UNIVERSITY OF LATVIA
FACULTY OF MEDICINE

QUANTITATIVE DETERMINATION OF THE MOBILITY OF THE NASAL VALVE

DIPLOMA THESIS

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Abstract

Introduction: The nasal valve area is the narrowest region of the entire upper airway. It is the mobile part of the nose seen as STARLING-resistor. Numerous procedures and spreader devices are published to widen the nasal valve or to stabilize it, but the indications are based only on the surgeon's experience.

Aim: To find out objective methods to determine the role of the nasal valve.

Material and Methods: In 30 healthy volunteers the deflection of elastic steel elements touching the lower nasal side at it deepest point and fixed at a headband was precisely measured by means of strain gauge elements. The deflection was calibrated by given calibration devices. A special 4-phase-rhinomanometer (4PR) with a big protective face mask allowed at the same time to measure airflow and differential pressure. The signals were recorded together with the deflection signals simultaneously on both sides. The measurements have been carried out as unilateral measurements according to anterior rhinomanometry. Data evaluation and PDF-editing were done by using programme "Octave GUI ".

Results: The nasal valve is mostly already moving during quiet breathing (D < 2 mm 32%; D > 2 mm 68 %). The airflow and its acceleration as well as the pressure difference generating a complete closure of the nose can be determined and has expectedly a high variance between individuals. Intended valve effect for sniffing starts in a range between 3 to 4 mm movement of the lateral nasal wall (D < 2 mm = 5%; D > 2 < 4 mm = 67 %; D > 4 mm = 28%). The obtained measurements show good intra-individual repeatability.

Conclusions: The nasal valve is one physiological unit. "External" and "internal" valve are only describing anatomical details. Loops in 4-phase-rhinomanometry represent the mobility of the lateral nasal wall. Strain gauge technique should be developed as Medical Product and can be incorporated in advanced rhinomanometers. The early onset of valve activity should be considered when planning surgical alterations of the nasal valve. The onset of deflection starts before the feeling of valve activity. Valve surgery and prostheses may lead to non-physiological conditions. A „rigid "or immobile nasal valve seems to be an exception.

Key words: lateral nasal wall, nasal valve, elastography, deflection

Kopsavilkums

Deguna vārsta kustīguma kvantitatīvs novērtējums

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Pamatojums: Deguna vārsts ir vissšaurākais reģions visos augšējos elpceļos. Tā ir kustīgā deguna daļa, kas tiek uzskatīta par STARLING-rezistoru. Lai paplašinātu vai stabilizētu deguna vārstu, ir publicētas dažādas palīgierīces un metodes, taču indikācijas to izmantošanai ir balstītas vien uz ķirurgu personīgo pieredzi.

Mērķis: Veikt objektīvu deguna vārsta lomas novērtējumu.

Materiāli un metodes: Pētījumā tika iekļauti 30 brīvprātīgie, kuriem ar elastīgu tērauda elementu, fiksētu pie galvas lentes un aprīkotu ar deformācijas sensoru (*strain gauge*), tika precīzi izmērīta deguna laterālās sienas novirze tās dziļākajā punktā elpošanas laikā. Novirzes kalibrācija tika veikta ar speciālām kalibrēšanas ierīcēm. Izmantojot speciālu 4-fāžu rinomanometru (4FR) ar lielu sejas aizsargmasku, vienlaicīgi tika mērīta gaisa plūsma un diferenciālais spiediens. Visi signāli tika ierakstīti vienlaicīgi abās pusēs. Visi mērījumi tika veikti vienpusēji, saskaņā ar priekšējo rinomanometriju. Datu apstrādei, rediģēšanai un analizēšanai tika izmantota programma "Octave GUI".

Rezultāti: Deguna vārsta darbība lielākoties ir novērojama jau fizioloģiskas elpošanas laikā (D < 2 mm 32%; D > 2 mm 68 %). Ir iespējams noteikt gaisa plūsmu un tās paātrinājumu, kā arī spiediena starpību, kas rada pilnīgu deguna slēgšanos. Starp indivīdiem ir novērojama liela individuālā atšķirība. Paredzamais vārsta efekts forsētas elpošanas laikā tika novērots pie 3 - 4 mm deguna laterālās sienas kustības (D < 2 mm = 5%; D > 2 < 4 mm = 67 %; D > 4 mm = 28%). Iegūtie mērījumi liecina par labu individuālo atkārtojamību.

Secinājumi: Deguna vārsts ir viena fizioloģiska struktūra. „Iekšējais" un „ārējais" deguna vārsts ir tikai anatomiski aprakstoši reģioni. 4FR grafiku cilpas ataino deguna laterālās sienas kustības. Deformācijas sensoru tehnoloģiju vajadzētu attīstīt kā medicīnas produktu un to var izmantot inkorporējot speciālos rinomanometros. Plānojot ķirurģisku iejaukšanos, ir nepieciešams apsvērt agrīnu deguna vārsta darbību, jo tā aktivizācija sākas jau pirms subjektīvas tā darbības sākuma. Deguna vārsta ķirurģija vai palīgierīces var novest pie ne fizioloģiskiem apstākļiem. Rigids vai nekustīgs vārsts, šķiet, ir izņēmums.

Atslēgas vārdi: laterālā deguna siena, deguna vārsts, elastogrāfija, novirze

Introduction

"Valves are structures that are responsible for regulation of the air or liquid flow within the human body. In the nose, the cartilage and the erectile tissue of the nasal cavities - especially those of the inferior nasal conchae and the nasal septum act as valves, regulating air flow". (Nigro, Nigro, Mion, & Mello, 2009)

To this day there is no complete agreement about the terminology of the nasal valve. However, it is known that the nasal valve area is the narrowest region of the entire upper airway and plays a key role in nasal breathing - it is the mobile part of the nose seen as STARLING-resistor.

Difficult nasal breathing is one of the most common complaint in the clinical practice of otorhinolaryngology. Up to now "4- phase rhinomanometry" is one of the major objective functional diagnostic methods to measure the quality of nasal breathing but still there is no one objective functional diagnostic methods that could determine exactly the role of the nasal valve during nasal breathing.

Numerous procedures and spreader devices are published to widen the nasal valve or to stabilize it, but the indications are based only on the surgeon's experience.

The aim of the study

To find out objective methods to determine the role of the nasal valve.

Objectives of the study

1. Quantification of the mobility of the lateral nasal wall under the influence of breathing
2. Verification of loops in 4-phase-rhinomanometry
3. To determine the indication for surgical or prosthetic procedures with influence on the nasal valve

Hypothesis

The nasal valve is not only a passive instrument to close the nasal airway for generating an under pressure to remove mucus or to generate vortices in "sniffing" but is also involved in the entire regulation of the human airway.

1. Literature review

1.1 Anatomy and physiology of the nose

The nose is the most prominent sensory organ of the face (O. Friedman, Cekic, & Gunel, 2017). It is structurally and functionally complex upper respiratory tract organ that provides two important functions: breathing and olfaction. As the primary entry point of the upper airways, it is responsible for warming, humidifying, and filtering of inspired air in ideal quality before it is transmitted to more delicate airways - lungs. Containing the olfactory epithelium, the nose is responsible also for detecting airborne odorant molecules providing the perception of smell (Standring, 2016).

The nose may be subdivided into an external nose, which opens anteriorly on to the face through the nostrils, and an internal portion of the nose, which open posteriorly into the nasopharynx through the posterior openings – choanae (Standring, 2016).

1.1.1 External nose

The shape of the external nasal skeleton is definided by the nasal bones, a pair of rectangular bones in the upper part of the nasal skeleton, bouned to the ascending frontal process of the maxilla, and by the paired upper lateral cartilages (lateral cartilages) and alar cartilages (lower lateral cartilages) in two lower thirds of the nasal skeleton. In the lateral portion of the nasal alea several accessory cartilages are located (see Fig. 1.1). The shape and stability of the alar cartilages not only determines the appearance of the nasal tip and shape of the nares, but is also important in maintaining an effective nasal breathing (Probst, 2000).

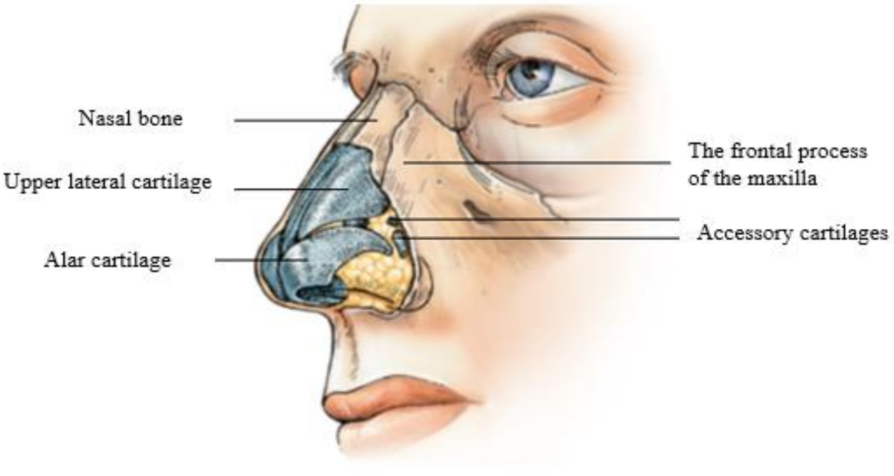


Figure 1.1 Components of the external nasal skeleton (Som, Lawson, Fatterpekar, Zinreich, & Shugar, 2011)

1.1.2 Internal nose

The internal portion of the nose is divided sagittally into the two cavities by the nasal septum, which forms the medial wall of the nasal cavity. The main components of the nasal septum are the vomer, the perpendicular plate of the ethmoid, the quadrangular cartilage, the membranous septum, and the columella. It is cephalically bony and cartilaginous and caudally membranous. Nasal septum is the most important central support for the nose (Ali Totonchi, 2018; Probst, 2000). Laterally, the nasal cavity is bounded by the lateral nasal walls, which contain several functionally important structures – inferior, middle and superior turbinates and their associated passages, openings to the paranasal sinuses and the nasolacrimal ductus (see Fig. 1.2) (Probst, 2000). The beginning of the nasal cavity anteriorly is the nasal vestibules. They are trumpet-shaped openings and each narrow from approximately 90 mm^2 at the nostril to 30 mm^2 right before starting point of the main nasal cavity – piriform aperture. This junction, just anterior to the tip of the inferior turbinate, is the narrowest point of the nasal airway - the nasal valve (Ronald Eccles, 2014; Probst, 2000). The paired nasal valves are main regulators of nasal air flow and resistance. Each of them is divided into external and internal portions, although often only the internal portion is regarded as the “nasal valve” or flow-limiting segment (Standring, 2016).

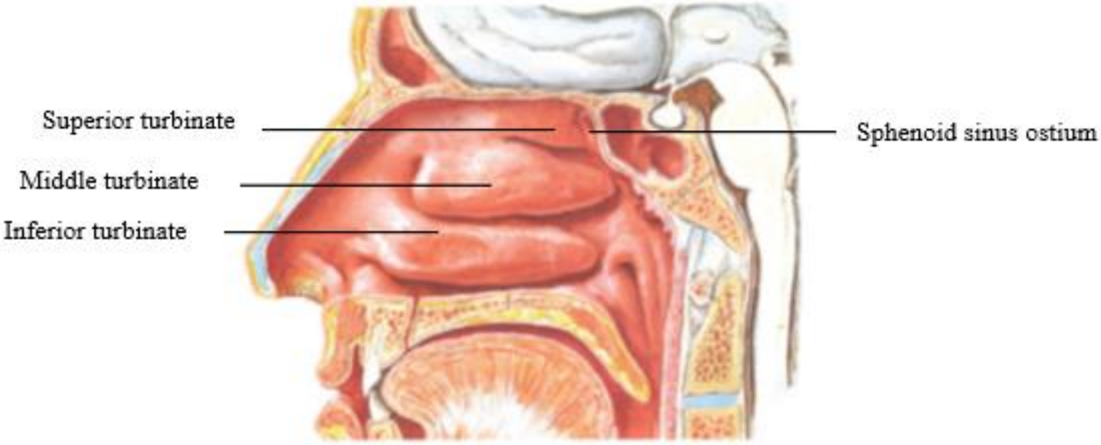


Figure 1.2 Sagittal view of the lateral nasal wall. There are three turbinates - the superior, middle, and inferior. The turbinates are covered with vein rich mucosa. Caudal to each turbinate is the opening of the sinuses (Som et al., 2011)

1.2 The nasal valve

1.2.1 History and definition of the nasal valve

Already 1882, the nasal valve was described by Zuckerland as follows: “The fold of the upper lateral cartilage and the wall of the nasal septum form a space leading into the nasal cavity that is much narrower than the external naris” (Behrbohm, 2016). In 1903 Mink was the first to identify the nasal valve as a single entity. He called this area “the nasal valve” because of its dynamic function in regulating the cross-sectional area of the nasal airway (Mink, 1963). In 1970 it has been characterised in more detail by Bridger (Bridger & Proctor, 1970).

To this day, there is no complete agreement about the nasal valve terminology and correct usage of the term “valve” (Vogt et al., 2010). Review of the numerous publications shows different terminology about the “nasal valve” like – nasal valve area, internal nasal valve and external nasal valve, or just nasal valve (Bloching, 2007; Hamilton, 2017; Som et al., 2011; Standring, 2016).

Rhinoplasty surgeons prefer the division into an external and internal nasal valve because they are distinct anatomic areas, while physiologists rather speak of the nasal valve area as “flow limiting segment” - the place of maximum flow resistance (Wexler & Davidson, 2004).

The nasal valve area is not a singular structure, but a complex three-dimensional construct consisting of several morphological structures. It is bounded by the mobile lateral nasal wall - the caudal margin of the upper lateral cartilage, its fibroadipose attachment to the piriform aperture and the anterior end of the inferior turbinate superiorly and laterally, the anterior septum and the tuberculum of Zuckerkandl medially and by the floor of the piriform aperture inferiorly. This region is the functional unit, that allows air flow regulation (Bloching, 2007; Standring, 2016).

Basing on the anatomical landmarks, there are two valve regions 1) the nostril and the vestibulum – the external nasal valve and 2) the region anteriorly outlined by the ostium internum and posteriorly by the isthmus nasi - the internal nasal valve (see Fig. 1.3 A,B) (Nigro et al., 2009; Shaida & Kenyon, 2000). It seems to be important, that both parts are forming a functional unit.

1.2.2 The internal nasal valve

The internal nasal valve is the upper part of the nasal valve area and it is the narrowest segment of the nasal airway and can contribute up to 50% of the total airway resistance. It is composed of the angle formed by the intersection of the nasal septum medially and the caudal margin of the upper lateral cartilage laterally, the floor of the nose inferiorly and the head of the inferior turbinate inferio-laterally. The angle – the nasal valve angle – between the nasal septum and the upper lateral cartilage in Caucasian population is usually 10 to 15 degree and up to 50 degree in different ethnic groups (see Fig. 1.3 A) (Bloching, 2007; Rohrich, 2009; Som et al., 2011).

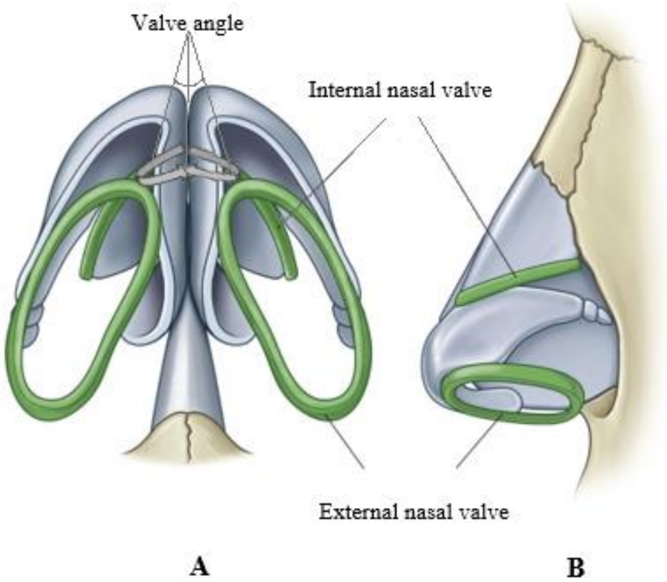


Figure 1.3 Presentation of the internal and external nasal valves (A and B). The nasal valve angle ranges between 10 and 50 degree in the different ethnic groups and often is variable between the two sides (A) (Ali Totonchi, 2018)

1.2.3 The external nasal valve

The external nasal valve is the cartilaginous vestibule bounded by nares and lateral alar sidewalls. The borders of this space are the nostril opening caudally, the septum and the medial crus of the alar cartilage medially, the lateral crus of the alar cartilage with the associated fatty-connective tissue of the wing of the nose anterolaterally, and the internal nasal valve opening posteriorly (Howard & Rohrich, 2002). The external valve tends to collapse at high flow rates even in normal individuals. The function of this valve depends on the structural integrity of the alar cartilages, perinasal musculature, and adequate soft tissue coverage (Hamilton, 2017; Standring, 2016).

1.2.4 Anatomical structures of the lateral nasal wall providing nasal valve stability and integrity

1.2.4.1 Upper Lateral Cartilage

The upper lateral cartilages are a pair of triangular cartilages that support the lateral nasal walls (see Fig. 1.4 A). Its anterior margin is thicker than the posterior margin. The upper part of the cartilage in the midline fuses with the septal cartilage and almost creates a single unit cephalically. The superior margin is attached to the nasal bone and frontal process of the maxilla, but the inferior margin is connected to the lateral crus of the alar cartilage. Laterally, the cartilage is attached indirectly to the margins of the piriform aperture leaving a space between the bone and upper lateral cartilage, which is called external lateral triangle and is surrounded by the caudal border of the upper lateral cartilages cephalically, the frontal process of the maxilla laterally and the cephalic border of the lower lateral cartilage caudally. The angle formed between the caudal end of the upper lateral cartilage and the septum is usually between 10 and 15 degree and represents the internal nasal valve – the narrowest cross-sectional area and the area of greatest airflow resistance (see Fig. 1.4). The cephalic portion of the upper lateral cartilage is overlapped by the nasal bone. The amount of overlap is highly variable and can range between 2 to 11 millimetres (Bahman Guyuron, 2012; Standring, 2016).

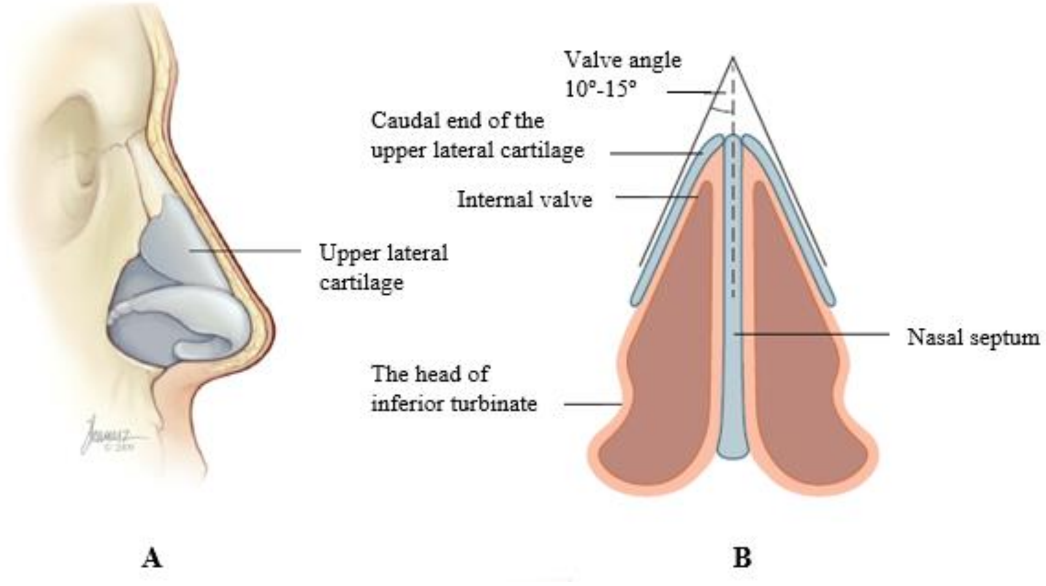


Figure 1.4 Triangular Upper lateral cartilage (A) and its position against the septum forming angle between and comprises the internal valve along with the border of the inferior turbinates (B) (Bahman Guyuron, 2012)

1.2.4.2 Alar Cartilage (Lower Lateral Cartilage)

Traditionally, the alar cartilage has been classified into two parts: medial crus and lateral crus that are connected by a dome segment or the middle crus (see Fig. 1.5). The complex and diverse shapes of middle crus have a very significant impact on the shape of the nasal lobule (Park, Suhk, & Nguyen, 2015). The paired alar cartilages are the primary structural components of the external nasal valve. Despite this, these cartilages are not usually as stiff as the septum (Hamilton, 2017).

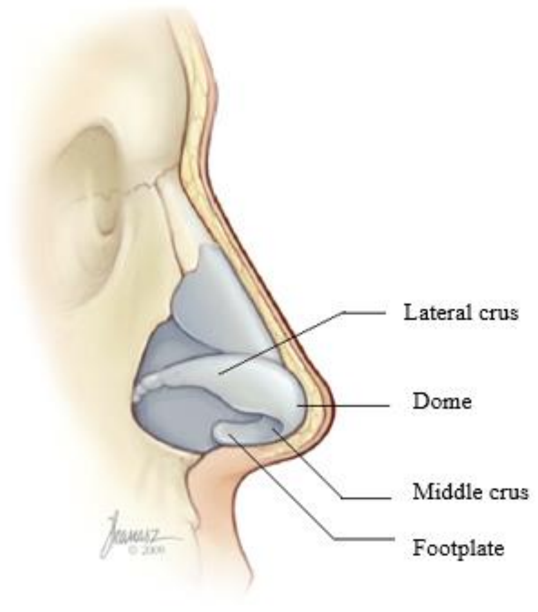


Figure 1.5 Structures of the alar cartilage

The medial crus is classified into a footplate and a columella segment. The medial crura on both sides are attached to each other by a small amount of fibroareolar tissue. Between the two-sided medial crura and the two-sided middle crura lies dense fibrous connective tissue in a horizontal direction. Thus, the two-sided medial crura and the two-sided middle crura are firmly attached to each other. The thick part located at the very front of fibrous connective tissue is referred to as the interdomal ligament (Park et al., 2015).

The lateral crus is the largest component of the nasal lobule and has an important role in defining the shape of the anterosuperior portion of the ala nasi (Park et al., 2015). When describing the position of the lateral crus, it is helpful to imagine that it is having both a long and a short axis (see Fig. 1.6) (Hamilton, 2016). The long axis is a line that bisects the dome and roughly bisects the lateral crus along its length and it should be oriented toward the lateral canthus (Constantian, 2005). When the long axis is positioned closer to the medial canthus or there is any narrowing between the dorsum and the long axis, the lateral crura are said to be cephalically malpositioned. Cephalically malpositioned lateral crura may cause dysmorphology of the tip and are a significant contributor to external nasal valve incompetence (Bahman Guyuron, 2012). The study by Constantian (2005) showed that all the patients with cephalically malpositioned lateral crura had external valve insufficiency.

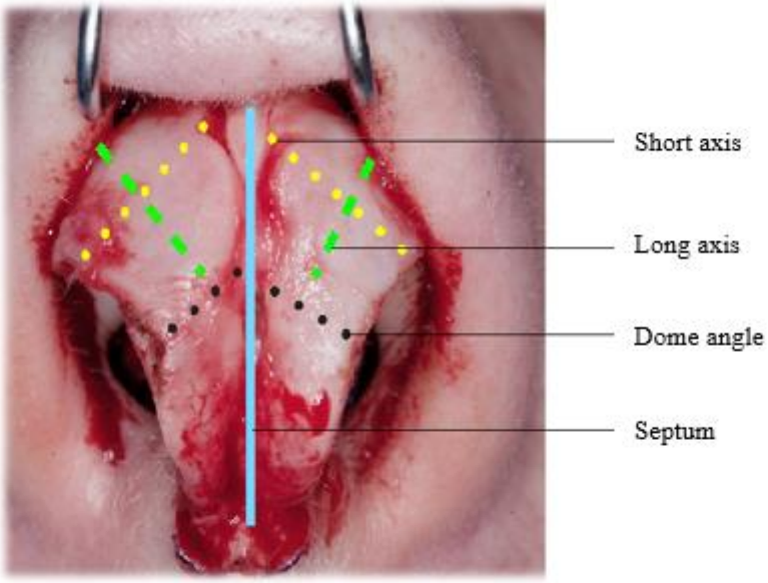


Figure 1.6 The dome angles are represented by the black dotted lines. The short axes of the lateral crura are the yellow dotted lines and the long axes - the green dashed lines (Hamilton, 2017)

The short axis is perpendicular to the long axis and extends from the cephalic border of the lateral crus to the caudal border. Ideally, it makes nearly a 90 degree angle with the septum (Toriumi, 2006). More acute angle provides the lateral crura sagittal malposition, thus decreasing the vestibular volume and also prone to acting like a hinge, predisposing to collapse of the external valve (Hamilton, 2017).

The lateral crus is narrow anteriorly, wider in the mid-portion and narrows again laterally. On the medial side, the lateral crus is in direct contact with the dome segment of the middle crus but on the lateral side, it is usually in contact with the first cartilage of an accessory cartilage chain that is in contact with the pyriform aperture (Bahman Guyuron, 2012; Park et al., 2015). The anterior portion of this cartilage can curve in a variety of directions and controls the convexity of the ala and provides support to the anterior half of the alar rim. Posteriorly it diverges and has more important rule to the function of the external valve than its contribution to the ala (Park et al., 2015). Ideally, the shape of the lateral crus should be gently convex or flat at a 45-degree angle to the vertical facial plane. Markedly convex lateral crura will often be internally recurvate and create a mass effect in the nasal vestibule. Concave lateral crura also decrease the volume of the external nasal valve and can lead to nasal obstruction (Bahman Guyuron, 2012; Hamilton, 2017).

Comparing Asian with Caucasian people, alar cartilage is shorter and weaker among Asian people (Park et al., 2015).

1.2.4.3 The intercartilaginous region

The connection between the caudal edge of the upper lateral cartilage and the cephalic edge of the lateral crus of the alar cartilage is quite unique and is referred to as the scroll area (Park et al., 2015). This intercartilaginous region is anatomically constant and normally the cephalic edge of the alar cartilage is curved and projects over the caudal edge of the lateral cartilages without touching them (Bloching, 2007). These two cartilages are overlapped in this way, thereby improving the function of the internal nasal valve (Park et al., 2015). The magnitude of the curling vary from patient to patient and can be significant enough to cause external visibility and fulness in this area (Bahman Guyuron, 2012). Theoretically, the intercartilaginous joint can be seen as diarthrosis with two degrees of freedom (Bloching, 2007).

Between the junction of upper lateral cartilage and the lateral crus of the alar cartilage are located sesamoid cartilages. They are connected by dense fibrous connective tissue, that also is adjacent to the perichondrium on the surface of the upper lateral cartilage and the alar cartilage lateral crus. These cartilages provide that the lateral crus can move smoothly above the upper lateral cartilage, that translational and rotational movements are possible in this joint. An inward and outward deflection is possible by the elastic properties of the alar cartilage (Bloching, 2007; Park et al., 2015).

The elasticity of the cartilage mainly depends on the free lower end of the lateral crus and its intense connection to the lateral cartilage. Any torsional forces in the area of the alar cartilage are associated with a deflection of the lateral cartilages (Bloching, 2007).

In the lateral area between the crus of the alar cartilage and the piriform aperture is located a chain of several cartilages - the accessory cartilages. They are interconnected with each other, also the lateral crus through the dense fibroareolar tissue. They are important for the shape of the nose (Bahman Guyuron, 2012; Park et al., 2015).

1.2.4.4 Soft tissue

Soft tissue envelope, dense fibrous, fibroareolar connective tissue between the cartilages and at the alar base area, they all are important in a sense to provide stability and integrity of the cartilages thus stabilisiating the area of the nasal valve (Ali Totonchi, 2018; Bahman Guyuron, 2012).

Another structure that plays a vital role in ensuring the valvular mechanism is the underlying perinasal musculature (see Fig. 1.7). The perinasal musculature mainly originates in the maxilla or in in the alar cartilage and inserts at the skin, aponeurosis of the nasal dorsum or the cura of the alar cartilages. It can be divided into an intrinsic (the origin and insertion is located within the perinasal area) and an extrinsic group. (Ali Totonchi, 2018; Bloching, 2007). The upper lateral cartilage is free of any muscle attachments or origins of muscles, only the *musculus nasalis* spans the dorsum of the nose. *M. nasalis* originates from the maxilla near the canine fossa and divides into *pars transversa* and *pars alaris*. *M. nasalis pars transversa* (*compressor nasi*) crosses the lateral cartilages and keeps the nasal skeleton, the intercartilaginous region and the nasal valve in place. It contracts the nostrils, thus narrowing the external nasal valve, and compresses the nose (Bloching, 2007; B. Guyuron, 2006). Another muscle that acts as a depressor and constrictor of the nostrils is *musculus depressor alea* (*musculus myrtiforme*). It originates from the border of the pyriform crest and then rises vertically up to the ala. Release of this muscle during alar base surgery has a beneficial effect on the external valve (Ali Totonchi, 2018; Bahman Guyuron, 2012).

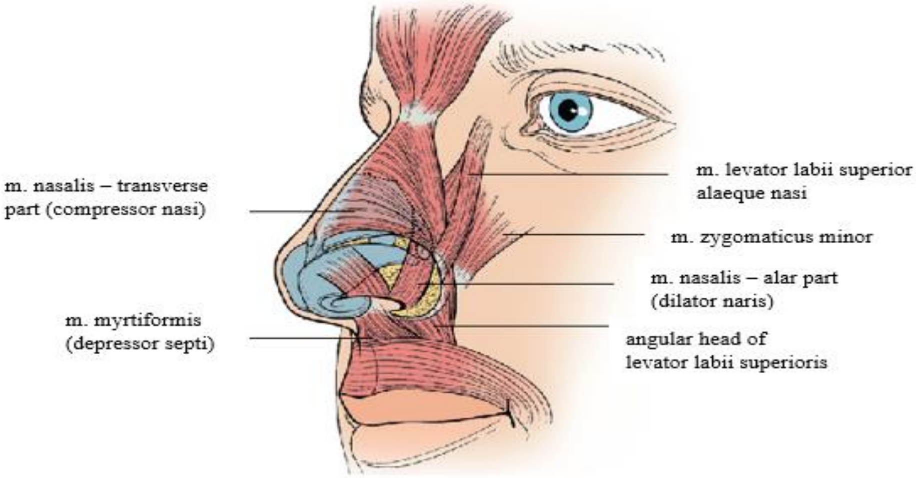


Figure 1.7 The anatomy of perinasal muscles (Som et al., 2011)

Two of the most important muscles with opening function that widens the nasal valve are *musculus dilator naris anterior* (*apices nasi*) and *m. nasalis pars alaris*. *M. dilatator naris anterior* originates at the lateral crus of the alar cartilage and inserts into the skin of the wing of the nose. It has a stabilising function on the external nasal valve and it acts as a primary dilator of the nostril indirectly opening also the area of the nasal valve (Bloching, 2007; Standring, 2016). The alar part of the nasalis muscle inserts at the accessory cartilages and the skin in the region of hinge area. This enables it to pull this structure in the lateral direction and widen the internal nasal valve (Bloching, 2007; Hamilton, 2016). Also the muscles from extrinsic group like *musculus levator labii superior alaeque nasi*, *musculus zygomaticus minor* acts like dilators and stabilise the lateral nasal wall (Ali Totonchi, 2018). Damage to this muscles may result in collapse of the external nasal valve (Bahman Guyuron, 2012).

Another structure worth mentioning is formed by the *vibrissae*. It is hair-bearing skin that is lined in the circumference of the vestibulum – the area of the external nasal valve, except the thin skin under the lateral crus and the mucosa of the septum (Hamilton, 2017; Standring, 2016). Despite it does not affect directly the stability of the lateral nasal wall, recently have been shown that this hair-bearing skin make a significant contribution to resistance in the external nasal valve. (Hamilton, 2017).

1.3 Physiology of the nasal valve area

On entering the nasal cavity, inspired air traverses the narrowest passage in the upper airways – the nasal valve area. It is a “flow limiting segment” – the place of maximum flow resistance. It is a dynamic structure, that due to its mobile nature, narrows and widens during the respiration and helps to realize the respiratory function (Bloching, 2007; Som et al., 2011). To protect the lower airways and lungs from unconditioned air, the nasal valve by collapsing does not allow extreme inspiration (Behrbohm, 2016; Vogt et al., 2010). It can be opened to a small extent by forced expiration and can be completely closed by forced inspiration (Vogt et al., 2010). However, the weakness of the valve – excessive mobility – can cause a nasal obstruction. Nose wings surrounding skin, mucosa, cartilage and subcutaneous muscles – all of them determine the stability and stiffness of the valve (O. Friedman, Koch, & Smith, 2012).

It is well known that external nose acts as Starling resistor - invested by Ernest Starling (Knowlton & Starling, 1912). As Starling resistor, it can be represented as a rigid tube with a collapsible segment which depends on external pressure changes. During inspiration, a pressure difference is created between the nasopharynx and the atmosphere, and the pressure in the nasal airway decreases towards the nasopharynx (Hamilton, 2017).

Due to the nasal cartilage elastic properties, the cartilaginous part of the external nose produces a negative intraluminal pressure as a result of Bernoulli's principle - as the velocity of a fluid increases, its pressure decreases. Bernoulli's principle defines flow through a tubular structure such that the flow at two ends is constant. When crossing a narrowed segment, in this case, the nasal valve area, flow velocity must increase thus it generates collapsing forces on the valves. These forces are reinforced during heavy inspiration or sniffing (Howard & Rohrich, 2002).

Bernoulli's principle can be mathematically substantiated using Poiseuille's Law which states that flow is directly proportional to the difference in pressure multiplied by the radius raised to the fourth power. Flow is also inversely proportional to the length of the tube (Howard & Rohrich, 2002).

$$\text{Flow} = \text{Constant }(K) \times dP \times r^4 / \text{Length}$$

According to this law, any changes in the radius in either direction or in a tube (nose) length have a great impact on the flow. In turn, a minimal increase in the size of the tube causes an exponential increase in flow (Ali Totonchi, 2018; Howard & Rohrich, 2002). The cross-sectional area varies throughout the nose, and since it is narrowest at the level of internal nasal valve, any changes in this area can have profound changes on nasal air flow. Clinically, decrease of the cross-section area could be seen due to nasal septum deviations, hypertrophy of the head of the lower turbinate, bony constrictions of the piriform aperture, anatomic variations of the cartilaginous lateral nasal wall or scarred stenosis of the nasal valves resulting in nasal obstruction (Ali Totonchi, 2018; O. Friedman et al., 2012; Howard & Rohrich, 2002).

An understanding of laminar and turbulent flow is also essential to a complete understanding of respiration and nasal air flow physiology and dynamics. The air flow variation depends on acceleration and grinding, as well as from the area and the length at which the air moves. Under ideal conditions, the flow of gases through a tube is laminar, but in vivo due to the natural conditions, nasal air flow is never truly laminar, because air flow does not follow a straight course through the nasal passage. Turbulent flow result when the laminar flow is compromised. To overcome turbulence, a greater pressure gradient must be generated. Most inspired air travels through the middle meatus with smaller amounts above and below (Ali Totonchi, 2018; Howard & Rohrich, 2002). Seren (2006) derived that the nasal valve essentially leads to transformation from laminar to turbulent flows. These statements are still hypothetic and have to be verified by Computational Fluid Dynamics (CFD).

1.4 Disorders of the nasal valve area

Since there are so many structures that plays an important role in the integrity and stability of the nasal valve, it is not surprising that there are multiple ways that nasal valve insufficiency can manifest.

Rhee and Kimbell (2012) summarize the problem of valve insufficiency as a problem of the opening being too narrow, the lateral wall being inadequately rigid, or both. Depending on the pathology, most of the authors summarise that disorders of the nasal valve can be distinguish as dynamic or statistic. Both disorders can occur at the same time (Bloching, 2007; Motamedi, Stephan, & Ries, 2016).

Obstruction at either the internal or external valve regions can be static, meaning that the magnitude of obstruction is not affected by negative inspiratory forces created by respiration (O. Friedman et al., 2017). Causes of static disorders include septal deviation, internal recurvature of the lateral crus, widened columella, sagitally malpositioned lateral crura, hypertrophy of the head of the lower turbinate, bony constrictions of the piriform aperture, or scarred stenosis of the nasal valves (Ghareeb, Patel, & Bakry, 2013; Hamilton, 2017). Vestibular stenosis is much more uncommon cause of static obstruction than it is stenosis in the area of internal valve region. Causes of the stenosis can be due to the infection, trauma, previous surgery or iatrogenic insults, leading to the injury of the mucosa or weakened cartilaginous support of the nasal valves with following scar formation and contracture (O. Friedman et al., 2012). Any narrowing and restriction of the cross-sectional area of the nasal valve plane according to Poiseuille’s law will lead to restricted mobility of the nasal valve, thereby causing sensation of nasal obstruction.

In contrast, dynamic collapse of the sidewall is triggered by the inspiratory negative pressures obstructs nasal breathing in inspiration (Motamedi et al., 2016). Dynamic causes include weakness in the alar cartilages – cephalically malpositioned lateral crura, also facial weakness due to neurogenic causes (facial nerve paralysis, stroke) that leads to muscle impairment (Ghareeb et al., 2013; Hamilton, 2017). The most common causes of nasal valve obstruction are previous rhinoplasty (79%), followed by nasal trauma (15%) and congenital anomaly (6%) (Ghareeb et al., 2013).

Pathologies of the nasal valve can also be divided into primary and secondary. Primary causes for the nasal valve impairment could be due to congenital sidewall weakness with resulting collapse phenomena or acquired by aging, while secondary due to previous nasal surgery after inappropriate resection of the cartilaginous supporting frame of the nose (Bloching, 2007). As in any other tissue, with increasing age, structural changes occur also in the cartilage involving a loss of the elastic properties that leads to changes of the static conditions. Also, age-related loss of tone to the nasal musculature can result in the drooping nose tip thus resulting in weakened lateral nasal wall. Since the rhinoplasty is the most common cause of the nasal valve insufficiency, despite the inappropriate resection of the cartilaginous supporting frame or the loss of function of the musculature, these previous mentioned congenital or age-related factors should be considered as possible contributor causes for nasal valve obstruction after surgery (Bloching, 2007).

1.5 Diagnosing the disorders of the nasal valve area

Disorders of the nasal valve are frequently overlooked and/or not included in a systematic examination thus resulting in false diagnoses and unsuccessful surgical treatments of impaired nasal breathing (Paccoi & Di Peco, 2007). Due to the complexity of nasal physiology and the patient's subjective factors, currently there is no particular examination method to evaluate the respiratory function of the nose in the region of the nasal valve area (Miman, Deliktas, Ozturan, Toplu, & Akarcay, 2006).

1.5.1 Subjective diagnostic methods

Bloching (2007) and Hamilton (2017) have carefully described the role of patient's history and physical examination - as the foundation of identifying the source of nasal valve dysfunction.

While taking patients history, it is helpful to watch how the patient breath. Is there noticeable collapse during quiet breathing or it appears only during in forced breathing, is it symmetrical or identifiable just in one nostril (Hamilton, 2017). During physical examination, the examiner also should do the inspection of the nose paying attention first to the external nose, then second to the internal nose during anterior rhinoscopy. Thick, sebaceous skin may result in weaker lateral support, a deep alar groove may indicate of malpositioned lateral crus. Also, a parenthesis deformity of the tip usually represents an underlying sagittal malposition of the lateral crus, while bulbous tip and alar retraction are often found in cephalically malpositioned lateral crura. Another structure that is necessary to be inspected is the opening of the nostrils. Narrowed nostril opening due to the over projected tip or widened columella from short medial crura - both can cause a static and/or dynamic obstruction. Also, asymmetric medal cruras could indicate a deviation of the caudal septum. During examination of the internal nose, the examiner must determine size and shape of the isthmus nasi, septal deviation, nasal valve angle, deformities of the lateral or alar cartilages, elasticity of the cartilages, cicatricial stenosis, size of the body piriform aperture and other characteristic signs that could indicate deficiency of the nasal valve (Bloching, 2007; Hamilton, 2017).

During examination, a lot of authors recommend to perform the Cottle’s manoeuvre, that was described for the first time by Heinberg and Kern in 1973. It involves widening of the nasal valve area by pulling it in lateral direction near the alar groove. For the involvement of the valve indicates an improvement of nasal breathing (Bloching, 2007; Hamilton, 2016). Hamilton (2016) emphasize that a standard Cottle manoeuvre is of little diagnostic value because it improves nasal breathing also to patients without nasal obstruction and a modified Cottles manoeuvre (see Fig. 1.8.) should be used instead (Fung, Hong, Moore, & Taylor, 2014; Hamilton, 2017).

After careful patient physical examination, next step to consider as standard for the exploration and evaluation of the nasal valve area is rigid or flexible nasal endoscopy (Hamilton, 2017). The role of nasal endoscopy investigating nasal cavity and the difference in the shape of the valve angle were described in a study by Miman et al. (2006).

Figure 1.8 Demonstration of the modified Cottle nasal valve manoeuvres ((A) = external valve; (B) = internal valve), with the curette placed (Fung et al., 2014)

1.5.2 Objective diagnostic methods

However, to the patient group that has subjective complains or objective findings, an objective functional diagnosis must be made. Still, objective measurements of the valve insufiency are challenging due to limited tests and its interpretations (Hamilton, 2017). Currently the most used methods to objectively evaluate nasal airway patency is:

1.5.2.1 Acoustic Rhinometry (AcR)

First described for clinical use by Hilberg in 1989. (Hilberg, Jackson, Swift, & Pedersen, 1989). AcR is an objective method for exploring the structural anatomy of the nasal cavity that is based on the comparison of emitted and reflected sound waves on the walls of the nasal cavity, thus it can objectively measure the minimal cross-sectional area (mCSA), volume of nasal cavity (NCV) and the distance from the nostril to the minimum cross-sectional area (MD) (Vogt et al., 2010).

In the review by Corey (2006), the role of AcR in clinical practice was described. His review provided an update of the new standard for interpretation and expanded clinical uses. One of her main conclusion was that it should be utilized to improve our ability to practice evidence-based medicine in rhinology (Corey, 2006).

Within a study in Rhinology (supplement 21), Cao et all (2010) compared nasal airflow resistance by 4-phase Rhinomanometry with nasal airway volumes by Acoustic Rhinometry in symptomatic and asymptomatic Chinese with nasal septum deviation. Their main conclusion for evaluating nasal patency of subjects with nasal septal deviation was that the objective techniques like 4-phase Rhinomanometry and AcR, have significant correlation and should be performed together to provide insight into the physiology and anatomy of nasal airflow (Vogt et al., 2010).

In the recent review of the literature on diagnosis of nasal obstruction by Valero et all (2018), it is said that AcR has much more benefits over Active Anterior Rhinomanometry when measuring nasal provocation test, due to its ability to measure NV and MCA of the nasal passages more quickly and easier, and with a high degree of sensitivity and specificity. However, when it is needed to interperate the results, it gets difficult, because of the normal nasal fossa variations due to the countless variabilities in the context of mid-facial growth and development, ethnic/racial characteristics, age, weight, etc. (Valero et al., 2018).

However, when diagnosing nasal valve disorders, AcR is an inappropriate method, because it can measure the volume of the nasal passage but will not account for the dynamic nature of valve collapse (Hamilton, 2017). One reason is the fixation of the measuring tube by pressure at the respective nostril.

1.5.2.2 "Classic" Rhinomanometry

Active Rhinomanometry can be distinguished between two measurement techniques after deriving the pressure difference between nasal entrance and choanae: the anterior and posterior methods (Vogt et al., 2010).

Active Anterior Rhinomanometry (AAR) is the recommended technique for the objective assessment of nasal airway resistance. This technique allows simultaneous measurement of the pressure gradient (Δp) and variations of the airflow ($\dot{V}$) in the nasal passages during the breathing cycle. AAR involves closing one nostril with a measuring pressure tube, the other nostril thereby serving as an extension of the tube. Measurements are taken before and after using decongestant nasal drops, thus allowing to difference whether nasal respiratory failure is more likely to be functional than structural. The International Committee on Standardization for the Objective Assessment of the Upper Airway (ISCOANA) advises AAR using a face mask and a computerized record of pressure, flow and resistances as the recommended test in daily clinical practice (Clement & Gordts, 2005; R. Eccles, 2011).

Active Posterior Rhinomanometry (APR) measures pressure difference via a tube in the mouth held by the lips and data is obtained from both sides of the nasal cavity. In order, to precisely measure total nasal resistance by APR, the soft palate and the tongue must be relaxed. Limited patient's ability to understand how to perform the measurement or differences in nasopharyngeal anatomy, rhinomanometric results obtained by APR are not always objective or comparable to results by AAR (Vogt et al., 2010).

1.5.2.3 "4-phase rhinomanometry" (4PR)

The term "4-phase rhinomanometry", formerly called "High Resolution rhinomanometry" for the first time was described by its creators (Vogt and Hoffrichter) already in 1994. The diagnostic aim of 4PR is to measure the intranasal pressure, flow and time variables necessary for maintaining an adequate oxygen supply through the nose. (Vogt et al., 2010)

In supplement 21 of "Rhinology", Vogt et al. (2010) after long lasting international multidisciplinary research presented a new type of rhinomanometry and its new parameters, thus outlining the difference between the “classical” and 4FR. The new parameters: Effective Resistance (Reff) and Vertex Resistance (VR) and their logarithmic transformations allowed to see the correlation about patient’s subjective sensation of obstruction and to classify obstruction within five classes (see Tab.Nr 1), as well as, to calculate and analyse 4 phases of the nasal respiratory cycle – acceleration and deceleration, both in inspiration and expiration (see Fig 1.8). After all, they considered that it should be implemented in the standards of ISCOANA (Vogt et al., 2010).

Table 1.1 Classification of nasal obstruction in Caucasians

	Log10R (VR, REFF)	Flow (ccm/s) Inspiration1/150 Pa	Obstruction, Resistance
1	< = 0.75	> 500	very low
2	0.75 - 1.00	300 - 500	low
3	1.00 - 1.25	180 - 300	moderate
4	1.25 - 1.50	60 - 180	high
5	> 1.50	< 60	very high

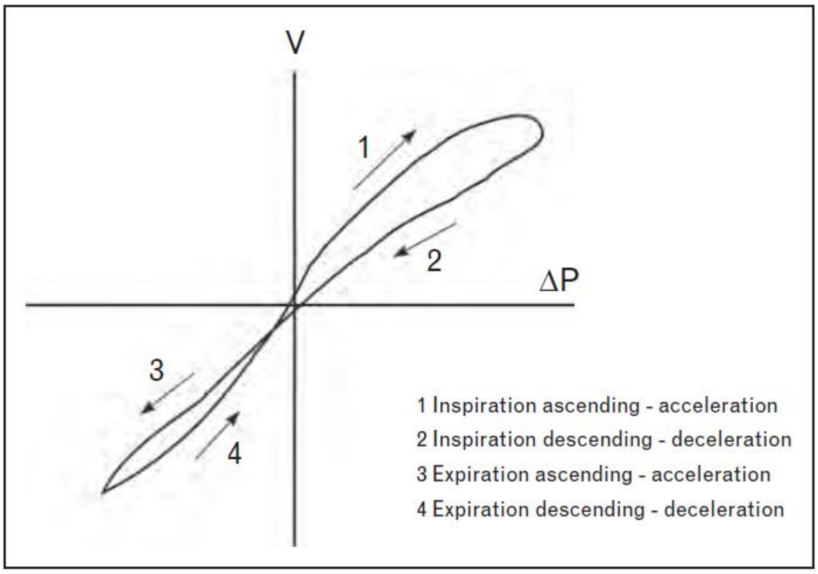


Figure 1.8 Four phases of the nasal breathing cycle (Vogt & Zhang, 2012)

Vogt et al. (2010) also describes the advantages of 4PR in the functional diagnosis of nasal valve problems. Since the motions of the nasal entrance are caused by the breathing and it can be visible from the shape of the 4PR-curves during all 4 phases of the nasal respiratory cycle, graphical and numerical solutions are present (see Fig. 1.9). Due to the elastic compartments of the nose on nasal breathing, graphs of valve action in 4PR always show an asymmetrical appearance with a wide, open loop at the inspiratory and a less prominent loop in the expiratory side (Vogt et al., 2010).

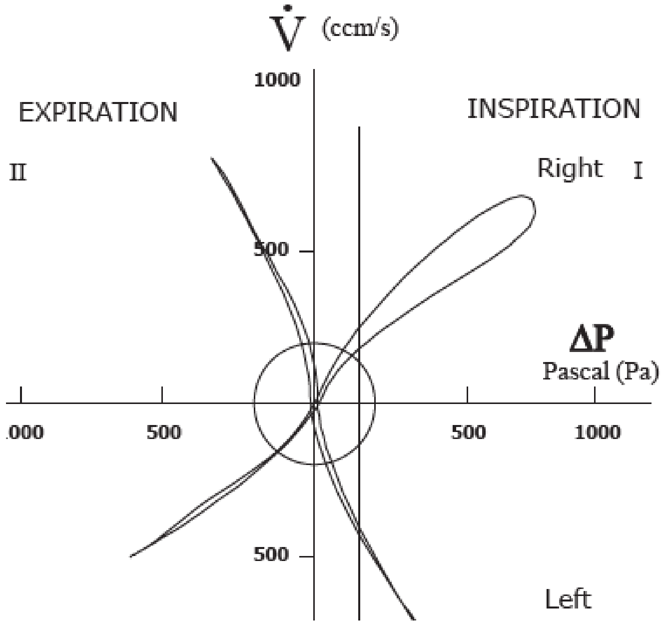


Figure 1.9 Graph of rhinomanometry (Vogt et al., 2010)

The loop formation into the graphs because of the behaviour of nasal valve, can be explained due to the Bernoulli’s phenomenon. Similar to the departing airplane, as the airplanes wing, the nasal wing during under pressure pulls inwards and narrows the nasal airway. During the decelerating (second) phase of nasal breathing, the nasal wing returns to its starting position due to remarkably lower nasal airstream as in the first phase (see Fig.) (Vogt & Zhang, 2012).

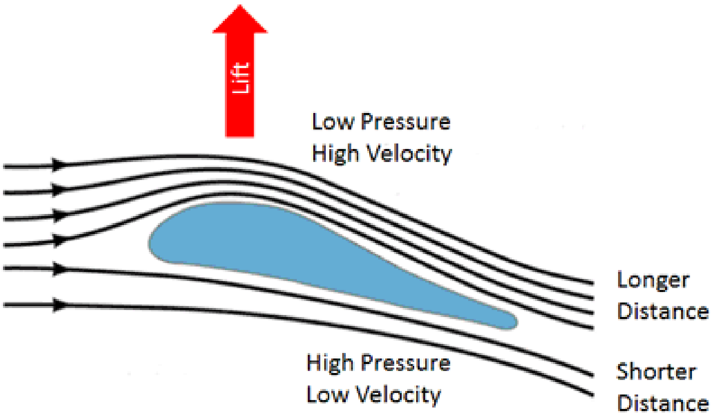


Figure 1.9 “Bernoulli’s phenomenon” (Lawson)

Looking at the 2-channel-time line (see Fig. 1.10) it can be seen, that the pressure is still increasing after a level of 580 Pa resp. cm/S, while the flow during the inspiration is not following anymore and starts to decrease, thus allowing even better to interpret the valve phenomenon.

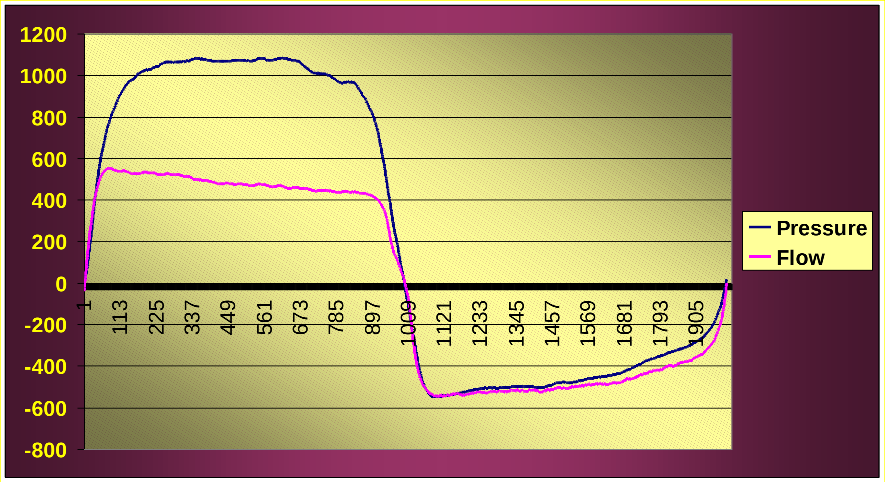


Figure 1.10 “Pressure and flow waves in 4-phase rhinomanometry” (Vogt 2010)

However, for better reflection the nasal valve action in rhinomanometric recordings, patients should to “sniff” quickly during the initial recording, because the degree of the collapse seen in the initial recording depends not just on the amount of flow but also on the acceleration of the flow. Thus, if there is any suspicion of a valve problem, different additional tests could be performed particularly in noses with weak soft tissue or cartilage structures. One method to get more information about the role of the nasal valve is to use a spreader-test. After insertion of the spreader devices and following 4PR tests, it can be predicted the possible success of functional surgery of the nasal valve (Vogt et al., 2010).

In the recent publication “The new agreement of the international RIGA consensus conference on nasal airway function tests” by Vogt et al. (2018), based on the consensus conference of the ISOANA in Riga, 2nd Nov. 2016, the authors outline the validity of objective measurements of the nasal airway. In summary, for rhinomanometry, the previously mentioned parameter the Effective Resistance was finally set as the parameter of high diagnostic relevance and Vertex Resistance as an additional numerical parameter with a strong correlation to the Effective Resistance.

1.6 Therapy of disorders of the nasal valve area

One of the most popular reasons why patients see an otorhinolaryngologist is because of the nasal breathing impairment. There is no doubt that disorders of the nasal valve area are significant contributor to causes of impaired nasal breathing. Since many structures play an important role in the integrity of nasal valve area, different therapy methods are present. The choice of treatment method is based on detailed patient examination, knowledge of the anatomy and physiology of the nasal valve area. The aims for treating disorders of the nasal valve area includes:

- widening of the angle of the nasal valve,
- stabilising the mobile lateral wall,
- correcting stenosis of the soft tissues, cartilage or bone (Bloching, 2007).

1.6.1 Nonsurgical treatment

Currently the mostly used nonsurgical method is self-holding dilators – external and internal ones. These devices provide widening the area of nasal valve and are alternative to those patients who are poor candidates for surgery. The most used external nasal dilators such as Breathe Right® (GlaxoSmithKline, 980 Great West Road, Brentford, Middlesex, TW8 9GS, UK) is stuck to the outer noise and work by stiffening and expanding the lateral nasal wall. Other commercial internal dilators of the nasal aperture for example as the Airmax® (Airmax

BV, Rhijngeestertraatweg 58A, 2341 BV Oegsteest, The Netherlands) are also proven as effective nonsurgical alternative (Bloching, 2007; Hamilton, 2016). After multiple studies it is considered that these dilators are a safe, inexpensive, and effective way to treat valve disfunction without surgery.

Another nonsurgical method to consider is the trimming of the nasal hair (*vibrissae*). Stoddard, Pallanch, and Hamilton (2015) have published by far the first study that describes the impact of *vibrissae* on subjective and objective measurements of nasal obstruction. They stratified 30 healthy participants into 3 groups based on the density of their *vibrissae*. To minimize the impact of the mucosa on nasal obstruction, a topical decongestant was used. Subjective measurements were then taken using a modified Nasal Obstruction Symptom Evaluation (NOSE) scale and objective measurements using 4PR rhinomanometer (RhinoLab GmbH, Freiburg, Germany) with a full-face mask to avoid any distortion of the external nose or vestibule or valve areas. Then the *vibrissae* were trimmed and both measurements were repeated. The participants with denser *vibrissae* noted a statistically significant improvement in both mentioned measurement methods. According to these data, *the vibrissae* were previously unstudied resistor to nasal air flow and were characterized as an inexpensive way to improve nasal breathing.

One more nonsurgical method that is described in literature to improve nasal valve function is physical therapy to improve muscular stenting of the valve. Vaiman, Eviatar, and Segal (2004) described the effectiveness of biofeedback combined with a home exercise program to train patients to better support the lateral nasal wall musculature. They studied 15 subjects and found that 86% of the patients had a significant enough subjective and objective improvement that they avoided following surgery. This type of physical therapy may be helpful to patients who are unable or unwilling to have surgery but still it is unclear if exercises alone are of benefit enough.

1.6.2 Surgical treatment

Nasal valve disorders complexity and variations of causes requires a systematic approach to surgery and that the surgeon be aware of the possible sites and types of abnormalities that may be present in sense to have ability to perform several surgical techniques in order to solve the present problems selectively (Bloching, 2007).

The primary goals of surgery of the nasal valve are essentially to restore normal anatomy of the nasal valve, to stabilise the mobile lateral nasal wall and improve airflow without increasing either rigidity or collapsibility of the nasal valve. In many cases, the stabilisation is performed simultaneously with the expansion of nasal valve angle (Bloching, 2007).

Anterior septoplasty and inferior turbinate reduction are the beginning of the treatment. Those are surgeries that can widen the nasal valve area but do not directly address the problem of lateral wall collapse or narrow nasal valve angle. To reach the previously mentioned goals, various methods through grafts or implants, transposition of the lateral alar cartilage or suspension surgery can be used (Bloching, 2007).

1.6.2.1 Grafts and implants for stabilising and widening the nasal valve area

“Batten Grafts”

Free-floating batten grafts are used in case of congenital or acquired weakness and/or a subtotal loss of the lateral crus of the alar cartilage. Using the septal, conchal or costal cartilage as autologous materials, the grafts are inserted into maximal weakness of the valve and fixed using absorbable suture material. Batten grafts for internal nasal valve should be placed over the scroll, but for the external valve – in line with or caudal to the lateral crus. A disadvantage of this technique is the neccesarity of the grafts certain thickness for stabilising a weak alar cartilage thus its possibility to become visible and even worsen patient’s obstruction (Bloching, 2007; Hamilton, 2017).

“Upper lateral splay grafts”

The principle of this graft is to stabilise the lateral cartilage from the outside thus it stretches the mobile lateral nasal wall. The most suitable autologous material is conchal cartilage because of its material characteristics and convexity. The graft can be inserted through an open, rarely through a closed access. Also, for this technique stabilisation by absorbable fine sutures is necessary. Disadvantages of the technique includes necessarity for the large graft, a possible lifting defect in the area of the auricle and a possibly visible widening of the external nose (Bloching, 2007).

“Spreader grafts”

“Spreader grafts” helps to avoid a functionally effective reduction of the cross section of the nasal valve after reduction rhinoplasty. This problem can occur after resection of a cartilaginous-bony hump with following medialisation of the lateral nasal wall. For avoiding this medialisation, it is suggested to insert 1-2 mm spreader grafts between the septum and the lateral cartilage into mucosal pocket and to fix them using absorbable fine mattress sutures. In this case, the septal cartilage is most suitable. Besides autologous materials, preshaped “spreader grafts” made of porous polyethylene are available (Bloching, 2007).

“Butterfly grafts”

This technique is based on grafts expansion the nasal valve trough a spring effect. Grafts are placed on the septum and under the cranial border of the alar cartilage thus stabilising and widening the internal and the external nasal valve. The most suitable material for this technique is auricle cartilage that has a sufficient internal stress (Bloching, 2007).

Breathe Implant®

The operating principle of the implant is similar to the butterfly graft. Formable and stable titanium implant in the form of a clip through an open rhinoplasty is placed onto the caudal ends of the lateral cartilages and the larger portion of the implant is overlapped by the cranial end of the alar cartilage. For the fixation not absorbable suture material through pre-shaped perforations of the titanium clip is used (Bloching, 2007).

1.6.2.2 Suture techniques for stabilising and widening the nasal valve area

“Paniello technique”

For the first time this technique was described by Paniello in 1996. The basis of this method is suspension of the cranial border of the alar cartilage upwards and outwards to the lower border of the orbita fixed to a screw inserted into the bone in the lower border of the orbita or through a suture directly to the bone through boreholes (Paniello, 1996). Modified fixation method has been describe by M. Friedman, Ibrahim, and Syed (2003). The method is based on the use of a titanium bone anchor that can be inserted into the bone through a stab incision in the lower border of the orbita or through a transconjunctival approach. They described the modified technique as more simple, safer, and equally effective. Various studies have been performed (Bloching, 2007; M. Friedman et al., 2003).

“Lateral rhinoplexy”

By analogy similar like the Paniello technique. In this method the lateral end of the alar cartilage is fixed in new position through an approach of the oral vestibule. However, despite its good functional and aesthetic results, it should be used only in selected cases (Bloching, 2007).

“Flaring suture”

In the bases of the method is directed mattress suture from the lateral portion of the lateral cartilage across the nasal dorsum to the opposite side. This suturing technique provides an increasement of the cross section of the nasal valve, thus widening the nasal valve angle. For better outcomes, to avoid lateral nasal wall’s medialisation, combination with “spreader grafts” is advised (Bloching, 2007).

“Horizontal mattress bending suture”

In this technique nasal valve stabilization and widening is accessed through a mattress suture separately of the two lateral cartilages with a not absorbable suture material. This method is suitable for patients with a tension nose who don’t want to change their external nose despite its reduced breathing function (Bloching, 2007).

“Mitek bone-anchored system”

White and Hamilton have recently described a technique of suture lateralization using a bone-anchors and expanded polytetrafluoroethylene sheet to pull external nasal valve in a more lateral direction. Permanent suture are placed from the malar eminence to the external nasal valve, simulating a Cottle manoeuvre (White & Hamilton, 2016). It has been shown to be a safe technique, especially useful in patients with facial paralysis with incomplete dilatory muscle tone in the nostril (Hamilton, 2017).

1.6.2.3 Grafts for stabilising and rotating the nasal tip

“Strut grafts”

The loss of support to the nasal base due to weakness of the cartilaginous supporting structures and/or an increasing loss of elasticity of the soft parts with increasing age can cause a nasal tip ptosis with following constriction of the nasal valve. Strut grafts can be made of autologous cartilage or pre-shaped implants can be used. The advantage of the implants is the combination of high rigidity and small material thickness. These grafts can be used alone or in addition with sutures that are placed between the alar cartilage and the nasal bone for elevating the nose tip. To rotate the nose with more precision the sutures between the medal crura and the septum could be added (Bloching, 2007; Hamilton, 2017).

“Caudal septal extendion and caudal septal replacement grafts”

These grafts allow to lengthen the caudal septum in case of its shortness or if it is of appropriate length, but the tip position must be stabilized so that it can be used as a stable fixation point for the medial crura. Ideally the graft should be a relatively straight segment of cartilage and wider at the base than at the tip thus allowing cephalically rotation of the lower lateral cartilage. Typically, it overlaps the existing caudal septum. For graft stabilization sutures between the medal cura and the caudal margin of the caudal extension graft is needed (Toriumi, 2006).

1.6.2.4 Lateral crus modification

A lot of publications are available for different techniques for modification of the lateral crura. To choose the most appropriate technique it is helpful first to identify the problems of lateral crura – the problems of lateral crura position, shape, or both (Hamilton, 2017).

For cephalically or sagittally malpositioned latera crura, a rotationplasty of the cartilage is indicated. Cephalic malposition is a problem of the long axis of the lateral crus, whereas sagittal malposition - of the short axis. The commonly used technique to solve problem of the cephalically malpositioned lateral crura is to release them free from the vestibular skin, reinforce them with or without lateral crural strut grafts, and reposition them more caudally. To correct sagittally malpositioned lateral crura often it is necessary to use more than 1 technique in the same patient. The main task correcting sagittal malposition is to elevate the caudal border of the lateral crus to the same height as the cephalic border, so the short axis becomes nearly perpendicular to the septum. Also, lateral crural strut grafts and spanning sutures can be used to reorient the lateral crura (Hamilton, 2016, 2017).

To correct the deformities of the lateral crura, lateral crural turn-in flaps for flattening and strengthening can be used. In this way these flaps score the lateral crus along its length and folds the cephalic segment caudally into a pocket between the lateral crus and the vestibular skin. Both layers of cartilage must be sutured together. Also, lateral crural strut grafts that are placed in same position is a reliable way to flatten and reinforce the lateral crura. In case of concave lateral crura, they can be excised lateral to the dome and reversed, thus changing concavity into a convexity. For too convex lateral crura, a simultaneous turn-in flap can be used to flatten it (Hamilton, 2017).

Depending on the pathology numerous other methods are available to widen the region of nasal valve. Correction of nasal tip deprojection, too wide columella or nasal valve collapse due to the structural stenosis, for example, scars after previous surgeries, tumour resection, burn trauma or facial paralysis is needed (Bloching, 2007; Hamilton, 2017).

Summarizing the data of diagnostic and surgical methods, it was not possible to find data or methods that could assess the quantitative properties especially of the lateral nasal wall and the effect of used surgical methods on it.

The aim of this work is to determine quantitatively the elastic properties of the lateral nasal wall using a new method – elastography – as applied to be patented by Vogt and Prill on February 2018 in Germany thus allowing the assessment of the need for and amount of functional rhinoplasty.

2. Materials and methods

2.1 Materials

2.1.1 Selection of volunteers

The study has been taking place between February and May 2018 in the “Clinic Headline” and the Center of Experimental Surgery of the Faculty of Medicine University of Latvia in Riga. Into the study 30 volunteers were enrolled, 11 males and 19 females between age of 20 and 61 with no previous history of nasal pathology or absence of acute respiratory tract infection in the preceding 2 weeks

2.1.2 Equipment

2.1.2.1 Elastography

The technical equipment was first practical realisation of an applied patent which was submitted on February 2018 by K. Vogt and Prill as German Patent. The built-up measurement device follows the picture below. (see Fig. 2.1)

The device was set up at the laboratory of MedTecResearch Krakow am See in Germany which is belonging to the Center of the Experimental Surgery of the Faculty of Medicine University of Latvia. The electronic parts have been added at the company PRETTL in Grevesmuehlen in Germany. The entire set up was following the principles of prototyping of a medical device following regulations of the EU.

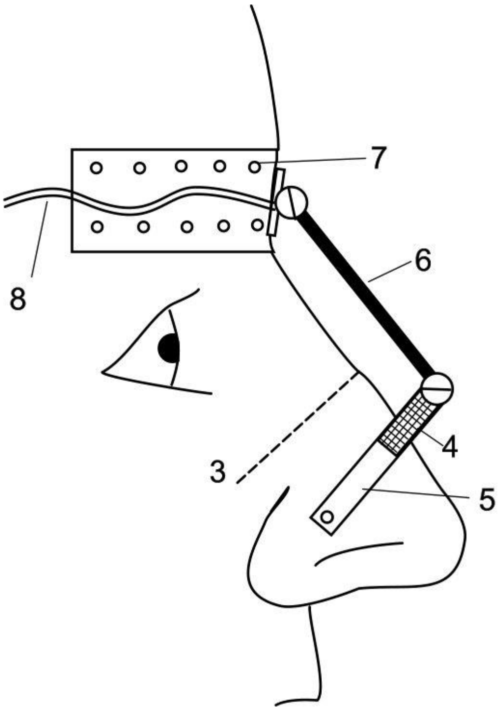


Figure 2.1 In the figure Nr.3 is the border between soft and hard tissue of the nose, Nr.7 is a fixating element attached to a headband, Nr.6 is a mechanical connection piece, Nr.5 is a feather strip on which strain gauges are fixed on both sides, Nr.8 is the connection to the electric measurement bridge

Because the fixation of the strain gauges is essential for the proper function of the measurement device, we describe in the following steps the used technology. A stainless, steel strip HASBERG (Germany) of the 11 cm length and 5 mm width was chosen and the centre of the stip was marked. (see Fig 2.2) After carefully cleaning electric of the surface contact elements were attached (see Fig 2.3) by special glue.

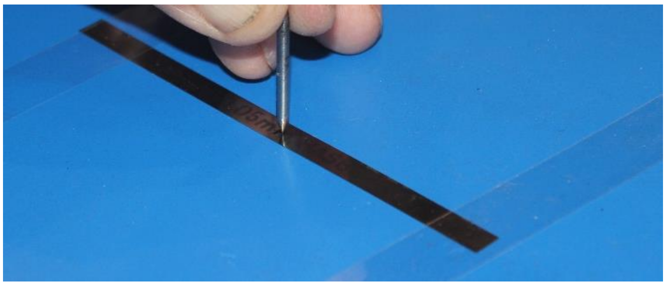


Figure 2.2 A stainless steel strip 11cm long and 5mm wide with marked centre

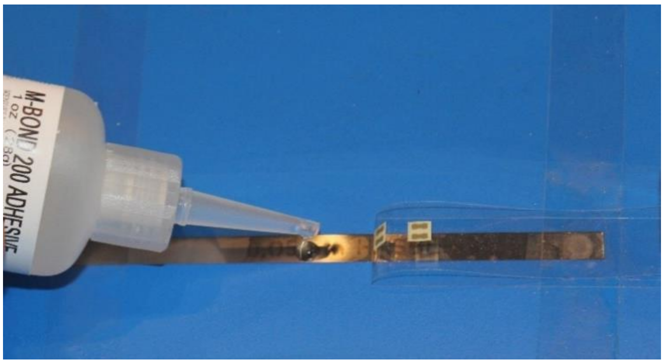


Figure 2.3 Attachment of electric contact elements

In the next step a wired strain gauge type **FAE-12S-35-S13EL-J** (MICRO-MEASUREMENTS) has been fixed in a distance about 2 cm. (see Fig. 2.4)

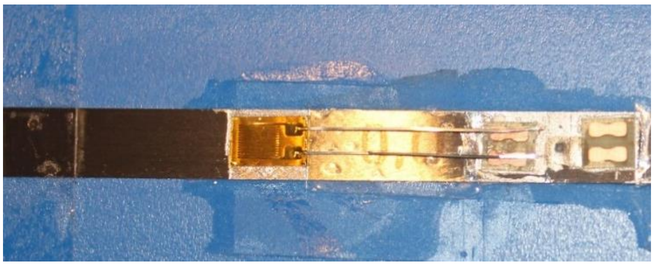


Figure 2.4 Strain gauge fixation

After fixation of the strain gauge wires by soldering, the strain gauges have been protected by elastic ACRYLIC COATING. (see Fig. 2.5)

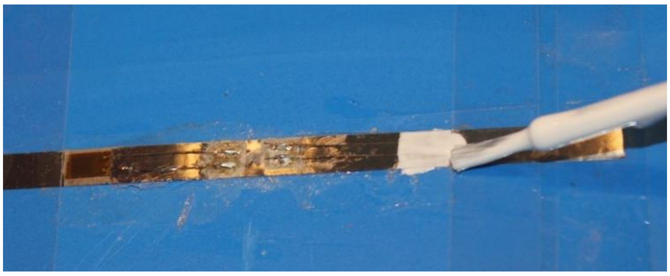


Figure 2.5 Strain gauge protection by elastic ACRYLIC COATING

The electric connections to the amplifier have been fixed by soldering. (see Fig. 2.6)

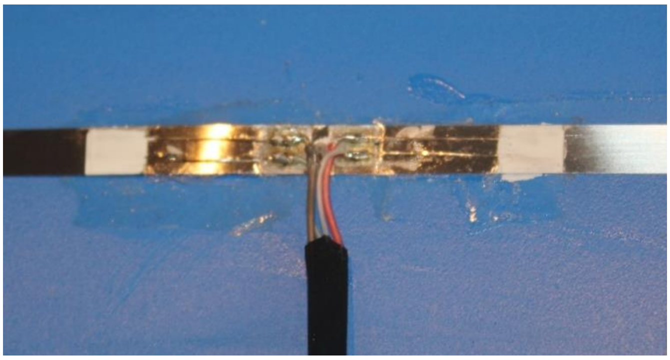


Figure 2.6 Electric contact connection with amplifier

The surface was protected again by coating. (see Fig. 2.7)

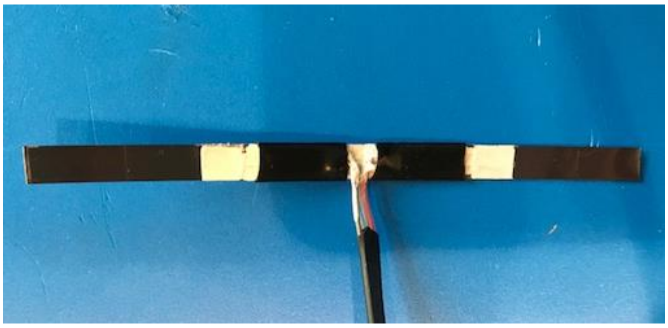


Figure 2.7 Surface protection by coating

The entire strain gauge unit was fixed at the metal bridge and attached by a bendable metal unit to the headband. (see Fig. 2.8)

Figure 2.8 Strain gauge unit fixation to the metal bridge and headband

The electrical realisation was first following the principle of a quarter-bridge and the amplifier was built in as an additional unit into the rhinomanometer 4RHINO (Sutter GmbH Germany). To obtain a higher electric signal, in a second version the strain gauges have been attached on both sides of the steel strip and the signal was won from a half-bridge amplifier.

A special measurement program RhinoDSM was set up based on the free program the LABVIEW. This program is using the signals for nasal flow and differential pressure separately depicted in channel 1 and channel 2. Channel 3 and channel 4 are showing time depending valve movements for the both sides.

2.1.2.2 The strain gauge technology

To measure the mechanical properties of the elastic structures of the nasal valve, Vogt and Prill (2018) have introduced the new method above by using the strain gauge technology. Strain gauges (also Strain gages) are sensors whose resistance varies in proportion to the amount of applied forces. Strain gauge technology is one of the most important electrical measurement techniques that can determine the mechanical quantities of an object by converting different types of forces into variable electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as object's internal resisting forces, in turn, strain is amount of deformation of material that occur. Strain can be positive (tensile), due to elongation, or negative (compressive), due to contraction. Similarly, we could assimilate created forces to the lateral nasal wall by nasal breathing - during inspiration and expiration. Thus, in certain conditions, the value of the influencing quantity can be derived from the measured strain value.

This method is widely used in experimental stress analysis. Such stress analysis by measuring the strain values that are determined in some material allows to determine the stress in the material, thus to predict its safety and durability (Unknown, 2016).

2.2 Methods

2.2.1 Measurements

The deflection of elastic steel elements touching the lower nasal side at it deepest point and fixed at a headband was precisely measured by means of strain gauge elements. The deflection was calibrated by commercial calibration devices. A special 4-phase-rhinomanometer (4PR) with a big protective face mask allowed at the same time to measure air flow and differential pressure. The signals were recorded together with the deflection signals simultaneously on both sides. The measurements have been carried out as unilateral measurements according to anterior rhinomanometry during quiet and in forced breathing.

2.2.2 Data analysis

For better demonstration all the data from RhinoDSM program have been transferred and evaluated in “Octave GUI” as PDF files.

Analysed parameters in PDF files:

- Flow in quiet breathing (F < 200 cm^3/s / F > 200 cm^3/s)
- Pressure in quiet breathing (P < 200 Pa / P > 200 Pa)
- Deflection in quiet breathing (D < 2 mm / D > 2 mm)
- Flow in forced breathing
- Pressure in forced breathing
- Deflection in forced breathing (D < 2mm / D >2 <4 mm / D > 2mm)

Basing on flow, pressure and deflection parameters in quiet breathing, all the measurements were stratified in groups.

For data processing and analysis, the Microsoft Excel 2016 program was used.

2.2.3 Ethical considerations

The Institute of Scientific Research Ethics of the Institute of Cardiology and Regenerative Medicine of the University of Latvia approved the study. The work is done in accordance with ethical, legal, and moral standards. All the volunteers were introduced to the study, its course, purpose and informed about the characteristics of the study and its non-invasiveness. Written informed consent was obtained from all volunteers.

3. Results

Thirty volunteers were included in the present study. Out of the 30 volunteers there were 11 (36.7%) men and 19 (63.3%) women with a mean age of 33.43±12.29 years.

3.1 General characteristics of the study population

Unilateral measurements from the entire study population from right and left side of the nose, were stratified according to the parameters of flow (F), pressure (P) and deflection (D) in quiet breathing.

Table 3.1 Unilateral measurements of the entire study population in quiet breathing

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

Table 3.1 shows the amount of deflection and the number of measurements with no deflection, less or over than 2 mm deflection depending of flow, pressure and deflection in quiet breathing:

- no deflection, seen in 0 measurements (n=0)
- clear deflection (< 2 mm), seen in P < 200 Pa (n=13; 22.8 %), F < 200 cm^3/s (n=10; 17.5 %), F > 200 cm^3/s (n=8; 14 %), P > 200 Pa (n=5; 8.8 %)
- high deflection (> 2 mm), seen in P > 200 Pa (n=31; 54.4 %), F < 200 cm^3/s (n=21; 36.8 %), F > 200 cm^3/s (n=18; 31.6 %), P < 200 Pa (n=8; 14 %)

According to characteristics of each measurement, all the measurements were further stratified into seven groups as shown in table 3.2.

Table 3.2 Characteristics of each measurement in quiet breathing stratified into seven groups

	Flow > 200 cm^3/s	**Flow < 200 cm^3/s**	**Pressure > 200 Pa**	**Pressure < 200 Pa**	**Deflection > 2mm**	**Deflection < 2mm**
Group-a (n, %)	18 (31.6)	-	18 (31.6)	-	18 (31.6)	-
Group-b (n, %)	2 (3.5)	-	2 (3.5)	-	-	2 (3.5)
Group-c (n, %)	-	8 (14.0)	-	8 (14.0)	8 (14.0)	-
Group-d (n, %)	6 (10.5)	-	-	6 (10.5)	-	6 (10.5)
Group-e (n, %)	-	13 (22.8)	13 (22.8)	-	13 (22.8)	-
Group-f (n, %)	-	3 (5.3)	3 (5.3)	-	-	3 (5.3)
Group-g (n, %)	-	7 (12.3)	-	7 (12.3)	-	7 (12.3)

Prevalence of the groups according to flow, pressure and deflection parameters in quiet breathing are shown in Figure 3.1.

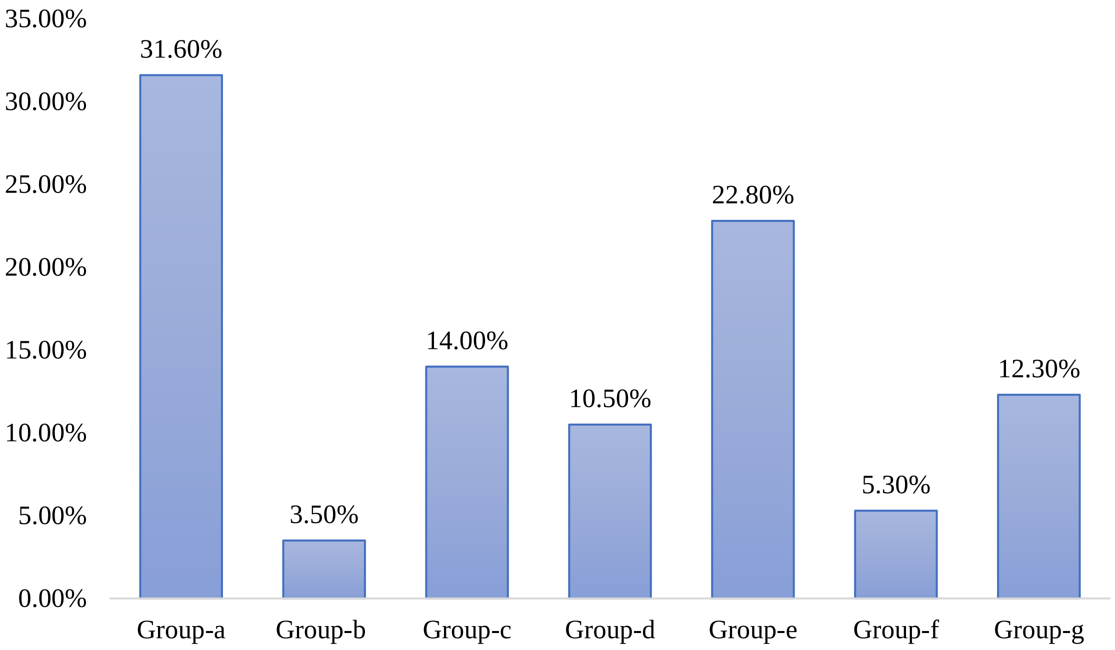


Figure 3.1 Prevalence of the groups

Table 3.2 shows group stratification according to flow, pressure and deflection parameters, while Figure 3.1 the prevalence of the groups. Most common groups in quiet breathing were:

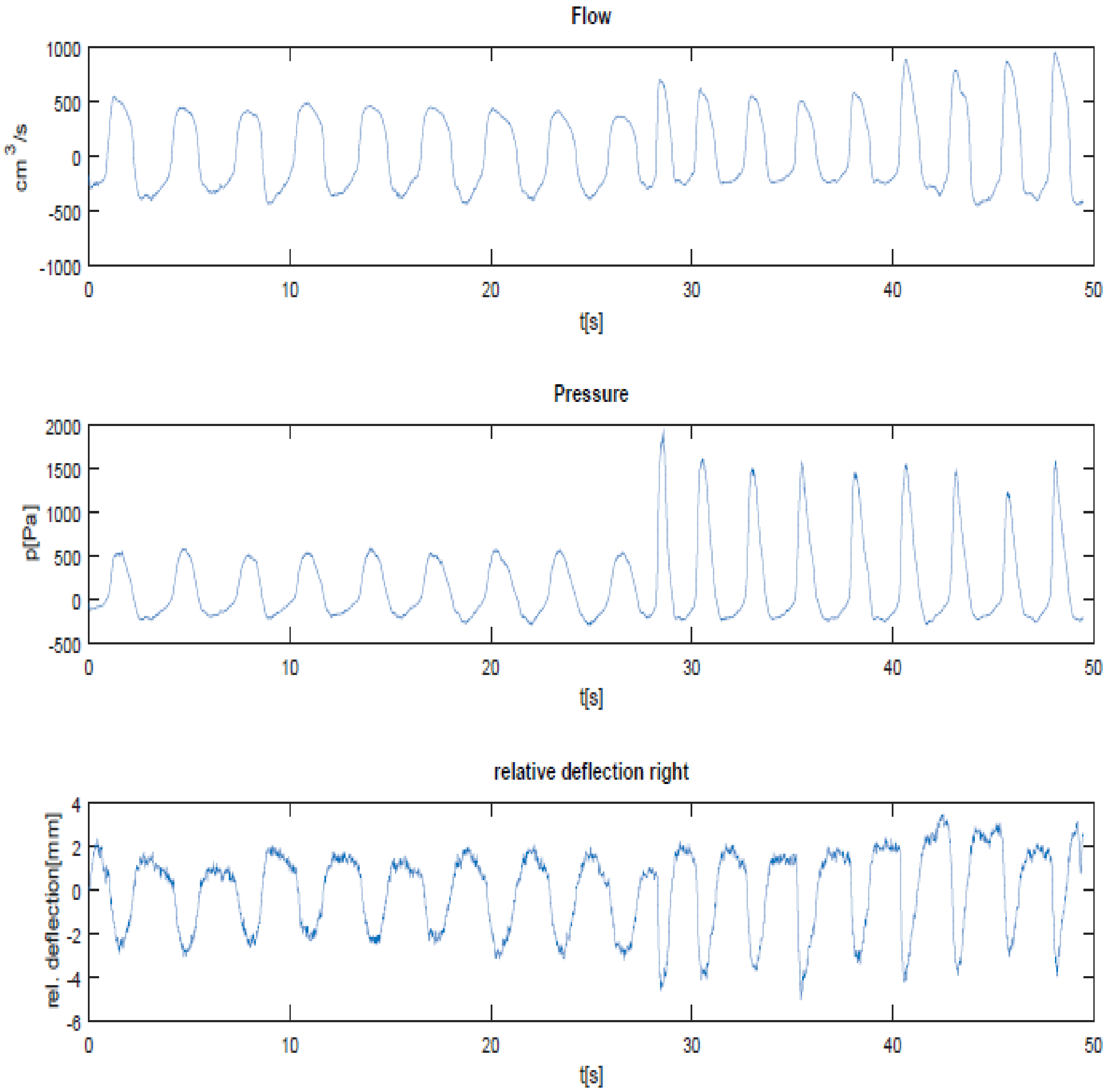
- Group-a (n=18; 31.6 %), where F > 200 cm^3/s, P > 200 Pa, D > 2mm
- Group-e (n=13; 22.8 %), where F < 200 cm^3/s, P > 200 Pa, D > 2mm
- Group-c (n=8; 14.0 %), where F < 200 cm^3/s, P < 200 Pa, D > 2mm
- Group-g (n=7; 12.30 %), where F < 200 cm3/s, P < 200 Pa, D < 2 mm

Least common:

- Group-d (n=6; 10.5 %), where F > 200 cm^3/s, P < 200 Pa, D < 2mm
- Group-f (n=3; 5.3 %), where F < 200 cm^3/s, P >200 Pa, D > 2mm
- Group-b (n=2; 3.5 %), where F < 200 cm^3/s, P > 200 Pa, D < 2mm

3.2 Characteristics of the groups

Measurements of the right and left side of the nose in (group-a) are characterized by a flow > 200 cm^3/s, pressure > 200 Pa and deflection > 2 mm, as observed in Figure 3.1.

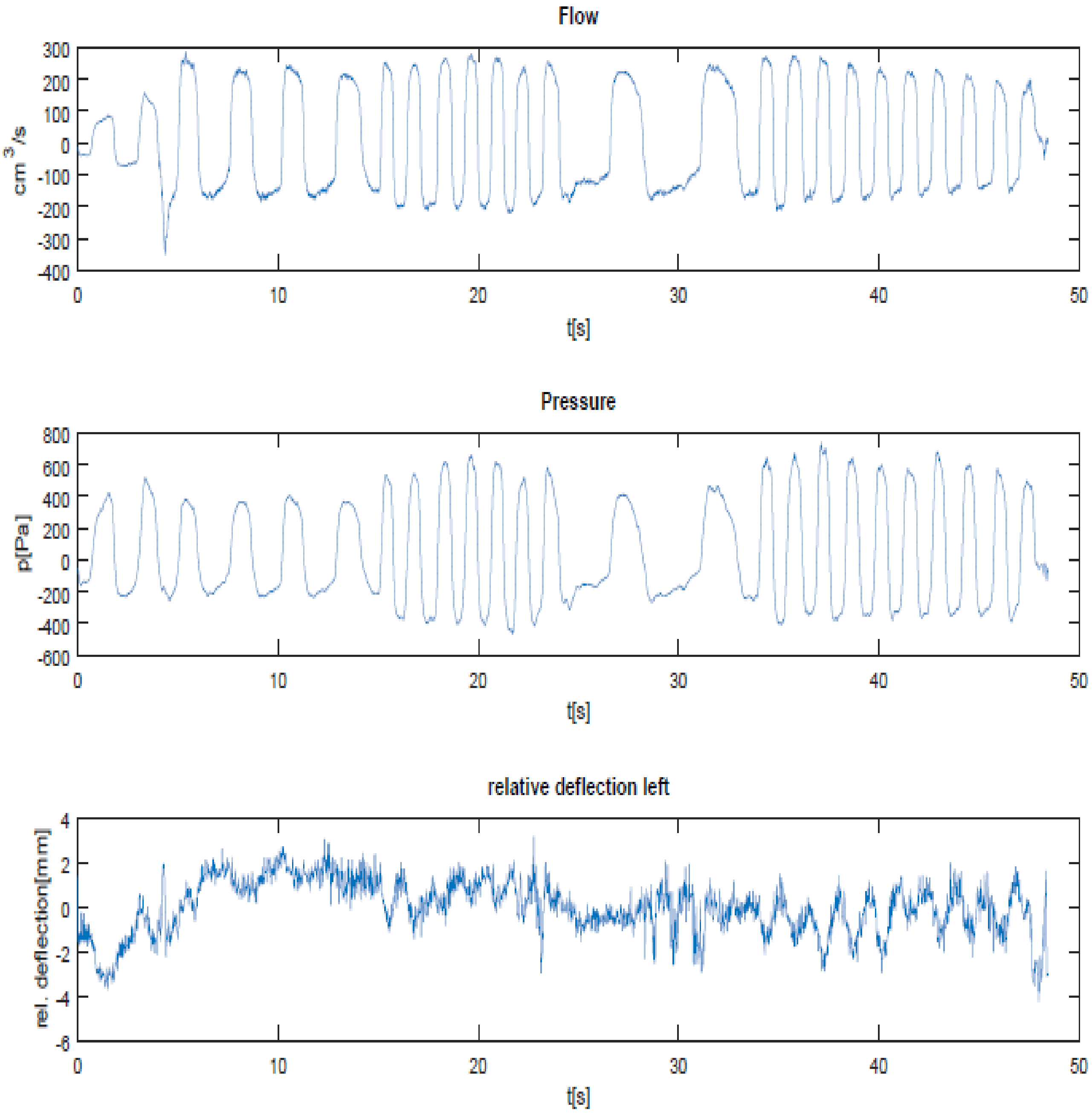

Flow

Pressure

relative deflection right

Figure 3.2 Group-a parameters; F > 200 cm^3/s, P > 200 Pa, D > 2mm

Measurements of the right and left side of the nose in (group-b) are characterized by a flow > 200 cm^3/s, pressure > 200 Pa and deflection < 2 mm, as observed in Figure 3.2.


Flow

Pressure

relative deflection left

Figure 3.3 Group-b parameters; F > 200 cm^3/s, P > 200 Pa, D < 2mm

Measurements of the right and left side of the nose in (group-c) are characterized by a flow < 200 cm^3/s, pressure < 200 Pa and deflection > 2 mm, as observed in Figure 3.3.

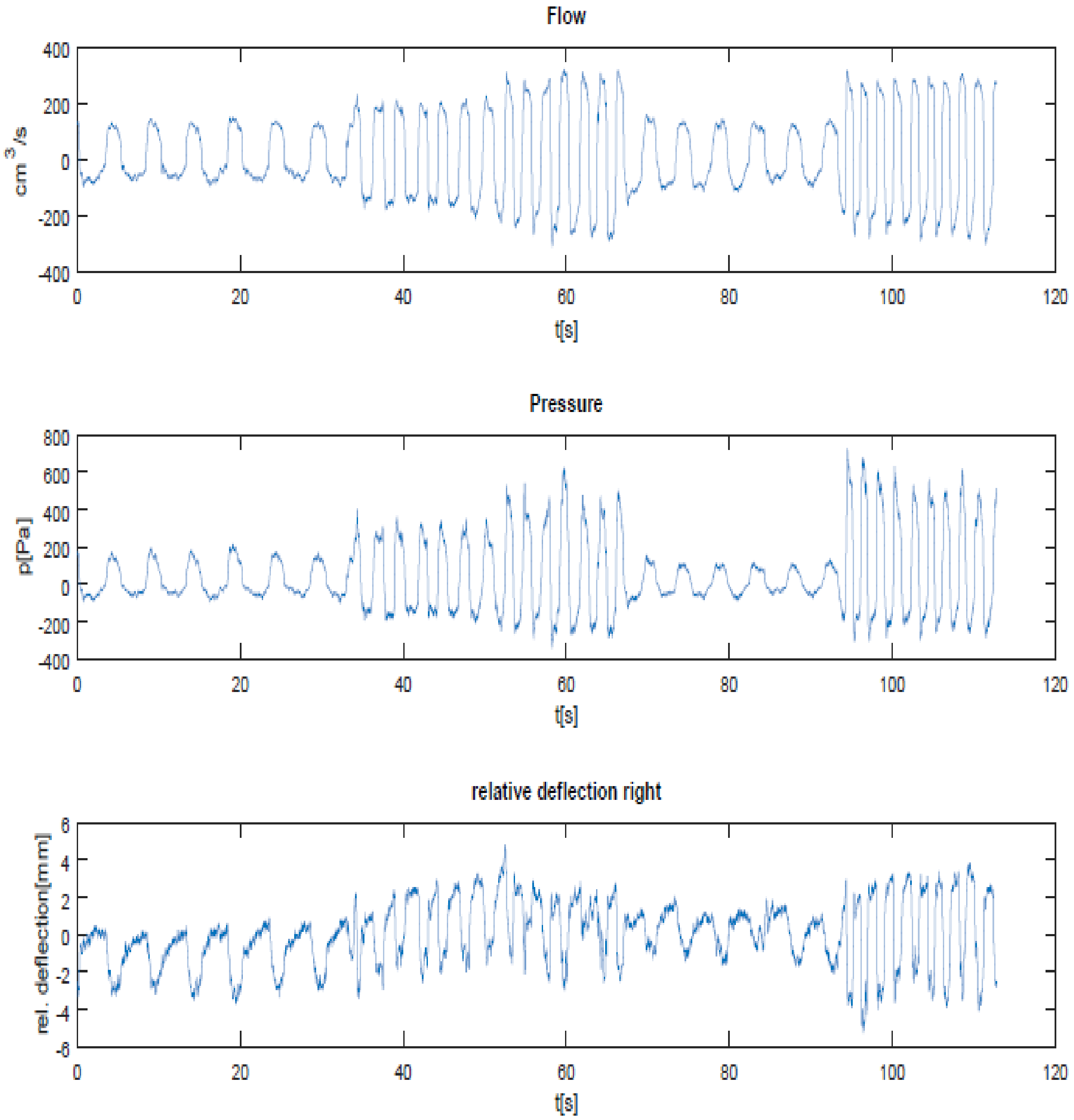
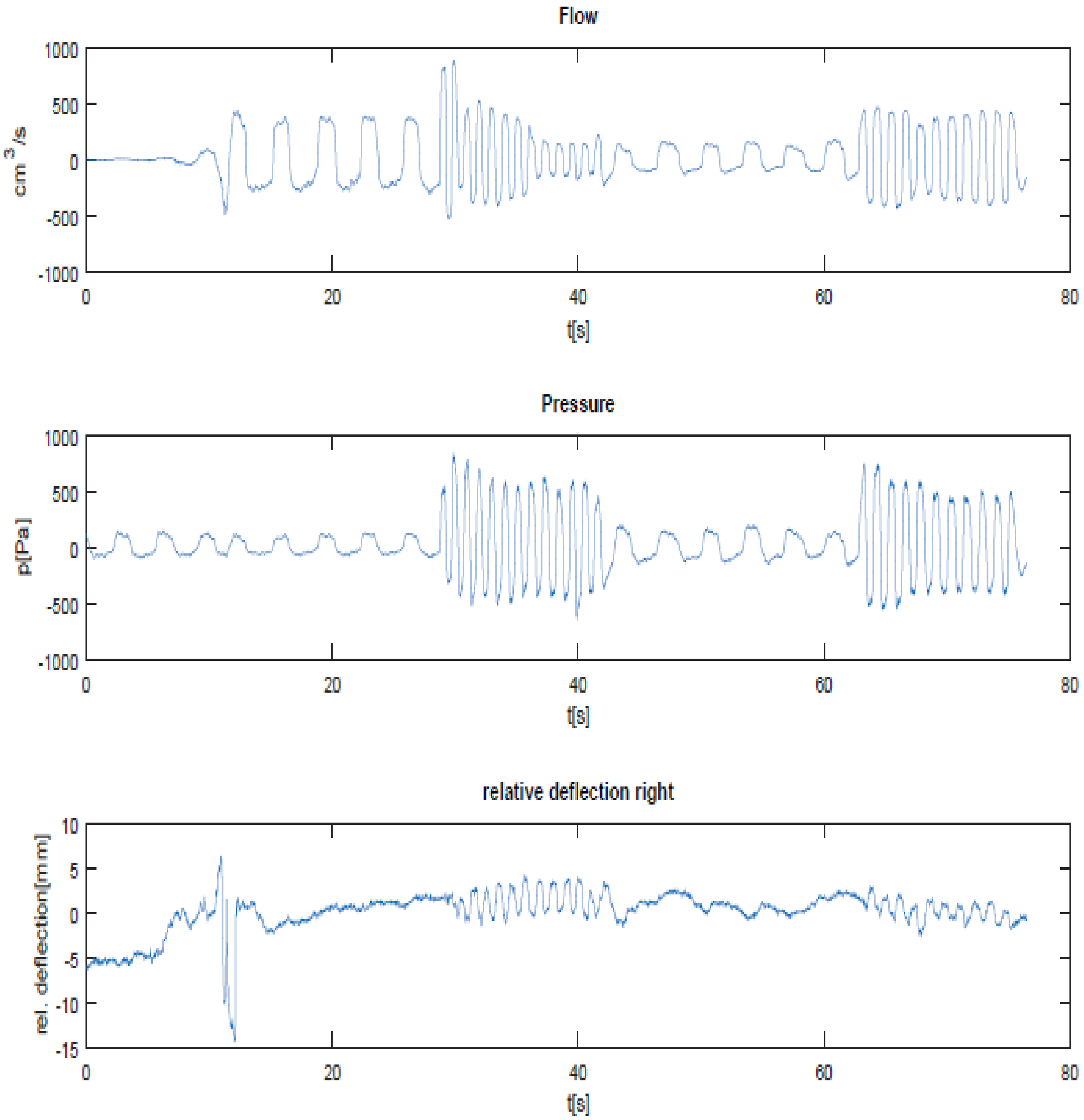


Figure 3.4 Group-c parameters; F < 200 cm^3/s, P < 200 Pa, D > 2mm

Measurements of the right and left side of the nose in (group-d) are characterized by a flow > 200 cm^3/s, pressure < 200 Pa and deflection < 2 mm, as observed in Figure 3.4.


Flow

Pressure

relative deflection right

Figure 3.5 Group-d; F > 200 cm^3/s, P < 200 Pa, D < 2mm

Measurements of the right and left side of the nose in (group-e) are characterized by a flow < 200 cm^3/s, pressure > 200 Pa and deflection > 2 mm, as observed in Figure 3.5.

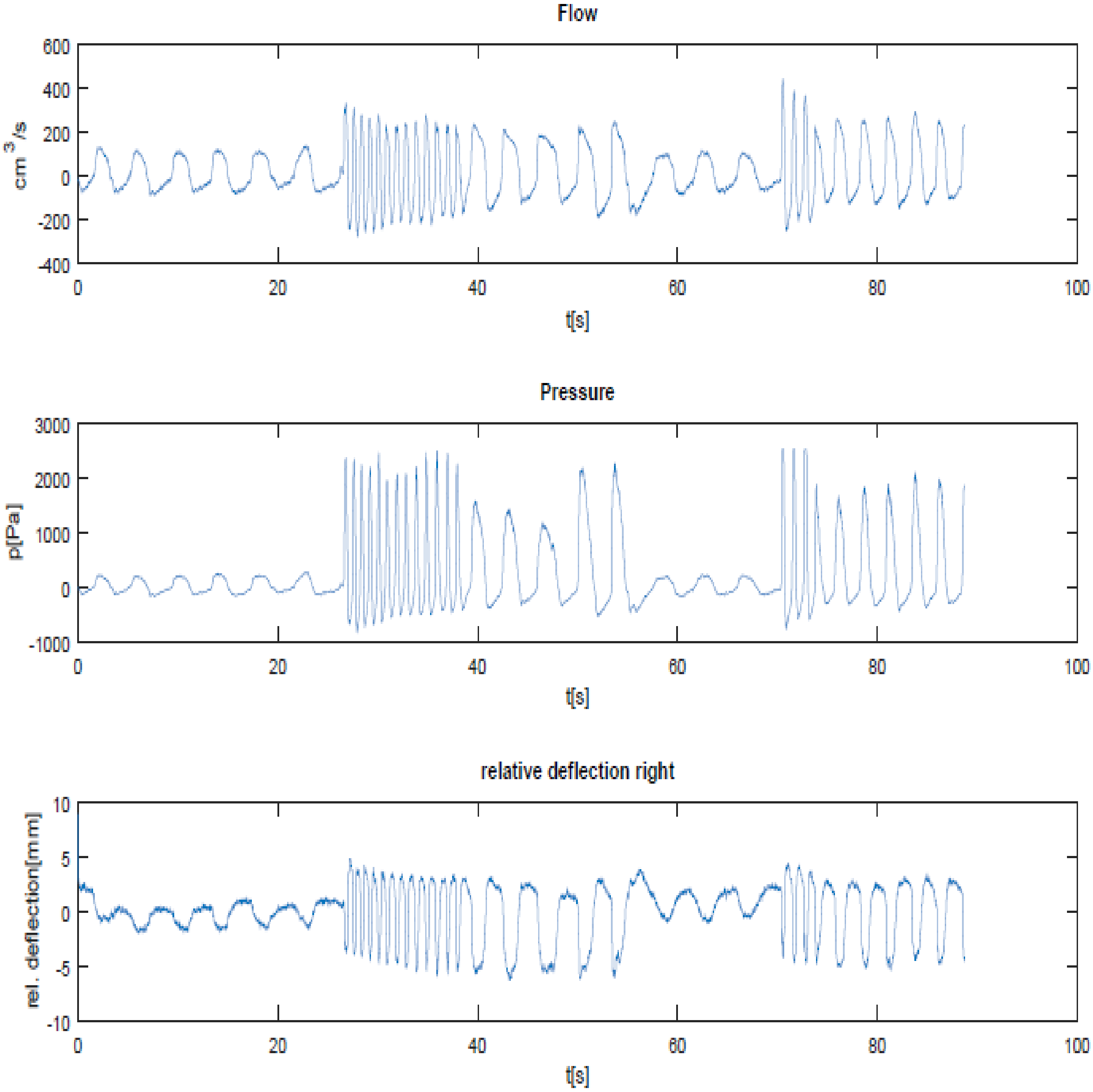


Figure 3.6 Group-e; F < 200 cm^3/s, P > 200 Pa, D > 2mm

Measurements of the right and left side of the nose in (group-f) are characterized by a flow < 200 cm^3/s, pressure > 200 Pa and deflection < 2 mm, as observed in Figure 3.6.

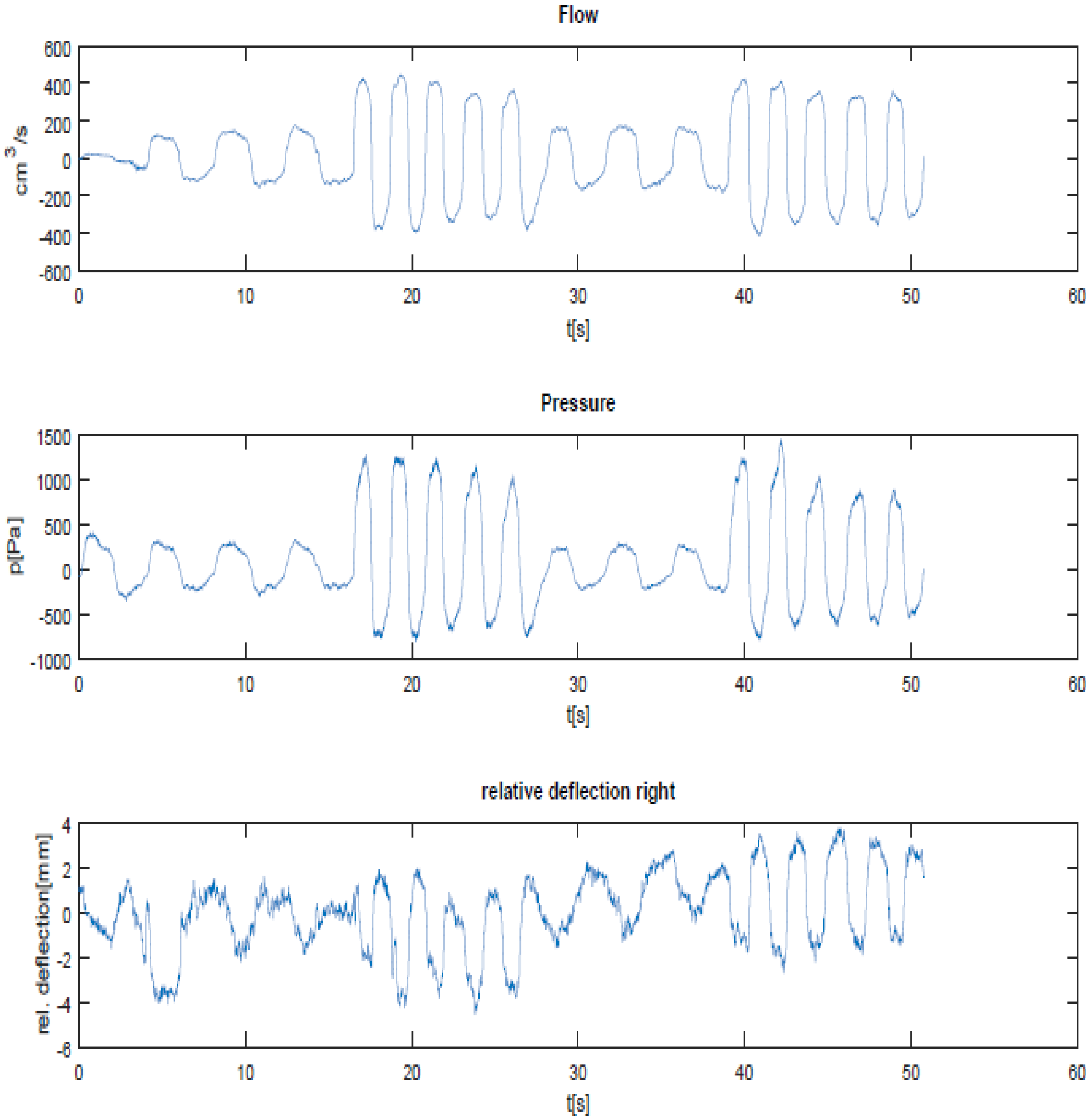


Figure 3.7 Group-f; F < 200 cm^3/s, P > 200 Pa, D < 2mm

Measurements of the right and left side of the nose in (group-g) are characterized by a flow < 200 cm^3/s, pressure < 200 Pa and deflection < 2 mm, as observed in Figure 3.7.

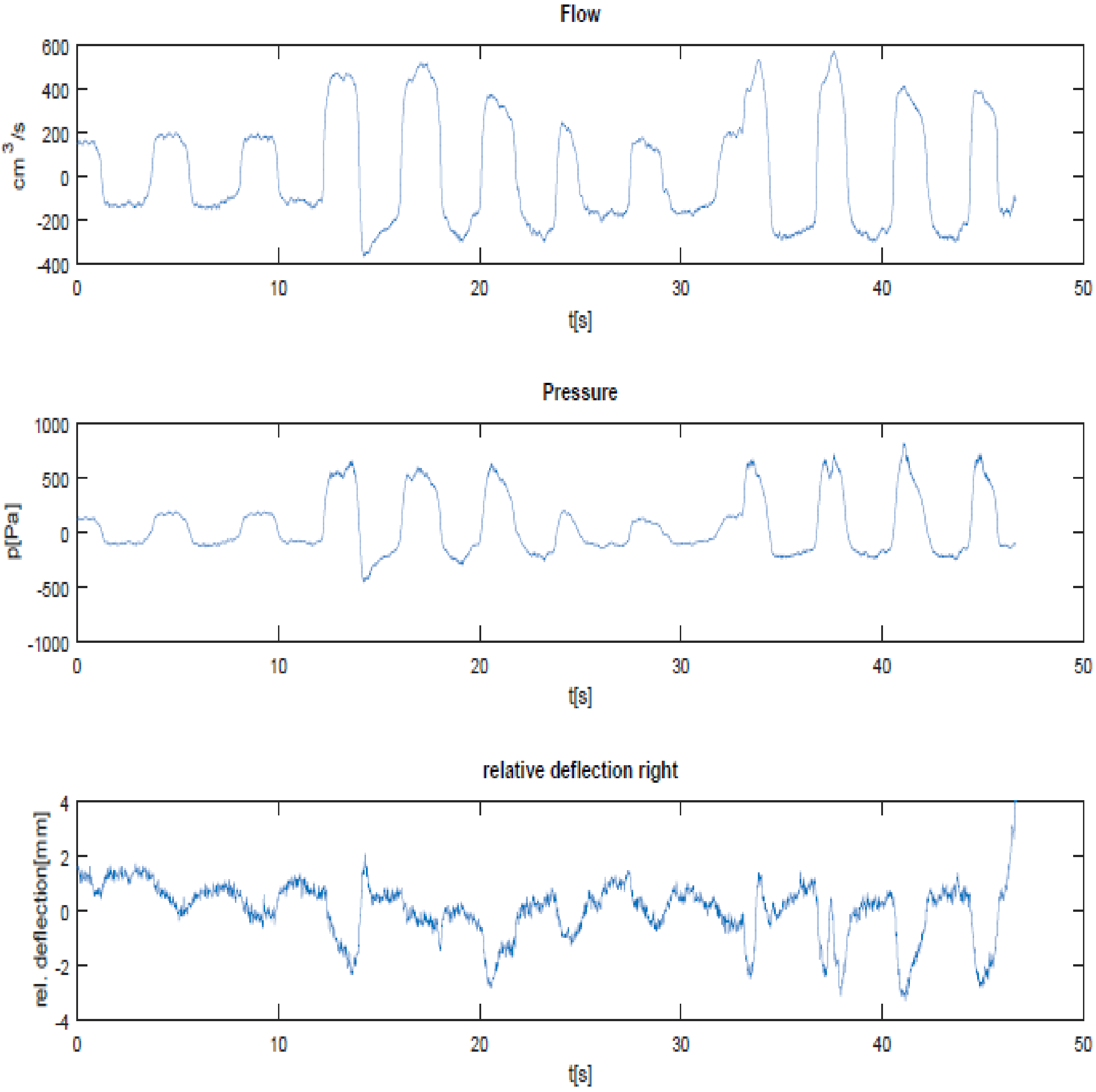


Figure 3.8 Group-g; F < 200 cm3/s, P < 200 Pa, D < 2 mm

3.3 Deflection of the lateral nasal wall

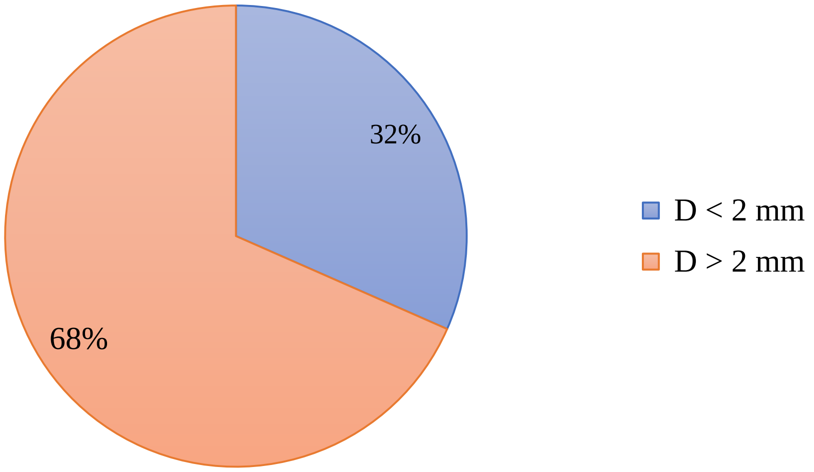


Figure 3.9 Deflection of the lateral nasal wall in quiet breathing

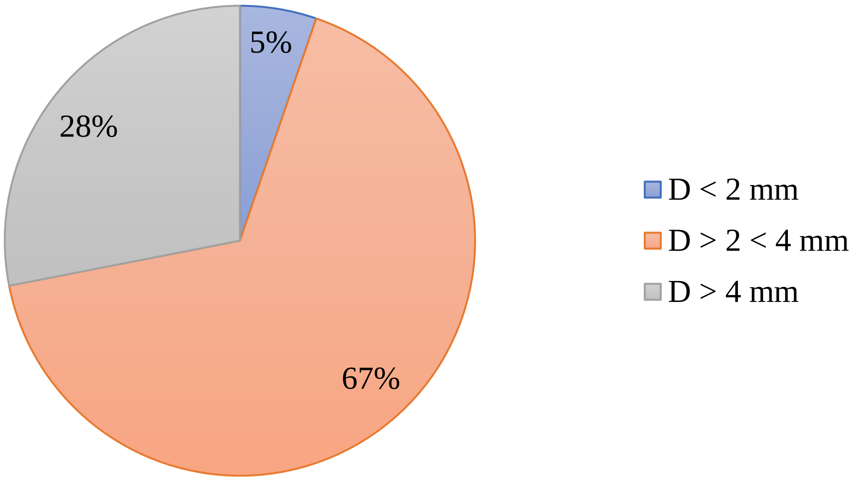


Figure 3.10 Deflection of the lateral nasal wall in forced breathing

Figure 3.9 and 3.10 shows deflection of the later nasal wall in the entire study population. Deflection in quiet breathing < 2 mm were (n=18; 32 %), > 2 mm (n=39; 68 %), while in quiet < 2 mm (n=3; 5 %), >2 < 4 mm (n=38; 67 %) and > 4 mm (n=16; 28 %).

4. Discussion

The primary intension of this work was the development of a complete new technique for the evaluation of the movement of the lateral nasal wall including a pilot study in healthy volunteers. Principally, different techniques can be used such as distance measurements by changing induction (Vogt and Prill 2018 patent # 10 2018 000 995.6), determining the changes of the cross-section area by micro camera or even in 4-phase-rhinomanometry as typical patterns.

Because the strain gauge technology is a high developed technology we decided to test first the application of this technique, looked for the best suitable strain gauges and tested two basic techniques for the electronic evaluation which is the quarter bridge technique and later the half bridge technique. During the basic experiments we found out that the half bridge technique as expected is superior to the quarter bridge technique because of the better signal and the higher distance between the signal and noise. In the present moment, the next task for the development of the here present strain gauge technology is the design of the fixation elements following the basic demands for a Medical Product. Up to now, the design of the first prototype of the fixation element to measure the movement of the nasal wings demands calibration separately for each side of the device, so it is not possible to reach symmetric results in bilateral measurements. That could be possible if the calibration would be equal in both sides.

Also, a bilateral measurement of the valve elongation will be possible within the next time by applying posterior rhinomanometry for the determination of the entire air-stream through both nasal sides. Current design also is not suitable enough during performance of the simultaneous measurements with 4FR using full face mask. The shape and/or size of the fixation element seems to be unsuitable because of its interaction in some cases with the face mask during its attachment on face in occasion causing displacement or the movement of the attached strips at the deepest point of the nasal wing. This interaction could be a reason for false signal of the deflection, thus imitating a movement of the nasal wing. These technical imperfections interferate the performance and the precision of the measurement. However, following the signals during the time of the measurement, it is detectable and allows to stop and exclude interrupted measurements. Also, after processed data analysis, following to the curves of the recorded signals, it is noticeable if the measurements have been interrupted. In this study such analysis allowed to exclude 3 out of the 60 measurements. Overall, the importance of the quality of the measurement is highly rated, because the simultaneous depiction of the standard rhinomanometric result and of the time related variations of pressure, flow and deflection could in-form about the relations between elastography and rhinomanometry. The technical development is going on within the “Rhinodiagnost”-program (IRASME-program of the European Community).

The results of the pilot study show clearly that the onset of the movement of the lateral nasal wall starts already in quiet breathing ($D < 2$ mm = 32 %; $D > 2$ mm = 68 %), where it has obviously a minor influence on the regulation of the nasal airstream, but it is very likely that even this minor movement in a range of two millimetres in both directions contributes to the feeling of the nasal breathing. Also, initial results suggest that there is no nasal breathing without movement of the nasal wing and the onset of deflection starts already before the sensation of valve activity.

The distribution of all measurements in groups based on pressure, flow and deflection parameters in quiet breathing clearly shows the superiority of the group-a (n=18; 31.6 %) and group-e (n=13; 22.8 %) where in both $P > 200$ Pa and $D > 2$ mm while F in group-a is over, but in group-e less than 200 cm^3/s. Such parameters would lead to the assumption that the pressure is the leading criteria to determine the elongation but then, analysing parameters of the next prominent groups, group-c (n=8; 14 %) and group-g (n=7; 12.3 %) where in both $P < 200$ Pa and $F < 200$ cm^3/s while D in group-c is over, in group-g less than 2 mm, we cannot find any regularity between the pressure, flow and deflection parameters. The analysis of the timeline differences between the signals are under progress by using the information obtained by the “EDF-Browser” program.

After the initial analysis of the curves in forced breathing, it is also clearly visible in most of them that as the flow increases, deflection is also increasing causing collapsing forces on the nasal valve, and that clearly confirms the Bernoulli’s principle. In our pilot study intended valve effect for sniffing starts in a range between 3 to 4 mm movement of the lateral nasal wall ($D < 2$ mm = 5%; $D > 2 < 4$ mm = 67 %; $D > 4$ mm = 28%). But to quantify it more precisely, it is necessary to improve the measurement system.

From our first experiments it is not yet also clear if the pressure or flow are the leading parameters to determine the elongation, and the ongoing experiments must answer the question if flow or the acceleration of the flow are determining the Bernoulli’s effect which leads to the narrowing of the nasal channel. From the here presented results it cannot yet be decided statistically. However, it is sure that the strain gauge technique applied is fast enough to follow the movement of the nasal wall, and a hysteresis if observed is a physiological phenomenon corresponding to the type C (elastic type) of rhinomanometric patterns as given by Vogt et al. (Vogt et al., 2010). Such a hysteresis was also confirmed by O’Neill and Tolley during the recent meeting of the SCONA Society in London (April 2018).

The elaboration of a clinical protocol showing the rhinomanometric figure as well the time-line of elastography is in progress.

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

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

5. Conclusions

1. It is necessary to redefine the terms “internal” and “external” nasal valves as only describing anatomical details and to consider the functional structure at the nasal entrance as one physiological unit.

2. This initial study confirms that loops in rhinomanometry, if they are asymmetric and in a higher extend visible during inspiration, are signs of high nasal valve movement.

3. Because of the clearly visible clinical meaning of the movement of the lateral nasal wall, that was confirmed by this study, elastography by strain gauge technology should be developed furthermore as a medical product following all legal requirements. In addition, medical instruments should be developed to determine the mechanical properties of the nasal wall.

4. Also, this study leads to thought, that the early onset of valve activity should be considered when planning surgical alterations of the lateral nasal wall. Valve surgery or prosthesis might implicate non-physiological conditions. A rigid or immobile nasal valve seems to be an exception.

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DOKUMENTĀRĀ LAPA

Diplomdarbs **„Deguna vārsta kustīguma kvantitatīvs novērtējums”** **(“Quantitative determination of the mobility of the nasal valve”)** izstrādāts LU Medicīnas fakultātē.

Ar savu parakstu apliecinu, ka pētījums veikts patstāvīgi, izmantoti tikai tajā norādītie informācijas avoti un iesniegtā darba elektroniskā kopija atbilst izdrukai.

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