Chapter 37: Evaluation of Nasal Breathing Function

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Nasal Breathing Function

Disturbance in a patient's sense of well-being due to problems with respiration can be both pulmonary and nasal in origin. This chapter describes the assessment of nasal breathing function. The method of evaluating other nasal functions - olfaction, filtering, humidification, ciliary function, and immune function - will not be covered.

The sensation of comfortable nasal breathing is a complex phenomenon. Many people enjoy the everyday act of breathing through the nose with their mouth closed, although some patients spend a lifetime mouth breathing without complaint (Niinimaa et al, 1981). In optimal nasal respiration, air would pass over the maximum amount of nasal mucosa with resulting humidification, cleansing, and warming but without the sensation of dyspnea.

Several factors may influence the sensation of comfortable nasal breathing, including the amount and type of nasal airflow, the sensation registered from the intranasal skin or mucosa by the passing air, and the condition of the nasal mucosa. The major portion of the airstream after the vestibule passes through the middle meatus and over the inferior turbinates (Lund, 1989). Nasal airflow is predominantly turbulent or mixed rather than laminar. It is not known whether the amount of airflow turbulence affects comfort in nasal breathing, although studies have shown a correlation between the amount of airflow and the symptom of nasal obstruction (McCaffrey and Kern, 1979a; Schumacher and Pain, 1979; Welch et al, 1985). Stimulation of cold receptors in the nasal vestibule and nerve endings in the nasal vestibular skin and the nasal mucosa can also play a role. In addition, the condition of the lining tissue in the dry atrophic nose can cause a sensation of disturbed nasal breathing. The most frequently studied of these three phenomena is the amount of airflow through the nose.

Many physiologic factors and pathologic conditions can affect the amount of airflow through the nose. The nasal pathologic conditions include mucosal hyperreactivity, septal or other structural deformities, polyps, tumors, sinus infection, granulations, and synechiae. Any of these conditions may be present but unnoticed in a person who breathes comfortably through the nose, or one of them may be the factor that limits airflow in a person who complains of nasal obstruction.

Assessment of Nasal Breathing Function

Patient history

The first step in assessing nasal breathing function is to obtain a thorough history. A questionnaire is sometimes used (McCaffrey and Kern, 1979a). The patient is asked about the symptom of nasal obstruction. If it is present, the side of obstruction, severity, frequency, duration, and exacerbating factors are all recorded. Several methods have been used for recording the severity of symptoms (Adams et al, 1985; Jones et al, 1989; Meltzer, 1988). We use the scale of none, mild, moderate, or severe. We also ask the patient to assess the side of obstruction and severity, both in general and at the time of examination or testing. All of these descriptions are the patient's subjective evaluation of nasal breathing function.

Nasal examination

The next step in evaluating nasal breathing is to examine the nose. Methods of recording rhinoscopic findings can be quite detailed (Hardcastle et al, 1988a). These methods include an assessment by the physician of the appearance of the intranasal anatomy, the cross-sectional area, and the condition of the lining tissues of the nose. It is a subjective assessment of anatomic factors that might affect the patient's nasal breathing. The last step in evaluation, an actual objective measurement of the physical parameters that occur during nasal breathing, is the focus of most of this chapter.

Objective testing of the nasal airway

Nasal airflow and transnasal pressure

Airflow occurs through the nose if there is a difference in pressure across the nasal airway with the airflow occurring from the area of higher pressure to the area of lower pressure. Although the pressure outside the nose is relatively constant, the pressure in the nasopharynx changes with respiratory movement of the chest. This change creates a pressure differential (the transnasal pressure) across the nose, and air moves back and forth through the nose with the phases of respiration.

Physical factors affecting the amount of flow

The rate of airflow through the nose depends on the length and cross-sectional area of the nasal airway, the pressure gradient across the nose, and the character of the airflow (laminar versus turbulent). The cross-sectional area of the nose is a major factor in determining airflow, with airflow increasing as the cross-sectional area increases. The cross-sectional area varies along the length of the nose. The effect of turbulence in the nasal airway has not been precisely quantified. Laminar flow occurs in a smooth-walled, straight tube at low flow rates, but turbulence occurs when irregularities are encountered in the tube, as would happen in the nose. Turbulent flow requires more energy but results in better mixing of the air.

Physical factors measured

The actual physical factors that can be objectively assessed by nasal airway testing are cross-sectional area of the nose, transnasal pressure and airflow, and volume of air in each breath. The symbols that will be used for transnasal pressure and flow are as follows:

deltaP = transnasal pressure

V = airflow

Cross-sectional area can be assessed using several methods. By recording pressure and flow over a given period of time, one can measure mean pressure and volume of each breath.

From these measurements other parameters can be calculated, which represent the relationship of these factors with each other at a single moment or during a specific time interval. An important example of the relationship of pressure and flow at a single moment is resistance, which is the ratio of pressure to flow, sometimes abbreviated as NAR or Rn. An example of the relationship of pressure and flow over time would be work, or mean pressure times flow.

Criteria of a good airway test

A number of desirable criteria for a nasal airway test have been described (Maran et al, 1971). These criteria include ease of performance using readily available equipment; no discomfort for the patient; no interference with the nasal anatomy or airflow; an objective means of assessment that is accurate, reproducible, and standardized; availability of normal values; use of physiologic levels of the parameters measured and clinical usefulness. Available tests vary in their ability to fulfill these criteria.

Types of objective tests of the nasal airway

Simple maneuvers

Several simple office maneuvers can be used to assess the nasal airway. At the turn of the century, methods used (Foxen et al, 1971; Hilberg et al, 1989) included breathing on a mirror or glass plate, assessing the sound of a forced expiration through the nose, and evaluating the pitch of the sound made by a patient humming while first one and then the other side of the nose was occluded.

A simple test is to occlude each side of the patient's nose and ask him or her to compare the nasal breathing through the two sides. To assess the effect of the nasal valve, the patient's cheek can be drawn back (positive Cottle sign) (Heinberg and Kern, 1973) to see whether a significant decrease in obstruction occurs. These tests are easy to perform and are noninvasive, but they require a subjective appraisal by the patient and thus are not easy to quantify accurately.

Measurement of peak flow

The readily available peak expiratory flow meter has been used to assess the nasal airway, and results have correlated with nasal resistance (Taylor et al, 1973), although others have stated that the method is unreliable and have recommended against its use (Connell, 1982).

Rhinomanometry

The most common method of objectively assessing the nasal airway currently is the simultaneous recording of the transnasal pressure and airflow. This method could be called *rhinorheomanometry,* but *rhinomanometry, rhinometry,* and *rhinomanography* are all names that have been applied to these measurements. The International Standards Committee has chosen the designated name *rhinomanometry* (Clement, 1984). This technique of recording pressure and flow simultaneously over a given time interval allows for study of the relationships between pressure, airflow, and time to give the most complete objective assessment of the passage of air through the nose.

Forced oscillation methods

In forced oscillation rhinomanometry (Fulton et al, 1984; Georgitis, 1985; Shelton et al, 1990), the oscillation of a loud speaker provides a complex signal of sinusoidal sound waves, which is coupled to the patient through a small mask and pneumotachometer.

Acoustic rhinometry

By presenting a shock wave to the nasal airway and then measuring the reflected sound, a profile of the cross-sectional areas through each side of the nose may be obtained. Hilberg et al (1989) believed that acoustic rhinometry provided less variability of results than those obtained with rhinomanometry. Further, they pointed out that the method requires little cooperation by the patient, is noninvasive, and is easy to perform.

One disadvantage of the test is that the area beyond a significant restriction may not be accurately estimated. They found in general that if the anterior area is greater than 0.7 cm^2, there will be significant error for more distal measurements. The results were reproducible except for some abnormal curves, which were thought to be related to coupling of the wave tube to the nostril, motion of the soft palate, swallowing, transient changes of sinus opening areas, or pressure changes in the nose.

Other studies

The cross-sectional area of the nose can be assessed by computed tomography (CT) or magnetic resonance imaging (MRI), although the correct scale factor must be known. Zedalis et al (1989) measured cross-sectional area in the nasal airway using fiberoptic rhinoscopy. Juto (1982) used a microscope to assess changes at a defined point in the nose to assess nasal congestion. Investigators have studied mucosal blood flow in the nose using laser Doppler velocimetry (Arbour et al, 1985). Nasometry measures the oral and nasal acoustic ratio across a specified frequency range. Parker et al (1990) thought that this test could be performed more easily than rhinomanometry, particularly in children, as it did not require a mask or pressure cannula. Of all these methods, rhinomanometry is the most commonly used and, therefore, will be the focus of the remainder of this chapter. With the current availability of microprocessorassisted devices, equipment capable of rapid and sophisticated airway assessment has become readily available. Of the other methods listed, acoustic rhinometry holds considerable promise and is being actively investigated.

Rhinomanometry Equipment and Methods

Foxen et al (1971) and Kosoy (1979) have presented a history of the development of rhinomanometry. Rhinomanometry is the simultaneous measurement of transnasal pressure and airflow. Various types of equipment and methods have been developed to perform this measurement.

Measurement of transnasal pressure

Pressure across the nose must be measured at the front and back of the nose so that the transnasal pressure difference can be determined. Three methods of transnasal pressure detection are currently in use: anterior rhinomanometry, posterior (peroral) rhinomanometry, and postnasal (or pernasal) rhinomanometry (Cole, 1989a). The major difference in these three approaches is the location of the pressure detector at the back of the nose. In the anterior method, it is placed at the opening to the nostril not being tested (Figs. 37-1 and 37-2). In the posterior method, the pressure detector is placed in or close to the posterior oropharynx (Fig. 37-3). For the postnasal (pernasal) technique (Cole, 1989a), the tube is placed in the posterior nose through one of the nostrils (Fig. 37-4). This method produces a mild irritation, which subsides as soon as the catheter is immobilized with tape. Cole et al (1989a) found no significant increase in resistance from the catheter.

A pressure transducer, which converts pressure into an electrical signal, is connected to the tubes from the pressure detection sites for the front and back of the nose. The pressure transducer is connected to the appropriate electronic circuit, often a carrier amplifier, so that changes in pressure result in a corresponding change in output voltage. This voltage is then read by a recording device.

Measurement of nasal airflow

Airflow can be measured directly at the nasal outlet or indirectly by assessing the change in volume of the thorax with respiration. Direct measurement of airflow at the nasal outlet can be accomplished with nozzle or mask. Nozzles are held by the patient at the opening to either nostril. When a nozzle is used for flow detection, the large diameter tube pressing on the nose may alter the intranasal anatomic relationships and thus alter the measurements. Various masks have been used that cover all or a portion of the face (Figs. 37-5 and 37-6), although a full-face mask is most commonly used.

Plethysmography is another way to assess airflow. A volume displacement body plethysmograph detects changes in the volume of the thorax by measuring the amount of air displaced from the plethysmograph during respiration. This respiratory volume change causes airflow through a laminal flow element in the wall of the plethysmograph. When the body plethysmograph is used, neither nozzles nor mask is needed.

In inductance plethysmography the movement of the chest is measured by transducers on a band encircling the thorax. This method was less precise and convenient than a body box plethysmograph (Cole, 1989a).

The flow of air is measured using a pneumotachograph or calibrated orifice. The pneumotachograph may be a tube with small-diameter channels or a wire or cloth mesh. These devices present a small resistance as the air travels to and from the nasal inlet or in and out of the thorax. The resistance is too small to be noticeable to the patient, but creates a pressure difference between the two sides of the pneumotachograph. This pressure difference corresponds to the rate of airflow. A second more sensitive transducer is used to measure the pressure difference across the pneumotachograph or orifice, and the output of this transducer through the appropriate electronic circuit provides a signal proportional to airflow.

Recording results of rhinomanometry

The electronic pressure and flow signals are read by another device. Strip chart recorders, oscilloscopes, x-y plotters, and computers have been used (Fig. 37-7). The computer is favored today because it can store and analyze the data as well as display and print it (Cole et al, 1980a; Pallanch, 1984). Because computers read and store numbers, the electronic signal that is an analog of pressure or flow is converted into a number by a converter. Various parameters can then be calculated from the pressure and flow data and stored by the computer. Computer software may filter the data, average it, or reject spurious data by imposing a specified allowable coefficient of variation (Cole, 1989a). Often simultaneous display of the pressure-flow curve is provided so that mask leaks or other problems with data collection can be detected during the test.

Calibration of equipment

The pressure transducer is most commonly calibrated using a water manometer (Fig. 37-8). The flow-measuring device can be calculated directly using a rotometer or flow-meter if a source of air with constant flow is available (Fig. 37-9). Another method for calibrating the flow is to calibrate the pressure transducer connected across the pneumotachograph if the pressure difference for a given flow in that pneumotachograph is known (Fig. 37-10). The pressure corresponding to a known flow rate is applied and the device is adjusted to register that rate.

An easier way to calibrate the rhinomanometer is to use an "artificial nose" (Fig. 37-11). This is a device with a known resistance that is put in line with the rhinomanometer to be calibrated.

Another rather elegant method of calibration is to deliver a known volume of air to the system through a known resistance (or artificial nose) (Fig. 37-12). In this method a large syringe can be used as the source of a known volume of airflow, and an absolute measurement of pressure and flow can be obtained. The frequency of calibration should be adequate for the equipment used to consistently give accurate results.

Active versus passive rhinomanometry

Active or passive methods can be used to measure the pressure and flow of air through the nose. One passive method is performed by measuring pressure as a subject holds his or her breath while air is pumped through the nose at a known rate. Active methods use the patient's own respiratory efforts as a source of pressure and flow. Active rhinomanometry is the method used predominantly today because it is thought to better represent the normal physiology of the nose, as it uses the patient's own normal respiratory efforts. It also allows assessment of the pressure/flow ratio at various locations on the pressure flow curve rather than at a single fixed flow or pressure.

Unilateral versus bilateral measurements

Although some investigators obtain only unilateral data, others also record airway results for the total nose. To obtain total nasal airway measurement, both sides of the nose can be measured together, or the total nasal airway values can be calculated from the unilateral measurements. Using the posterior (peroral) or postnasal methods, the total airway can be measured directly. The anterior method of pressure detection does not allow direct measurement of the total airway because one side of the nose is plugged. Thus with the anterior method the total nasal airway values must be calculated from the two unilateral measurements. For parallel nasal airways, the flows of the right and left side of the nose can be added to obtain the total nasal airflow if the pressure is the same across each side of the nose (Fig. 37-13).

Total resistance calculated from data obtained by the anterior method has been found to be as follows: the same (Georgitis, 1985), greater than (Unno et al, 1986), and 16% less than (Jones et al, 1987a) total resistance measured directly by the posterior (peroral) method. If there is a greater pressure drop using posterior rhinomanometry because of the additional pharyngeal component, then resistance (P/V) should be higher using the posterior rather than the anterior method. When unilateral resistance was measured by both posterior and anterior methods, the posterior method was found to yield a higher resistance value (Holmstrom and Kumlien, 1988). The only difference in the manner in which these unilateral techniques were applied was that the posterior method also assessed any pressure difference across the nasopharynx. Cole et al (1989) compared total resistance measured directly with a catheter in the mouth (peroral posterior method) with total resistance measured using a catheter just behind the nose (postnasal method) and found the posterior method yielded 9% higher resistance values. They attributed this increase to the effects of tongue, palate, and pharyngeal wall on the patency of the pharyngeal aperture.

Jones et al (1987a) measured unilateral and total resistance using only posterior (peroral) methods and found no significant difference between calculated and measured total resistance in the nondecongested nose.

Other comparisons of the different methods

In general, anterior rhinomanometry is most widely used as a clinical tool because it is easily performed. Anterior and pernasal methods require little patient efforts or cooperation, and the anterior method does not require a tube in the nose or mouth. By contrast, in the posterior method the patient must be coached in the correct positioning of the tongue and palate to keep both the oropharynx and nasopharynx open so that the technique can be performed. Various failure rates have been reported in coaching patients to perform the posterior method: 0% (Solow and Greve, 1980), 1.4% in 100 pediatric patients (Parker et al, 1989), 10% (Connell, 1982), 15% (Foxen et al, 1971), 15% in 5000 patients (Cole, 1989a), 16% to 50% for five investigators (Gordts et al, 1989), 20% (Schumacher, 1989), 47% (Rivron, 1990), and 50% (Georgitis, 1985).

The posterior method has yielded more variable results than other methods (Cole, 1989a; Georgitis, 1985; Salman et al, 1971; Shelton et al, 1990), although one study reported less variable results (Solow and Greve, 1980). In the nondecongested nose, results obtained using a postnasal (pernasal) catheter were less variable than either the traditional peroral posterior method or the anterior method (Cole et al, 1989).

The anterior nozzle method may distort the nasal alae and the anterior method cannot be used to measure the nasal airway in a patient with a nasal septal perforation. The anterior and postnasal methods will not assess adenoid hypertrophy, and none of the rhinomanometric methods work if the nose is totally obstructed.

Use of decongestion

Measurements are often made before and after decongestion of the nose. Decongestion can be accomplished using drugs or physical exercise. Jessen and Malm (1988) found xylometazoline spray more effective than drops or exercise for decongestion of the nose, and they noted that exercise is clinically labor intensive, requires extra space and equipment, and cannot be accomplished by some patients.

Assessment of the nasal valve

Some authors have recommended additional maneuvers to assess the function of the nasal valve, that area bounded by the nasal septum, the caudal end of the upper lateral cartilages, and the tip of the inferior turbinate (Fig. 37-14). The nasal airway has been held open using tygon tubing (Berkinshaw et al, 1987), sticks (Haight and Cole, 1983), a custom wire stent (Guillette and Penny, 1990), and retraction on the cheek (Rivron, 1990). A significant decrease in resistance with use of the stent indicates the nares, vestibule, or valve as a site of obstruction. If little change in resistance results, a restriction could be attributed to factors posterior to the valve area. Rivron's retraction of the cheek mimics a positive Cottle sign. Heinberg and Kern (1973) have pointed out the possibility of a false-negative Cottle sign resulting from scar tissue immobilizing the valve.

Typical clinical testing

The most commonly used method of performing rhinomanometry is with the anterior mask method before and after decongestion of both sides of the nose. The data are displayed and read using a computer- or microprocessor-based device.

The apparatus must first be warmed up and stable and should be properly calibrated. There should be no deformation of the nostrils and no mouth breathing during the test. The standard test is performed in the sitting position, with the pressure-detecting line taped over the opening of the nose on the side not being measured (see Figs. 37-1 and Fig. 37-2). The pressure line is then connected and the mask is applied. The patient is instructed to breathe normally. The technician assesses the pressure-flow curve and looks for any evidence of mask leak or other problems. After the data collection is completed successfully, the other side of the nose is measured in the same way. Decongestant is then sprayed into each side of the nose. Five minutes later the nose is sprayed again for further decongestion. Ten minutes later both sides of the nose are measured again as in the first phase of the test. The results are then calculated and printed by the computer. The data in the computer are then stored in a file for that patient along with pertinent history and physical findings.

For children, a smaller face mask can be used, but the test is performed in the same way as for adults. For patients whose chief complaint is nasal obstruction when recumbent, additional studies are performed. Before decongesting the nose, the patient is studied in the sitting, supine, right-side lying and left-side lying positions. Decongestion is then performed and the patient is again studied in each of these positions. For patients with suspected allergic rhinitis nasal provocation testing can be performed.

Methods of Reporting Nasal Pressure and Flow Readings

Once the pressure and flow data have been collected, appropriate filtering, averaging, and selection of data can be completed. The results are then assessed and reported using one of several available methods.

Examining the pressure-flow curve

One way to appraise the data is to examine the pressure-flow curve. In nasal breathing the difference in pressure across the nose causes air to flow through the nose (Fig. 37-15, A). If an increase in transnasal pressure caused an increase in flow that was always of the same proportion, the nasal pressure-flow plot would be a straight line. In reality, the plot is usually curved (Fig. 37-15, B to E), forming an S or sigmoid shape. The amount of curvature can vary among different pressure-flow curves. In a more obstructed airway, the pressure required to generate a certain flow is greater. The accepted standard in displaying the pressure-flow curve is to put pressure on the x-axis and flow on the y-axis. With this arrangement, the greater the pressure to flow ratio the closer the curve to the pressure axis (Fig. 37-16). Thus curves representing a more obstructed airway will be rotated more in a clockwise direction and lie closer to the pressure axis.

Reporting parameters

Reporting inspiratory or expiratory values

In some studies no significant difference has been found between inspiratory or expiratory resistance values (Berkinshaw et al, 1987; Shelton et al, 1990). Others have found that inspiratory resistance is significantly lower than expiratory resistance at lower flows (Kenyon, 1987; Schumacher et al, 1985; Viani et al, 1990). Haight and Cole (1983), on the other hand, found that during quiet respiration the resistance was higher during inspiration.

Connell (1982) thought that although expiration is important in most pulmonary disease, it would be more logical to measure nasal patency during inspiration stating, "Have you ever heard of a patient complaining that he cannot exhale through his nose?" The international standard (Clement, 1984) is to report values obtained from inspiration.

Parameters - resistance and conductance

One result that can be reported is resistance or the ratio of pressure to flow. Conductance (the ratio of flow to pressure) can also be reported. Both of these parameters vary at different points on the curve because the pressure-flow relationship is nonlinear. To allow comparisons between the results from a patient at different times or between different patients, a method must be used that will pick the point at which to report this ratio in a consistent fashion.

Resistance at a designated flow or pressure. Resistance can be reported at a designated flow or a designated pressure (Fig. 37-17). If the nose is very obstructed, then a designated flow may not be reached. Reporting resistance at a designated pressure of 150 Pa is an international standard (Clement, 1984). Voluntary increase in ventilation may be necessary for some subjects to reach a designated pressure of 150 or even 100 Pa (Cole and Havas, 1986; Naito et al, 1989). As an alternative to reporting resistance at a certain pressure, some report the flow value corresponding to that pressure (Bachmann, 1976). This approach allows direct calculation of the total airway by simply adding the flows from each side.

Maximum and mean resistance. Maximum resistance (McCaffrey and Kern, 1979a) and mean resistance (Cole et al, 1980a) have also been used to report results. An advantage of both of these methods is that a result can be obtained in all patients because it is not necessary to reach a designated point on the curve. In calculating maximum resistance, the patient breathes normally and resistance is found from the maximum pressure and flow values reached (Fig. 37-17). A computer averaging system is needed to obtain mean resistance, Naito et al (1989) found that maximum resistance results were nearly identical to mean resistance results, as near peak flows are present through most of quiet respiration.

Resistance at a designated radius. Broms et al (1982a) concluded that individual pressure-flow curves could be described uniquely by using a point at a given radius from the origin (Fig. 37-17). Results could be found for most patients because the pressure-flow curve for most patients will go further than a radius of 2.

Resistance at the origin of the pressure-flow curve. Some investigators (Georgitis, 1985; Solow and Greve, 1980) have reported resistance at the origin of the pressure-flow plot. This technique is accomplished by drawing a line through the curve at the origin and measuring its slope. Schumacher (1987) thought that this method allowed results to be obtained for all individuals, but pointed out the disadvantage that it measured the resistance at a point in the respiratory cycle where there was no sensation of obstruction.

Conversion between different methods of reporting nasal resistance. Different methods of reporting have yielded different results (Eichler and Lenz, 1985; Shelton et al, 1990), although sometimes the amount of difference can be small (Naito et al, 1989). Ways of converting between the results obtained for different methods have been proposed (Eichler and Lenz, 1985), but such a conversion is not possible because in different methods, the resistance values are obtained at different locations on the pressure-flow curve (Fig. 37-17). Because any pressure-flow curve may have a different amount of curvilinearity, the resistance values obtained at different places on the curves can vary in rank order, even within results using the same method (Fig. 37-18). The International Standards Committee (Clement, 1984) has designated flow at 150 Pa or resistance at radius 2 to be the standard options for reporting results.

Parameters - reporting cross-sectional area derived from rhinomanometry results

Rhinomanometric methods have been used to estimate cross-sectional area of the nose (Foxen et al, 1971; Hoshino et al, 1988; Reeves et al, 1970; Rivron, 1990). In studies deriving cross-sectional area from rhinomanometric data, the total airway cross-sectional area is equal to the sum of the cross-sectional area for the right and left sides of the nose (Foxen et al, 1971; Hoshino et al, 1988; Rivron, 1990).

Parameters - reporting pressure-flow curve coefficients or exponents

Another way to derive a single numerical representation of the pressure-flow data without a reference point is to find the coefficient(s) or exponent for a model fitting the pressure-flow curve. As one moves away from the origin on the curve, the relationship of pressure to flow becomes nonlinear. This relationship represents the more turbulent condition that usually prevails in the nose and is thought necessary for the normal nasal function of exchanging particulates, water and heat (Cole, 1989a; Schumacher, 1989). As one moves to more distant points on the pressure flow curve, the transnasal pressure increases faster than the transnasal flow changes. Consequently, the resistance is generally higher at more distant points along the nasal pressure-flow curve. The flow may reach a limit at which it does not increase with further pressure increase (Bridger, 1970).

Models of the pressure-flow curve. Several models of the nonlinear relationship of the pressure-flow curve have been proposed. Using these models increases the complexity of the testing system. Whether they will provide more useful parameters will depend on their ability to better correlate test results with symptoms.

Pallanch (1984) has studied the ability of a number of models to fit the data in a variety of pressure-flow curves. The best fit to the data was accomplished using the polynomial model.

Parameters - reporting values that include relationship to time

Power has been used as a parameter (Walker et al, 1985). Power is the product of pressure and flow times a constant at a given moment. Schumacher (1989) stated that nasal power varies with flow, so it would vary through the respiratory cycle. A reference flow would need to be specified when reporting power as a parameter.

Cole et al (1979) have expressed results as work. This parameter is equivalent to mean pressure times volume. Work depends on the rate of ventilation. Schumacher (1987) pointed out that since work is affected by minute volume, it would be effort dependent unless expressed as work per unit volume. Cole et al (1980a) found that work (in Joules) per liter increased linearly with ventilation.

Parameters - amount of change after decongestion

The response of the nasal airway to decongestion could be a useful parameter. Reeves et al (1970) found a 50% decrease in resistance after decongestion. We have found a small number of patients who experienced unexpected increased airway resistance after decongestion with 1% phenylephrine. Schumacher (1989) thought that decongestion was not infallible in determining structural versus mucosal problems, as some mucosal problems are not affected by decongestion, whereas decongestion can significantly change the restriction next to some large structural problems.

Parameters - difference between sides of the nose

Another proposed method is to report the difference in resistance between the two sides of the nose in relation to the total airway resistance (Postema et al, 1980).

Recommendation of the International Committee on Standardization of Rhinomanometry

The International Committee on Standardization of Rhinomanometry (Clement, 1984; Kern, 1977, 1981) concluded that active anterior rhinomanometry is the preferred method of measurement. The techniques for measurement should include sealing of the pressure line to the nostril (usually with tape), a transparent face mask to ensure lack of kinking of the pressure line and no deformation of the nostrils, a linear pneumotachograph, and daily calibration. The method of decongestion of the nostrils should be specified.

Each measurement should be the mean of three to five recordings in each nostril. Measurements should be made with the patient seated after a rest period of at least 30 minutes. Nasal resistance is reported either at pressure of 75, 150, and 300 Pa (if reached) or at radius 2. Rhinomanometric values should be expressed in SI units with pressure in pascals and flow in cm^3/sec (100 Pa = 1.0 cm H_2O, 1000 cm^3/sec = 1 L/sec). Nasal resistance is reported in Pa/cm^3/sec (.1 Pa/cm^3/sec = 1 cm H_2O/L/sec).

Sources of variability in nasal airway testing

The coefficient of variation has often been used to describe the variability found during testing. Rivron (1990) reported the coefficient of variation of just the rhinomanometer at 3.4% by measuring a tube held in the patient's mouth.

Variability in individual measurements

Averaged values are though to result in less variation than instantaneous values (Cole et al, 1985).

The nasal cycle

The nasal cycle is the normal periodic alternating congestion and decongestion of the respective sides of the nose. It has been found in 72% to 80% of individuals (Hasegawa and Kern, 1978; Heetderks, 1927). This cycle results in significant variability in unilateral nasal airway measurements (Hasegawa et al, 1979). Hasegawa found the mean duration of the cycle was 2.9 hours, with a range of 1 to 6 hours. However, total nasal resistance remains relatively constant (Hasegawa and Kern, 1978). Therefore, some investigators recommend that total resistance should be the parameter reported to decrease the variability in results. There is greater variation in results obtained at different times than between those obtained during the same session (Solow and Greve, 1980) as would be expected with the presence of the nasal cycle.

Alae nasi dilation and vestibular collapse

The muscles that attach to the nasal alae are shown in Fig. 37-19. Solow and Greve (1980) reported that when one nostril is blocked, the opposite alar muscle tonus is increased, with a possible effect on the resistance of the side being measured when a pressure catheter occludes the contralateral nasal airway. However, Haight and Cole (1983) found that the resistance of one side of the nose was not affected by occluding the opposite side.

Bridger (1970) demonstrated that with deep inspiration a critical transmural pressure brings on partial vestibular collapse and flow limitation. Haight and Cole (1983) found that alar muscle activity increased during inspiration as respiratory minute volumes and nasal resistance get larger. Paralysis of the alar muscles leads to inspiratory collapse, which indicates that the alar muscles act together to augment vestibular rigidity and are directed toward preventing this collapse.

Some variability can result from the nasal alae, but alar dilatation probably does not contribute significantly to variability of results, particularly in the normal individual, as the alar muscles tend to work toward stabilization of the vestibular wall. In the person with valve pathology or disruption of the alar muscles, however (eg, postrhinoplasty), alar collapse may cause variability. This can be discovered by performing the valve stenting maneuvers mentioned earlier.

Equipment

Sandham (1988) reported that his early rhinomanometer had a long warm-up time, producing variation in measurements when the machine was first turned on. Berkinshaw et al (1987) recommended the use of a heated pneumotachograph to prevent variation due to moisture.

Potential causes of variability due to the nozzle technique have been cited (Kern, 1977). Masks have introduced some variability in results (Cole et al, 1988b; Solow and Greve, 1980). Visual feedback, using a real-time display of the pressure-flow curve, has been valuable to reduce variability by detecting air leaks or other artifacts (Sandham, 1988; Schumacher, 1989; Solow and Greve, 1980).

Secretions or instrumentation

Nasal secretions can increase nasal resistance (Forsyth et al, 1983a) and should be cleared before the test. Cole et al (1980b) found no effect on the variability of nasal resistance caused by nose blowing. They found no effect on variability of total nasal resistance caused by instrumentation with a nasal speculum, but McLean et al (1976) did.

Effect of temperature or humidity

Cold air increases nasal resistance (Forsyth et al, 1983a; Salman et al, 1971). Ivarsson and Malm (1990) found no significant effect on total nasal resistance with changes in humidity.

Exercise or stress

Cole et al (1980b) found no increase in variability of total resistance with moderate exercise. With vigorous exercise, there was a marked reduction in resistance that lasted less than 20 minutes. Forsyth et al (1983b) found that resistance decreased with intensity of exercise but not with duration of exercise. Stress and anxiety reduce nasal resistance, and this response is thought to be mediated by the hypothalamus (Eccles and Lee, 1981).

Rate and depth of breathing CO_2

Increased rate of respiration can result in hysteresis (Fig. 37-20). Hyperventilation increases nasal resistance (Dallimore and Eccles, 1977; McCaffrey and Kern, 1979b); breathing CO_2 decreases nasal resistance (McCaffrey and Kern, 1979b; Strohl et al, 1982). Hasegawa and Kern (1978) used a constant bias airflow inside the mask to remove CO_2 or water vapor, but this does not seem to be necessary for brief testing.

Body position

Hasegawa (1982) verified that resistance is greatest when supine and least when in the upright sitting position. A larger relative increase in resistance was found with similar positioning of patients with allergic rhinitis or upper respiratory infection (Rundcrantz, 1969).

When the patient is in the recumbent lateral position, the resistance is greatest on the side where pressure is applied to the body (Haight and Cole, 1986). The magnitude and duration of the effect increases as the period of recumbency increases. Pressure to specific areas causes the unilateral change in resistance. The reflex is present in most, but not all, people. Thus for rhinomanometric testing, the patient should sit symmetrically on the chair without placing uneven pressure on any of these areas.

Time of day

Schumacher (1989) recommended that testing be done at the same time each day for a given individual because of the diurnal variation in nasal resistance which he reported to be highest at night and in the early morning.

Chemical irritants

Cole et al (1980b) found no change in variability of total nasal resistance in normal subjects and in patients with rhinitis after exposure to ozone, sulfur dioxide, or cigarette smoke.

Effect of medication

Cole et al (1980b) reported a marked reduction of 20% to 50% in mean total resistance that occurred after treatment with xylometazoline chloride. Other common medications taken by patients with nasal symptoms can affect nasal resistance. Schumacher (1989) reported an average increase in resistance of 20% when saline was sprayed in each nostril. McLean et al (1976) found that a 22.5% mean rise in resistance due to saline could be inhibited by atropine, suggesting parasympathetic stimulation as a mechanism. Cole et al (1980b) found no effect on the airway from saline spray. Aspirin can cause a small increase in nasal resistance (Jones et al, 1985). Havas et al (1986) found that antihistamine treatment may increase the nasal resistance in the unchallenged nose. Oral or inhaled medications, even aspirin or saline sprays, should be discontinued for an adequate period of time before performing the test.

Gender, height, weight, age, and anthropologic type

Some investigators have found a correlation of nasal resistance with height (Broms, 1982; Jessen and Malm, 1988; Pallanch et al, 1985). No correlation has been found in adults between nasal resistance and gender (Broms, 1982; Hasegawa et al, 1979), weight (Broms, 1982; Jessen and Malm, 1988), or age (Broms, 1982; Jessen and Malm, 1988). Others have reported a decrease in nasal resistance with age in adults (Cole, 1988; Hasegawa et al, 1979).

Several authors have found a correlation in children between nasal resistance and age (Masing, 1979; Parker et al, 1989; Principato and Wolf, 1985; Saito and Nishihata, 1981). Stocks and Godrey (1978) reported that resistance in infants was six times higher than in adults. It significantly decreases with age approaching adult values by age 16 (Saito and Nishihata, 1981). Parker et al (1989) reported the incremental decrease in resistance that can be expected for each year of childhood. Ohki et al (1991) found greater nasal resistance in whites than in blacks, with Asians being intermediate between them.

Ideal test environment to minimize variability

Because multiple sources of variability are potentially present, one cannot always be sure which factor is most responsible for a measured variability in results. One should try to control all sources of variability without affecting the clinical information sought. Cole (1989b) proposed that to avoid variability, subjects should avoid exercise and exposure to climatic extremes for 30 minutes before testing. Patients should not be taking any interfering medications. Distortion of the alae should be avoided. Measurement should be performed in a comfortable, stable, nonirritating environment. Jones et al (1987b) recommended use of a visual breathing cycle display programmed to assist patients in uniform breathing during the test. He used a real-time display of the pressure-flow curve to detect any problems with technique so that they could be immediately remedied. He used a quiet, well-ventilated room with constant temperature and humidity, no bright sunshine, and the patient sitting in a comfortable chair. He recommended explaining the test procedure and the equipment first to help alleviate patient anxiety. The patient had no tobacco or coffee before the test. Knowledge of the factors that can affect variability of results allows investigators to take appropriate measures to obtain the most precise results.

Normal Values of Nasal Airway Test Results

Most reports of normal resistance have been based on the values for small groups of control subjects. One goal of the International Committee (Clement, 1984; Kern, 1977, 1981) has been to establish normal values at various centers using the recommended methods for consistent reporting of the results.

Reported normal values in the literature

One problem in reporting normal values is the criteria used for selection of normal subjects.

Tables 37-1 and 37-2 present unilateral and total values for normal resistance that have been reported in the literature. Note that the values often cannot be directly compared because they were obtained using different points on the pressure-flow curve.

Normal range for nasal resistance values

Normal range can be shown by a shaded area on the plot of the pressure-flow curve (Fig. 37-21). One problem encountered in studying a "normal" population is that resistance values are not normally (in a statistical sense) distributed (McCaffrey and Kern, 1979b; Pallanch et al, 1985). For statistical analyses transformation can be performed to normalize the distribution of the data (Broms et al, 1982a; Hamilton, 1978; Hasegawa et al, 1979; Pallanch et al, 1985), or nonparametric statistical methods can be used (McCaffrey and Kern, 1979a).

Comparison of Rhinomanometry and Rhinoscopy

Hardcastle et al (1988a) asked if rhinomanometry simply quantifies the information obtained with rhinoscopy or if it measures something else. Does rhinoscopy provide enough information to eliminate the need for rhinomanometry? To answer this question one needs to look at what rhinoscopy and rhinomanometry can do and how they compare with each other.

Purpose of rhinoscopy

Rhinoscopy provides a view of the condition of the nasal mucosa, as well as the presence of excessive secretions or intranasal growths. In addition it gives the observer subjective appraisal of the areas of cross-sectional narrowing in the nasal airway. This appraisal can include estimation of a number of parameters, including turbinate size; turbinate-to-septum distances, width of the nostril, valve area, and floor of the nose; and diameters of the middle meatus (Hardcastle et al, 1988a).

Purpose of rhinomanometry

Rhinomanometry, when performed using the pressure drop across the entire nose, primarily reflects the narrowest effective cross-sectional area of the nasal airway, as the greatest part of the resistance drop occurs at the narrowest site.

Bridger (1970) showed that in some patients there is a collapsible portion of the nasal airway that at high flows can restrict the amount of air flow when a critical pressure is reached. He stated that this flow-limiting segment (FLS) extended from the caudal end of the upper lateral cartilage to the piriform aperture. He pointed out that the distal orifice of the FLS was bounded by the caudal margin of the upper lateral cartilages and the nasal septum; Mink called this the *ostium internum* and considered it to be the narrowest part of the nasal airway. Other synonyms have been used to describe this area: os internum, limen vestibuli, valve area, valve region, and area 2 (Kern, 1978).

Bridger (1970) located the FLS in different subjects by measuring the pressure throughout a catheter passed along the floor of the nose. The point of collapse in normal subjects with deep inspiration was located 0.5 to 1.5 cm deeper in the nose than the caudal end of the upper lateral cartilage and was related to the distal end of the inferior turbinate. In patients with breathing problems, the point of collapse was closer to the caudal end of the upper lateral cartilage. As less pressure was required at maximum flow to cause collapse, the location of the site tended to be closer to the opening of the nares.

Haight and Cole (1983) passed a catheter along the floor of the nose and confirmed that, in subjects without alar collapse, the greatest resistance drop occurred at the level of the anterior end of the inferior turbinate in the first few millimeters inside of the piriform aperture (isthmus nasi). They also found that this site of greatest change in resistance was unchanged by decongesting or congesting the nasal tissues. This site corresponds to the area found to be narrowest by Bachmann (1972) in his studies of casts of the nose and to the anterior part of the turbinal valve (Kern, 1978), which is considered FLS in platyrrhine noses. Bachmann (1982) pointed out that stenting the valve angle open may improve the airway in the case of an anterior restriction by increasing the size of the lower portion of this isthmus.

In patients who had no alar collapse, Haight and Cole (1983) found by splinting the vestibule open that one third of the nasal airway resistance occurred in the nasal vestibule, and two thirds of the resistance occurred in the area of the piriform aperture within the bony cavum. The bony cavum is that part of the nasal airway posterior to the piriform aperture. This ratio occurred whether or not the nose was decongested. They found a further increase in resistance from alar collapse, but only in patients with paralysis of the alar muscles or with higher inspiratory effort through only one side of the nose. From Bridger's study (1970) one would conclude that in some patients with anterior pathology a greater proportion of the resistance drop might occur in the parts of the nose anterior to the piriform aperture.

These studies required use of a pressure catheter at various locations in the nose. Other studies have shown the ability of rhinomanometric results to assess pathology when the entire transnasal pressure is measured. Cole et al (1988a) and Chaban et al (1988) simulated septal deviations to study their effect on nasal resistance to airflow. They showed that site, size, and position of pathology can affect the magnitude of resistance to airflow.

Correlation between rhinoscopy and rhinomanometry

Common ground

A significant correlation has been found between rhinoscopy and the results of rhinomanometry (Hardcastle et al, 1988a; Keay et al, 1987). Hardcastle et al (1988a) thought that it was difficult to choose a single most important rhinoscopic parameter. Using rhinomanometric methods, the critical pressure of collapse at maximal flow corresponded to anterior nasal pathology, which can be seen by rhinoscopy (Bridger, 1970; Santiago et al, 1986). Santiago et al (1986) noted that plateauing of the pressure-flow curve can reflect collapse of the FLS in patients with valve pathology. Guillete and Perry (1990) found a significant correlation between changes in resistance with stenting of the nares and valve pathology.

Differences in results

Although Hardcastle et al (1988a) found a correlation between rhinoscopy and rhinomanometry, they thought it was weak in the patients they studied, the majority of whom were normal. This correlation between rhinoscopy and rhinomanometry has not always been reported. Hardcastle et al (1988a) believed that the difference between results from rhinoscopy and rhinomanometry was sufficient to suggest that they might measure different but related phenomena.

The imperfect correlation between rhinoscopy and rhinomanometry could be due to several factors, including the variability of each technique and the limitations each might have in reflecting the actual physical parameter being assessed. Because each technique is variable, comparing them would necessarily be somewhat imprecise. An example of rhinoscopic variability can be found in the study by Keay et al (1987) who reported interobserver changes resulting from the nasal cycle.

In some patients, rhinoscopy may reveal suspected pathology that rhinomanometry does not corroborate. Hypothetically, one could find an area of pathology that looked significant at a site that was not as narrow as the most critical area, so that its effect would not be reflected in the rhinomanometric results. Cole et al (1988a) and Chaban et al (1988) found that some of the simulated obstructions in the bony cavum of the nose that looked like impressive pathology on rhinoscopic examination produced only insignificant elevations in resistance. They noted that the airstream was apparently able to find relatively nonresistive routes that were not always seen on clinical examination. In other patients, rhinomanometry may reveal abnormal findings that rhinoscopy had not found, which may represent a site of increased resistance not immediately apparent to the examiner, thus warranting a second look.

Both rhinoscopy and rhinomanometry can provide information about the nasal airway. Rhinomanometry has some potential advantages over rhinoscopy. It is objective and perhaps less variable. However, since the two modalities can provide different information, by using both, the clinician might obtain a more complete understanding of a patient's nasal airway. The true test of the clinical worth of each is the way in which they correlate with symptoms.

Correlation Between Results of Rhinomanometry and Symptoms of Nasal Obstruction

Several methods have been used to study the correlation between the results of rhinomanometry and the symptom of nasal obstruction. One method is to determine whether there is a difference between a group of normal subjects and a group with symptoms of obstruction.

Comparison of group results - normal versus obstructed

Unilateral airway

A significant difference has been found between median or mean resistance of the obstructed side of the nose in patients with unilateral symptoms and the unilateral resistance of a group of normals (Gordon et al, 1989; McCaffrey and Kern, 1979a). A difference was not found with the nonobstructed side in the symptomatic patients. In patients with bilateral symptoms, the right-sided resistance for those with moderate and severe symptoms and the left-sided resistance for those with moderate symptoms was significantly greater than the median unilateral resistance for the non-obstructed patients (McCaffrey and Kern, 1979a).

Total airway

Total resistance for those patients with moderate and severe bilateral symptoms and for those patients with moderate and severe unilateral symptoms was greater than the median total resistance for nonobstructed patients (McCaffrey and Kern, 1979a).

Both unilateral and total resistance may be related to the patient symptoms. In the patient with bilateral symptoms, the amount of unilateral abnormality may not be as great. It is not known whether unilateral or total results give the most meaningful correlation with symptoms, but McCaffrey and Kern (1979a) though the total resistance would be the most important determinant of the patient's sense of well-being. Arbour and Kern (1975) described the phenomenon of paradoxical nasal obstruction in which the effect of the more open side of the nose on the total resistance was the determining factor in the presence or absence of obstructive symptoms.

It is apparent that there is a difference between the group of obstructed individuals and the group with no symptoms; however, there is a large overlap between the airway values for these two groups (Fig. 37-22) (Cole, 1988; Jones et al, 1989; Pallanch et al, 1985). This overlap has caused some investigators to question the validity of assuming a correlation between rhinomanometric results and symptoms in any given individual.

Findings in individuals

One way to study the correlation between rhinomanometric results and symptoms is to determine whether any difference between the symptoms in each side of the nose correlates with any difference in airflow between the two sides in individual subjects. Another method would be to determine whether difference in degree of obstruction is reflected in difference in magnitude of rhinomanometric results. Still another way to address the question is to determine whether any change in nasal resistance after decongestion, challenge testing, or therapy correlates with symptoms. Studies have applied these methods of investigation in both normal patients and symptomatic patients.

Normal individuals

Some investigators have studied the correlation of rhinomanometric results with nasal symptoms in groups of normal or predominantly normal subjects. Often these investigators have found no correlation between airway testing results and degree of obstruction in patients who do not generally have symptoms.

Symptomatic patients

Studies on symptomatic patients have more easily found a correlation between nasal resistance and the degree of obstruction. A correlation has been demonstrated between nasal resistance and the degree of obstruction in symptomatic patients (Schumacher and Pain, 1979; Welch et al, 1985), although not in all studies (Kimlien and Schiratzke, 1979). Significant correlation of resistance values with symptoms is found best in patients who are symptomatic and have higher resistance values but is not so readily found in normal asymptomatic subjects. A larger change in airflow may be needed for some individuals to detect a change in subjective obstruction. Jones et al (1985) thought that large changes in resistance might correlate with symptoms; but small changes, such as those found in subjects who took aspirin, did not correlate. In clinical work with obstructed patients, larger values may be encountered; thus correlation would be expected to occur and the lack of correlation in asymptomatic patients may not pose a problem.

Threshold value

Because a correlation of resistance values with symptoms has been demonstrated, there should be an individual threshold level of resistance at which a patient would begin to feel obstructed. Based on available data, at least some individuals also would be expected to be able to distinguish varying degrees of obstruction, which would correspond to certain resistance values. A large overlap (Fig. 37-22) is present in the distribution of resistance values between obstructed and nonobstructed populations. The wide overlap speaks against a single population threshold resistance at which symptomatic obstruction would occur. Instead, it appears that there must be a range of individual threshold values that vary from person to person. If there is a wide range of the threshold resistance, then comparisons between groups may need relatively large changes in resistance to demonstrate a correlation with symptoms. The range of values for such individual obstructive threshold resistances has not been clearly delineated. Some authors have estimated threshold values (Cole, 1989; Gordon et al, 1989; McCaffrey and Kern, 1979a; Mertz et al, 1984).

Site of sensation of obstruction

In the study by Wight et al (1988b), radical turbinectomy resulted in a greater chance for improvement in symptoms than anterior turbinectomy, even though both resulted in decrease in resistance. If symptoms corresponded only to the airflow and if airflow improvement is reflected by the improvement in resistance, then one would expect symptomatic improvement in both cases. There are two possible explanations for why this did not occur. One is that more than airflow is involved in the experience of symptoms. The additional effect on nasal mucosal innervation of the more radical procedure may account for the symptomatic improvement in this group. It is also possible that an airflow phenomenon is occurring along the turbinate, which causes persistent symptoms but is of such smaller magnitude than the larger anterior pressure drop that it is not reflected in the improved resistance result. This theory would suggest that more posterior pathology, which appears to cause no significant increase in resistance, might still be important to correct to provide symptomatic relief. This approach would be consistent with Bachmann's statement that the effect of the anatomy in the posterior sector of the nose has been undervalued (Bachmann, 1976).

If changes in resistance do not always correspond to changes in symptoms, then what else is involved in causing the sensation of airway compromise? Burrow et al (1983) found that exposure to aromatic substances such as menthol, camphor, or eucalyptol caused the sensation of increased nasal patency despite no change in nasal resistance. These volatile oils increase the sensitivity of cold receptors by raising the temperature at which they respond. By increasing cold receptor reactivity in nerve endings of the nasal vestibule, the subject feels the nose is more open. Jones et al (1987c) found that lignocaine injected in the nasal vestibule caused the sensation of nasal obstruction in subjects without change in nasal resistance. This finding supported their hypothesis that the amount of activity of the cold receptors affected the sensation of obstruction. They thought that cold receptors primarily reside in the vestibular skin. They surmised that the major part of the mechanism responsible for registering the sensation of airflow resided in the nasal vestibule.

Unlike the vestibular skin, when the nasal mucosa was anesthetized (Jones et al, 1986), subjects reported that the nose was more patent despite the lack of change in nasal resistance. If both vestibular (by injection) and cavum were anesthetized, the sensation was one of obstruction. They hypothesized that receptors in the vestibule are responsible for signaling patency and receptors in the cavum are responsible for signaling obstruction. The patients of Wight et al (1988a) who had anterior turbinectomy and still felt obstructed may have felt so because of persistent stimulation of the nerve endings on the remaining portions of the turbinates even though their nasal resistance was improved.

Other factors that may affect the symptom of obstruction

Dry atrophic nasal mucosa can also cause the complaint of obstruction. Cole (1988) thought that some patients, including those with atrophic rhinitis, may have altered nasal sensation, which they misinterpret as obstruction to airflow. Poor pulmonary function can also cause a patient to complain of nasal dyspnea. Cole (1988) noted that some patients suffer from cardiopulmonary insufficiency and find any nasal resistance load intolerable. It is also important to consider the case of the patient who complains of nasal dyspnea despite a widely patent normal appearing airway. Objective testing that can verify the presence of a normal airway would help the clinician avoid unnecessary treatment.

Clinical Usefulness of Rhinomanometry

Several issues have been raised about the clinical usefulness of an objective airway test.

Does rhinomanometry provide more information than rhinoscopy does?

Hardcastle et al (1988a) stated that many clinicians think that compared with rhinoscopy, rhinomanometry gives little additional information. To some extent both correlate with symptoms, although rhinomanometry, but not rhinoscopy, correlated with degree of obstruction (Hardcastle et al, 1988b). This finding may occur because the examiner cannot directly detect the actual amount of airflow. Bachmann (1976) has emphasized that the two tests should be performed together because the synthesis of the simultaneous information they provide can be useful in the clinical evaluation of a patient. It was noted earlier that he two methods of assessment can complement each other in providing information about how the nasal airway modifies airflow through it. Rhinomanometry cannot identify the actual appearance of pathology, but it does indicate how much airflow actually occurs through the nose at such sites. Furthermore, by using variable points of pressure detection, rhinomanometry can assess the relative amount of airflow occurring in various regions of the nose.

Does rhinomanometry provide more information than asking the patient about symptoms?

Jones et al (1989) stated that rhinomanometry is not widely used clinically because it is difficult to perform. Furthermore, they though that it may be easier just to ask patients how they feel. It was shown previously that rhinomanometry correlated with symptoms and that the symptom of nasal obstruction is a complex phenomenon. Although many patients may describe symptoms consistent with their physical findings and their response to treatment, the availability of an objective assessment of the nasal airway can provide additional data for understanding these situations.

Can rhinomanometry identify the symptomatic patient?

Gertner et al (1984) stated that a nasal airway test must be able to distinguish between patients with a normal airway and those with airflow obstruction. They pointed out that obstruction varies among people and may be linked to personality. Investigators have hoped that rhinomanometry could reveal who has significant obstruction. It appears that a certain level of airflow in specific locations in the nose is needed to stimulate the receptors to register the sensation of patency or obstruction. This level of airflow may vary from one individual to another; thus it is not always possible to identify who will feel obstructed just based on airway data. Neither rhinomanometry nor rhinoscopy can identify who feels obstructed. Rather than ask whether rhinomanometric results can help to distinguish those patients who have significant airway obstruction one should ask whether rhinomanometric results along with rhinoscopy can help us discover more about the nature of the pathology causing a patient's complaint of significant airway obstruction.

Rhinomanometry can aid rhinoscopy in discovering sites of modification of airflow that might alter the stimulation of different areas of innervation in the nose. To improve symptoms, a significant enough modification in airflow must occur at specific nasal receptor sites. To assess the modification to airflow that occurs with treatment, the amount and location of airflow changes must be determined. Rhinoscopy can assess the anatomy, and rhinomanometry can assess the amount and predominant location of airflow in the nose. Because of these capabilities the combination of these modalities can be useful to study airway phenomena to better understand a patient's response to medical or surgical treatment.

Clinical Applications of Rhinomanometry

In addition to being useful for the clinical evaluation of nasal obstruction, rhinomanometry can also be useful for other clinical applications.

Assessment of patients with sleep apnea

As previously mentioned, rhinomanometry can be used to assess the change in resistance that occurs when the patient is supine. This change can be more severe in the patient with sleep apnea (Anch et al, 1982).

Allergy challenge testing

Nasal challenge testing is performed by introducing a specific allergen into the nose to assess the pathophysiologic changes that result. This use emerged from the desire to directly test the organ affected by allergy rather than to rely on the indirect reaction manifested by skin tests (Bachmann and Bachert, 1987; Schumacher and Pain, 1979; Wihl and Malm, 1985). Nasal provocation testing dates from 1873 (Clement et al, 1981). A technique was sought that would be reproducible, deliver a constant concentration of the challenging antigen, and provide objective noninvasive assessment of the response to the challenge. Provocation testing using rhinomanometry offered the promise of fulfilling these criteria. Fireman (1988) pointed out the advantage of rhinomanometry in providing numbers that enable calculation of percent change from a baseline value, which he noted would be difficult to assess with symptom scores alone.

A universal consensus as to the usefulness of challenge testing does not exist. Different techniques and thresholds are used. Some investigators measure the total nose and some measure only one side. Some use a 40% threshold increase in resistance (Bachmann and Bachert, 1987), whereas others use 25%, 30%, or 100% increases. Further consensus and standardization should help to establish the usefulness of this test.

Preoperative and postoperative assessment

Several investigators have found a significant decrease in nasal resistance in the more obstructed side of the nose after septal surgery (Broms et al, 1982b; Gordon et al, 1989; Holmstrom and Kumlien, 1988; Jalowayski et al, 1983; Jessen and Malm, 1988; Kosoy, 1979;

Nofal and Thomas, 1990) and after turbinate surgery (Jones et al, 1985; Wight et al, 1988a, b). In the previous section we noted that a number of these investigators found a corresponding improvement in symptoms (Broms et al, 1982b; Holmstrom and Kumlien, 1988; Jones et al, 1985; Mertz et al, 1984). Patients with high preoperative resistance appear more likely to be satisfied with surgery than those with preoperatively normal resistance. Clinicians have varying opinions about the usefulness of rhinomanometry in preoperative assessment. It can help to objectively assess the effect of surgery on the airway.

Other uses

Rhinomanometry has also been used for assessment of nasopharyngeal patency and velopharyngeal function, for assessment of the effect of environmental factors or irritants (Cole, 1988), for research in nasal physiology, and for medicolegal assessment after trauma. Because it does not rely on subjective assessment by the patient or clinician, rhinomanometry has been a useful way to assess the effect of intranasal medications.

Summary

Rhinomanometry can further explain the relationship between symptoms and physical findings. Simultaneous rhinoscopic evaluation and symptom assessment are key elements in enhancing the usefulness of rhinomanometry (Bachmann, 1976). Repeated testing over time is more useful than a single test. Rhinomanometry can be, as Williams (1968) stated, "an adjunctive examination to combine history, physical examination and above all, clinical experience to arrive at a well reasoned conclusion". Future work will further define and refine the clinical applications of rhinomanometry. Those who wish to obtain all available information about the nasal airway will continue to use objective methods of assessing nasal patency for the "wider understanding of nasal functions" (Cottle, 1968) that such tests provide in assessing patients who complain of nasal obstruction.