The Diaphragm: a Hidden but Essential Organ for the Mammal and the Human

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Abstract The diaphragm is the only organ which only and all mammals have and without which no mammals can live. The human is the only mammal which keeps the diaphragm parallel to the ground even during locomotion. Abdominal breathing mode maximizes the diaphragmatic motion using abdominal muscles, and control precisely exhaled air velocity. Controlled exhaled airflow generates sophisticated vocalization, singing, and finally the language. We propose novel nomenclatures for the mammal and the human. The former be the diaphragmal, and the latter be the horizontal diaphragmal, alias Homo cantale.

1 Introduction: Is the Mammal Adequately Defined?

The mammal has been characterized by viviparity and milk. However, monotremes such as duckbills are oviparous. Mammalian males do not secrete milk. In addition, milk is not indispensable for survivals of mammalian babies if they are given alternative nutriments. In general, an ideal definition of a group is given by an attribute which is possessed by only and all members of the group and without which no members can exist. Is there any such organ in the mammalian body? Yes, it is the diaphragm. Duckbills and of course mammalian males have diaphragms. The crocodile has a diaphragm-like structure, but it does not separate completely thoracic and abdominal cavities (Gans and Clerk 1976). Only and all mammals have diaphragms which separate the body space into two independent cavities. In addition, no mammals can live without diaphragms. Congenital diaphragmatic dysplasia causes the death just after birth due to pulmonary hypoplasia. Traumatic diaphragmatic rupture is also fatal because the lung is compressed by abdominal organs. Thus, the diaphragm is an organ which ideally defines the mammal. Furthermore, the diaphragm allows the mammalian mother to grow her fetus without suffering from respiratory failure. In other words, the diaphragm gave the mammal a new option of reproductive strategy, viviparity, as a by-product of the lung evolution.
The Mammal Has Lungs Of Health And Sustainability: LOHAS

Although the diaphragm is an essential organ for the mammal, the mammal has not been characterized by its respiratory system. The reason may be that the mammalian lung is much less efficient than the avian lung in terms of gas exchange (Brown et al. 1997). Recent paleontological studies have revealed that the dinosaur is the ancestor of the bird because of the similarity in the respiratory system between them. The high oxygen uptake in the dinosaur is thought to be the cause of their gigantic body size. However, the present conqueror on the earth is not the bird but the mammal. Why did the bird escape to the sky? Here, let us briefly review the lung evolution in vertebrates.

Amphibians, having no ribs, cannot create negative pressure within the lung. They keep inhaled air in throat sacs, create positive pressure by contacting the throat sacs, and push the air into the lungs (Gans et al. 1969). Reptiles, gifted ribs, inhale the air into the lungs directly by negative pressure created by the motion of rib cages. Mammals, gifted the diaphragm, inhale more air by more negative pressure created by diaphragmatic motion as a bellows. Alveoli, dead ends of the airway tree, are highly compliant so as to ventilate a lot of air, and highly complex in shape so as to acquire huge surface area for gas exchange. Although the ventilation volume and the structural complexity of the lung increased along the evolution, all these animals perform to-and-fro ventilation. On the other hand, avian lungs realize flow-through ventilation by the use of several air sacs, homologic to air bladders in the fish (Brown et al. 1997). The gas exchange space in avian lungs is numerous non-deformable air capillaries of 3–10 µm meters in diameter arising from parabronchi with the diameter of 300 µm (Brown et al. 1997). Since air sacs supply fresh air to the lung even during expiratory phase, the oxygen uptake is much higher in birds than other vertebrates.

The lung function has been assessed mainly by gas-exchange efficiency. However, it is unavoidable for animals using oxygen in the atmosphere to inhale floating particles. If the oxygen concentration in the air is enough, treatment of inhaled particles may be crucial for survival. The most harmless treatment of inhaled particles is to exhale them again with expiratory airflow. It is experimentally known that deposition ratios of 0.5-µm particle are 50% in birds and 10% in mammals (Mensah and Brain 1982; Heyder 2004). This difference can be explained by the structural difference of the lung. The gas exchange space in avian lungs consists of air capillaries of 3–10 µm in diameter, much narrower than the alveoli in mammalian lungs. The high oxygen uptake in avian lungs is obtained by narrowing respective air spaces, that increases the risk of particle deposition. We have performed airflow simulation within human alveolar duct by the use of computational fluid dynamics(Kitaoka et al. 2009). Although conventional textbooks of respiratory physiology tell us that there is little air flow in the alveolus (Lumb 2000), our simulation result showed apparent intra-alveolar flow, which would prevent the alveolar wall from particle deposition.

Thus, mammalian lungs are less efficient in oxygen uptake but more healthy and sustainable against environmental change causing air pollution. The LOHAS (Lungs Of Health And Sustainability) is thought to be the survival basis of mammals. The extinction of dinosaurs is still an enigma. Dinosaurs might be killed by pneumoconiosis of particles generated by impacts of meteorites and/or volcanic eruptions.
3 The Origin of the Human Upright: Horizontal Diaphragm

The human is the only mammal which stands and walks upright. There are several hypothesis regarding the origin of the human upright (Stanford 2003); to set upper limbs free in order to use tools and/or to carry foods, to set eyes at high position in order to seek enemies and/or foods, etc. However, there has been no established hypothesis yet. We now propose a novel hypothesis which explains the relationship between the upright, the diaphragm, and the origin of language.

Recent comparative neurophysiologic research has revealed that some of finches have song syntax and use their songs as communication tools (Okanoya 2004). We have noticed that singing animals, not only finches but also frogs, rock rabbits, gibbons, and so on, sing their songs at upright. Vocalization is performed by acoustic sources in the upper airway and air-pumping organs. All animals on the earth receive gravity effect. We suppose that the most precise control of the airflow velocity is realized when the air pump moves along gravity direction. We suppose this is the reason why singing posture is upright. The best singer of all mammals, the human, sets the diaphragm horizontal and pushes the lung along gravity direction. Walking upright allows the human to perform sophisticated vocal communication even during locomotion. Thus, we hypothesize that the human became upright in order to sing well anytime and that the horizontal diaphragm brought languages to the human.

4 Ventilation Distribution During Abdominal Breathing

Asian countries have their own breathing modes for healthcare such as Yoga in India and Qigon in China. In Japan, a kind of abdominal breathing mode, called Tanden breathing, has been used in martial arts and classic entertainments like Noh. Tanden means the central portion of the abdominal cavity. Tanden breathing intends to displace the diaphragm at most and the rib cage at least by regulating tonus of abdominal muscles. Figure.1 shows an example of abdominal breathing by a 62 y/o male Noh singer. During post-inspiratory phase, he protrudes the anterior abdominal wall and the diaphragm is shifted downward. He sings during expiratory phase, and the diaphragm is gradually shifted upward.

Physiological effects of abdominal breathing have conventionally been explained in terms of autonomic nervous system or psychosomatic correlations. We hypothesized that intra-pulmonary ventilation distribution must be different between abdominal breathing and common breathing. Since there is no modality to measure precisely ventilation distribution at upright, we computationally simulated ventilation distribution by the use of our 4D lung model (Kitaoka and Kawase 2007). We regarded the lung tissue as a porous elastic body like a sponge, and modeled lung deformation during slow breathing based on elastic mechanics. Ventilated volume at each acinus during breathing was computed (Figs. 2 and 3).
Computed ventilation volume at the apex was 44% of that at the basis under standard condition. Abdominal breathing was mimicked by assigning no deformation in non-gravitational directions. At that time, the ratio of ventilation volume at the apex against that at the basis increased to 69%. This simulation result indicated that abdominal breathing enhanced diaphragmatic displacement and improved ventilation in the apex, non-dependant zone at upright. It is well known that preferential site of pulmonary tuberculosis, the most threatening disease in old Japan, is the apex. The poor ventilation in the apex causes poor clearance of inhaled particles. Old Japanese people might empirically recognize a preventive effect of abdominal breathing against pulmonary tuberculosis.
5 Conclusions

In this paper, we have proposed novel hypotheses regarding two famous evolutional enigmas which have not been considered in relation to breathing. One is that the dinosaur extinguished due to pneumoconiosis caused by impacts of meteorites and/or volcanic eruptions, as a result of seeking gas-exchange efficiency at the cost of sustainability of the lung. The other is that the human became upright for singing rather than for foods. Such evolutional hypotheses cannot be tested experimentally. Our hypothesis may be wrong, but must be useful as historical lessons. In order not to be the second dinosaur, the human has to manage submicron particles in the air including virus and artificial nano materials. We believe that our hypothesis regarding the upright will make people more pleasant and more peaceful than other previous hypotheses.

We have proposed one more hypothesis that abdominal breathing reduces gravitational ventilation inhomogeneity. The diaphragmatic movement along gravity direction is thought to be the key of the human lung sustainability as well as vocalization. This hypothesis will be tested in the future when ventilation imaging technique is sufficiently developed.

Finally, we propose novel nomenclatures for the mammal and the human. The mammal be the “diaphragmal”. The human be “horizontal diaphragmal”, alias “Homo cantale”, where cantale is “sing” in Italian.

References


