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INTERNAL ATMOSPHERE

by

HUBERTUS STRUGHOLD, M.D., PH D.
Department of Space Medicine
School of Aviation Medicine USAF
Randolph Air Force Base, Texas

Internal atmosphere, is a concept that originated in biology; it refers to a body of air contained within an organism itself and is in communication with the external atmosphere. This phenomenon is found in all of the realms of the living world. In man and animals it serves the purpose of gas exchange in the processes of respiration and transpiration; in plants it serves additionally for gas exchange in carbon dioxide assimilation, or photo-synthesis. Without a doubt, it represents a biological--or more precisely--an ecological principle of great significance in the development of living beings.

The phenomenon of internal atmosphere has become the basis for experiments in respiratory physiology and more recently for high altitude research in aviation medicine. For these reasons a synoptic study of the internal atmosphere is most apropos.

The Morphological Picture

Animal Kingdom - Inasmuch as the body surface of an organism is large in relation to its mass and the stage of development is primitive, the body surface is adequate for gas exchange in respiration. With a decrease of the ratio surface to mass (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 extoderm, or entoderm. These outerpockets or gills appear in the primitive stage in annelides and molluscs, are developed to a greater degree in crustaceans and fish, and are recessive in their amphibians. All of these animals live in water or in very humid air.

With the transition of these on to dry land, the development of the respiratory surface turns to the interior and through this process we arrive at the lungs of vertebrates and the tracheal system of insects.

The lungs are ingrowths of the entoderm. Insofar as their surface is concerned they are manifested in three stages:

(a) Simple lung sacks (lungfish, newt)

(b) Spaces divided by septa (frog)

(c) Alveolar structure (warm blooded animals)

In birds, the lungs are connected with voluminous airsacks which extend even into the bones.

In man, the alveolar structure reaches 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 air body represents only two-thirds that of the external air, and that carbon dioxide pressure is one hundred times greater than that of the outer atmosphere. This is the proper atmosphere with which the body fluids and cells are in direct gas exchange. This internal atmosphere, however, becomes the ambient milieu for bacteria and virus, if they are inhaled into the lungs. 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 exhibit up to 10 pairs of openings on both sides of the body. These stigmata or spiracles lead into air-filled tubes (tracheae) which in turn branch into very fine tubes (tracheolae), and 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 outer atmosphere diffusion is sufficient in primitive insects (diffusion tracheae). In higher insects ventilation movements become necessary (ventilation tracheae). In many insects the tubal system is connected with airsacks. Little is known about the chemical composition of the tracheal air. It has been found that the percent of oxygen content is somewhat lower than that of the atmosphere; the tracheal system is somewhat similar to the airing system found within the leaves of plants. Indeed, one might even call it plantlike.

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 may extend from 10 to 30 times that of the outer leaf surface. With the ambient air the "aerenchyma" is in communication 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 the pores are adjustable, the humidity of the air 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 consume it for respiration during the night. Indeed, analysis of the intercellular air yields an oxygen content of 30 to 60 volume percent. This means that the plants - temporarily at least - live under higher oxygen pressure than that of the atmospheric air. Furthermore, the intercellular airspaces store carbon dioxide, produced by respiration during the night, to be used for photosynthesis the next day. The significance of these spaces for water balance, however, can be discussed later.

Intercellular airspaces are to be found in all plants down to the thallophytes. However, in the latter, true pores are not yet present but only indications of them in the form of a localized loosening of the otherwise very dense mycelium (Cyphellae). In the next higher subdivision - the bryophytes - we find true adjustable pores each of which belongs to an air compartment (liver moss). So much for the occurrence of internal atmosphere in the world of plants. Further information can be found in the textbooks and handbooks on Zoology and Botany.

Thus, the phenomenon of the internal atmosphere--as we have just shown--extends through a great part of the living world. Without a doubt, it represents a physiological-ecological principle of general significance which may be summarized in two points:

(a) By the principle of the internal atmosphere, the area of gas exchange of the organism is brought into balance by the demand which results from rising organization and increasing mass, and

(b) It serves as a buffer against variations in climate and, with some exceptions, facilitates existence under extreme environmental conditions. These points may lead to the various considerations that follow:

1/ Paleobiological Aspects

As previously mentioned, the phenomenon of internal atmosphere has already existed in the primitive plants such as lichens and mosses. Fossil lichens and mosses are found in the early Paleozoic or Paleophytic era. Therefore, in all probability, as far back as 500 million years ago we can trace the appearance of internal atmosphere in plants. The possibility of its existence in the Proterozoic and Archaic eras cannot be ignored. Actual proofs are missing for these justly-called cryctozoic eras. Thexx phenomenon of internal atmosphere is fully developed in the later appearing vascular plants.

In the animal kingdom, internal atmosphere in the form of lungs came into existence for the first time in the early Devonian periOd (320 million years ago). It was the lungfish that introduced the epoch of internal atmosphere within the realm of animals. They probably existed even in the Silurian period (350 millinn 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 lungsacks (newt) appeared in the Devonian period, while others with subdivided sacks in the Carboniferous period (300 million years ago). The development of the alveolar structure of the lungs may have taken place in the Persian period (240 million years ago).

For the benefit of completeness, it may be added that from the Phylum Mullusca the order of pulmonata developed the principle of internal atmosphere in the Carboniferous period. Finally the tracheal system may have come into existence in the Silurian period. The millipods, which are provided with such an aeration system, appeared in this period. In the Devonian period, the first wingless insects followed. (See the palaentological time table.)

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 xxx acquisition. This is the foundation on which warm blooded animals have attained the fulness of life. It is the prerequisite for such higher development as establishing a thermal regulation, achieving the ability to walk upright, to fly, and to attain the higher activity of the brain. All of these were developed with relatively great speed. In the plant realm too, internal atmosphere is necessary to bring about the luxuriant development of vegetation beyond the primitive level of thallus plants up to the blossoming plants of today.

At this point the question "Can we draw conclusions from the phenomenon of internal atmosphere about the historical development of the earth's atmosphere?" may be raised.

In the late Paleozoic period - about 300 million years ago - for the first time insects appeared and developed into giant specimens. For example, the libell-like meganeuse (dragon-fly) had a wing span of two feet, a length of one foot, and a chest expansion of more than one inch. The insects of today fall far below this size. A. Krogh has calculated that the tracheal system permits the existence of only relatively small insects because it allows only a limited oxygen supply. In other words, the tracheal system, apart from the exoskeleton, is a limiting factor in the size of the body. For the giant insects, tracheal respiration might--according to A. Krogh--be just sufficient if we presuppose ventilation trachea, low metabolism and a mild climate. However, the fact that at one time giant insects did exist and that no such specimens are now in existance, could probably be due to a different constitution of the atmosphere. It would be very presumptuous to venture the opinion that oxygen pressure was higher at that time than it is today; still, it must be considered that a luxuriant vegetation--which left behind our abundant coal deposits--existed at that time. As is well known, vegetation determines the oxygen content of the atmosphere from the aspect of production. Calculations have shown that the land vegetation of today is capable of producing our present oxygen content in the air (1.2×10^{21} g) in less than 30,000 years. The Carboniferous period (Mississippi and Pennsylvania) however, lasted about 70 million years. The

Permian period which followed was characterized by a glacial epoch during which oxygen production was certainly lower.

It would be absurd to assume that the atmospheric oxygen pressure was always the same as today. Oxygen measurements in the atmosphere date back only 150 years, during which time no change in the oxygen content of the air was found. Considering the shortness of this time span, such a change is not to be expected. A century and a half is less than one 100 millionth of geological time (2×10^9 years) and less than one 30 millionth of Phanerozoic time (5×10^8 years).

Another paleobiological point may be worthy of mention. The carriers of lungs show a tendency to keep constant the constitution of their alveolar air under oxygen deficiency. This is accomplished, for instance, by hyperventilation. It is tempting to compare the constancy of the internal atmosphere with that of certain properties of the blood. The salt content of the blood shows a similarity to that of seawater. It is presumed that this may be a hereditary feature from the epoch of the fishes, and that the amphibians have preserved the chemical constitution of marine animals long after their transition onto dry land. It may be possible that the internal atmosphere of warm blooded animals is a relic of the atmospheric constitution of the era when amphibians inhabited the land.

The high carbon dioxide concentration of the alveolar air is very striking. It might point to a higher carbon dioxide pressure of the atmosphere in former times, as has occasionally been assumed in literature. If this assumption is correct, it could mean that man still carrys a bit of the Paleozoic era in his chest.

2. Medical Paleobiological Aspect

Returning to the earlier statements that the internal atmosphere becomes an environmental millieu for bacteria and viruses if they are inhaled; 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 percent of carbon dioxide.

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

Paleologically, carbon dioxide philic bacteria are perhaps very old organisms. If so, when inhaled they return into their own medium which has been preserved from the Proterozoic era within our inner atmosphere. These possibilities may merit attention from the medical as well as from the Paleobiological aspects.

3. Aeromedical and Space 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 much more rapidly with increasing altitudes than it should, according to the oxygen pressure of inspired air or inhaled oxygen. Therefore, the constitution of the alveolar air is a more accurate criterion of the degree of hypoxia than the ambient 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 pressure becomes zero at an altitude of 52,000 feet, because the corresponding total air pressure (about 87 mm Hg) is comprised of carbon dioxide and water vapor only. At least atmospheric oxygen, still present in these layers of the outer atmosphere, is prevented from entering the alveoli because of the presence of 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. However, below this altitude they would find themselves in the state of hypoxia.

Thus, the consideration of the principle of the internal atmosphere may help to clarify the terminology of oxygen deficiency, (hypoxia-anoxia), which differs greatly in physiological and aeromedical literature. From the space-medical point of view with regard to oxygen, the example demonstrates that above 52,000 feet we find ourselves practically in space. On the basis of the alveolar air, or in other words, of the internal atmosphere, this altitude is space-equivalent.

In contrast to these considerations, the phenomenon of the internal atmosphere could also facilitate the tolerance of extreme atmospheric conditions. This has already been explained in the discussions of the chlorophyll-bearing plants. For example, if the hypothetical vegetations on Mars, where the atmosphere is found to contain sufficient carbon dioxide but no oxygen, developed features similar to those of terrestrial vegetation in the form of the internal atmosphere, then the objections to their existence from the aspect of physiology would lose weight.

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(By Strughold)

Summary: The existence of internal atmosphere in the living world has been discussed: In the plant kingdom in the form of the intercellular airspaces of the leaves; in the animal kingdom in the form of the tracheae in tracheates, and in the form of lungs in fish, amphibians, reptiles, mammals, and birds. Special attention has been given to the internal atmosphere of man (alveolar air). The wide distribution of the principle of internal atmosphere gives it the significance of a general biological principle. This has been explained from the viewpoint of paleobiology, medicine, aviation medicine and space medicine.

H/Strughold/mbn

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