Tutorial

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NASAL AIRWAY INTERFERENCE: CONSIDERATIONS FOR EVALUATION

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The possible interactions and interrelationships in oral-facial form and function have created an ongoing controversy in dentistry and medicine as to cause and effect. The dental specialty area of orthodontics has been especially active in claims and counterclaims regarding mode of breathing and developing facial form. Some clinicians and researchers believe that the mode of breathing can influence facial form and occlusal status. Proponents of such viewpoints often recommend a variety of operations to clear the airway of suspected components of airway interference. Other clinicians and researchers feel that there are no clear correlations between breathing pattern and facial form.

The controversy surrounding airway interference has a great deal of impact on the speech clinician and orofacial myologist. Treatment decisions as to the physiological necessity of modifying the mode of respiration or rest postures of the lips and tongue, or the influence of such postures on speech patterning, are dependent on one's philosophy of the phenomenon involved but should also reflect a complete and objective examination. The clinician is challenged to describe clearly the anatomy and physiology, to sort out the influence of structural and anatomical variations and to make an objective assessment of nasal airway patency.

Key to this assessment is an appreciation of the nasal mode of respiration and those factors which influence it. The nose is an intricate, tortuous passage with the responsibility of warming, humidifying and purifying air before it enters the respiratory mechanism. The normal flow of air through the nasal cavities in breathing depends on the patency (or opening) of these cavities. The patency of the nasal chambers is dynamic and reflects the influence of multiple factors including cyclical dilation and constriction of the vessels in the nasal mucosa, allergic reaction, head and oral posture, temperature of the inspired air, systemic medications, exercise and structural (anatomical) variations. Patency can also be affected by nasal decongestants and surgical modification of the nasopharyngeal airway. The interaction between and among these various factors can confound the evaluation of nasal patency.

Respiration for speech and non-speech activities is an ongoing, adaptive process. The adaptations involved may relate to anatomical factors in the respiratory tree, or physiological demands in the environment. When the nasal cavity is not adequately patent, adjustments in oral and pharyngeal posture must take place in order to allow respiration to proceed effectively. In some instances

resting oral postures may be influenced and habit response patterns may be developed. These adjustments of oral posture are the broad subject of this journal special issue. More specific to the article, the discussion is of those factors which influence nasal patency and the techniques available for measuring the degree of nasal patency.

CONTROVERSY

A longstanding controversy exists about dental arch malrelationships and nasal airway impairment. Some offer the observation that normal nasal patency is a prerequisite for normal muscular balance in the face, jaws and dentition. Pressures and tensions of soft tissues are thought to influence the shape or morphology of facial bones (Quinn, 1983), and speculation regarding this association has existed for over a century (Meyer, 1870; Times, 1872; Morrison, 1931; Leader, 1934; and Hartsook, 1946). The following are contended to be consequences of mouth breathing (Joseph, 1982): Adenoid facies (currently a questionable concept); increased lower face height; increased mandibular angle; lowered tongue position; retention of tongue thrust swallow; shallow maxillary and mandibular complex; narrowed maxillary arch, frequent cross-bite and anterior open bite; alteration of head posture; miscellaneous allergic findings include circles under lower eyelid, marginal eyelid eczema and infected conjunctivitis. Geographic tongue and nocturnal bruxism may also exist.

Initially, it was postulated that mouthbreathing altered oral and nasal air pressures. Altered development of the oral-facial structure was believed to be caused by: (1) Alteration of normal air currents and pressures in the oral and nasal cavities (Morrison, 1931). (2) The oral airstream hindering the normal downward palatal growth (Morrison, 1931). Raised negative pressure between and oral and nasal passages leading to a high palatal vault (Angle, 1907).

Another theory about orofacial form and function interactions suggests that the muscular forces of the tongue, cheeks and lips acting upon the maxillary arch are disrupted when the patient is mouthbreathing. That is, a mouth breather positions the tongue in a forward and downward position and as a result the tongue cannot counteract the forces of the cheeks and lips upon the maxilla (Linder-Aronson, 1970; Harvold, Tomer, Vargervick and Chierici, 1981; Dunn, Green and Cunat, 1973).

Conversely, others contend that there is no simple rela-

tionship between facial morphology and mode of breathing (Kingsley, 1889; Humphreys and Leighton, 1950; Gwynne-Evans and Ballard, 1959; Leech, 1958; O'Ryan, Gallagher, LaBanc and Epker 1982; Martin, Vig and Warren, 1981).

Some who support this latter contention have observed that a high palatal arch is a congenital trait rather than the result of mouth breathing (Kingsley, 1889). Others have observed an equal distribution of malocclusions in nose and mouth breathers and that one-half of subjects with open-mouth posture actually breathe nasally (Warren, 1984; Humphreys and Leighton, 1950). Others have observed constant growth patterns regardless of mode of breathing (Gwynne-Evans and Ballard, 1959). Still others have observed that less than one-third of individuals with lip incompetence were mouth breathers (Leech, 1958).

After reviewing the literature pertaining to this controversy, O'Ryan, Gallagher, LaBanc and Epker (1982) concluded that there may be some relationship between nasal airway function and dentofacial form. They add that the literature does not support a simple relationship. Rather, the relationship is a complex interaction between hereditary and environmental influences. They suggest that further investigations should focus on questions of: (1) The objective proportion of oral and nasal respiration in individuals with various dentofacial characteristics. (2) The dentofacial characteristics of individuals classified by reliable, objective measures of nasal patency. (3) Alterations of dentofacial growth with alteration of nasorespiratory function. Is the alteration of growth predictable?

This controversy is also complicated by our inability to define some of the terms in use. *Mouthbreathing* remains an undefined and an incorrectly used term. It is probably frequently confused with *lip incompetence*. Moreover, a lips apart posture does not automatically indicate impairment of the nasal airway, and does not mean oral air flow. Frequently the tongue occludes the oral cavity posterior to the lips apart posture (Warren, 1984). The term *adenoid facies* has also been used to refer to this posture. This term presumes that the adenoids are obstructing the airway and *mouthbreathing* is necessitated. The terms *mouthbreathing* and *adenoid facies* are presumptuous and often incorrectly used because of the lack of objective information about nasal airway patency and the degree to which the adenoids impinge upon the airway.

Gwynne-Evans and Ballard (1959) reported that flaccidity of the oral and pharyngeal musculature or swelling of the anterior nasal mucosa are more frequently responsible for mouth breathing in children than is adenoid involvement. Others have reported that mouth breathing is often self-correcting after puberty because of the involution of hypertrophied tonsillar and adenoid tissue. Concurrently, the nasopharyngeal dimensions increase because of craniofacial growth (Subtelnly, 1957).

Nasal breathing, at rest, must shift to at least intermittent mouth breathing at some point as nasal resistance increases. Warren, Trier and Bevin (1974), observed clinically that mouth breathing was more frequently observed when nasal resistance (a measure to be

discussed in detail later in this article) was greater than 4.5cmH₂O/LPS. Mertz, McCaffrey and Kern (1984) and McCaffrey and Kern (1979b) suggest that nasal resistance in the range of 3 to 3.6cmH₂O/LPS may result in significant nasal obstruction. Recently Vig, Sarver, Hall and Warren (1981) offered the observation that a nasal resistance of 4.5cmH₂O/LPS may sometimes be too low to serve as a critical value for determining when mouth breathing becomes mandatory.

There has been at least one attempt to define *mouthbreathing* with objective measures. Gurley and Vig (1982) described the components of an apparatus named "Simultaneous Nasal and Oral Respirometric Technique" (SNORT). The apparatus uses four pneumotachographs which are assigned to record nasal inspiration, nasal expiration, oral inspiration and oral expiration. The authors note that although research with this apparatus is only beginning it will eventually allow the quantification of *mouthbreathing*.

FACTORS INFLUENCING NASAL PATENCY

Anatomical and Physiological Considerations

Reviews of the nasopharyngeal anatomy can be found in many reference texts including Sicher and DuBrul (1975), Zemlin (1981), and Paparella and Shumrick (1980). The nasal airway can be delineated into several regions (Figure 1). Each area is subject to specific abnormalities which may impair nasal patency. The vestibule can be collapsed by the deformation of the ala cartilage seen frequently in complete clefts of the lip (Warren, Duany and Fisher, 1969). The liminal valve area is generally the narrowest area of the anterior nasal passage (Bateman and Mason, 1984). The liminal valve may be contracted during inhalation (by the Bernoulli principle) to narrow the passage further. As a result this is a critical area and any subtle deformity in this area may cause a marked nasal airway obstruction (Kern, 1973).

FIGURE 1

Cross-section of the nasal and nasopharyngeal airways. Area 1 is the anterior nasal cavity which is often the site of constriction due to collapse of the ala cartilage in cleft lip/palate individuals. Area 2 is the liminal valve area. Area 3 is the inferior turbinate. Area 4 is the adenoid or pharyngeal tonsil.

There are three turbinates on the lateral wall. The inferior nasal turbinate is an important flow regulator (Bridger, 1970). The inferior turbinate is a separate bone while the middle and superior are part of the ethmoid bone. The turbinates are covered with a highly vascular tissue covered with pseudostratified ciliated columnar

epithelium. The submucosa contains serous secreting glands plus large cavernous spaces similar to erectile tissue. The ciliated epithelium is highly active and its motion moves the mucosal film toward the nasopharynx. This action serves to filter out dust, pollen and other particles in the inspired air.

Nasal mucosal temperature is regulated by the arterial blood flow through the cavernous tissue of the nasal turbinates and the nasal mucosa. Inspired air is heated as it passes over the mucosa. Cold, dry inspired air (e.g. 0°C) dilates the arterial vessels and distends the turbinates. Warm, humid inspired air creates ischemia of the superficial vessels and congestion of the cavernous tissue. This also results in turbinate distention and impairs nasal patency.

Inspired air is also humidified and filtered within the nasal cavity. Filtration is achieved through mucociliary function which can propel particles forward by nose blowing or posteriorly for swallowing or elimination by coughing. It has also been postulated that the secretory IgA which is present in the mucus defends against airborne disease (Abramson and Harker, 1973). Any factor which might decrease mucociliary flow tends to impede the clearing of inhaled particles and may weaken the defense against airborne infection.

The pharynx contains a ring of lymphatic tissue called Waldeyer's ring which includes the pharyngeal tonsils (or adenoids), the palatine tonsils (or tonsils) and the lingual tonsils on the base of the tongue. Hypertrophy of the adenoids or the pharyngeal tonsils can lead to complete nasal obstruction because they are in a common airway.

Subtelnny (1957) observed that adenoids grow at a rapid rate from 6 months to one year until age two or three years when they occupy approximately one-half of the nasopharyngeal cavity. Thereafter, the adenoids continue to grow in a downward and forward direction but at a somewhat slower rate until they reach a peak at about age 10 to 11 years, or sometimes as late as 14 to 15 years. After the peak is reached the adenoids begin to involute and are negligible in appearance by adulthood.

Leech (1958) and Moyers (1963) noted that enlargement of the adenoids can cause mouth breathing. However, it has been suggested that the absolute size of adenoids is not as important as the relative size of the adenoids in the nasopharynx. This point has been demonstrated by Lubarth (1960), Ricketts (1968), Linder-Aronson (1970) and Emslie, Massler and Zwemer (1952).

The width of the nasopharynx is thought to be stable after two years, however the vertical dimension of the nasopharynx continues to increase until age 17 to 18. This increase is due to the downward growth of the palate (maxilla) carrying the soft palate away from the cranial base and thereby increasing both nasal and nasopharyngeal heights (Subtelnny, 1957). These independently growing areas indicate that a fine state of equilibrium in their growth is required or imbalance will result. Such imbalance is likely to occur when the adenoids develop too fast or when the palate grows away too slowly. The instability of this relationship is seen un-

til 12 years of age, meaning that obstruction is common up until this age. After 12 years of age the nasopharyngeal depth increases when the adenoids begin to regress. Thus, the number of cases of nasal obstruction seen after age 12 is reduced (Subtelnny, 1975).

Diamond (1980) presents an excellent review of the dilemma of tonsillectomy/adenoidectomy. He cites evidence which suggest that the tonsils are possibly involved in the development and maintenance of the immune system. Further, these lymphatic tissues are at strategic sites in the respiratory tract to react to the initial antigen exposure. The decision to remove these tissues should be made only after weighing the possible benefits of improved breathing against the possible compromise of immunologic response.

Nasal Response To Structural Variations

Specific structural anomalies are associated with increases in nasal resistance. Nasal resistance is found to be higher in the cleft lip and/or palate population than in a comparable group of non-cleft subjects (Warren, Duany and Fischer, 1969). Presumably this is caused by retarded maxillary growth (Aduss and Pruzansky, 1967; and Foster, 1962), septal deformities, atresia of the nostrils and turbinate hypertrophy (Drettner, 1960) which serve to reduce the size of the nasal airway. The frequency of nasal deformities is greater when the lip and palate are involved than when only the palate is involved (Warren, Duany and Fischer, 1969).

Management of velopharyngeal incompetence (VPI) has been demonstrated to increase nasal resistance (Warren, Trier and Bevin, 1974). In this study pharyngoplasties (pharyngeal flap) were observed to increase resistance in children but had almost no effect on resistance in adults.

The lips are in easy contact for tidal breathing. It is easy to presume oral air flow and nasal airway interference when the lips are apart. However, a lips apart posture or *lip incompetence* may be precipitated by several anatomical variations (Bateman and Mason, 1984). Vertical maxillary excess is a condition in which the vertical height of the anterior maxilla is greater than the vertical height of the upper lip. Thus, with the teeth in occlusion the lips do not close without additional effort. Often the mentalis muscle is observed to contract in an effort to elevate the lower lip to contact the upper. Lip incompetence may also be the result of severe Class II or Class III malocclusions, severe positive or negative overjet or an open bite.

While a degree of nasal patency is necessary for adequate nasal respiration, an overly patent nasal airway is characterized by certain deleterious effects. Rhinitis sicca or dryness has been attributed to excessive air flow because of surgical removal of turbinates and the subsequent reduction of mucosal area, the destruction of cilia secondary to scarring, tissue atrophy and endstage infection (Courtiss, Goldwyn and O'Brian, 1978). Secondly, the loss of ciliary function is suspected of precipitating *ozena*, a foul smelling nasal discharge of unknown etiology. It is hypothesized that the reduced ciliary

function can no longer filter microorganisms, and crusting results.

VARIATIONS IN BREATHING: Adults vs Children and Infants

Nasal Breathing Cycle

In adults the patency of each nostril is not static. Rather, there is an alternating congestion and decongestion of the nasal turbinates referred to as the nasal breathing cycle. The cycle averages three hours but, may vary from one to several hours. Though long recognized, the nasal breathing cycle (Kayser, 1895) remains poorly understood (Kern, 1973). The nasal breathing cycle occurs in approximately 80 percent of adults (Kern, 1973). Although the resistance in each nasal passage varies in a rhythmical fashion, the total resistance of both passages remains the same. Thus, the normal adult may not experience any sense of obstruction.

Unlike adults, children display a cyclical fluctuation in their nasal patency that is not an alternating cycle. Rather, both nostrils are observed to experience congestion and decongestion in unison. As a result the total nasal resistance is elevated during certain periods of the day to the level of obstruction (Van Cauwenberge and Deleye, 1984). This may help explain observed "mouth breathing" in some children who are without any apparent mechanical nasal obstruction and who may have normal nasal resistance at the time of rhinomanometry. Further, this kind of cyclical obstruction could precipitate oral habits that are retained during periods of decongestion.

Children also vary from adults in the length of the breathing cycles. The cycle in adults ranges from one to several hours and averages three hours (Hasegawa and Kern, 1977), while in children the cycle averages 57 minutes (Van Cauwenberge and Deleye, 1984). The nature of the cycle in both children and adults is such that a single rhinomanometry test is not sufficient to accurately measure nasal patency. Optimally, adults should be tested several times during the day while children should be tested several times within a one to two hour period.

It has been suggested that a mature autonomic nervous system is required to establish a breathing cycle (Kuening, 1968). The alternating cycle observed in normal adults allows maintenance of a constant nasal resistance needed for optimal heating and humidification of inspired air. Hasegawa (1982) speculated that the cycle may be induced by cyclical increases and decreases in sympathetic activity. The observation of a nonalternating cycle as seen in children may reflect a still immature autonomic system (Kuening, 1968).

Mode of Respiration

Adaptations of the breathing patterns of infants are very different from the adaptations of adults. Whereas adults make a smooth transition from a nasal to an oral mode of breathing, infants are obligatory nasal breathers and must learn to breathe through the mouth. Difficulty in oral breathing is particularly pronounced during sleep. This may be the result of the relatively long soft palate in infants which extends behind the tongue nearly to the level

of the epiglottis. In infants, at rest, it has been observed that the uvula and epiglottis appear to be in contact. While this forms an obstructed channel from the nose to the trachea it prevents oropharyngeal respiration. This serves to narrow the oropharynx (a common airway) and may relate to difficulties with oral breathing in infants.

Konno, Togawa, and Hoshino (1980) observed that infants in their study endeavored to breathe through the nose against what was believed to be high airway resistance. However, when the nostrils were completely occluded bilaterally (with cotton balls coated with vaseline) the infants did not enter into oral breathing smoothly. Most continued to breathe through a narrow space between the upper and lower lips which was produced passively by inward and outward shift of the lip margins from the increase in airway pressure. Some of the infants during the period of hypoventilation showed occasional gasping with hyperventilation. Progressive lowering of PO_2 (percent oxygen) was prevented in some infants by increasing respiratory effort and in others by periodic awakening from sleep with occasional hyperventilation. This same pattern has been observed for individuals with upper airway obstruction from disease processes such as adenoid and tonsillar hypertrophy.

Further, Konno, Togawa and Hoshino (1980) also observed three types of ventilatory changes in ten infants. Four of the infants demonstrated periodic breathing changes in which the periods of hypoventilation were alternated with occasional periods of hyperventilation. In these infants esophageal pressure, tidal volume and PO_2 showed concomitant fluctuation. PO_2 lowered during hypoventilation and was compensated by periodic hyperventilation. A second type of change was observed in five of the infants who compensated by marked increases in respiratory effort and tidal volume. PO_2 decreased temporarily but returned to its original level after five to ten minutes. The third type observed was a marked increase in esophageal pressure with decrease of tidal volume. PO_2 level remained decreased as much as one hour, however at no point did PO_2 lowering progress to the point that subjects developed clinical cyanosis.

Nasal Responses To Changes In Body Posture

Increased nasal stuffiness when reclining is a frequent complaint. Studies of the influence of body posture have demonstrated that reclining (supine position) increases nasal resistance specially in patients with allergic rhinitis (Rundcrantz, 1964) and in patients with common colds (Rundcrantz, 1969). Furthermore, Hasegawa and Saito (1979) found that postural changes in nasal resistance were more marked in patients with allergic rhinitis than in normal subjects.

Hasegawa (1982) also described an interaction between the nasal cycle and posture in normal breathers. That is, increasing degrees of supination will precipitate increased resistance in the congested nostril, yet the free-breathing nostril remains stable with no increase in resistance. The mechanism for changes in nasal resistance with this type of postural change is not clear.

Rundcrantz (1964) suggested that vascular dilation due to stimulation of parasympathetic nerve fibers was the cause in patients with allergic rhinitis.

Nasal Responses To Ambient Temperature And Exercise

The nasal mucosa responds to the level of environmental temperature and to the level of bodily activity (i.e., exercise) differentially. Nasal patency is decreased in resting individuals breathing cold air (e.g., 0°C; Drettnier, 1960; Cole, Forsyth and Haight, 1983). On the other hand, nasal patency can be improved by exercise such as a brisk walk (Richerson and Seeborn, 1968; Baumann and Masing, 1970; Hasegawa and Kern, 1977).

In addition, an interesting interaction between breathing cold air and simultaneous exercise has been reported. Cole, Forsyth and Haight (1983) demonstrated that the decrease in nasal patency caused by breathing cold air plateaus in 20 minutes. This can be reversed by exercise in the continued presence of the cold stimulus. Further, the magnitude of decongestion is directly related to the level of exercise.

Breath-holding and rebreathing, like exercise, also induce constriction of the nasal mucosa (Tatum, 1923). These changes are possibly caused by the rise of PCO₂ (percent carbon dioxide) which stimulates chemical receptors in the body precipitating an increase in sympathetic tone in the nasal cavity. This in turn constricts the nasal mucosa and increases nasal patency (McCaffrey and Kern, 1979a, 1979b).

Nasal Response To Systemic Medications

An important source of diagnostic information is the medication history of the patient. Prescribed medications can be the source of "rebound rhinitis" similar to that which follows the use of vasoconstrictors (Mabry, 1982). Increases in parasympathetic stimulation or decreases in sympathetic stimulation usually result in the engorgement of the sinusoidal venous spaces and swelling of the turbinates (Scott-Brown, Ballentyne and Groves, 1965).

Medications prescribed for hypertension generally reduce sympathetic activity, although the modes of action are variable. Nonselective beta blockers (e.g., propranolol and nadolol) generally induce nasal stuffiness since they block the response to sympathetic nerve impulses equally at all sites of the body. On the other hand, cardioselective beta blockers (e.g., metoprolol, atenolol and toamisol) normally do not produce nasal stuffiness because they selectively block nerve impulses only to the cardiac muscle. Antipsychotic drugs generally possess alpha-antiadrenergic action to some degree which decrease sympathetic stimulation and lead to turbinate engorgement (Ballin, 1980).

Nasal stuffiness can occur during pregnancy because of increased estrogen titers. Nasal stuffiness can also occur as a result of contraceptive pills. Although the mechanism is unclear, a direct hormonal effect on the turbinate stroma is likely (Ballin, 1980). In most cases the symptoms subside with the withdrawal of the medica-

tion. However, in some cases permanent stromal hypertrophy may occur. This may be treated with corticosteroids (Mabry, 1982) or may require surgical reduction (Mabry, 1983).

Treatment Of Nasal Airway Interference

Surgical correction of nasal airway interference is a frequent subject of discussion in the surgical literature. However, it has been only recently that discussion includes objective measures of nasal patency prior to and following surgery.

Mygind (1980) offered the observation that just as the otologist needs audiometry pre and post-operatively so does the rhinologist need rhinomanometry. He further observes that although rhinomanometry is used almost exclusively by writers of articles dealing with rhinomanometry, it should enjoy more widespread use by the surgeon who is concerned about appropriate patient selection and the functional results of surgery as a simple matter of quality control. Warren (1984) strongly states that the risks of surgery require that the selection of such treatment should be based on solid and tangible considerations. The assessment of structures and their function should be performed in a quantitative manner requiring reproducible data.

Responses to this challenge are found in the surgical literature. There are numerous reports which use rhinomanometry to evaluate nasal surgical outcome (Broms, Jonson and Malm, 1982; Nicklasson and Lunden, 1982; Courtiss and Goldwyn, 1983; Jalowayski, Yuh, Koziel and Davidson, 1983; Mertz, McCaffrey and Kern, 1984). Some studies were of the effects of single surgical procedures such as septoplasty (Broms, Jonson and Malm, 1982; Nicklasson and Lunden, 1982; Mertz, McCaffrey and Kern, 1984), while others evaluated the outcomes of multiple procedures (Courtiss and Goldwyn, 1983; Jalowayski, Yuh, Koziel and Davidson, 1983). Anterior rhinomanometry (described later in this article) was used in each of these studies.

A high degree of correlation was reported for the pre-operative severity of obstruction and the post-operative improvement. That is, patients with severe obstructions pre-operatively reported improved breathing post-operatively and were measured to have improved breathing (Broms, Jonson and Malm, 1982). Patients who reported improved breathing post-operatively had improved nasal resistance averaging 1.2cmH₂O/LPS (Mertz, Caffrey and Kern, 1984). They further observed that the symptoms of individuals with low nasal resistance were probably not due to anterior septal deviations since correcting the deviation did not improve nasal airway resistance. Broms, Jonson and Malm (1982) observed that neither a detailed history nor rhinoscopy could adequately distinguish between patients with and without a skeletal stenosis. Rather, rhinomanometry was necessary for selecting patients for surgery. They further observed, as did Mertz, McCaffrey and Kern (1984), that patients with low resistance did not benefit from surgery. They added that in these patients surgery should be done only for cosmetic reasons. They also

reported that allergic patients are less likely to feel relief post-operatively. They concluded that rhinomanometry with a properly decongested nose is indispensable when selecting candidates for septal surgery.

Jalowayski, Yuh, Kozial and Davidson (1983) used active anterior rhinomanometry to evaluate nasal patency in 36 patients prior to and following nasal surgery. They concluded that rhinomanometry provides an effective, simple, noninvasive and objective measure of nasal airway patency. Rhinomanometric measures were significantly different between normals and patients selected for nasal surgery. Rhinomanometric measures demonstrated improved patency post-operatively. Not surprisingly, septoplasties frequently improved patency on one side while reducing patency on the other. Of the various nasal surgical techniques evaluated, resection of bony spurs, outfracture of the turbinates and a combined septoplasty and division of the upper lateral cartilages provided the most improvement post-operatively.

Nicklasson and Lunden (1982) used anterior rhinomanometry to evaluate 14 normal and 36 patients who presented with nasal problems. The 36 patients were evaluated prior to surgery and three months later. Pre-operative testing was completed before and after the use of a nasal decongestant. The authors stated that rhinomanometric measures distinguished between mucosal swelling and skeletal deformity and was a useful tool in selecting patients who would benefit from surgery. Moreover, they stated that objective measures may help the surgeon evaluate the validity of an operation.

Martinez, Nissen, Stock and Tesmer (1983) studied 40 patients who underwent total inferior turbinectomies. Clinical examination and a questionnaire were used to evaluate nasal patency. Clinical examination revealed patent airways without mucosal atrophy, chronic inflammation or excessive dryness. Further, a biopsy of the nasal mucosa was taken from one patient at the site of the previous inferior turbinate. Microscopic examination demonstrated regeneration of normal pseudostratified ciliated columnar epithelium with formation of mucous and serous glands. The authors concluded that a total inferior turbinectomy should be considered when routine septoplasty fails to provide an adequate nasal air flow.

Orthodontic Treatment

It has been observed that patients with constricted maxillary arches have increased nasal resistance. Attempts to improve nasal airway patency by orthodontic means have focused on maxillary expansion. Wertz (1968) measured nasal air flow with a warm-wire manometer subsequent to opening the midpalatal suture. He summarized that only nasal obstructions in the anterior-inferior portion of the nasal cavity would be improved with maxillary suture opening.

Hershey, Stewart and Warren (1976) used rhinomanometric measures of nasal resistance, posterior-anterior radiographs and dental casts to monitor the effects of rapid maxillary expansion. They observed that rapid maxillary expansion is an effective method for expanding narrow maxillary arches and also reduced nasal resistance from levels associated with mouth breathing

to levels compatible with normal nasal respiration.

Hartgerink, Vig and Abbott (1987) reported a reduction in the median nasal resistance after rapid maxillary arch expansion. The effect was stable for the one year follow-up period. The largest increase in nasal cross-sectional area was at the anterior nares. However, they reported large individual variations among patients and warned that the results could not be predicted for any one patient.

MEASUREMENT OF NASAL PATENCY

The measurement of nasal patency has long been of interest. Much of our understanding of nasal physiology and the effects of surgery, temperature and posture has been enhanced because rhinomanometry has provided objective measures. The objective assessment of nasal airway patency is typically achieved by the simultaneous measurement of nasal air pressure and nasal air flow. This was first employed by Zwardenaker (1889). Airway patency has been estimated from radiographic study (Holmberg and Linder-Aronson, 1979). This technique has been criticized since radiographs provide only two-dimensional images of a three-dimensional structure. Moreover, artifacts caused by superimposition of shadows may result in inaccurate conclusions regarding airway patency (Warren, 1984).

Recently there has been a renewal of interest in measuring nasal airway patency. This appears to arise from controversy over the use of the term *mouthbreathing* (Gurley and Vig, 1982), controversy over nasal surgery being recommended and performed for certain dental arch conditions, and the current availability of objective, valid instruments for measuring nasal airway patency (Mygind, 1980; Connell, 1982; Riski, 1983; Clement and Hirsch, 1984; Warren 1984).

Test procedures and instrumentation often vary across examiners. Some use nasal airflow, some calculate nasal resistance from the measured pressure drop and the transnasal air flow rate. One examiner suggests the use of calculated, minimal nasal cross-sectional area rather than nasal resistance. Recently, standards of testing have been proposed in hopes of making comparisons meaningful (Clement, 1984).

It has been suggested that because subjective nasal examination and the patient's own impressions did not correlate with the rhinomanometric findings, that rhinomanometry is of limited use. In fact, rhinomanometry is an objective finding governed by the laws of fluid mechanics and if correctly carried out, reflects the real situation. In instances where it does not correlate well with subjective findings, Clement and Hirsch (1984) suggest a critical reconsideration of the subjective inspection to try to find the error.

Test Procedure

Tests of nasal airway patency should be able to delineate a unilateral versus a bilateral obstruction and should be able to differentiate a structural problem (requiring surgical management), from a condition of allergic tissue hypertrophy (requiring medical management). Although

testing can provide some information about the nature of an obstruction it cannot pinpoint the exact site of obstruction. For the latter, a complete nasal exam performed by an ENT specialist is required. Quinn (1983) adds that if an obstruction is not found, appropriate referral for allergy, neurology, pulmonary, cardiac or other disciplines may be necessary.

Kern (1968) and Quinn (1978) also offer suggestions for the information that should be obtained while interviewing and examining a patient. Kern (1973) suggests the following test protocol. The patient is in a seated upright position and is asked to breathe normally as in quiet respiration. Prior to testing, the patient should be asked to clear the nose of excess nasal secretions. Our own clinical experience has been that nasal patency can be improved as much as 50% with this single maneuver. That is, *poor nasal hygiene* is often the primary cause of poor nasal patency.

The following test sequence is suggested: A. Before use of topical vasoconstrictor: (1) Bilateral measures; (2) Unilateral measures [non-test side is occluded with cotton or gauze soaked with vaseline]. B. After use of topical vasoconstrictor: (1) Repeat A. 1; (2) Repeat A. 2.

Test Techniques

There are numerous methodological variations that have been applied to *rhinomanometry* or *rhinometry*. The former term is preferred by some (Clement and Hirsch, 1984) while the latter is preferred by others (Graamans, 1981 and Connell, 1982). The technique may be anterior or posterior; active or passive. Measures may be taken at constant flow rates or constant pressure. Yet, all variations are similar in that they rely on a measured pressure drop through the nasal cavity(ies) and a measured air flow rate.

There is still disagreement on whether anterior or posterior rhinomanometry should be used. The proponents of the former argue that anterior rhinomanometry requires less patient cooperation and can be used more universally (Mygind, 1980). Proponents of the latter argue that posterior rhinomanometry can measure both nasal passages simultaneously and that this technique does not distort the anterior valve (Graamans, 1981). Despite differences, each technique uses pressure transducers, pneumotachometers and recording equipment. The purpose here is to describe these various rhinomanometric techniques and the advantages and disadvantages of each.

Active Posterior Rhinomanometry

The pressure drop through the nose and the rate of air flow are measured while the patient breathes actively (Figure 2). Air flow is collected by a mask. P_1 is measured by a catheter inserted through the mask and the closed lips into the posterior oral cavity. P_2 is measured by a second catheter that is inserted into the mask.

Advantages: (1) Does not deform the anterior valve of the nose. This is a frequent site of obstruction in the complete cleft lip and palate population (Warren, Duany and Fischer, 1969). (2) Both nostrils are recorded

simultaneously (total nasal resistance). (3) Measurements can be made even when there is total obstruction of one nostril. (4) A unique application is the use of theoretical hydraulic principles to estimate minimal cross-sectional area of the nose (Warren 1984). This application is discussed in more detail in a subsequent consideration of unique methods of testing.

FIGURE 2

Active posterior rhinomanometry. 1 is the differential pressure transducer recording P_1 from the posterior oral cavity and P_2 from within the mask (external to the nose). 2 and 3 are the pneumotachometer with its associated pressure transducer which record the air flow velocity. This method allows either binasal or uninasal measurement.

Disadvantages: (1) One nostril must be sealed, without deforming the anterior valve of the working nostril, in order to obtain unilateral measures. (2) More time consuming procedure. (3) Leaks may be introduced if the mask does not fit properly. This may be reduced by using an anesthesia mask with an inflatable cuff. Also a clear, transparent mask will facilitate visual monitoring of mouth posture and catheter placement. (4) Reports suggest that 30-50 percent of patients cannot relax the posterior tongue sufficiently to perform the task (Kern, 1973). This can be overcome to a large degree by requiring the patient to protrude the tongue and to close the lips around the protruded tongue and catheter. Success rate can be elevated to near 100% with this simple maneuver (Riski, 1983). (5) A mask that is too small can deform the anterior nose. A clear mask allows visual inspection to avoid this problem.

Active Anterior Rhinomanometry

This technique requires catheters in each nostril. The catheter in the closed nostril measures the pressure in that nostril. This is an estimate of P_1 , or the pressure in the nasopharynx. The catheter in the second nostril measures P_2 and nasal air flow (Figure 3, p. 18).

Advantages: (1) It is an easily and rapidly completed procedure. Young children and infants may be tested because little active participation is required. It may be performed without a mask to eliminate nasal deformation.

Disadvantages: (1) Catheters may deform the anterior nasal valve and invalidate measures. (2) Pressure gradient measurement requires that the catheter be smaller than smallest diameter of the nose (Nakano, 1967). (3) Various sizes of catheters are needed to fit properly. A conical shaped nasal olive may allow a more airtight fit. (4) Measures are obtained on one nostril at a time and total nasal resistance must be calculated. (5) Measurement is not possible when one nasal cavity is completely obstructed or when there is a septal perforation.

(6) Breathing through one nostril may be oppressive for patients with partial obstruction. This may lead to abnormal breathing patterns.

FIGURE 3

Active anterior rhinomanometry. 1 is the differential pressure transducer recording P_1 from left or test nostril and P_2 from the right or nontest nostril. 2 and 3 are the pneumotachometer and its associated pressure transducer which record air flow velocity.

Passive Anterior Rhinomanometry

In this technique a catheter is inserted into the test nostril and the second nostril remains open. Air at a fixed airflow rate (e.g. 250cc/sec) is delivered into the nostril. The pressure induced by the nasal resistance to the air flow is measured at the external nose (Figure 4).

FIGURE 4

Passive anterior rhinomanometry. 1 is an air flow pump which delivers air to the test nostril at a fixed air flow rate (e.g., 250cc/sec). The second nostril remains open. 2 is a pressure transducer which measures the pressure inducer by nasal resistance.

Advantages: (1) It is a fast, easy procedure. (2) Minimal patient cooperation is needed. (3) Measures are possible when one side is obstructed.

Disadvantages: (1) It has many of the disadvantages of anterior rhinomanometry. It may deform the anterior nasal valve, tests one nostril at a time, and several sizes of catheters are needed which must be smaller than smallest diameter of the nose. (2) Septal perforation precludes measurement. (3) Patients must hold their breath. (4) Instrumentation lacks sensitivity.

Nasal Cross-Sectional Area

An adaptation of pressure-flow instrumentation has been described by Warren (1984) who demonstrates that a valid method of measuring nasal airway patency can be obtained using a modification of the theoretical hydraulic principle. The principle assumes that the smallest cross-sectional area of the nasal airway can be calculated if the pressure drop through the airway and

the rate of air flow through the airway are measured simultaneously. This technique was initially developed to estimate the orifice size of a velopharyngeal incompetence (Warren, 1964) and its reliability has been demonstrated in other studies (Lubker, 1969; Smith and Weinberg, 1980, 1982).

The technique uses active posterior rhinomanometry (Figure 2). Data from eighteen adults (greater than 15 years of age), with clinically normal nasal airways revealed an average, smallest cross-sectional area of $.62\text{cm}^2$, $\text{SD} = 0.17$. The average, smallest cross-sectional area for twenty-six children (8-11 years of age) was 0.43cm^2 , $\text{SD} = 0.08$. Warren states that this measure of nasal patency has a significant advantage over standard measures of nasal resistance which must be made at a standard air flow rate. Additional investigation by Warren, Lehman, and Hinton (1984) indicated that (for adults) a nasal cross-sectional area greater than 0.4cm^2 is adequate. A nasal area less than 0.4cm^2 necessitates mouth breathing. However, severe unilateral airway impairments can produce mouth breathing symptoms even when the total nasal area is greater than 0.4cm^2 . Thus, there is a strong need for unilateral as well as bilateral measures.

It is understood that nasal resistance is flow dependent. Thus, as the demand for flow increases, such as during exertion, resistance will increase, and mouth breathing will be needed to lower resistance. Parting the lips slightly (2-3mm) can reduce the pressure differential between the mouth and nose by 50-75% (Hinton, Warren and Hairfield, 1986).

While abnormally high nasal resistance does necessitate mouth breathing symptoms it also appears that some degree of nasal resistance is necessary. Warren, Hairfield, Seaton and Hinton (1987) found that nasal resistance did not fall much below $1.9\text{cm H}_2\text{O/LPS}$. They suggested that some degree of resistance is necessary to serve as a respiratory brake. This assists in adequate alveolar gas exchange.

Summary

The nasopharyngeal airway is the natural portal of the respiratory tract. Its purpose is to warm, humidify and filter inspired air. The patency of the nasal and pharyngeal airways is critical if it is to perform these functions. Patency depends on a very complex interrelationship of structural and anatomical variations, responses to the autonomic nervous system, allergins, exercise level, temperature of breathed air, systemic medications and body posture. Patency can also be influenced by nasal decongestants and surgical modification of the nasopharyngeal anatomy. As important as this airway would appear to be, its normal physiology, and the interrelationships of these numerous factors and the impact of growth of the face are not completely understood.

The total scope of the problem far exceeds the boundaries of this article but rather, includes bodies of literature from the fields of allergy, otorhinolaryngology, growth and development, medicine, orthodontics and orofacial myology. It is clear that these multiple and complex interactions must be appreciated and are often best

evaluated by a team of specialists from those fields listed above.

The diagnosis and treatment of airway problems have a scope much broader than the consideration of facial growth. Rather, they impact the overall health of the individual. This is a timely topic because of the active in-

terest that exists among specialists, and the spirited discussion that it evokes. Key to the improvement of our understanding of normal and abnormal breathing and the treatment of airway problems is cooperation and communication among specialists who are using objective measures to describe their observations.

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