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The Biophysical Modeling of the Respiratory Apparatus in the Human Organism

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ABSTRACT

The respiratory apparatus is a subsystem of the human body. According to system theory, this phenomenon can be called a hierarchical order. This hierarchical order is broken down into further levels because the breathing apparatus also has further subsystems. The entire respiratory process is characterized by two basic physical laws: diffusion and osmosis. These two phenomena allow gas exchange at the level of the pulmonary alveoli and capillaries as well. The process of breathing is done by the breathing muscles and the heart. The function of normal and deep breathing have been given. In the framework of biophysical modeling, the symbiotic relationship between respiratory frequency and amplitude was analyzed. Then we examined the so-called two-level control. It must be emphasized that the existence of a hypothetical secondary brain is only a hypothesis. We have designed a block diagram of the breathing apparatus. We have emphasized that the breathing apparatus is the first priority for people.

Keywords: *Respiratory Apparatus, Biophysical Modeling, Block Diagram, Hypothetical Second-Dary Brain*

Introduction

Breathing, more specifically the breathing of the lungs is the exchange of gas in the lungs. The airway entrance is the nostril, followed by the nasal cavity, oropharyngeal, larynx, trachea, and bronchial system. Air can get into the airways orally as well, though this is the way to take in food, but the two meet in the pharynx and cross each other. The airways are not involved in the exchange of gas, and for this reason they are called "dead spaces". Breathing of the skin also plays a secondary role in breathing, through the pores of the skin, the gases pass directly into the capillaries (Vincze, 2018a).

The essential condition for breathing is that the composition of the air surrounding the human body is adequate (oxygen 20.94%, carbon dioxide 0.03%, other nitrogen, noble gases and water vapor), the air pressure is around $1.3.10^5$ N/m^2 and there should be minimal contamination of the air. The frequency of human respiration every 16–18 minutes.

The living organism sets many boundaries for its respiratory processes (Bittar *et al*., 2015). Gas exchange can only take place at certain speed, the amount of air inhaled and exhaled can vary within certain limits, and the level of contamination in the air must not exceed certain critical values. The presence of CO in the air is extremely dangerous because it creates an irreversible bond between CO and the hemoglobin of the red blood cells that carry the gases.

It is extremely important for the possibility of constant breathing, because for the average person, if you do not breathe for more than 5 minutes, brain death and then death will occur. This is documented in Table 1.

Table 1: The priority of the apparatus in the human organism.

Apparatus	Priority
Respiratory apparatus	I.
Circulatory apparatus	II.
Excretory apparatus	III.
Digestive apparatus	IV.
Reproductive apparatus	xxx

Some infectious respiratory diseases are listed in Table 2 (Hogg and Timens, 2009).

Table 2: Some infectious respiratory diseases.

Pathogen	Disease(s)
Adenovirus	Infections of the lower and upper respiratory tract, conjunctivitis
Rhinovirus	Infections of the upper respiratory tract
Influenza A, B virus	Influenza
Respiratory syncytial virus	Bronchiolitis, pneumonia

Respiratory diseases are greatly influenced by a very common bad habit of a certain group of humankind: smoking (Lacasse and Taskin, 1988), which is responsible for 95% of respiratory cancers (Ashley and Harris, 2016). The results of imaging procedures (X-ray, CT, MRI, ultrasound, etc.) are not used in this section because they are used in the diagnosis that is not the subject of this section.

The biophysical modeling of the mobility of respiratory gases

The concentration and partial pressure of oxygen in the lungs is higher than that of oxygen in the blood, so it is transferred into the blood through osmosis. The concentration of CO_2 and the partial pressure is higher in the blood than in the air, so it is released from the blood through the wall of the pulmonary alveoli, also by osmosis. Blood carries oxygen to the tissues, where it transmits and picks up CO_2. Both phenomena also occur through osmosis. Nitrogen plays a passive role and does not change its concentration during respiration. See Table 3.

Table 3: The breath concentrations.

	Parameters	Air in inhalation	Air in exhalation	Air in alveolus	Arterial blood	Venous blood
O_2	Pressure (Hgmm)	158,25	116	100	95	37
	concent. (%)	20,97	16	14		
CO_2	pressure (Hgmm)	0,3	28	40	40	46
	concent. (%)	0,03	3–4	5–7		
N_2	pressure (Hgmm)	596	568	573	573	573
	concent. (%)	79	78,8	78,8		
Water	pressure (Hgmm)	5,00	47	47	47	47
	vapour					

Respiratory rate at rest is 16 per minute for men and 18 for women. The frequency and amplitude of respiratory movements vary depending on the body's need for O_2 and, in particular, the amount of CO_2 produced. Lung ventilation adapts to the changing needs of the body through extremely fine mechanisms that constantly regulate ventilation by changing the frequency and amplitude of breathing. If the need requires a surplus, the frequency first increases, then the amplitude, then the frequency again, and again the amplitude. Along with the changes in lung ventilation, the circulatory device adapts properly in order to keep the gas exchange at a level appropriate to the needs of the tissues (Vincze, 2018b).

The exchange of the major respiratory gases (O_2 and CO_2) in the lungs and tissues takes place on the basis of certain physical laws, biophysical mechanisms and the properties of the wall of the alveoli – capillaries and the cell membrane (Vincze, 2015).

Gas exchange between the environment and the lungs is in accordance with diffusion laws. Thus, this process is characterized by Fick's first and second laws:

Fick's first law:

$$\Delta x = -D \frac{dc}{dt} \Delta S \, \Delta t$$

where: Δx – mass of gas flowing; D – diffusion constant for the given gas type; dc – concentration difference; dt – time; ΔS – surface of the flow.

Fick's second law:

$$\left(\frac{\partial c}{\partial t}\right)_x = D \, . \left(\frac{\partial^2 c}{\partial x^2}\right)_t$$

Thus, in a given location, the change in concentration over time is proportional to the change in location of the concentration's gradient in a given time.

The lung is a member of the respiratory system, which actually consists of two lungs. The lungs (lungs) are connected to the upper respiratory tract by the two main bronchi formed by the fork-like division of the trachea. The tidal capacity of the lungs is 4,000-4,500 cm^3. Through the 300 million alveoli in the lungs, gases flow back and forth through the cell membrane in accordance with the law of osmosis. In living organisms, the membrane functions as a semi-permeable membrane.

The osmotic flux always goes from the lower concentration solution to the higher concentration solution. This means that there is no equilibrium between the two phases and the solvent diffuses through the membrane until the hydrostatic pressure difference created is equalized.

The pressure by which we can prevent osmosis from happening is called osmotic pressure. The value of osmotic pressure can be calculated according to van't Hoff's law:

$$\mathbf{p = R . T .} \frac{c}{M}$$

where: **c/M** – the number of moles of the material; **R** – the universal gas constant; **T** – absolute temperature. Osmotic pressure results in a certain mass transport, which means that work is performed. We can define this osmotic work as follows:

$$L = \int_{p_0}^{p_0+\pi} p \; dV$$

where: $\mathbf{p_0}$ – initial pressure; π – osmotic pressure. Based on the laws of gas, we obtain the following expression for osmotic pressure:

$$\boldsymbol{L} = -\int_{p_0}^{p_0+\pi} \frac{n.R.T.dp}{p^2} = n.R.T \; ln \; \frac{p_0}{p_0+\pi}$$

So, if we want to transport a material against osmotic pressure, it can only be done by external energy investment. This work is done by the respiratory muscles.

In the lungs, gases pass into the blood, which, through the heart (systemic circulation), deliver gases back and forth to the cells at the capillary level, also in accordance with the law of osmosis. This work is performed by the heart. So, in the exchange of gas (O_2 and CO_2) between the environment and the human body, all the work is done by the respiratory muscles and the heart.

The main function of the lungs is to supply the blood with oxygen and to remove the carbon dioxide produced by metabolism from the cells, at the level of the capillaries, also through the bloodstream (Vincze, 2018a). To measure function, it is sufficient to measure the partial pressure of arterial blood oxygen and carbon dioxide. The alveolar partial pressure of oxygen is calculated by the following formula, which is called the alveolar gas equation:

$$P_AO_2 = P_lO_2 - P_ACO_2\left[F_lO_2 + \frac{1-F_lO_2}{R}\right]$$

where: P_AO_2 – alveolar partial oxygen pressure; P_1O_2 – partial pressure of inhaled oxygen at body temperature; P_2CO_2 – partial pressure of carbon dioxide in arterial blood; F_1O_2 – fractional oxygen concentration of the inhaled gas; R – the respiratory quotient.

Modeling of rhythmic breathing

Recognizing the sequence of events led to the development of the concept of time. Our statements regarding events taking place in the past, present, future, later or simultaneously used in everyday life all refer to the sequence of events that occur independently or are related to each other. To quantify time, we use a scalar quantity, which will be denoted as **t** in the following. 1 and 2 are two consecutive events. In this case, $\mathbf{t_1<t_2}$ can be used if the events follow in sequence 1, 2, respectively. For order 2, 1, inequality $\mathbf{t_2<t_1}$ applies. For events occurring simultaneously $\mathbf{t_1=t_2}$ should be used.

By introducing the concept of time, the characterization of the event becomes more complete: we can specify the “place” and “time” of the event. At the same time, there is an opportunity to describe movements – changes (Vincze, 2007).

In this case, the rhythmic changes are modeled as follows: There is given a periodic function of discrete value (**F**): **F(t) = F(t+T)** in the following format:

$$F(t) = \begin{cases} Z_1 & n.T < t \le n.T + t_1 \\ Z_2 & n.T + t_1 < t \le n.T + t_2 \\ \dots\dots\dots\dots & \\ Z_k & n.T + t_{k-1} < t \le (n+1).T \end{cases}$$

$$t_1 < t_2 < \dots < t_{k-1} < T$$

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where: **T** – the period; **t** – time, **k** – number of qualitatively possible states.

Consider human deep breathing: contraction of the respiratory muscles (inhalation – Z_1), relaxation (exhalation – Z_3) and two interruptions (Z_2) and (Z_4). In this case there are 4 states. Note the rhythmic change function (F_1). Consider a period of deep breathing as 20 s.

$$F_1(t) = \begin{cases} Z_1 & n.20 < t \leq n.20 + 4 \\ Z_2 & n.20 + 4 < t \leq n.20 + 11 \\ Z_3 & n.20 + 11 < t \leq n.20 + 17 \\ Z_4 & n.20 + 17 < t \leq (n+1).20 \end{cases}$$

Any change that results in a continuously changing value of a biophysical parameter in the living system and can be characterized by an average value is called a “quantitative” rhythmic change. The fluctuation is around the average value, which does not necessarily show a symmetric change.

This can develop in any living system where, contrary to evolving from equilibrium, the system seeks to restore its original state through so-called negative feedback (Vincze, 2020). Let’s denote with **o(t)** the exit output and the mean value of the characteristic parameter on the system is $\mathbf{o^*(t)}$; after the adjustment, the values of the outputs obtained shall be denoted with

$$\mathbf{o(t_1), o(t_2)\ o(t_3), \ldots, o(t_n) = o^*(t);}$$

$$\text{if} \qquad \mathbf{t_1 < t_2 < t_3 < \ldots < t_n.}$$

We talk about a negative inverse value, if the following two conditions are satisfied:

$$\mathbf{|o^*(t) - o(t_1)| > |o^*(t) - o(t_2)| > |o^*(t) - o(t_3)| > \ldots > |o^*(t) - o(t_n)|}$$

$$\frac{d\left|o(t_i) - o^*(t)\right|}{dt} \leq 0.$$

In order for the biophysical parameter characteristic of the living system to be returned by negative feedback mechanisms, the system requires generalized forces **f(x)**, which is considered to be proportional to the displacement **x**.

Such a linear force produces a “quantitative” change in rhythm, in which the deviation of the respiratory rate **x** from the average is a sinusoidal function of time:

$$x = A \cdot \sin(B.t + \varphi)$$

where: **A** – the maximum deviation of the biophysical parameter from the average; **B** – constant that determines the rhythmicity of the biophysical parameter; φ – the value of the phase difference at the moment of initial observation.

The block diagram of the breathing apparatus

In our opinion, the respiratory device should have a control associated with its own structure, which is likely to consist of neurons with hyperordonated spatial structure, called the "hypothetical secondary brain", which performs certain control functions (Vincze and Vincze-Tiszay, 2019). This "hypothetical secondary brain" of the respiratory tract, in humans, functions continuously throughout their life, only so poorly controlled that it has not yet been detected and discovered by scientific research in addition to the dominant role of the central nervous system. This is just a hypothesis, but the block diagram (Fig. 1) shows the hypothetical secondary brain.

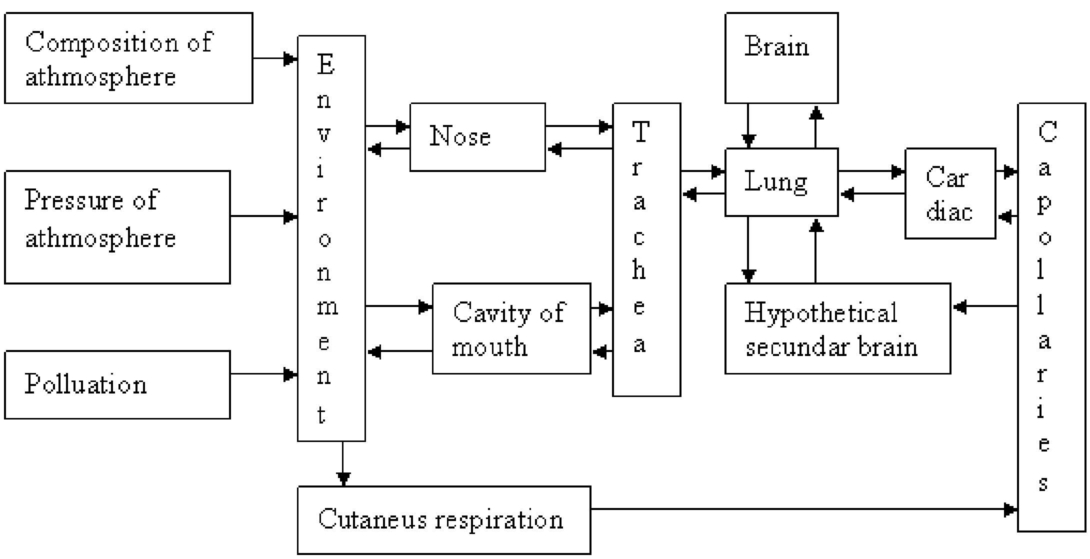

Figure 1: The block diagram of the respiratory apparatus in the human organism.

Important respiratory diseases such as those resulting from smoking, regular use of drugs, environmental contamination or respiratory tumors are not shown in the block diagram. Thus, the block diagram is a control scheme of the normal state of the breathing apparatus, and it provides a general outline thereof. It can be expanded especially to cover specific respiratory disease states. For example, medication is not included either.

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