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Nasopulmonary Physiology

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The role of the nose in health and in respiration has been greatly neglected by physicians. Ignorance of nasopulmonary activity persists despite more than a century of basic physiological research, clinical experience, and, more recently, availability of specialized equipment for nasorespiratory and nasopulmonary testing. This chapter will attempt to demonstrate that such neglect adversely affects patient welfare, including that of many patients seen outside ear, nose, and throat clinics.

In his many publications and lectures from the 1950s through the 1980s, the late Dr. Maurice H. Cottle attempted to renew interest in nineteenth century history of nasal therapy and surgery. He also pioneered development of an instrument for measuring nasal breathing pressures. He became so closely identified with diagnosis of and surgery for certain nasal problems that they became known as the "Cottle syndromes." He stated repeatedly that many remote rhinologic causes of symptoms that he diagnosed were sometimes not believed by doctors or patients (Cottle, 1987). These causal relationships of nasal origin will be described in this chapter.*

1. The Role of the Nose in Breathing and Respiration

The act of breathing and the function of respiration are not synonymous. *Breathing* is the transport of air in through the upper and lower airways to the

*This chapter is based on the teachings of Dr. Maurice H. Cottle (1898–1981), founder of the American Rhinologic Society (Cottle, 1980, 1981), reviewed and updated by Dr. Barelli (Barelli *et al.*, 1987).

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alveolar cells with sufficient pressure, moisture, warmth, and cleanliness to ensure optimal conditions for oxygen (O_2) uptake and for elimination of carbon dioxide (CO_2) brought to the alveoli by the blood stream. *Respiration* includes all the processes involved in bringing O_2 to every cell in the body and removing CO_2 from tissues and organs after aerobic cellular metabolism has been completed. Nasal reflex responses play an important role in respiration.

The human nasal aperture consists not only of nostrils but of two noses, right and left, each independent yet coordinated into a single functional unit separated by a nasal septum. These structures, together with the *turbinates* (Fig. 1) and the nasal wall mucosa, combine to provide a regulating mechanism for efficient nasal breathing. In breathing and respiration, the nose has many functions which are important supplements to the roles played by the lungs, heart, and other organ systems. Cottle (1958) stated that there are at least thirty such functions known. To understand nasal function fully, one would need to know the anthropological, embryological, anatomical, and developmental aspects, as well as the effects of injury to the nose. In this chapter, only the major and a few of the less well known, but equally important, roles that the nose subserves will be discussed.

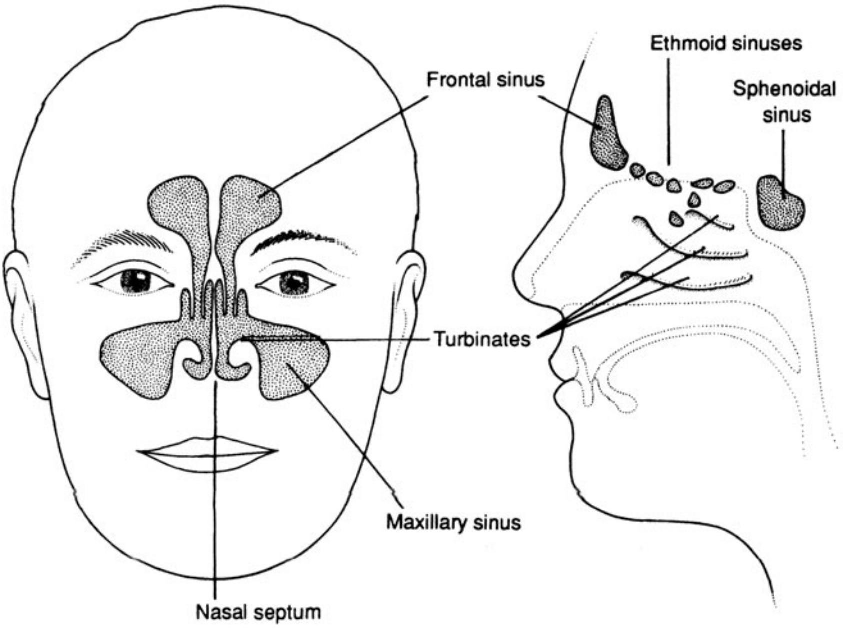

Figure 1. Nasal structures.

1.1. Preparation of Air for the Lungs

The nose warms, humidifies, and cleanses air to prepare it for delivery to the lower airways. The nasal mucosa, with its blanket of cilia and network of arteries, veins, and lymphatics, provides a protective barrier. The autonomic nervous system and anatomic control of the nasal mucosa provide, when contacted by bacteria or by chemical or gaseous stimuli, reflex cholinergic responses which influence the beat and secretions of the mucosa through ciliary activity.

1.2. Control of Air Stream

During both inspiration and expiration, the external nose and the internal nose, with its baffles, culs-de-sac, valves, and turbinates, influence the air stream in many complicated ways. The nose regulates direction and velocity of the air stream to maximize exposure to a network of fine arteries, veins, lymphatics, and sensory and autonomic nerves, and to the mucous blanket (van Dishoeck, 1936). Whirls and eddies cause dust particles to impinge on optimal areas for deposit.

The nose creates pressure differences between the lungs and the external apertures (Chapter 1) which assure flow of the air stream, and consequently O_2, to the heart and lungs (Mink, 1920; Widdicombe, 1986).

The nose alternates the main air stream from one nasal chamber to the other about every 2–4 hours. These changes are brought about by rhythmic, cyclic alterations in the size of the turbinates, whether the head is upright or reclining (Kern, 1986; Stoksted, 1952; Werntz *et al.*, 1983).

1.3. Olfaction

The nose directs, and prolongs the stay of, air over the olfactory receptors. The human nose lost much of its fine ability for olfaction and assumed the more important role of a respiratory receptor area. However, our sense of smell is still integrated through the rhinencephalon, a primitive portion of the brain that remains deeply involved with all bodily structures and functions and is still of great importance.

1.4. Nasal Resistances

Nose breathing imposes approximately 50 percent more resistance to the air stream in normal individuals than does mouth breathing, resulting in 10–20 percent more O_2 uptake (Cottle, 1972; Rohrer, 1915). Resistance during inhalation is regulated by the turbinates in wide noses and by other structures in narrow noses. There must be adequate nasal resistance to breathing to maintain elasticity of the lungs (Cottle, 1980). Breathing through the mouth when the nose is obstructed usually imposes too little resistance and can lead to micro-areas of poor ventilation in the lungs (atelectasis). Alternatively, many years of breathing against excessive resistance, as with nasal obstruction, may also cause micro-areas of poor ventilation (emphysema).

Ogura confirmed that a nasopulmonary nervous system exists by which breathing through a constantly blocked nose can alter pulmonary function in a reflex manner (Cottle, 1981; Ogura *et al.*, 1964). He also found that in nasal obstruction the hemilateral lung complied to this increased resistance (Ogura and Harvey, 1971; Ogura *et al.*, 1964).

1.5. Body Temperature

Through a reflex nasal response, body temperature is influenced by the temperature and moisture of expired air (Scott, 1954; Weiner, 1954).

1.6. Nasal Reflexes

The nose provides constant stimulation by air currents of the trigeminal and other olfactory cranial nerve connections in the nasal mucosa (Nishihira and McCaffrey, 1987). This stimulation engenders many reflex responses. One common nasal reflex is the sneeze, which is a protective mechanism. The trigeminal nerve, with its extensive distribution throughout the nasal mucosa, receiving tactile sensations and often painful impulses with each breath, also has profound and intimate connections with many parts of the brain and spinal cord. The nose is thereby connected with practically all the important structures supplied by the cranial and cervical nerves (Mitchell, 1964). Reflex responses and referred phenomena are well established between the nose and ears, throat, and larynx; the nose and heart, lungs, and diaphragm; and even the nose and abdominal contents (Mink, 1920; Samzelius-Lejdstrom, 1939). Sercer (1930) identified a reflex relationship between each nasal fossa and the corresponding hemithorax. Where there is aberration of this reflex, many clinical symptoms can occur. Voydeville (1951) cited, as important evidence of the effects of nasal phenomena on the act of breathing, the fact that unilateral nasal narrowing (stenosis) can decrease the play of the diaphragm on the same side by 2–5 cm (Cottle, 1980).

1.7. Nasal Reflexes and the Cardiovascular System

Physiologists have noted the striking reflexes that stimulation of the nasal mucosa can evoke, affecting not only respiration but the heart and peripheral blood vessels as well (Allison, 1974). These reflexes are described as among the most powerful of those observed in the experimental laboratory. Responses may depend on the strength of the stimuli. For example, mild olfactory stimulants may cause an increase in breathing, whereas strong irritants can depress respiration or even cause apnea; other irritants can cause bradycardia or hypertension (Angell James and de Burgh Daly, 1969). Exaggerated responses of breathing can occur in patients with certain pathological conditions of the nose and in those with increased irritability of the trigeminal nerve (Angell James and de Burgh Daly, 1969).

In many seagoing mammals, the diving reflex plays an important role. The nose, when closed off, sends certain messages and causes the circulatory system to allow heart and respiration rates to slow or cease, thus allowing more O_2 to the heart and brain for survival. In humans, some reflexes, apparently derived from the diving reflex, have little useful purpose (except for the protective apnea that exposure to noxious fumes evokes), and may even be dangerous. Many doctors and nonmedically trained persons are still woefully ignorant of the fact that these reflexes can cause syncope or sudden death through vagally mediated cardiac inhibition (Allison, 1977; Cottle, 1980).

Nasal reflexes, coupled with the resistance of the nose, increase the efficiency of the lungs and improve the ultimate effectiveness of heart action (Albert and Winters, 1966; Butler, 1960; Edison and Kerth, 1973). This results in a better alkali reserve in the blood, necessary to maintain body chemistry by lowering the percentage of lactic acid in the blood (Luescher, 1930). Lactic acid is an important chemical maintaining a regular rhythm of the heart, rising and falling with breathing. All other body muscles are kept in tone by this mechanism and all the above factors increase the capacity for work (Kreewinsch, 1932).

1.8. Sleep and Postural Adjustment

The nose effects a different type of cycling during sleep than the cycling it effects during the waking state. When one lies with the head to one side, the turbinates of the lower nostril become congested. The chamber narrows and the lumen is closed: thus, breathing during sleep is *unilateral.* The nose initiates movement of the head from one side to the other, which in turn inaugurates a major movement and turning of the body. This head-and-body-moving cycle initiated by the nose ensures maximum rest during sleep (Cole and Haight, 1984). A poorly functioning nose may allow the body and head to remain in one position and can cause symptoms such as backaches, numbness, cramps, and circulatory deficits (Davies *et al.*, 1989; Javorka *et al.*, 1985). Thus, when the normal function of the nose is disturbed or impaired, disturbed sleep may occur.

1.9. Nose versus Mouth Breathing

In addition to those differences described above, another striking physiological difference between nasal breathing and mouth breathing is that the work of lung movement is approximately doubled when breathing is done through the nose, due to increased resistance. Nasal breathing is *involuntary* (Butler, 1960; Cottle, 1981). Mouth, or *voluntary,* breathing occurs when there is difficulty breathing through the nose, such as in exertion, under stress, and—in particular—when cardiac, pulmonary, or other illness hampers the supply of oxygen to the tissues. Thus, nasal versus mouth breathing is a "trade-off." The former increases the work of breathing but provides many benefits in comparison to the latter.

2. The Role of the Rhinologist

As understanding of nasal physiology increases, so does awareness of the special relationship of the function of the nose and upper airways to general health. Our view is that, in addition to the present practice of diagnosing anatomical or physiological aberrations, rhinologists should assess the *functioning* of the nose with nasal pressure (*rhinomanometry*) and nasopulmonary tests. A good nasal history is very important. Cottle (1980, 1981) taught that a thorough history of the patient's complaints will give important information regarding the relationship of the nose to the patient's habits and health. One should know the ethnic background, method of birth delivery, and history of childhood or recent nasal injuries, which might give clues to development of nasal problems. The patient should be asked whether he/she breathes through the nose or mouth at rest and work, how quickly during work or stress, in what conditions must he/she resort to mouth breathing, and when he/she experiences "shortness of breath" or momentary syncope.

Because quality of sleep is in good measure dependent on nasal function, special attention should be paid to sleep habits: Does the patient habitually sleep more on one side? Does the patient awake fatigued? How many pillows are needed? Is the bed torn up? Does the patient snore? The quality of sleep, the quality of breathing, and the quality of life can all depend on adequate nasal function (Issa and Sullivan, 1984; McNicholas *et al.*, 1987).

2.1. Nasal Examination

The outside of the nose is examined: the alignment of the external nose, its width, and its size can affect the resistance and work of breathing. With instruments such as headlamp, speculum, applicator wires, and special endoscopic equipment, the internal nose is examined and the sinuses are transluminated. Observation is made of the vestibule, valves, turbinates, lateral walls, septum, and floor of the nose for pathology or for too little or too much space; the turgescence of the turbinates and their response to shrinkage can give much information about nasal function. X rays, CAT scans of the head, and ultrasound can each add to the final diagnosis of the rhinologic problem.

2.2. *Nasal Pressure Tests (Rhinomanometry)*

In the process of breathing, the outside air pressure is transmitted through the entire respiratory system, including sinus cavities, eustachian tubes, trachea, bronchi, and alveoli. The pressure measured at the nose in inspiration and expiration is called *nasal pressure*. Abnormal, or absence of, pressure can aggravate nasal and pulmonary problems and exacerbate disabilities due to chronic lung, heart, and vascular problems. Pressure can influence diffusion of O_2 through alveolar and epithelial walls and of hemoglobin through plasma into red blood cells.

Cottle (1980) suggested an objective, accurate method of determining nasal function, easily available and applicable in routine clinical use: with a nozzle in one nostril, the pressure of the air stream as it flows in and out of the other nostril can be observed on a manometer. Recordings obtained with the Cottle nasal pressure-flow-transducer system allow study of a typical nasal breath in detail. Cottle (1958; 1968) identified many aberrations in rhinomanometric graphs, which are useful in diagnosis. Irregularities in breathing pattern amplitude and frequency, and reversal in ratios of pressure and time during inspiration and expiration, can often denote local derangements in the nose. Increases in breathing pressures are associated with nasal obstruction or adenoid hypertrophy. Other conditions such as breath holding, hyperventilation, and exercise, because of their effects on flow, pressure, and rate of breathing, can affect nasal resistance (Hasagawa and Kern, 1978).

When breathing through the nose or even through the mouth becomes difficult, a person automatically assumes a pattern of breathing that most easily fulfils requirements, or else lowers or otherwise modifies his/her requirements and life-style to meet a diminished oxygen supply and other respiratory disturbances. There are more than 100 combinations of ways, positions, and patterns of breathing that disturbed respiration may evoke. Even a superficial survey will reveal that the average person uses 20 to 30 different breathing modes in normal life (Cottle, 1980).

The rate of breathing is an important factor in health and significant aberrations may also be observed on the pressure curve. Negus (1957) claimed that a person must breathe ten times per minute in order to adequately ventilate the lungs (but see Chapters 11 and 15). A rate of more than 20 was considered rapid.

Slow breathing (less than ten per min) may occur with low pressure in Caucasians with long-standing nasal injuries, and with high pressure in young people with chronic nasal blockage. Rapid but typically *regular* breathing is observed in adults with pulmonary disease and in children with adenoid hypertrophy. When breathing is rapid but *irregular,* an emotional disturbance is probable.

Rhinomanometry is increasingly recognized as a valuable adjunct to the examination and diagnosis, and should be used before and after medical or surgical management of rhinologic and upper airway obstructions.

2.3. Sinus (Nasoantral) Pressure Tests

With changes in permeability of the *ostia* (openings to the maxillary sinuses), a variety of symptoms and irritability occur, including headache, sore throat, ear disturbances, cough, and ocular discomfort. Reestablishment of a functioning ostium is so frequently and quickly followed by relief of complaints that it is deemed of prime importance to bring this clinical entity to the attention of clinicians. The permeability of the ostia may be determined with pressure studies. If partial blockage of the aperture occurs, whether in the sinus, the nasal chamber, or the ostium itself, a decrease in antrum pressure is seen. With total obstruction, no pressure recording from within the sinus is obtainable.

2.4. Nasocardiovascular Relationships

Cottle (1981) pointed out that nineteenth century treatises not only recognized the nasal reflexes of sneezing and lacrimation but, astonishingly, the neurological relationship of the nose to the heart and lungs. He awakened much interest in these influences of the nose and upper airways. He demonstrated that pauses in the respiratory cycle ("mid-cycle rests") are sometimes seen in patients with histories of heart disease, with or without discernible nasal pathology (Kern, 1986). Finally, Cottle (1980) suggested that one of the most significant findings from pressure recordings is that the presence of mid-cycle rests in young and older adults can predict development of recognizable cardiac pathology months or even years later. This phenomenon has been recognized by some cardiologists but its predictive value has yet to be formally established by prospective trials. Such observations warrant further nasopulmonary and cardiac studies.

2.5. Nasopulmonary Tests

For further screening of nasal function, nasopulmonary tests using a pressure flow recorder with a spirometer will give tidal volume through each nostril. Additional tests through the nose can be performed with a digital spirometer, to measure forced vital capacity, flow rates, maximum voluntary ventilation, and inspiratory capacity. Parameters measured through the nose may then be correlated with those measured through the mouth. Combined with physical examination and history, these tests provide more accurate diagnoses of upper airway and pulmonary diseases. They also allow periodic comparative evaluations, to assess results of treatment or surgical procedures and to provide medicolegal documentation.

2.6. Middle Turbinate Syndrome

The middle turbinates, neighboring septum, and lateral wall constitute the area where nerves are very abundant. If the middle turbinates are constricted, compressed, or deformed, and thus even more vulnerable to disturbing impulses, the following symptoms can occur: headache, facial pain, colds, sinus disturbances, chest pain, shortness of breath, irritability, poor concentration, cold hands and feet, and other vascular insufficiencies, such as cardiac arrhythmia. Symptom relief is often achieved by anesthetizing the mucosa over the middle turbinate area with a cocaine solution. If relief is immediate, nearly complete, and lasts for at least ten hours, it can be assumed that a morphological, or other pathological, change in or near the middle turbinate is present. Simple medical or appropriate surgical treatment would therefore be expected to alleviate the patient's symptoms.

2.7. Nasal Surgery

When disturbances of the nose are found, subtotal nasal-septal resection and reconstruction, especially in the area of the middle turbinate, is often part of the therapeutic regimen. For example, hyperventilation symptoms can often occur in joggers with partially blocked noses. Following good corrective nasal surgery, the symptoms usually disappear, and following poor surgical techniques, they continue or worsen.

3. Psychological Aspects

The intimate association between the nose and the psyche has often and justifiably been emphasized (Holmes *et al.*, 1950). Anxiety-related disturbances involving nervousness, tension, impaired concentration, and other symptoms may have an origin in the nose and are often similar to symptoms caused by hyperventilation. In our view, rhinologic screening is imperative for patients with such complaints who have typically undergone extensive but unproductive medical surveys and psychiatric workups.

4. Conclusion

Total evaluation of a patient's health should include estimation of nasal function disturbances. Rhinomanometry and nasopulmonary tests have made significant contributions to research and diagnosis of human illness, and should be considered by other clinicians concerned with breathing and the process of respiration.

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