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NASAL FUNCTION AND EVALUATION

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The rational evaluation and management of nasal obstruction must be based on an understanding of the fundamental facts of nasal structure and function. The structure of the nasal airway is complex, because it is composed of markedly different regions. The support changes from soft tissue to cartilage to bone. The lining changes from skin to mucosa. These structural components must be understood in relation to the function of the nose as an airway and as a protector of the lower airways.

THE NASAL AIRWAY

The nasal mucosa is a complex organ responsible for several of the functions of the nasal airway. The mucosal surface area of the nasal airway is approximately 150 cm^2. The functions of this tissue are to provide heat and fluid exchange for warming and humidifying inspired air, to alter nasal airway resistance through congestion and decongestion of the nasal mucosa blood vessels, to clean and filter inspired air by means of impaction on the moist mucus-coated surface, and to sense the environment with specialized (olfactory) and general (trigeminal) sensory nerves. These functions are provided by the nasal blood vessels, nasal glands, and the mucociliary system.

Nasal Blood Vessels

The vascular bed of any organ can be functionally divided into resistance vessels, which control the blood flow to the organ, exchange vessels, which are responsible for filtration and absorption of fluid, and capacitance vessels, which are responsible for blood volume. The resistance vessels are arterioles and precapillary sphincters that account for more than 80% of the vascular resistance to blood flow. The capillaries are the main exchange vessels, and the veins are the main capacitance vessels.

The submucosa of the nasal epithelium contains a rich network of highly specialized blood vessels related to its role of heating and humidifying inspired air. The venous sinusoids of the nasal mucosa are particularly well developed to control the size of the nasal airway. Specialized arteriovenous anastomoses allow blood to bypass the capillary bed and pass directly into the venous sinusoids. Figure 23.1 shows the functional arrangement of these vessels. The arterioles regulate blood flow to the nasal mucosa by means of contraction of their precapillary sphincters. The blood flow to the mucosa heats the inspired air and supplies the venous sinusoids with blood to control airway resistance.

FIGURE 23.1. Functional arrangement of the nasal vascular system.

Nasal blood vessels receive motor control from both the sympathetic and parasympathetic nervous systems (1). The sensory nerve fibers in the nasal mucosa can control nasal blood vessels through release of neurotransmitters during axon reflexes. The sensory nerves reach the nose primarily in the first and second divisions of the trigeminal nerve. The sympathetic preganglionic nerves arise in the thoracic spinal cord and travel in the sympathetic chain to the superior cervical ganglion, where they synapse with the postganglionic fibers. The postganglionic fibers reach the nasal mucosa through the vidian nerve. The parasympathetic preganglionic nerves arise in the brainstem and travel in the facial nerve and greater superficial petrosal nerve to the sphenopalatine ganglion, where they synapse with postganglionic fibers. The postganglionic parasympathetic fibers travel to the nasal mucosa with the sympathetic fibers in the vidian nerve.

Sympathetic Vasomotor Control

The blood vessels of the nose are normally under sympathetic vasoconstrictor tone. The sympathetic neurotransmitter once was thought to be only norepinephrine. Now there is evidence that other neurotransmitters are involved in the sympathetic effects on the nasal mucosal blood vessels. These include avian pancreatic polypeptide and neuropeptide Y (2).

Parasympathetic Vasomotor Control

The main action of the parasympathetic nerves of the nasal mucosa is controlling secretion; however, there are important parasympathetic vasomotor effects. Studies have shown parasympathetic dilatation of both capacitance and resistance vessels and increases in venous volume and blood flow in the nasal mu-cosa. Although the parasympathetic neurotransmitter has been assumed to be acetylcholine, vasoactive intestinal polypeptide and peptide histamine isoleucine are related peptides that have been identified in parasympathetic nerve endings in the nasal mucosa.

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These peptides have known vasodilating effects and may play a role in parasympathetic vasodilation of the nasal mucosa.

Other Vasoactive Mediators

Substance P, a peptide containing 11 amino acids, is present in both the central and peripheral nervous systems. Substance P has several pharmacologic effects, including stimulation of smooth muscle, vasodilation, and stimulation of nasal secretion (3). Substance P mediates vasodilation and increased vascular permeability, and it may be the neurotransmitter responsible for vasodilation in response to chemical and mechanical stimulation. Vasodilation of nasal blood vessels is produced by both H_1 and H_2 histamine receptor agonists. Leukotriene D_4, another local mediator in immunologic reactions, has been shown to produce vasodilation. This response may be important in local vasomotor control during immunologic reactions and may be responsible for the nasal congestion of allergic rhinitis.

Nasal Glands and Secretion

Secretion of mucus by the nasal glands is an essential component of nasal airway function. The secretion provides a wetted surface to humidify the inspired air, a means to entrap and transport particulate material filtered from inspired air, and a fluid environment for the action of cilia. Mucus is produced by the goblet cells (unicellular intraepithelial mucous glands) and submucosal mucous and seromucous glands. Production of mucus is under neural control primarily by the parasympathetic neurons that reach the mucosa through the vidian nerve. Secretion is stimulated by the release of acetylcholine from the parasympathetic neurons. This effect is blocked by atropine.

Mucociliary Function

The mucociliary system is an important defense component of the respiratory system but has special importance for a nasal airway exposed to environmental contamination. The mucociliary system is composed of the ciliated respiratory epithelium, the mucous blanket, and the mucus-producing glands. This system provides a mechanism for maintaining a constantly moist surface for humidification and cleaning of inspired air and a means to eliminate excess glandular production and debris from the nasal airway. The nasal respiratory epithelium is pseudostratified ciliated epithelium. Each ciliated cell contains 50 to 100 cilia 5 to 7 μm long. The cilia beat at a rate of 800 to 1,000 strokes per minute (4). The action of the cilia produces mass movement of the mucous blanket at a rate of 3 to 35 mm per minute in the human nose.

Mucous Blanket

Lucas and Douglas first described the two-layer structure of the mucous layer. The layer surrounding the cilia—the periciliary fluid—is a serous fluid probably produced by the ciliated cells themselves. Overlying the periciliary fluid is a viscoelastic mucous layer produced by the submucosal glands and the goblet cells within the epithelium (Fig. 23.2). As the cilia beat, the tips of the cilia propel the mucous layer. The direction of transport of the mucous blanket follows a pattern determined by the orientation of the cilia beat. Transportation of mucus in the nose is generally in a posterior direction. This ensures clearance of excess mucus with the entrapped particles into the posterior pharynx, where it is swallowed. In the sinuses, the pattern of mucus transport is consistently in the direction of the sinus ostia. In this way, mucus, particulates, and potentially pathogenic bacteria are cleared from the sinuses. Disruption of this transport system inevitably results in bacterial sinusitis.

FIGURE 23.2. Nasal mucociliary system. The cilia beat in the serous fluid layer, and the tips of the cilia engage the mucous layer during the propulsion phase of the stroke.

RESPIRATION

The nasal airway is the entrance to the respiratory tract. Although respiration can occur through the mouth when respiratory demands are high, respiration occurs preferentially through the nose. The respiratory functions of the nose include preparation of inspired air for the lower respiratory tract by means of warming and humidification, protection of the lower

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airway by means of removing noxious particulates and soluble gas, and regulation of airway resistance.

Modification of Inspired Air

The upper airways provide an important protective function by heating ambient air to a temperature of 37°C and saturating it with water vapor. This is a suitable environment for alveolar gas exchange. The demands placed on the upper airway vary with the ambient conditions of temperature and humidity. The heat for warming and the water for humidification of the ambient air are provided by the moist, highly vascular mucosa of the upper airway, particularly the nose. Conditions that reduce the effective surface area of the nasal mucosa available for exchange, such as atrophic rhinitis, impair this essential function of the nasal airway.

Nasal Airway Resistance

Resistance of the nasal airway accounts for more than 50% of total airway resistance. Although humans can breathe through the nose, mouth, or both, breathing during rest is mainly through the nose. The usual reasons given for the preference of nasal breathing are (a) improved humidification and warming of inspired air, (b) improved filtering of particulate matter in the inspired air, and (c) smoothing the pattern of respiration by nasal resistance. The nasal airway can be divided into three distinct regions, each with a different mechanism for the physiologic control of nasal resistance. These regions are the nasal vestibule, the nasal valve, and the nasal cavum (5).

Nasal Vestibule

The nasal vestibule is the skin-lined region beginning anteriorly at the nares and extending to the level of the caudal end of the upper lateral cartilage. The support of the vestibule is the alar cartilage and its muscular and fibrous attachments. The nasal alae are subject to pressure changes during the cycle of respiration. During inspiration there is relatively negative pressure within the vestibule. Because of the lack of rigid support of the ala during inspiration, internal negative pressure tends to collapse this segment of the airway. This tendency is normally largely overcome with activation of the dilator nares muscles during inspiration. These muscles are innervated by the facial nerve and normally contract just before the onset of active inspiration (6). With increased ventilation produced by exercise, activity of the dilator nares muscle increases to prevent an increase in resistance of this segment of the airway.

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Nasal Valve

The nasal valve is the region of the nasal airway extending from the caudal end of the upper lateral cartilage to the anterior end of the interior turbinate. It is located approximately 1.3 cm from the nares. This is the narrowest segment of the nasal airway and is the major flow-resistive segment of the nasal airway (7). Measurements made from casts of the nasal airway give an average cross-sectional area of 0.73 cm^2 for this region. In a normal nose, the nasal valve region is the narrowest segment of the nasal airway. As air enters this constricted segment of the airway, airflow accelerates, and intraluminal pressure decreases according to the Bernoulli principle. This decrease in pressure can collapse this segment of the airway during inspiration if the upper lateral cartilage is anatomically weak or has been surgically detached from the septal cartilage. The erectile tissues of the nasal septum and tip of the inferior turbinate impinge on the nasal valve. Engorgement of these tissues can increase the resistance of this segment of the nasal airway.

Nasal Cavum

The nasal cavum is the region of the nasal airway posterior to the piriform aperture. The resistance of this segment of the nasal airway is determined primarily by the degree of engorgement of the erectile tissues of the turbinates and the septum. However, the relative contribution of this segment of the airway to total nasal resistance is small. Many studies have shown that the greatest contribution of nasal airway resistance is made by the anterior nasal airway, even in the state of congestion. Acoustic rhinometry has shown that the tip of the inferior turbinate narrows the nasal airway just posterior to the nasal valve. It is here that engorgement of the erectile tissue of the turbinate has the greatest influence on the resistance of the nasal airway.

Control of Nasal Resistance

The baseline resistance of the nasal airway can be remarkably constant when measured over a period of days or weeks. Most healthy adults without symptoms of nasal disease have a nasal resistance ranging from 0.15 to 0.3 Pa/cm^3 per second (8,9). However, nasal resistance changes with posture, disease, physiologic state, and psychologic factors. Airway resistance can increase or decrease depending on the physiologic demands for gas exchange. The major sites for regulation of airway resistance are the dilator nares muscles of the external nose and the venous sinusoids of the nasal turbinates.

Action of Dilator Nares

The muscles of the external nose, particularly the dilator nares muscles, have phasic respiratory activity. This activity is enhanced during exercise and during increased ventilation. The dilator nares muscles have a role in preventing an increase in nasal resistance by means of dynamic collapse of the ala. In some cases these muscles actually reduce resistance to airflow during hyperventilation.

Vascular Control of Resistance

The other major factor controlling nasal resistance is the state of vascular congestion of the nasal mucosa. Because the nasal airway is a rigid bony cavity, changes in the volume of the nasal mucosa can effectively alter the dimensions of the nasal airway. This fact is obvious with the severe nasal obstruction that result from congestion of the nasal mucosa during upper respiratory tract infection. Besides pathologic alterations in the nasal airway with disease, there is physiologic variability in the nasal airway as a result of vascular changes.

Nasal Cycle

The nasal cycle is the observed intrinsic variability of the nasal airway resistance that occurs in a cyclic pattern in as many as 40% of persons (10). This cyclic engorgement and decongestion of the cavernous tissue of the nose have been known since the beginning of the nineteenth century. The cycle has a duration of 2 to 6 hours. During the cycle, one side of the nose congests while the opposite side decongests. This means that total nasal resistance remains essentially constant despite the localized alternating congestion of each side of the nose.

Positional Effect

Lateral recumbence produces congestion of the nasal chamber in the lower position and disrupts the normal cycle of alternating congestion and decongestion (nasal cycle). This phenomenon is a neural response to stimulation of pressure receptors on the surface of the body. If pressure is applied to the side of the body, congestion of the ipsilateral side of the nose occurs.

Nasal Vascular Reflexes

Additional physiologic reflexes affecting the nasal vessels have been studied. Because the nose is a part of the respiratory tract, it would be expected that the nasal airway would participate in respiratory reflexes. The phenomenon of nasal decongestion occurring with hypercapnia has been studied in humans and animals. The reflex reduction in nasal resistance that occurs with hypercapnia and hypoxia is mediated by the sympathetic nervous system (11). The reduction in nasal resistance closely follows the increased ventilation that occurs with these stimuli. Exercise, another known stimulator of ventilation, also has an effect on nasal resistance. Nasal decongestion occurs promptly with the beginning of exercise and is proportional to the increase in ventilation that occurs with the exercise (12).

EVALUATION OF THE NASAL AIRWAY

Evaluation of an obstructed nasal airway requires accurate information about the anatomic and functional abnormalities producing the symptom of obstruction. With an accurate knowledge of the anatomic abnormality and its functional consequences, a plan of treatment based on an understanding of the effects of surgery on the airway can be formulated. In the past, technical difficulties limited the use of tests of nasal function;

however, methods have been devised to quantify nasal respiratory function. The oldest and most widely used technique is rhinomanometry. Rhinomanometry is used to measure the pressure needed to produce airflow through the nasal airway. Various methods have been used to measure respiratory nasal airflow for at least a century. Because rhinomanometry does not measure the location of nasal obstruction, it can be of limited use clinically. The newer technique of acoustic rhinometry shows promise in providing a measure of the cross-sectional area of the airway at various points. This is accomplished by means of analysis of sound pulses reflected by the nasal airway.

Rhinomanometry

Rhinomanometry is a technique for measuring nasal airway resistance as a diagnostic tool for the evaluation of nasal airway function. It allows functional assessment of the adequacy of the nasal airway and combined with rhinoscopic examination and other diagnostic techniques allows diagnosis of nasal airway insufficiency.

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The limitations of rhinomanometry must be recognized. It does not provide enough information for a diagnosis or about the cause of nasal obstruction. Rather it provides an objective measurement of nasal resistance at a specific time (8,9).

Nasal Aerodynamics

A basic knowledge of the characteristics of nasal airflow is necessary to understand the applications and limitations of rhinomanometry. Airflow through the nose follows the basic physical laws first elaborated by Poiseuille and Reynolds. However, airflow in the nose is complicated by the irregular contour of the nasal cavity, areas of marked constriction and abrupt changes in direction of airflow, regions with collapsible segments, and areas in which the dimensions of the airway are under muscular and vascular control. These complicating factors impose limitations on interpretation of nasal resistance measurements, because the nasal airway cannot be represented as an ideal tube, as assumed by the simplest physical law of fluid flow.

Laminar Flow

The simplest type of airflow is laminar flow. Laminar flow occurs when there is no gross mixing in the airstream from one region to another. In this type of flow, the air molecules follow streamlines, each layer or lamina sliding smoothly past adjacent regions (Fig. 23.3). The resistance to laminar flow depends only on the dimensions of the conduit and the viscosity of the fluid.

FIGURE 23.3. Diagram shows laminar airflow. In laminar flow, there is no mixing within the airstream (*arrows*). The pressure difference between points *P1* and *P2* is linearly related to the flow (*V*) by a constant (*K*).

Turbulent Flow

If the flow rate exceeds a critical value, the air molecules deviate from the streamline flow, and mixing occurs in the fluid. This is called *turbulence* (Fig. 23.4). Turbulence occurs when the Reynolds number exceeds 2,000. This corresponds to a flow of approximately 250 to 500 cm^3/s in the nose. Under conditions of turbulent flow, a simple relation between pressure and flow cannot easily be determined. Simplified theoretic considerations show that in turbulence, pressure is related to the square of flow. When turbulence occurs, resistance to airflow depends on factors other than the size of the conduit. During turbulence, factors such as wall roughness and flow separation can produce differences in the measured resistance of conduits of the same size.

FIGURE 23.4. Diagram shows turbulent airflow. In turbulent airflow, there is mixing within the airstream (*arrows*). The pressure difference between points *P1* and *P2* is related to approximately the second power of the flow.

In the airway, the relation between pressure and flow is more complex, and only an approximation of the ideal relation between pressure and flow occurs. The curve obtained is not a linear relation, as would occur if nasal airflow were laminar, but is a sigmoid curve. Under turbulent conditions, the flow curve departs from the laminar flow curve. This deviation increases with increasing flow rate. Conditions other than turbulence can account for the nonlinearity of the pressure-flow relation in the nasal airway. Regions of orifice flow or collapse of the airway can produce nonlinear pressure-flow relations.

Orifice Flow

When gas flows through a conduit with localized constriction, orifice flow can occur (Fig. 23.5). Flow through an orifice has a nonlinear pressure-flow relation. The pressure to produce flow through an orifice depends on the hydraulic cross-section of the orifice. An orifice smaller than the rest of the lumen determines the resistance of the whole conduit. This is shown in Fig. 23.5. The orifice is a flow-limiting segment and largely determines the resistance of the airway. Orifice flow can occur physiologically within the nasal valve area. This leads to the observation that the flow-limiting segment of the nasal airway occurs in the region of the nasal valve.

FIGURE 23.5. Diagram shows orifice flow. A short constriction accelerates the airstream with divergent flow beyond the constriction. The pressure difference between points *P1* and *P2* is related to the second power of the flow.

Collapsible Segments

Consideration of the resistance properties of the nasal airway often entails the implicit assumption that the walls of the nasal cavity are rigid. This is valid for flow in the bony cavum of the nasal airway, but it is not for the compliant region of the nasal vestibule and valve. The lateral pressure within a conduit depends on the rate of flow, according to the Bernoulli principle. As airflow accelerates through a constriction, lateral pressure decreases. Compliance of the area of constriction can allow collapse. Collapse of the nasal valve can occur, and this factor can lead to a nonlinear pressure-flow relation. Collapse is characterized by an asymmetric pressure-flow curve during the inspiration and expiration flow limitation occurring on inspiration.

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Measurement of Nasal Resistance

Nasal resistance is the numerical relation between transnasal pressure and flow. Pressure (P) divided by flow (V) is resistance (R), as follows:

$$R = P/V$$

The previous description of laminar flow showed that the relation between pressure and flow (resistance) is a constant; however, during turbulence, orifice flow, or flow in a collapsible tube, resistance depends on flow rate, and a nonlinear relation results. Therefore, the numerically calculated resistance varies from point to point along the pressure-flow curve (Fig. 23.6). To obtain a consistent value of resistance that can be compared, it is necessary to specify a specific point on the pressure-flow curve to calculate resistance. In the accepted method, a specific pressure point (usually 150 or 300 Pa) is selected, and flow is measured at this point.

FIGURE 23.6. Typical curvilinear relation between pressure and flow for the nasal airway. Because of the contributions of turbulence and orifice flow, pressure and flow are not linearly related in the nasal airway.

Bilateral Nasal Resistance

When only unilateral nasal resistance is measured directly, it is still possible to calculate the resistance of the nasal airway as a whole (right and left sides together). Total nasal resistance can be estimated with the parallel resistance formula to derive total resistance (R_c) from measured right (R_r) and left (R_l) resistance:

$$R_t = (R_l \times R_r)/(R_l + R_r)$$

This equation is strictly true only for the laminar flow condition. For nasal resistance, this equation gives only an approximation because nasal flow is not laminar. This equation is most nearly correct if the measured resistances are approximately equal. An alternative, if nasal resistance is measured as a constant pressure point, is to measure exact total resistance because the flows in parallel resistors are additive. This yields the simple formula for total resistance:

$$R_t = P/(flow_r + flow_l)$$

Methods of Rhinomanometry

To determine the resistive properties of the nose, it is necessary simultaneously to measure pressure and flow through the nose. With pressure and flow, a quantitative value for nasal resistance can be calculated and a graphic representation of the pressure-flow relation made.

Anterior Rhinomanometry

Anterior rhinomanometry is measurement of transnasal pressure at the anterior end of the nose. If one nostril is occluded, the pressure in that nostril equals the pressure in the nasopharynx because the occluded airway can be considered a rigid tube with its proximal end exposed to nasopharyngeal pressure (Fig. 23.7). If a differential pressure transducer is inserted into the occluded nostril, the difference between atmospheric pressure and nasal pressure equals the pressure difference between the nasopharynx and the air. This is the driving pressure for airflow through the unobstructed nostril. With this method, resistance can be measured in only one nostril at a time. Total nasal resistance can be calculated with one of the parallel resistance formulas previously described.

FIGURE 23.7. Diagram shows the technique of anterior rhinomanometry. The figure is an axial view of the nasal airway and nasopharynx (*NP*). The pressure in the nasopharynx is measured at the nostril (*P1*) by means of occluding the nostril with a rubber bulb. Because no airflow occurs through this side of the nose, the pressure measured at the nostril (*P1*) equals the pressure in the nasopharynx. The flow (*V*) is measured with a pneumotachograph attached to a mask.

Anterior rhinomanometry has inherent limitations. It cannot be satisfactorily used in cases of complete occlusion of one nasal

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passage. Nasal septal perforation or marked flaccidity of the septum makes the measurements unreliable. Anterior rhinomanometry also produces the nonphysiologic condition that all airflow must occur through one side of the nose during measurement. This means that even under resting conditions the measurements can be made only over short time periods because breathing may be restricted when respiration occurs through only one side of the nose. To overcome this difficulty and allow measurement of nasal resistance of both nostrils simultaneously, the method of posterior rhinomanometry was developed.

Posterior Rhinomanometry

In posterior rhinomanometry, air pressure in the nasopharynx is measured with a catheter placed in the mouth. In this technique, the lips are sealed around the catheter so no airflow occurs through the mouth. Because neither nostril is occluded, it is possible to measure bilateral nasal resistance directly. The pressure transducer catheter placed in the mouth accurately measures nasopharyngeal pressure as long as the palate is not contracted tightly against the base of the tongue, which would occlude the communication between the oral cavity and the nasopharynx. The difference between nasopharyngeal pressure and atmospheric pressure is the driving pressure for nasal airflow.

Clinical Technique of Rhinomanometry

The basic clinical technique of anterior mask rhinomanometry is shown in Fig. 23.8. This technique has been chosen for routine use because it is reproducible, can be performed with modest investment in equipment, and provides the data necessary for clinical evaluation of nasal resistance. Nasal airflow is measured as shown in Fig. 23.8 with a tightly fitting face mask applied to the face. The mask has a large central aperture connected to a low-resistance pneumotachograph flowmeter. The pneumotachograph converts the flow signal to a differential pressure that can be measured with an electronic pressure transducer.

FIGURE 23.8. Clinical rhinomanometry by means of the anterior technique. A nasal pressure catheter is used to measure transnasal pressure and a mask pneumotachograph to measure airflow. Pressure-flow relation and resistance are calculated with a computer at a standard pressure of 150 Pa.

Transnasal pressure is measured at the nostril (anterior rhinomanometry). The pressure-measuring catheter passes through the mask and is attached to the nostril with either tape or a soft sponge rubber bulb. It is important that a pressure-tight seal be achieved at the nostril. A second catheter is used to measure air pressure inside the mask. These two pressure catheters are attached to a differential pressure transducer to measure transnasal pressure. The outputs of the electronic pressure transducers are amplified and recorded as a pressure-flow diagram. Recording can be done with an oscilloscope, an X-Y plotter, or a computer equipped with appropriate interface electronics and software. Computer-based rhinomanometry systems meeting these specifications are produced by several manufacturers. A commercial unit chosen for clinical use should produce a pressure-flow diagram and standard nasal resistance. In addition to this basic function, several units provide features that may prove useful in particular circumstances.

Reporting Data

At an international rhinomanometry meeting in 1986 several standards were proposed for implementation of rhinomanometry. These standards were considered minimal for reporting and comparing data on nasal airway resistance. The basic method proposed was anterior mask rhinomanometry as described previously. The minimal reporting value was chosen as the airflow or resistance calculated at 150 Pa pressure.

Interpretation of Rhinomanometric Findings

Although rhinomanometry provides only one aspect of the clinical evaluation of nasal obstruction, the information obtained about the functional capacity of the nasal airway cannot be acquired with other methods of evaluation. In general, there are two major types of nasal obstruction: mucosal hypertrophy or congestion and structural deformity of the nasal airway. When nasal resistance is determined before and after maximum nasal decongestion with a topical decongestant, it is possible to determine the relative importance of mucosal and structural factors in producing nasal obstruction.

Calculated resistance can be compared with predetermined normal ranges found for persons without symptoms. Mucosal obstruction usually is expected to be corrected with topical

decongestion. Structural abnormalities causing nasal obstruction are not expected to be in the normal range after decongestion. Normal nasal resistance values and ranges have been established. There is not an absolute upper limit of normal nasal resistance; however, a nasal resistance greater than 0.3 Pa/cm^3 per second usually is symptomatic. The threshold for subjective obstruction, however, varies. Some persons with apparently normal or slightly elevated nasal resistance have obstructive symptoms at times. Several measurements obtained with rhinomanometry provide important information about the nasal airway. These are unilateral nasal resistance before decongestion, total nasal resistance before decongestion, the effect of decongestion on nasal resistance, and the presence of airway collapse.

Unilateral Nasal Resistance

There is considerable variability in unilateral nasal resistance because of normal physiologic responses, the nasal cycle, and anatomic differences in the nasal airway. Despite this variability, there is a close correlation between symptomatic obstruction of the nasal airway and measured nasal resistance when large populations are studied. Because of differences in individual thresholds for obstruction, it is difficult to set strict limits on the normal range of unilateral nasal resistance.

Total Nasal Resistance

Total nasal resistance is less variable than unilateral nasal resistance because it incorporates both nasal airways and thus is not affected by the nasal cycle. For this reason, it is a better predictor of the presence of obstructive symptoms. A total nasal resistance greater than 0.3 Pa/cm^3 per second usually is symptomatic and is likely to be associated with symptoms of severe obstruction (9). Patients treated for nasal obstruction with septal surgery are more likely to have subjective improvement if the initial nasal resistance is greater than 0.3 Pa/cm^3 per second (13).

Effect of Decongestion

Nasal decongestion with topical vasoconstrictors decreases nasal resistance. A marked reduction in nasal resistance after decongestion to a “normal” value suggests that mucosal disease (vasomotor rhinitis, allergic rhinitis, or rhinitis medicamentosa) is a major contributor to the nasal obstruction. If, however, decongestion causes less than a 35% decrease in resistance, especially if asymmetry persists in the unilateral nasal resistances after decongestion, a structural cause, such as septal deformity, conchal hypertrophy, stenosis, or concha bullosa, can be inferred.

Airway Collapse

Rhinomanometry is particularly useful in the diagnosis of nasal obstruction due to dynamic changes in the nasal airway, because rhinoscopic examination may not detect these abnormalities. Nasal alar collapse, or nasal valve collapse, is a dynamic phenomenon in which the resilient cartilaginous and fibrofatty structures of the nasal ala collapse during inspiration. This phenomenon may be due to localized obstruction in the nares region that leads to excessive negative pressure in the region of the vestibule and nasal valve during inspiration. If the negative pressure in the nasal airway is sufficient to overcome the elasticity of the cartilage, the airway collapses, and nasal resistance increases with increasing effort. The typical rhinomanometric finding with such collapse is an asymmetric nasal pressure-flow curve. Because collapse occurs only during inspiration, inspiratory resistance is higher than expiratory resistance. Collapse produces flow

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limitation that can be detected as a plateau on the pressure-flow curve (Fig. 23.9).

FIGURE 23.9. Pressure-flow relation under laminar, turbulent, and collapse conditions. In laminar flow, the pressure-flow relation is linear. In turbulent flow conditions, the pressure-flow relation is curvilinear. When collapse occurs, there is plateauing of the inspiratory phase of the cycle and asymmetry between the inspiratory and expiratory phases.

Acoustic Rhinometry

Acoustic rhinometry is a method of noninvasive measurement of the cross-sectional area of regions of the nasal airway. The technique is based on analysis of a sound pulse reflected from the airway. The examination is rapid and noninvasive and requires minimal cooperation from the subject. The results are reproducible and highly accurate. A graph is produced of nasal cross-sectional area as a function of distance from the nostril. Unlike rhinomanometry, acoustic rhinometry does not require nasal airflow. The main advantage over rhinomanometry in evaluating the nasal airway is the ability to find narrow segments of the airway. Acoustic rhinometry, however, does not measure the effect of the narrow regions on airflow dynamics or airway resistance. It is a tool best used in conjunction with rhinomanometry for functional assessment of the airway.

Theory of Acoustic Rhinometry

Jackson et al. (14) showed it is possible to use reflected acoustic energy to measure the cross-sectional area of the airways as a function of distance. If an acoustic pulse is introduced into the airway, the intensity, phase, and time delay of the reflected sound energy wave are determined by the size and location of narrowing. It is possible to convert mathematically the reflected sound pulse into a map of the cross-sectional area of the airway versus the distance from the site of introduction of the pulse.

In 1989, Hilberg et al. (15) performed the first acoustic rhinometric examination and used similar techniques to evaluate the geometric features of the nasal cavity. In acoustic rhinometry, a short-duration sound pulse produced by a sound generator is directed into the nasal airway through a wave tube. As it travels through the airway, the sound pulse is partially reflected when a change in cross-sectional area is encountered. The transmitted and reflected signals are recorded with a microphone and digitized with a computer. The computer performs mathematical analysis of the reflected wave and produces an area-distance plot (echogram) (Fig. 23.10). The volume of the nasal cavity can be calculated by means of mathematical integration of contiguous cross-sectional areas. This technique has been used to evaluate the geometric features of the nasal cavities of healthy persons, the preoperative and postoperative condition of patients undergoing septoplasty, nasal airway obstruction among children, and response to medical therapy among patients with nasal polyposis.

FIGURE 23.10. Method of acoustic rhinometry. The sound pulse is produced in a wave tube to produce an acoustic signal. The reflected sound is recorded with a microphone in the wave tube. The reflected wave is compared with the incident wave to assess the geometric features of the airway. For reproducible results, the wave tube must be coupled to the nostril with an airtight seal and must not distort the soft tissue of the nares.

Many authors have validated the accuracy of acoustic rhinometry in assessment of the cross-sectional area of the nasal cavity (16). The original description of acoustic reflection technique showed that the area distal to severe constriction may not be accurately estimated. Roithmann et al. (17) showed that supporting the subject's chin with a nasal adapter that does not invade the nasal cavity but just engages the rim of the nostril avoids distortion of the anatomic structures in the nose and provides more accurate results. Care must be taken to ensure an interface seal between nostril and nasal adapter. Any acoustic leakage causes measurement error.

Characteristics of Rhinograms

Acoustic rhinometric echograms are area-distance plots with peaks and troughs that represent widening and narrowing of the airway. Adults with subjective normal nasal patency have a characteristic plot (Fig. 23.11). The initial flat tracing represents the nosepiece. The next depression (I notch) corresponds with the functional isthmus nasi. The second trough (C notch), after a small peak, corresponds with the head of the inferior turbinate. The tracing then slopes upward (climbing W) with small peaks and troughs that correspond to the posterior nasal cavity and its increasing cross-sectional area. Echograms must be interpreted in conjunction with the examiner's rhinoscopic findings.

FIGURE 23.11. Typical acoustic rhinogram shows a rising W pattern with an initial I notch and later C notch.

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Examination of a typical acoustic rhinogram shows several characteristics. The region of maximum narrowing lies within the first 2 cm of the airway. The average distance of the region of maximum constriction is considered to be 1.73 cm. This corresponds to the anatomic location of the nasal valve. Vasoconstriction of the nasal mucosa does not markedly change this region of narrowing. Slightly farther along the airway, at approximately 2 cm, is another region of narrowing. This region is normally less narrow than the nasal valve. In a nose with mucosal congestion, however, this region may be more constricted than the nasal valve. This region responds to vasoconstrictive agents. The anatomic location of this region is at the piriform aperture at the level of the head of the inferior turbinate.

Acoustic rhinometry supports rhinometric findings that the flow-limiting segment of the nose is anterior to the inferior turbinate. Grymer et al. (18) examined 82 patients with subjective normal nasal patency and compared acoustic rhinometric findings before and after decongestion with direct measurement of the columella-inferior turbinate distance. Comparison of the echograms with the direct measurements showed that the minimal cross-sectional area (MCA) is anterior in the nasal cavity within the first 2 cm of the airway and is localized at the head of the inferior turbinate in some persons and more anteriorly at the nasal valve in others. In a separate study, Grymer et al. (19) obtained echograms before and after septoplasty on patients with septal deviation. The size of the MCA correlated with the subjective severity of nasal obstruction: subjective symptoms of obstruction with a smaller MCA and no nasal obstruction with a larger MCA. The subjects who served as controls and those with objectively small and moderate septal deviation with subjectively normal nasal patency had a mean MCA of 0.7 cm^2 preoperatively. Subjects with the feeling of nearly total obstruction and objectively severe septal deformity had a mean MCA of 0.3 cm^2. Postoperative measurements correlated positively with dissatisfaction. Dissatisfied patients had an average MCA of 0.45 cm^2. The satisfied group had an average MCA of 0.74 cm^2. These results emphasize the three-dimensional boundaries of the nasal valve and that patients' subjective symptoms are directly proportional to the degree of obstruction in the anterior nasal cavity. Whether the obstruction is caused by skeletal or mucosal abnormality, acoustic rhinometry may be used for accurate quantification of the effects. Acoustic rhinometry can be used to quantify the mucosal decongestion produced by topical vasoconstrictors (Fig. 23.12).

FIGURE 23.12. Acoustic rhinogram before and after vasoconstriction produced by application of a topical vasoconstrictor. The *decongested curve* shows an increase in cross-sectional area most apparent in the region of the nasal turbinates.

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Use of Acoustic Rhinograms

The usefulness of acoustic rhinography is not completely defined. The technique appears to have promise for quantifying the degree and location of narrowing in the anterior region of the nose. Its advantage over rhinomanometry is that it allows localization of abnormalities, and this may allow better diagnosis and better determination of appropriate surgical procedures. The region most easily evaluated with acoustic rhinometry is the region best evaluated visually. Acoustic rhinometry alone does provide information about the effect of narrowing on resistance. For this, rhinomanometry is necessary.

No single method of evaluating the nasal airway correlates with pathologic findings and the patient's subjective symptoms. Nasal endoscopy and imaging studies provide anatomic display but do not quantify nasal obstruction. Rhinomanometry can be useful in determining whether a documented intranasal deformity increases nasal resistance and therefore causes functional disturbance (13). Acoustic rhinometry can be used for accurate location and quantification of areas of obstruction in the anterior nasal cavity. This technique provides objective data to assess the need for surgical correction, to document postsurgical outcome, and to monitor medical therapy for inflammatory nasal disorders. Because the technique is rapid and noninvasive, it is an ideal method of evaluating possible nasal airway obstruction in children (20). Acoustic rhinometry does not replace previous methods of evaluation of the patency of the nasal cavity but provides objective documentation that is accurate and reproducible.

HIGHLIGHTS

- The function of the nasal airways is to warm, humidify, clean, and regulate the flow of inspired air.
- The nasal blood vessels are controlled by sympathetic and parasympathetic nerves as well as locally released mediators, which include substance P, histamine, and leukotrienes.
- The nasal mucociliary system is essential for the clearance of mucus, debris, and bacteria from the paranasal sinuses and nasal airway.
- The three functional regions of the nasal airway for regulation of airflow are the nasal vestibule, the nasal valve, and the nasal cavum.
- The nasal valve is the narrowest and highest-resistance segment of the nasal airway.
- Rhinomanometry is used for quantifying the resistance of the nasal airway.
- A total nasal airway resistance greater than 0.3 Pa/cm^3 per second usually is symptomatic.
- The types of nasal obstruction identified with rhinomanometry are mucosal obstruction, structural obstruction, and dynamic airway collapse.
- Acoustic rhinometry is a method for measuring nasal airway dimensions with reflected sound waves.
- Acoustic rhinometry can help identify the location of flow-limiting segments in the nasal airway.

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