty results from all surgical centres in the country (http://kvalitet.onh.nu/) available to the general population. National health authorities encourage potential patients to look at these results, and for obvious reasons the profession follows them carefully. In Sweden we registered nearly 4000 septoplasties during 2008-2010. On average for the whole country 24%, that is nearly 1000 patients, were not satisfied with the result of their operation six months postoperatively. The range of patients not satisfied with their septoplasty was 0-60% from different hospitals in Sweden. This is not acceptable, neither from the patients', the rhinologists', nor from a health economics' perspective. It is crucial to select patients with a reasonable expectation of a positive outcome. In Sweden most septoplasties are done as day care surgery under general anaesthesia, and the patient is on sick leave for a week postoperatively.

In 1982 Broms et al showed that of 100 patients who underwent septoplasty, 26 (26%) were not satisfied with the operation (Broms et al 1982c). In their material, 28% had normal preoperative NAR values. Among the patients with preoperatively pathological NAR, 90% had reduced NAR postoperatively, but only 81% were satisfied with the operation. This was 30 years ago, yet we still get the same rate of patients not satisfied with their septoplasty. Other authors have found similar rates of 80-83% for patient satisfaction after septoplasty with or without turbinoplasty (Bohlin et al 1994; Uppal et al 2005).

Selection of patients for nasal surgery

Septoplasty with or without turbinoplasty is a frequently performed ENT procedure to straighten a deviated nasal septum and increase the anterior intranasal space. The rhinologist's decision and patient selection for septal surgery is based on a combination of:

- the anatomy of the nasal cavity (anterior and posterior rhinoscopy)
- the patient's history and subjective assessment of nasal obstruction
- the objective measurement of nasal resistance, flow and dimensions.

Rhinoscopy

The rhinoscopic examination done by the surgeon is subjective, as it is based on the frame of reference of the examiner. In 1961 Cottle divided the internal nose into five areas:

Area 1: The external ostium or naris

Area 2: The valve area or the internal ostium

Area 3: The area underneath the bony and cartilaginous vault

Area 4: The anterior part of the nasal cavity, including the heads of the turbinates and the infundibulum

Area 5: The dorsal part of the nasal cavity including the tales of the turbinates.

This five area division was taken over by several authors, but some authors like Masing 1977 and Rettinger 1988 gave "area 3" to another region, "the premaxillary area". Huizing 2003 suggested a subdivision into three anatomical-physiological parts:

Anterior segment: (the upstream area) the nostril, vestibule and valve area

Middle segment: (the functional area) the mucosa-lined nasal cavity with the turbinates, septum and the sinus ostia

Posterior segment: (the downstream area) the tales of the turbinates, the anterior wall of the sphenoid and the choanae.

No widely accepted objective classification of septal deviations has been developed for routine use but some classification drafts have been made (Baumann I 2007; Guyuron B 1999; Zielnik-Jurkiewicz et al 2006).

Septal deviations are common in the population with studies showing prevalences over 50% (Jessen et al 1989b). Yet, for the majority of people it is not associated with any nasal complaints and therefore does not require surgical treatment (Perez et al 2000; Roblin et al 2003).

The clinician is often confronted with the question whether the presence of a septal deformity is the main cause of the subjective obstruction. And the answer is not always clear. Accurate preoperative evaluation is therefore very important, as other causes of nasal obstruction frequently tend to be underestimated when the surgeon focuses the attention to an obviously deviated septum.

Studies have shown a significant association between postoperative subjective improvement in nasal obstruction and an anterior location of the septal deviation (Konstantinidis et al 2005). Patients with anterior deviation had a greater postoperative improvement compared to patients with anteroposterior and posterior deviations (Dinis et al 2002). This is because the highest nasal resistance is mostly found anteriorly in the nasal cavity, in the valve area (Kjaergaard et al 2008).

Nasal obstruction can be caused by other conditions such as turbinate hypertrophy, adenoid hypertrophy, nasal polyposis or nasal mucosal disease (allergic rhinitis/ hyperreactivity). Therefore both anterior and posterior rhinoscopy should be done diagnostically. The fiberoptic endoscope is a valuable tool here. The rhinoscopy should also be performed both on the undecongested and decongested nasal cavity to visualize the mucosal component of the nasal obstruction. This is very important in nasal surgery decision making since we operate on the skeletal structures bone and cartilage.

Subjective nasal obstruction

The subjective nasal obstruction is the main symptom that brings the patient in contact with the surgeon. And this is what matters to the patient, who has no interest in any values of NAR, MCA or other objective dimensions. By definition, subjective sensation of nasal obstruction is difficult to quantify, unless it is nearly complete. However, assessments of patients' perception of the nasal symptoms with special validated questionnaires (VAS, NOSE, SNOT-22 and others) (Buckland et al 2003; Stewart et al 2004) should be taken into account in the decision to proceed with surgery, because patients with high scores in these surveys have a better postoperative outcome (Marais et al 1994).

André et al concluded after a review of 16 articles in which correlations were sought between subjective and objective nasal obstruction measured with rhinomanometry and acoustic rhinometry: “the correlation is still uncertain and that limits the use of objective measurements in routine rhinologic practice or for quantifying surgical results” (Andre et al 2009). This could be due to the fact that the location of NAR is in the valve region, while the sensation of nasal obstruction could also be related to other areas in the nasal cavity or to other factors than flow, resistance and dimensions.

Another complicating factor regarding experienced patency is the importance of the sensorium of the nasal cavity (Lindemann et al 2008). Studies have shown that inhaling menthol, certain volatile oils, camphor, eucalyptus or vanilla causes a perceived increase in nasal patency without a corresponding reduction in NAR (Burrow et al 1983; Eccles et al 1983). Conversely, it has been shown that local anaesthesia of the nasal vestibule produced sensations of nasal obstruction without change in NAR (Jones et al 1987).

In study II we found that the side difference in v_2 between the two nasal cavities should be larger than 20˚ before the participants could significantly feel the side difference according to VAS assessments. This threshold could be a valuable tool in a checklist for the clinical decision making on septal surgery. When we get rhinomanometric NAR side differences larger than 20˚, and the side with the highest NAR corresponds to the side with subjective obstruction, then this could be one of the keystones indicating beneficial outcome of nasal surgery. We know that patients with unilateral obstruction have higher odds for postoperative satisfaction (Pirila et al 2001). And symmetrical nasal airflow is an important factor for the patient’s satisfaction after septoplasty (McKee et al 1994).

It is highly important for the decision on septoplasty that the subjective and the objective obstructions are on the same side of the nasal cavity. We found in study II that as much as 18% of our 1000 patients had a paradoxical sensation of the nasal obstruction (Kern et al 1976; Kim et al 2007). That means, they felt more obstructed, by VAS assessments, on the side with lowest NAR during quiet breathing (Hirschberg et al 1998; Kern et al 1976; Thulesius et al 2012). But most of these patients in study II had v_2 side differences under 20˚ (Figure 12), so a majority of them were not in the group of patients with distinct unilateral nasal obstruction who would benefit the most from a septoplasty.

The patient history

From a multiple logistic regression analysis in study I we found that patients with pathological NAR plus a history of allergy had a nine times higher odds of being spontaneously improved long term from subjective nasal obstruction compared to patients without a history of allergy (OR 9.0, 1.5-52.5, 95% CI). This in contrast to the findings of Karatzanis who showed that patients with both allergic rhinitis and septal deviation were more likely to be less satisfied after septoplasty as compared to patients without allergy (Karatzanis et al 2009). In a follow-up by Holmström and Kumlien it was shown that of 57 septoplasties based only on clinical examination, 19% (11 patients) were not satisfied 1.5-3.5 years postoperatively (Holmström et al 1988). Eight of these patients (73%) had vasomotor rhinitis or nasal allergy. This states the importance of a comprehensive patient history. In conclusion we should be restrictive with septoplasty in patients with a history of nasal mucosal disease, which should be treated first.

Age and gender

The multiple logistic regression analysis in study I showed an OR of 1.1 (1.01-1.14, 95% CI) for increased age. This means that for every year of increased age at baseline, there was an odds of 1.1 (10%) of being spontaneously improved from nasal obstruction at follow-up after 7-9 years without a septoplasty. So, statistically, a patient 7.25 years older than another patient at baseline had a 100% increased odds to be improved at follow-up compared to the 7.25 years younger patient.

We can only speculate about the reasons why NAR decreased with increasing age. Atrophy of the aging mucosa may eventually make it easier to decongest the mucosa, which then will have lower rhinomanometric NAR. It could also be so that the nose grows with age and that the nasal cavity gets bigger as shown earlier (Goldstein 1936). Other studies have shown that both length and height of the external nose increase with age (Damon et al 1972; Edelstein 1996). So especially for elderly patients we could be more restrictive with septoplasties and recommend a “wait and see” policy. Studies on the nasal epithelium using electron microscopy have not shown age-related changes in the number of ciliated cells or other distinct differences in the nasal mucosa , but changes in the viscoelastic properties of the nasal mucosa may predispose the elderly to nasal crusting which can cause feelings of obstruction (Kushnic et al 1992).

Perhaps should the normal values for NAR not only be length adjusted as recommended by Broms (Broms 1982), but also age adjusted? The ISCR has not dealt with normal values at all, probably due to the wide range of manufacturers of equipment. However, many authors have presented their normal materials (Gordon et al 1989; Sipilä et al 1992; Suzina et al 2003; Zapletal et al 2002). We did not find any significant correlation between gender and NAR in study I, and neither did the aforementioned authors.

Objective measurement of nasal airway resistance

Acoustic rhinometry allows a determination of the cross-sectional area of the nasal cavity as a function of the distance into the nasal cavity and gives a two-dimensional picture of the cavity. It is a static measurement and says nothing about dynamics like the resistance or the flow. Yet it can be an important complement in a checklist for nasal surgery.

All tests or measurements involving patient cooperation can be criticized for not being fully objective. However, in study III and IV we found no signs of the participants being habituated to the procedure.

We cannot fully rely on the patient's subjective assessment of nasal obstruction as we have shown in study II, where 18% showed paradoxical sensations. Also, rhinoscopic findings are not significantly correlated to the NAR. So, we must have reproducible objective measurements of the NAR to optimize our decision making on septal surgery or not.

The rhinomanometry can also reveal a mucosal disease like allergy or hyperreactivity since we always do the rhinomanometric measurements before and after decongestion of the nasal mucosa. It is the decongested NAR which is of interest and relevant in the decision on nasal surgery, because the surgery is done on the skeletal structures bone and cartilage. The standardized decongestion (Clement et al 2005) with a α_2-sympathomimetic agent (e.g. oxymetazoline or xylometazoline 2 sprays of 50μg in each nostril: repeated after 5 minutes with a single spray) normally gives a 40% reduction of NAR (Caenen et al 2005). In study III we found a 33% mean reduction of NAR by decongestion with xylometazoline. In study IV we treated the patients with the topical glucocorticosteroid budesonide during five months. This treatment gave a supplementary 40% reduction of the NAR as compared to decongestion with xylometazoline only. This study also showed that the undecongested mean NAR was reduced by 25% during treatment with budesonide.

The exact mode of action of glucocorticoids on the nasal mucosa has still not been clarified. And since no signs of vasoconstriction has been found (Bende et al 1983; Cervin et al 2001), it could be the treatment of a subclinical inflammatory mucosal oedema. Note that none of the participants in our study had any subjective or objective symptoms of rhinitis.

We started the treatment of the participants with budesonide in study IV one week before the first rhinomanometric measurement. The participants were carefully told to spray laterally in the nose to avoid the risk of septal perforation, especially those with septal deviations (Cervin et al 1998). Even the first measurement gave a significant reduction of NAR as compared to a similar period without budesonide treatment. Future studies will show if we should treat patients with topical glucocorticoids one week or shorter prior to the rhinomanometric measurement to get a more reproducible NAR in nasal surgery decision making.

Careful patient selection is the mainstay of a successful outcome of septal surgery. That is why rhinomanometry definitely has a place in the investigation of nasal obstruction. Most studies on patient satisfaction after septoplasty have shown improved results when rhinomanometry and acoustic rhinometry were taken into account in the decision to proceed to surgery (Bohlin et al 1994; Holmström et al 1988; Pirila et al 2001). And, as we have shown in studies III and IV**,** the rhinomanometry can be made more reliable and reproducible by improving the decongestion of the nasal mucosa or treatment of a submucosal inflammation. In this way we can measure the NAR caused mainly by cartilage and bone, which are the structures correc-ted in septal surgery. But the rhinomanometric decongested NAR must be seen in relation to a careful patient history and rhinoscopy. Hopefully, a better selection of patients will increase the number of patients satisfied after septoplasty.

Conclusions

At present we have no generally accepted method of screening patients for nasal septal surgery like the vision test for sight, the audiogram for hearing, or the spirometry for lung function. But if we put together all the knowledge we have found in this thesis and other studies into a checklist for septoplasty, eventually the amount of unnecessary septoplasties could be reduced and the patients more satisfied after nasal septal surgery. However, we must do more studies in the subjectively nasal healthy population to get the rhinomanometric NAR adjusted to both length and age.

Suggested checklist in favor of nasal septal surgery:

- Subjective unilateral nasal obstruction ☐
- High score on VAS for nasal blockage ☐
- Anterior unilateral septal deviation ☐
- No history of allergic rhinitis or hyperreactivity ☐
- No nasal polyps or adenoids ☐
- History of nasal trauma ☐
- NAR unilaterally pathological ☐
- NAR pathological during GCS-treatment ☐
- Subjective narrow side = objective narrow side ☐
- NAR (v_2) side difference $>20^{\circ}$ ☐
- AR shows pathological MCA in the valve area ☐
- NPR correlates to NAR, MCA and VAS ☐

If most of these boxes can be checked, the chances for a successful outcome of nasal septoplasty should be good.

Populärvetenskaplig sammanfattning på svenska

Nästäppa, som betyder svårigheter att andas med näsan är ett vanligt symtom i befolkningen, och en vanlig orsak till att patienter söker vård. Kronisk nästäppa är ett frekvent symtom (ca 40 % av vuxna) som ofta medför munandning med torra slemhinnor i munhåla och svalg samt snarkning till följd.

Nässkiljeväggen, septum, delar näshålan i två hålrum, som möts i nässvalget. På sidoväggarnas insida finns tre näsmusslor av ben, som hänger ned i hålrummet, vilket gör att näsan får en stor yta. Hela denna yta är täckt av slemhinna beklädd med flimmerhår. Alldeles innanför öppningarna sitter hårstrån som fungerar som ett grovt luftfilter. Små partiklar som ändå kommer in i näsan fastnar i slemmet och förs ner till svalget med hjälp av flimmerhåren. Slemhinnan är dessutom viktig för att göra inandningsluften fuktig. Luften värms upp tack vare ett nätverk av små blodkärl, som ligger under slemhinnan. Vårt luktorgan finns inbäddad i slemhinnan i näshålans tak. Inandningsluften behöver därför komma upp mot nästaket för att vi skall känna lukt.

Näsans trängsta parti, näsvalvet, påträffas någon centimeter in från näsöppningen. Näsan har en riklig nervförsörjning bestående av så kallade sympatiska, parasympatiska och sensoriska nerver. Nästäppa kan påverkas av överfunktion av parasympatiska nerver respektive underfunktion av sympatiska nerver. Fyllnad av blodkärlen i slemhinnan ger mindre plats i näshålan och man upplever nästäppa som sedan släpper när blodfyllnaden minskar.

I befolkningen finns en hög andel av personer med sneda nässkiljeväggar (=septumdeviation), studier har visat en förekomst av upp mot 50%. De flesta är medfödda och ger inga symtom alls. Men en septumdeviation som förtränger näskaviteten och ger nästäppa kan åtgärdas med en operation, septumplastik, där man rätar upp skiljeväggen.

Att avgöra om en patient kan få nytta av en septumplastik är inte enkelt. Från det svenska kvalitetsregistret för septumplastik som är öppet för befolkningen (http://kvalitet.onh.nu/), ser man från perioden 2008-2010 att av de inregistrerade knappt 4000 septumplastiker som utfördes i Sverige, var 76% nöjda med sin operation 6 månader efteråt. Men det betyder samtidigt att 24% alltså nästan 1000 patienter, inte var nöjda med resultatet av sin operation. En hög andel av de som genomgår septumplastik i Sverige gör det i full narkos. Ibland är patienten inlagd på sjukhus ett dygn efter operationen. Och vanligtvis är patienten sjukskriven en vecka efter operationen. Det innebär således ett onödigt lidande och en betydande samhällsekonomisk kostnad för dessa 1000 patienter, som inte blir bra efter sin operation.

För bedömning av nästäppan, i syfte att hitta orsaken, har vi olika frågeformulärer om patientens subjektiva bedömning av nästäppans svårighetsgrad t.ex. VAS (Visual Analogue Scale), SNOT-22 (Sinonasal Outcome Test) eller NOSE (Nasal Obstruction Symptom Evaluation scale). Läkaren gör även en noggrann klinisk undersökning av hela näsan både före och efter avsvällning av slemhinnan. Enligt Svenskt Rhinologiskt Sällskaps konsensus 2004 bör man även göra en eller flera objektiva mätningar av näsflödesmotståndet som rhinomanometri, akustisk rhinometri, rinospirometri, PNIF (Peak Nasal Inspiratory Flow) m.fl.

Aktiv främre rhinomanometri innebär att luftflödet och lufttrycket mäts i en näskavitet i taget på en sittande patient som andas lugnt, och därefter beräknas näsandningsmotståndet. Metoden är känslig och störs av variationer i nässlemhinnans tjocklek. Man sväller därför av slemhinnan med nässpray för att mäta om ett högt motstånd är orsakat av ben-/broskförträngningar i näshålan, t.ex. en sned nässkiljevägg.

Akustisk rinometri innebär att man använder akustisk reflektion för att bestämma näskavitetens geometriska utseende. Det är en ren statisk undersökning som också görs på en sittande patient som andas lugnt.

PNIF och rinospirometri är enklare mätmetoder som ger mera grova mått på näsandningen, största inandningsflöde via näsan och andel som varje näskavitet bidrar med till näsandningen.

Poiseuilles lag som vi minns från fysiken ($Q = (\pi\Delta P/8\eta L) R^4$, där Q = flödet, P = tryckgradienten, L = längden på röret och R = radien) beskriver flödet av en gas eller vätska i förhållande till radien på ett rör. Av formeln kan man se att en relativt sett liten minskning av radien ger en fyrapotens större flödesmotstånd. Detta är applicerbart på näsan ,där små inskränkningar av näskavitetens radie har stort inflytande på andningsmotståndet i näsan.

Många studier har visat att patienternas skattning av sin nästäppa överensstämmer dåligt med de kliniska fynden samt de objektiva mätningarna av näsflödesmotståndet. Detta komplicerar läkarens val av rätt patient till septumkirurgi. Det är därför av största vikt att de objektiva metoderna är bra, och att resultaten är reproducerbara och tillförlitliga. I våra fyra studier har vi granskat hur vi använder rhinomanometri i den kliniska verksamheten i utredningen av nästäppa och hur tillförlitliga resultaten är.

I studie I gjorde vi en långtidsuppföljning av 44 patienter som tidigare var på vår väntelista för septumplastik, men som av olika anledningar inte blev opererade. Vi fann att 36% inte längre hade några större problem med nästäppa efter 8 år. Speciellt patienter som hade näsallergi i sin sjukhistoria eller var äldre var spontant förbättrade.

I studie II granskade vi resultat från 1000 patienters rhinomanometriundersökning och deras subjektiva skattningar av nästäppan. Vi fann att 18% av patienterna paradoxalt nog upplevde den vida näskaviteten som mest täppt. Och vi fann att det bör vara en sidoskillnad i näsandningsmotståndet på över 20˚ i v_2, som är ett matematisk mått på nästäppa, för att patienten ska kunna känna av denna sidoskillnad subjektivt.

I studie III lät vi 9 personer mäta sitt näsandningsmotstånd varannan vecka i 5 månader för att se om resultaten var stabila över tid. Vi fann en stor variation av näsandningsmotståndet vilket gör det svårt att avgöra utifrån ett enda värde, om en patient lämpar sig för septumplastik.

Studie IV var en upprepning av studie III, men deltagarna använde dessutom kortisonnässpray under tiden för att behandla en eventuell underliggande inflammation i slemhinnan. Vi fick ett bättre reproducerbart resultat med minskad variabilitet av NAR och även 40% lägre NAR-värden.

Vi har alltså gjort långtidsuppföljning på patienter med nästäppa som inte har opererats och sett att näsallergi och högre ålder var faktorer som ökade chansen att bli spontant förbättrade. Högre ålder kan således ibland motivera en ”vänta och se” strategi. Vi har granskat samband mellan subjektivt och objektivt näsandningsmotstånd och funnit ett samband mellan sidoskillnaderna mellan de två näshalvorna, som kan användas kliniskt i urvalet av patienter till septumplastik.

Vi studerade reproducerbarheten av näsandningsmotstånd och fann att den varierade en hel del. Vi försökte förbättra resultaten från rhinomanometrin genom att behandla med kortisonnässpray, och vi fick då mindre variabilitet i näsandningsmotståndet över tiden. Vi har således visat att aktiv främre rhinomanometri med mätning av näsandningsmotståndet i varje näshåla var för sig, har en viktig roll i utredningen av nästäppa. Den är också viktig för urvalet av patienter till näsoperation. Vi behöver dock ha normalvärden som utöver att vara längdjusterade även är åldersjusterade. Allt för att kunna bli bättre på att erbjuda rätt patient septumplastik, så att ännu flera blir nöjda med sin operation. Vi har slutligen gjort en checklista med en rad faktorer som kan förbättra urvalet och utfallet av septumplastik.

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