HEAT AND MOISTURE EXCHANGES IN RESPIRATORY MUCOUS MEMBRANE

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INTRODUCTION

Ontogenetic and phylogenetic evidence leads one to the conclusion that the nose first developed as an organ of olfaction (1). The endorgan of smell depends upon the diffusion of chemical substances thru a liquid medium and the primitive olfactory organ was a relatively simple structure. The amoeba as it approaches a particle of food demonstrates a response to olfaction in its simplest form.

"Fishes have" two pits lined with chemoreceptor cells situated at the anterior extremity and demonstrate an early form of olfactory apparatus independent of other systems which later become intimately related with it. Nevertheless, even here the respiratory and locomotory organs contribute to the effectiveness of the sense of smell by bringing the liquid menstruum toward the organ of olfaction. It is therefore feasible to consider locomation and respiration as accessory organs of smell although they are independently essential for survival of the species.

In order for the olfactory apparatus to function effectively on land, where the organism is surrounded by air with an inadequate liquid content, the olfactory organ became more complicated in structure and became intimately associated with the respiratory system. This partnership resulted in the development of a very efficient and effective organ in warm blooded vertebrates. The arrangement which enhanced the sense of smell also contributed significantly to making the nose an effective organ for preparing inspired air for exchange of gases in the lung alveoli.

It is prudent, I believe, not to attribute greater importance to one nasal function or another. If we compare the intranasal structure of the macrosmatic mammals with that of man we cannot help but be impressed with the formers complexity and conclude that the nasal chambers of the seal, for example, are constructed to enhance olfaction. On the other hand, it serves to warm and humidify air very effectively under all enviromental conditions. Both functions are necessary for survival of individual and species.

Comparatively, the intranasal structure of primates is less complex than most lower vertebrate forms. This is attributed to the fact that primates depend more on their highly, developed visual sense for survival than on olfaction.

Man has evolved a simpler nasal organ with a less keen sense of smell and an unique heat controlling mechanism, independent of the respiratory system. The respiratory demands have, however, remained essentially unchanged. As a matter of fact, because of his so-called superior intelligence, he has contrived to place greater stress on this retrogressive organ (2). Despite the loss of intranasal complexity necessary for keen olfaction, air conditioning and body heat regulation, it has been repeatedly demonstrated that heating and moistening of air by the nose is adequate to prepare inspired air for the vital process of pulmonary gas exchange (3, 4, 5).

Some physiological studies indicate that the nasal mucosa alone can adequately condition inspired air under moderate conditions of temperature and humidity (5). Other studies have lead to the conclusion that the human nose cannot prepare air adequately under extremely low temperatures and moisture content (6). Nonetheless, the nasal mucosa being first in line to receive the raw material is at the mercy of the physical laws governing heat and moisture exchange of gases.

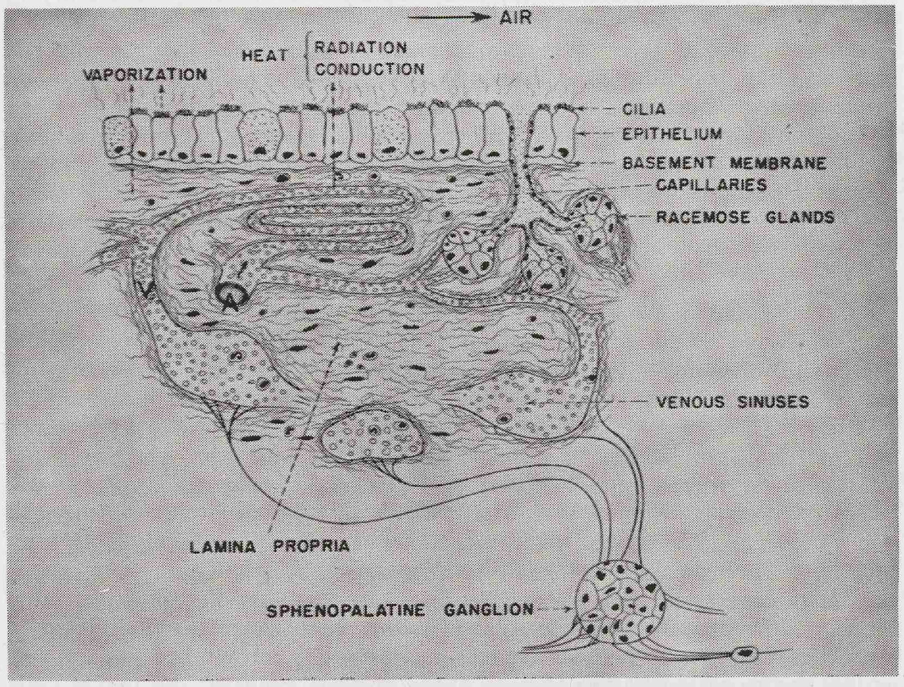

Figure 1. Diagram of the nasal air conditioning system
Diagramme du système nasal de conditionnement de l'air.

Mechanism of Heat and Moisture Exchange in Respiratory Mucous Membrane

Air entering the human nose is usually below saturation and also lower than the temperature of the body core. When it reaches the lung it is either completely saturated with moisture or very near saturation, and is warmed to body temperature. Heat transfer, in general, occurs by the physical processes of convection, conduction and radiation. Because of the rapid movement of air across the nasal mucosa, radiation seems to play the major role. Conduction from the vascular spaces toward the mucosal surface and outer lamina of air currents is second in importance. Convection is a slow process and probably contributes little to the heating process.

Molecules of water leave the surface of the mucosa and become a gas mixing with the air passing over it. This process is known as vaporization. The rate of vaporization of water depends upon such factors as temperature, surface area, vapor pressures and ventilation (movement of gas above the mucosal surface). (7) In the confined areas of the nose these factors favor rapid uptake of moisture from the mucosal surface toward the lamellae of inspired air. During expiration the highly saturated and heated air loses water and heat to the cooler and dryer surface.

The extensive surface area in noses of animals with a keen sense of smell not only warms and moistens inspired air rapidly and efficiently but the drying effect on the mucous membrane is less traumatic than in the human nose where the surface area is less extensive. In tracheotomized patients the inspired air is warmed and moistened to a remarkable extent before it reaches the bifurcation placing a great burden on the tracheal membrane (5). The tracheotomized patient benefits from the recovery of moisture and heat from the lower respiratory passages during expiration in much the same manner as the nose does (7).

Sources of Respiratory Moisture

1. Transudation: Sir Victor Negus (8) is convinced that the large amount of water released by the nasal mucosa cannot be derived from secretory glands. He basis his conclusions on two pieces of evidence. The consistency of mucus is too great to supply the amount of moisture necessary to saturate inspired air. Secondly, the work of Florey, Carleton and Walls (9) showed that mucus disappeared almost completely from the mucus glands of the trachea under atropinization although the amount of water given off was not reduced. Their conclusion was that moisture in the respiratory tract was due to transudation rather than secretion. On the other hand Craig and Smith (10) has demonstrated that forty percent to eighty percent of water can be removed from the mucus before any appreciable change in viscosity occurs. The racemose secretory glands in the mucosa have serous elements and there is evidence that one type of secretory cell can change into another or that the mucous cell can secrete a non mucous material. The goblet cells continue to secrete when the respiratory membrane is atropinized.

Considering the extreme thinness of the epithelium, transudation probably plays a significant role in providing moisture. In transudation fluid originates in arterial capillaries passing into the lamina propia because of the hydrostatic pressure gradient in favor of the capillary to connective tissue direction. Negus (8) says that although the hydrostatic pressure of lamina propria is low it is sufficient for water to pass to the epithelial surface because of the osmotic pressure of surface mucus.

2. Secretion: The respiratory mucous membrane of the nose contains an abundant supply of glands. Histologically, the glands appear either as serous or mucus and in places are mixed. Goblet cells also appear in abundance in the

respiratory lining membrane and produce the glycoprotein mucin. The relative number of glands in the respiratory tract secreting a serous material is not known. Cells which are histologically classed as serous are characteristically found in gland structures which secrete enzymes. In the respiratory mucous membrane, however, no enzymatic activity has been demonstrated. It is probable that these cells serve to supply water to the surface membrane to keep the viscosity of mucus at a low level.

When inspired air reaches the lung alveoli it is completely saturated with moisture. Here oxygen and carbon dioxide freely diffuse between the air sacs and capillaries obeying the physical laws governing the passage of dissolved gases thru membranes. The hydrostatic pressure of the moisture in alveolar air appears to balance the osmotic pressure of plasma so that no fluid exchange occurs in the lung alveoli.

Biochemical Considerations

The biochemical processes involved in heat and moisture exchange through respiratory mucous membrane in general and nasal mucosa in particular has received little attention, per se. Cellular metabolism involving proteins and carbohydrates with its many complicated chemical transformations through the mediation of oxidative and reductive enzymes occurs in nasal tissue as in tissue elsewhere in the body. Heat and moisture exchange involves physical processes chiefly; the chemical reactions, in the main, are concerned with maintaining the integrity of the tissues.

Interference with normal cellular and intercellular chemistry as occurs in nasal infections and allergy, glandular abnormalities, emotional disturbances, and imbalances in the autonomic nervous system can produce changes in the respiratory mucosa which interfere with the movement of air through the nasal chambers. The lamina propia with its rich vascular supply contains connective tissue cells in which the usual high concentration of potassium and phosphate ions is maintained by the selective permeability of their surface membranes. The intercellular fluid predominates in sodium and chloride.

The intercellular tissue is formed by the movement of electrolytes and water through capillary walls, the elaboration of the fibrillar elements collagen, elastin and reticulin by the fibroblasts and the amorphous ground substance hyaluronic acid (11). Hyaluronic acid, which belongs to the group of carbohydrates called muco polysaccharids, is capable of holding water in colloid suspension as a gel. There is evidence that abnormalities in the chemistry of this substance results in mucosal swelling and nasal obstruction. Corticosteroids and ACTH play an important role in maintaining the integrity of collagen and ground substance as do the sex hormones.

Negus (8) emphasizes the role of the calcium ion in the permeability of membranes and believes that this ion plays a major role in the passage of water through the respiratory epithelium and endothelium. Hydrogen ion concentration also affects the health of the mucosal tissue. Congested nasal mucosa in disease states often are on the alkaline side of PH 7. Normal nasal tissue and fluids are on the acid side.

SUMMARY

1. Comparative studies show that the nose began as an organ of olfaction and later became intimately associated with the respiratory system. Both olfaction and respiration benefited from this association.

2. The human nose appears to be a retrogressive organ in the sense that the accessory structures of olfaction seen in macrosmatic animals are not present and the turbinal structures are conspicuously less developed. Nevertheless, experiments, indicate that the human nose warms and moistens air quite effectively, being aided by the recovery of heat and moisture from the lower respiratory tract during expiration.

3. The moisture is picked up from the mucosal surface in accordance with the physical laws of vaporization.

4. Glandular secretions were thought to be the only source of water. There is now evidence that transudation through the thin mucous membrane plays an important part.

5. Inspired air is heated mainly by the processes of radiation and conduction from the rich blood supply of the nasal turbinates.

6. Biochemical processes involved in heat and moisture exchange are concerned with maintaining the integrity of nasal tissue. Abnormal metabolism in the lamina propia causes retention of fluids, swelling and nasal obstruction.

ÉCHANGES DE CHALEUR ET D'HUMIDITÉ AU NIVEAU DE LA MUQUEUSE DE L'APPAREIL RESPIRATOIRE

1. Des études comparatives ont montré que le nez représentait l'organe de l'olfaction. Plus tard, il devint intimement lié à l'appareil respiratoire. Olfaction et respiration ont bénéficié de ce fait.

2. Le nez humain semble être un organe en voie de régression. En effet, les structures accessoires d'olfaction que l'on peut voir chez certains animaux ayant un sens olfactif bien développé, sont absentes dans le nez humain. De plus, les cornets y sont notablement moins développés. Cependant certaines expériences démontrent que le nez humain est capable de réchauffer et d'humidifier l'air inspiré d'une manière efficace. La chaleur et l'humidité provenant de la partie inférieure de l'appareil respiratoire sont récupérées durant l'expiration.

3. L'air inspiré est humidifié par l'évaporation d'eau à partir de la muqueuse, d'après les lois de la physique.

4. On pensait que les sécrétions glandulaires étaient la seule source de vapeur d'eau. Il est évident que la transsudation à travers la mince membrane muqueuse joue un rôle important en ce sens.

5. L'air inspiré est réchauffé principalement par un processus de radiation et de conduction, à partir du territoire richement vascularisé des cornets nasaux.

6. Les phénomènes biochimiques mis en cause au cours de l'échange de chaleur et d'humidité interviennent dans le maintien de l'intégrité des tissus de l'organe nasal. Un métabolisme anormal de la lamina propria produit une rétention de liquides, un gonflement et une obstruction nasale.

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