The Principle of the "Internal Atmosphere"

Geobiological and Astrobiological Aspects

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INTERNAL ATMOSPHERE is a term frequently used in biology. It refers to a body of air which is found inside an organism but is in functional communication with the ambient atmosphere. This phenomenon is observed in all realms of the living world except in the most primitive organisms. It plays a vital role in the two basic processes of gas exchange: respiration and photosynthesis. In both respects the internal atmosphere represents a biological, or more precisely, an ecological principle of greatest significance in the development and existence of the living world and offers an interesting platform for paleobiological, clinical-medical, aerospace medical, and astrobiological considerations. Before we discuss these aspects, let us first review the morphological picture and the various functions of the internal atmosphere.[1-6]

ANATOMY AND PHYSIOLOGICAL FUNCTIONS

Animal Kingdom:—Provided the body surface of an organism is large in relation to its mass, and the stage of development is primitive, as in bacteria, the body surface is adequate for metabolic gas exchange. With a decrease of the surface to mass ratio (S/M) the outer skin becomes insufficient as a respiratory surface, and the development of a specific respiratory area on a larger scale takes place. This is accomplished first by localized folds of the ectoderm (outer embryonic layer) or entoderm (inner embryonic layer). These outpocketings or gills appear in a primitive stage in annelids and mollusks, are developed to a greater degree in crustaceans and fish, and are recessive in the amphibians. All of these animals live in water or in very humid air.

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With the transition of these animals onto dry land, the development of the respiratory surface turns to the interior of the body in the form of *lungs* observed in vertebrates and in the form of the *tracheal system* of insects.

The lungs are ingrowths of the entoderm and are found in three developmental stages: (a) simple lung sacs (lungfish, newt), (b) spaces divided by septa (frog), and (c) alveolar structure (warm-blooded animals).

The lungs of birds are connected with voluminous airsacs which extend even into the bones.

In man, the alveolar structure achieves a respiratory area of 60 to 100 m^2. The air body (alveolar air) which in this way is interposed between the blood and the outer atmosphere amounts to about 3 liters. It is noteworthy that oxygen pressure in this inner air body is only two-thirds that of the external air, and that carbon dioxide pressure is 100 times higher than that of the ambient atmosphere. This is the atmosphere proper with which the body fluids and cells are in direct gas exchange. This internal atmosphere, however, becomes the ambient gaseous milieu for bacteria, if they are inhaled. We shall return to this important point later.

While the lungs are ontogenetically ingrowths of the entoderm, the tracheae of the insects are ingrowths of the ectoderm. These animals show up to ten pairs of openings on both sides of the body. These stigmata lead into air-filled tubes (tracheae) which branch into smaller tubes (tracheolae), which finally end between—or even within—the body cells. Gas exchange between the inner atmosphere within this system of tubes and the tissue, is achieved by way of diffusion. For gas exchange with the ambient atmosphere diffusion is sufficient in primitive insects (diffusion tracheae). In higher insects ventilatory movements become necessary (ventilation tracheae). In many insects the tubal system is connected with airsacs.

Little is known about the chemical composition of the tracheal air. It has been found that the volume per cent of oxygen content is somewhat lower than that of the atmosphere. The tracheal system is similar to the airing system found within the leaves of plants; indeed, one might even call it plantlike.

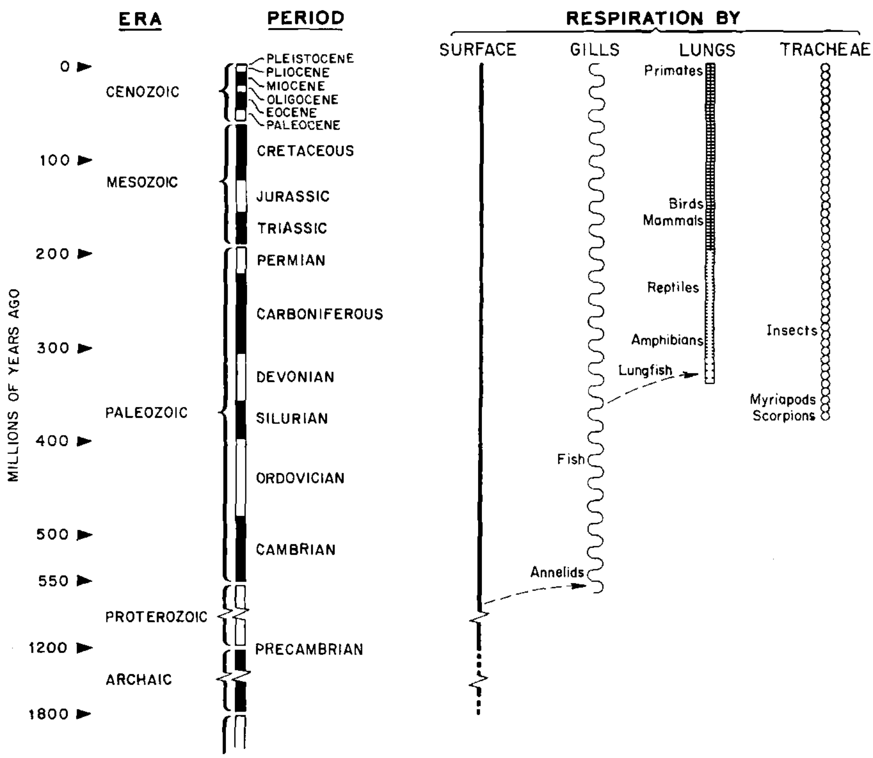

Fig. 1. The ontological development of respiratory surfaces and of the principle of the internal atmosphere.

Plant Kingdom:—In the plant kingdom, the internal atmosphere is of interest in this discussion only insofar as it is found in the *intercellular spaces* of the leaves. The labyrinthine arrangement of these spaces leads to an enormous enlargement of the internal surface, which is 10 to 30 times larger than that of the outer leaf surface. The air in this specialized respiratory tissue called "aerenchyma," is in communication with the outer air through microscopically small openings (stomata) of which up to 100 to 300 per mm^2 occupy the upper or lower side of the leaf. It may be mentioned that these pores are adjustable, the humidity of the air and sunlight being the regulating factor.

In plants, the internal atmosphere serves the purpose of photosynthesis in addition to respiration and transpiration. Oxygen produced in this process during the day is stored in the intercellular air spaces so that the plant can use it for respiration during the night. Indeed, analysis of the intercellular air yields an oxygen content of 30 to 60 volume per cent. This means that the plants—temporarily at least—live under a higher oxygen pressure than that found in the atmospheric air (21 volume per cent). Furthermore, the intercellular air spaces store carbon dioxide produced in metabolism during the night to be used for photosynthesis the next day. They are especially large in water plants, which have no direct access to atmospheric oxygen. Their significance for water balance of land plants must also be mentioned.

Intercellular airspaces are found in all plants down to the lichens which belong to the thallophytes, the lowest subdivision of plants. However, in the thallophytes true pores are not yet present but only indications of them in the form of a localized loosening of the otherwise very dense mycelium. But in the next higher subdivision—the bryophytes (moss)—we find true adjustable pores each of which belongs to an air compartment.

As we have seen, the phenomenon of the internal atmosphere is found throughout a great part of the living world. Without doubt, it represents a physiological-ecological principle of general significance which may be summarized in two points: (1) the principle of the internal atmosphere brings the area of gas exchange of the organism into balance with the metabolic need which results from rising organization and increasing mass, and (2) the internal atmosphere serves as a buffer against variations in climate and thus facilitates existence of life under extreme environmental conditions.

These points lead to the following considerations:

Paleobiological Aspect:—As previously mentioned, the phenomenon of the internal atmosphere is observed in the primitive plants such as lichens and mosses. Fossil lichens and mosses are found in the early Paleozoic or Paleophytic era (see the paleontological time table in Figure 1). Therefore, in all probability we can trace the appearance of internal atmospheres in plants back as far as 500 million years. They are fully developed in the later appearing vascular plants. The possibility of their existence in the Proterozoic and Archaic eras cannot be ignored. Actual proofs however are missing for these aptly-called cryptozoic eras.

In the animal kingdom, an internal atmosphere in the form of lungs came into existence for the first time in the early Devonian period (350 million years ago). It was the lungfish that started the *epoch of internal atmospheres* within the realm of animals. They probably existed even in the Silurian period (380 million years ago). Living fossils of this kind are preserved in the lungfish of Australia (Epicerodus), of South America (Lepidosiren), and of Africa (Protopterus). Amphibians with simple lung-sacs (newt) appeared in the Devonian period, and related animals with subdivided sacs appeared in the Carboniferous period (300 million years ago). The development of the alveolar structure of the lungs may have taken place in the Permian period (230 million years ago). It may be added that the order of Pulmonata of the Phylum Mollusca developed an internal atmosphere in the Carboniferous period. The tracheal system may have come into existence already in the Silurian period. The millipods, which are provided with such an aeration system, appeared at this time. In the Devonian period, the first wingless insects followed.

If we assume that living beings have existed on earth for two billion years, then the phenomenon of the internal atmosphere has been in existence only during the last quarter of this time and therefore it is a relatively recent acquisition. It is the foundation for the highly developed stages of warm-blooded animals. It is the prerequisite for such higher functional developments as thermal regulation, the ability to walk upright, to fly, and for attaining higher activities of the brain. All of these functions have been developed in a relatively short time.

The tracheal respiratory system made possible the development of giant specimens such as the libell-like Meganeuse (dragon-fly), which had a wing span of 60 cm, a length of 30 cm, and a chest expansion of more than 3 cm. For some unknown reason they have disappeared and the insects of today are far below this size.

In the plant realm, too, an internal atmosphere has been necessary to bring about the luxuriant development of vegetation beyond the primitive level of thallus plants up to the blossoming plants of today.

Medical-Paleobiological Aspect:—As mentioned before, the internal atmosphere becomes the environmental milieu for inhaled bacteria. In this respect, the internal atmosphere offers an interesting medical-paleological aspect. Bacteriological studies have revealed that an increased concentration of carbon dioxide generally promotes the growth of bacteria; for many bacteria the optimum lies between 5 and 10 volume per cent of carbon dioxide.

Therefore, it is not surprising that pneumonia strikes down a man of good health within a few days because the pneumococci find an ideal carbon dioxide environment in the internal atmosphere for explosive multiplication. The carbon dioxide optimum of bacillus tuberculosis lies between 2 and 3 volume per cent. According to the opinion of many geologists bacteria, algae, and other low organisms were the first and only organisms in the Proterozoic era, at a time when the carbon dioxide pressure was probably higher than it is today.

Paleontologically, carbon dioxide-philic bacteria are perhaps very old organisms. If so, when inhaled they return into their proper medium which has been preserved from the Proterozoic era within our pulmonal atmosphere. These possibilities may merit attention from the medical as well as from the paleobiological point of view.

Aerospace Medical Aspect:—Flight to higher altitudes has made the internal atmosphere an especially important topic in aeromedical research. The fact that the alveolar air always shows a relatively high carbon dioxide pressure (40 mm Hg) and water vapor pressure (47 mm Hg) causes hypoxia to increase with increasing altitude much more rapidly than according to the decreasing oxygen pressure of the inhaled ambient air. Therefore, the constitution of the alveolar air is a more accurate criterion for the degree of hypoxia than the surrounding air, and consequently is an important physiological basis for high-altitude research.

The study of the alveolar air shows the interesting fact that its oxygen partial pressure becomes zero at an altitude of about 15 km (10 mi) because the corresponding total air pressure (about 87 mm Hg) involves carbon dioxide and water vapor only. Atmospheric oxygen, still present in these high layers of the atmosphere, is prevented from entering the alveoli because of the presence of the other gases. This means that flyers above such an altitude, if not protected by a pressurized suit or a pressure cabin would be subjected to complete anoxia. Below this altitude they would find themselves in the state of hypoxia.

Astrobiological Aspect:—The phenomenon of the internal atmosphere can also facilitate the tolerance of extreme environmental conditions, as indicated in the discussions of the chlorophyll-bearing water plants. If the hypothetical vegetation on Mars has developed features similar to those of terrestrial plants in the form of an internal atmosphere in intercellular air spaces, such a biological "life supporting system" would facilitate its existence in the oxygen-poor but carbon-dioxide-rich Martian atmosphere. There is good reason to assume that the internal atmosphere is not only a geobiological but a general astrobiological or cosmic phenomenon. Furthermore, if low plant specimens provided with an internal atmosphere mechanism are brought by space vehicles into the different atmospheres of other planets, they might have a better chance for survival by manufacturing in the intercellular spaces an earth-like air for respiration and transpiration.

REFERENCES

1. Hunter, G. W. and Hunter, F. R.: College Zoology. Philadelphia-London: W. B. Saunders Company, 1949.
2. Mavor, I. W.: General Biology. New York: The Macmillan Company, 1948.
3. Smith, G. M.: Textbook of General Botany. New York: The Macmillan Company, 1946.
4. Strughold, H.: The Green and Red Planet. Albuquerque, New Mexico: New Mexico University Press, 1953.
5. Swinnerton, H. H.: Outlines of Paleontology. London: Edward Arnold, 1950.
6. Weatherwax, P.: Plant Biology. Philadelphia-London: W. B. Saunders Company, 1948.