

Parameters of Athlete Respiratory System Dependence on Organism Hormonal Status during Hypoxic Mixtures Inhalation: Research on Mathematical Models

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Abstract

Inhalation of gas mixture with 11% of oxygen by women athletes at different phases of menstrual cycle was simulated using mathematical model of the functional respiratory system. As initial data we used the data of lung and alveolar ventilation, gas composition of exhaled and alveolar air, minute volume of blood, characteristics of blood oxygen; these data were obtained by measurements at different phases of menstrual cycle. Parameters of economy, intensity, efficiency of organism oxygen regimes, parameters of hypoxic state and respiratory function of blood were calculated. These data were taken further for the mathematical model of respiratory gases mass transfer; the model simulated the inhalation of gas mixture with 11% oxygen in different phases of menstrual cycle of women athletes. The minute blood volumes, tissue blood flows, partial pressures and oxygen tension in the alveolar space, arterial and mixed venous blood in brain, in heart tissue, in skeletal muscles and in tissues of other organs were calculated as well. Our results demonstrated the specificity of women athletes' functional self-regulation by calculations on mathematical model of their functional respiratory system reactions on hypoxic mixtures inspiration. Therefore, we also demonstrated women athletes' adaptive capacities to hypoxia under the hormonal status cyclic changes at different phases of menstrual cycle. Preliminary studies demonstrated that in conditions of hypoxia caused by breathing of gas mixture with 11% oxygen without compensatory increase in pulmonary and systemic circulatory ventilation, the oxygen tension in organism tissues may be lower than critical level and with varying degrees in different phases of menstrual cycle.

Obtained results demonstrate the necessity of further study of athletes' organisms' individual reactions at hypoxia conditions for scientific substantiation of sports training for women taking into account biological characteristics of their organisms.

Keywords

Functional Respiratory System; Hypoxic Hypoxia; Adaptation of the Female Organism; Phases of the Menstrual Cycle; Mathematical Model of the Respiratory System; Athletes' Training Process

Introduction

The peculiarities of female organism adaptation to physical and mental stresses, to oxygen deficiency in the inspired air and to various climatic conditions have not been studied enough. This happens despite the fact that in modern society women work, it seems, in all branches of science and technology, they are active in sport, together

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with men they overcome all maximal possible training loads not only at sea level, but also in mountain conditions. In contemporary sport of highest achievements the training loads have reached such values that their influences on organism are close to the limits of individual adaptation possibilities [1]. Organism adaptation to physical loads such as reduced oxygen content in the inspired air is one of the main problems in sports physiology and medicine.

The systemic approach for managing the process of athletes training in which the sportive results are used as systemic factors allows us to carry out detailed analysis of the process of athletes training and the role of female organism biological specificity in this process [2, 3]. Also it allows us to analyze peculiarities of organism reactions on perturbations of internal and external environment at different phases of menstrual cycle; hypoxic hypoxia is seen as one of the most usual such perturbation [1, 4].

Despite the large number of studies [4-6], there are actually still the studies of regularities in the formation of female organism adaptive reactions to changes of external or internal environment, the nature of female organism biological features influence (cycles of its systems functions linked with the changes in sex hormones' concentrations in the blood of woman organism at different phases of menstrual cycle) on the mental states and physical work capacity of such athletes [2, 7, 8].

There was assumed that together with general patterns of organism's response to environmental factors, the response of the female organism to hypoxic hypoxia would be changed throughout the menstrual cycle.

In the sphere of investigators' interest there are the numbers of insufficiently studied reactions of functional respiratory system on the changes in hormonal state of woman's organism during different phases of menstrual cycle and, in particular, the nature of organism oxygen modes. One of the good models for this reactions studying is a model of cyclic changes in sex hormones content throughout the menstrual cycle. Investigations of changes in functional respiratory system, states of organism oxygen modes have not only theoretical, but also practical meaning, because they determine in great degree the women work capacity [1, 9, 10].

Methods

Athletes work capacity, development of their endurance is due, in the first order, to aerobic work capacity that is determined by the development and state of functional respiratory system. It includes organs of

external respiration, blood circulation, blood respiratory function, and mechanisms that provide tissue respiration with their complex nervous and humoral regulation [10].

In the process of modern athletes training such nontraditional tool has been used, as training process in mountain conditions and interval hypoxic training aimed on the increasing of endurance and functional respiratory system development [9, 10]. However, despite the long-term use of the mountain climate, the peculiarities of the female organism reaction to the oxygen low partial pressure in inspired air at different phases of menstrual cycle requires further studies, because the female sex hormones (oestrogens) are an important link in the adaptive - trophic organism reactions. This group of hormones provides opportunities for adequate adaptation of woman's organism to various disturbances, including physical stresses, as well as to oxygen deficiency in the inspired air. The influence of hormonal status changes on athlete organism functional state and work capacity permit us to suggest that the athlete's organism reaction to inhaling of gas mixtures with a low oxygen content at different phases of menstrual cycle will be unequal [10].

Therefore our work continues to study the functional respiratory system reactions on changes in hormonal state of the female athlete's organism throughout the menstrual cycle. The results of the study of organism's reaction to inhalation of gas hypoxic mixture with 11% oxygen (hypoxic test is 10 minutes) in different phases of the menstrual cycle were presented in [1]. However, modern methods do not permit to determine the degree of tissue hypoxia [11] and to identify the functional resource of woman's organism on this basis. Therefore, an imitation modeling can provide essential help for trainers and sports physicians.

The purpose of this study was to determine the reaction of functional respiratory system and to reveal the tissue hypoxia degree for women athletes during the inhalation of hypoxic gas mixture at different phases of menstrual cycle.

To solve this problem, the mathematical models of mass transfer and mass exchange of respiratory gases in human organism was applied [12, 13]. The used versions were presented in [14, 15] in connections with the problems we solved.

To obtain the initial data for respiration process simulation, the healthy girls with normal menstrual function were examined. The studies were carried out once in each phase of the cycle. The phases of the cycle were

determined using the special questionnaire, according to daily measurement of basal temperature, the phenomenon of “fern” (cytological test of estrogen saturation of their organisms).

The minute volume of respiration, the gas composition of the exhaled and alveolar air and the parameters characterizing the hemodynamic and blood systems were also determined.

On their base we calculated indicators characterizing the state of respiratory and blood circulation systems (oxygen consumption rate, respiratory volume, respiratory coefficient, minute volume of respiration, systolic volume) and indicators characterizing the economy, intensity and effectiveness of respiratory system and hemodynamics (ventilation and hemodynamic equivalents, speed of oxygen consumption in some areas of its mass transfer, oxygen effects of respiratory and cardiac cycles, and etc.) [16, 17].

Further, using these calculated parameters and data obtained as a result of survey, the hypoxia conditions were simulated and partial pressures and strains of respiratory gases in the alveolar air, arterial blood and mixed venous

blood, in blood of tissue capillaries were calculated [14, 15, 18-21].

On mathematical model of functional respiratory system, an imitation of inhalation by athletes of normoxic and hypoxic mixture with 11% oxygen in different phases of menstrual cycle was performed. For individualization of respiratory system model, the following initial data obtained as a result of functional examination were used: oxygen consumption speed, minute blood volume, organism weight, hemoglobin content, and respiratory coefficient. The initial data for calculations were presented in Table 1. The studies were carried out on the model with four tissues. At the same time, the oxygen consumption speeds in tissue regions were distributed as follows: in brain 14.65%, in heart tissues 7.87%, in skeletal muscles 30.2%, and on all other tissues 43%. As for the systemic blood flow, its part in brain tissues was 15.5%, in heart muscles 4.46%, in skeletal muscles 20% and 60% in tissues of other organs. Following abbreviations were suggested: volume of respiration per minute (VRM) and volume of blood per minute (VBM)

Table 1: Initial Data for the Simulation of Inhalation of Gas mixture that Correlate with Conditions of Normoxia and Hypoxia with 11 % Oxygen for Different Concentration of Sex Hormones in Women Athletes’ Organisms

| Indices | % O ₂ | MC Phases | | | | |
|--|------------------|-----------|-------|-------|-------|-------|
| | | I | II | III | IV | V |
| <i>Q</i> , ml/s | 21 | 57,93 | 61,74 | 62,48 | 66,72 | 67,28 |
| | 11 | 79,0 | 77,14 | 80,66 | 79,14 | 83,15 |
| <i>q_iO₂</i> , ml/s | 21 | 3,26 | 2,91 | 3,33 | 2,93 | 2,75 |
| | 11 | 2,46 | 4,73 | 4,12 | 4,077 | 3,46 |
| <i>RQ</i> | 21 | 0,86 | 0,81 | 0,92 | 0,80 | 0,90 |
| | 11 | 0,85 | 0,94 | 0,85 | 0,84 | 0,85 |
| <i>V_r</i> , ml | 21 | 388,4 | 352,6 | 400,6 | 345,3 | 310,0 |
| | 11 | 444,6 | 469,6 | 544,2 | 439,8 | 422,6 |
| <i>Hb</i> | 21 | 124,5 | 125,5 | 120,9 | 122,0 | 126,6 |
| | 11 | 124,9 | 124,1 | 123,0 | 124,7 | 130,8 |
| <i>t</i> , s | 21 | 3,57 | 3,7 | 3,4 | 3,57 | 2,9 |
| | 11 | 3,4 | 3,8 | 3,5 | 3,5 | 3,57 |
| <i>W</i> , kg | 21 | 56 | 56 | 56,5 | 57 | 57,5 |
| | 11 | 56 | 56 | 56,5 | 57 | 57,5 |

Results

The analysis of obtained results demonstrated that due to the fact that the amount of sex hormones change substantially during menstrual cycle, the reactions of respiratory and blood circulation systems of women to various disturbances depend on the hormonal status.

Thus, during the first phase of menstrual cycle for the compensation of hypoxic hypoxia, an increase in blood flow from 3960.0 to 5350.8 ml/min (by 35%) was necessary, while the minute volume of respiration increased from 1397 ml/min to 1513 ml/min (total on 8%). During the second phase of menstrual cycle compensatory effects demonstrated an increase of systemic blood flow by 26% (from 4083 ml/min to 5142 ml / min) and pulmonary ventilation by 40% (from 1306 ml/min to 1833 ml/min). During the third phase of menstrual cycle, the reaction of compensatory effects was approximately the

same - the systemic blood flow increased by 23% (from 4176 ml/min to 5142 ml / min), and pulmonary ventilation by 24% (from 1361 ml/min to 1701 ml / min). During the fourth phase there was an increase in the minute volume of blood from 4572 ml/min to 5484 ml/min (by 20%), and the minute volume of respiration increased from 1242 ml/min to 1537 ml/min (by 25%). During the fifth phase of menstrual cycle, when the hypoxic hypoxia was compensated, the systemic blood flow increased from 4619.4 ml/min to 5772 ml/min (by 25%), and pulmonary ventilation increased from 899 ml/min to 1523 ml/min (by 59%). The dynamics of changes in the minute volume of respiration and the minute volume of blood during the inhalation of the normoxic mixture and the mixture with 11% oxygen is shown according to phases of menstrual cycle in Figure 1.

Figure 1: Changes in Ventilation and Systemic Blood Flow (in ml) During the Inhalation of Normoxic Mixture and Mixture with 11% Oxygen at Different Phases of Menstrual Cycle

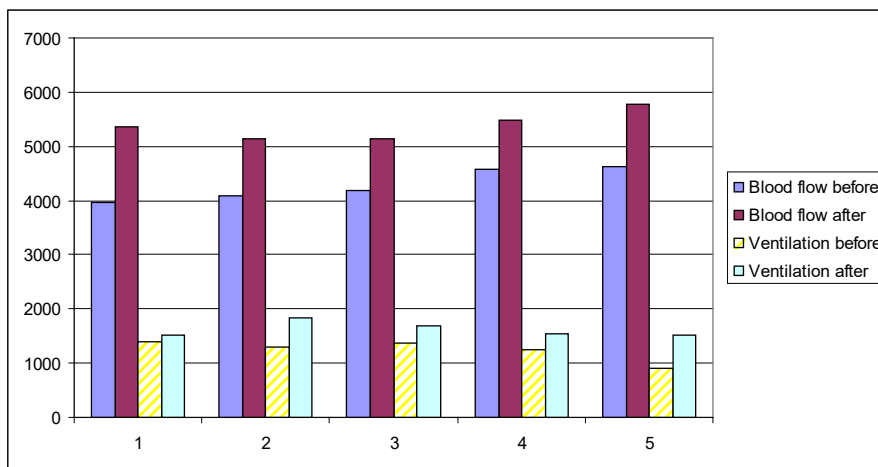
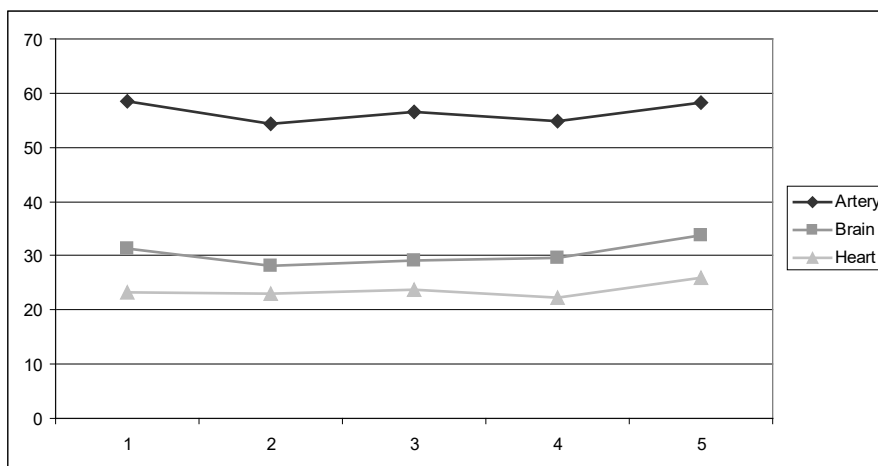


Figure 2: Oxygen Tensions (in mm Hg) in the Arterial Blood and Tissues of Brain and Heart During the Inhalation of the Mixture with 11% Oxygen at Different Phases of Menstrual Cycle



It is also interesting to note that different levels of arterial hypoxemia and degrees of tissue hypoxia were observed at different phases of menstrual cycle. Results of simulation modeling are shown in Figure 2. Thus, in the first phase, when inhaled gas mixture contained 11% oxygen, the arterial blood pressure was 58.61 mm Hg, in brain tissues 31.29 mm Hg, and in heart muscle 23.27 mm Hg. During the second phase, the oxygen tension in arterial blood was 54.33 mm Hg, in brain and heart tissues it was 28.03 and 23.05 mm Hg, respectively. During the third phase of the cycle, of arterial blood pressure was 56.53 mm Hg, in brain tissues it was 29.08 mm Hg, in the heart - 23.81 mm Hg. During the fourth phase of menstrual cycle, of arterial blood decreased to 54.94 mm Hg, while in brain and heart tissues these values were 29.65 and 22.22 mm Hg, respectively. During the fifth phase, the oxygen tension in the arterial blood was 58.3 mm Hg, in brain it was 33.89 mm Hg, and in the heart muscle it was 26.01 mm Hg.

It is known [9] that the level of oxygen tension in tissues depends on blood supply and intensity of oxidative processes in them. Thus, the velocity of oxygen consumption by brain tissues was reduced if the oxygen partial pressure in the inspired gas mixture decreased below 100 mm Hg [10].

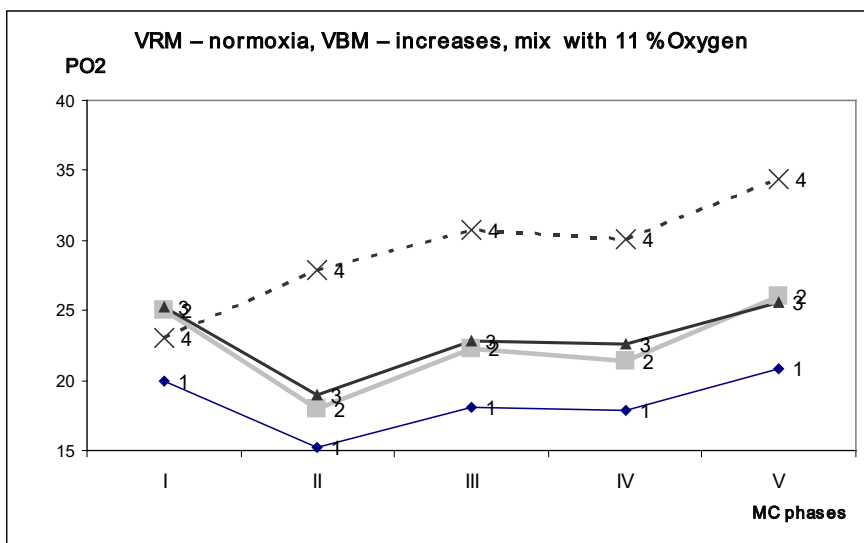
Under the conditions of hypoxic hypoxia, with 11% O₂ in the inhaled air, oxygen tensions in the brain, heart, skeletal muscles and other organs were significantly reduced [14]. Thus, in conditions of normoxia, even small differences in blood volumes per minute (VBM) (at the

second phase of menstrual cycle VBM was less by 489 ml/min in comparison with the fourth phase), led to decrease in oxygen tension in brain by 2.1 mm Hg, in heart - 1.6 mm Hg, in mixed venous blood - by 1.6 mm Hg. in comparison with the fourth phase. The slight increase of VBM during the fifth phase relatively to the second phase by 537 ml/min caused more visible differences in oxygen tensions in studied tissues in these phases: in brain was lower by 3.28 mm Hg, in heart muscle by 2.66 mm Hg, in skeletal muscles - by 2.3 mm Hg. It was possible to notice that in comparison with cardiac muscle, the reactions on hypoxic hypoxia in brain tissues were more pronounced.

With a VBM increase by 633 ml/min in the fifth phase relative to the second phase, the inhalation of hypoxic mixture with 11% oxygen would lead to even more significant decrease: in brain tissues it have been decreased by 5.33 mm Hg, in cardiac muscle by 2.43 mm Hg, in skeletal muscles by 4.5 mm Hg, in tissues of other organs by 4.4 mm Hg. Oxygen tension in tissues decreased below critical levels, this led to the decrease of velocity of oxygen consumption in them, and, as a result, to changes in their functions. In mixed venous blood, oxygen tension has been reduced by 4.1 mm Hg, so, pronounced venous hypoxemia would be registered.

Further, the compensatory role of local self-regulatory mechanisms in the prevention of tissue hypoxia using gas mixture with 11 % oxygen for respiration imitation during menstrual cycle was studied at our model. The following series of experiments were carried out.

Figure 3: Dynamics of Oxygen Tension in Tissues: 1-Heart, 2-Brain, 3-Skeletal Muscles, 4 - Other Tissues According to Phases of the Cycle with Compensation Only Due to the Blood Circulation System. MC - Menstrual Cycle



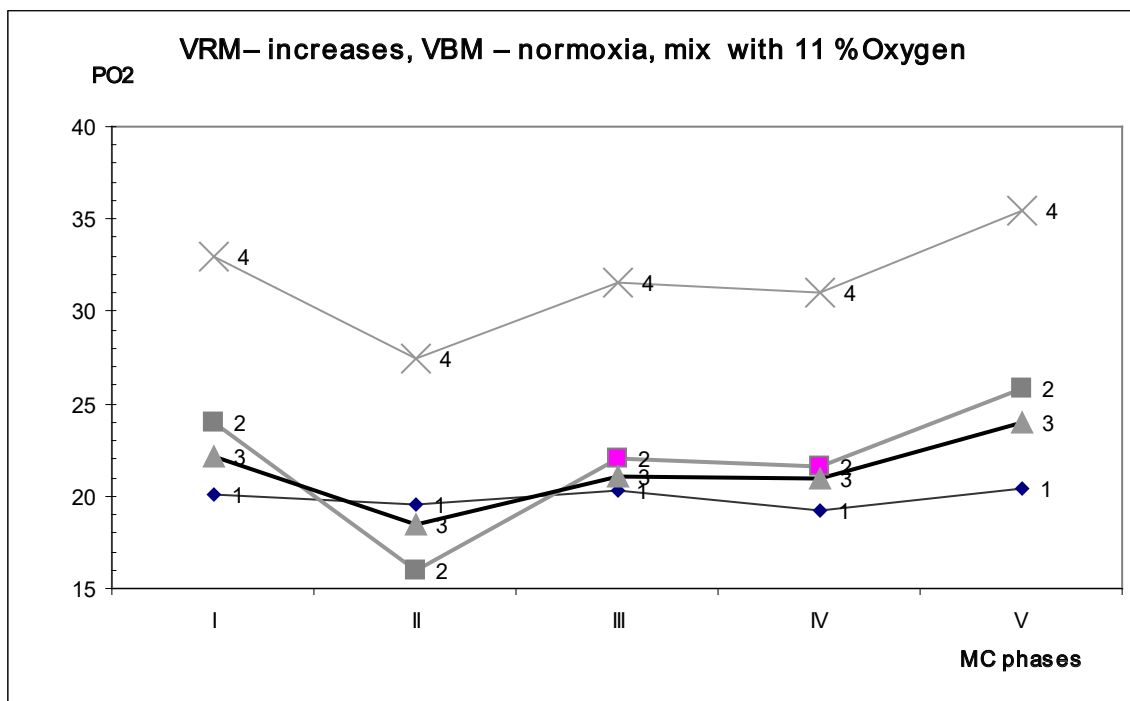
Experiment 1

VRM was permanent; the compensation is only due to VBM. In Figure 3 the results of imitation of athletes' inhalation of mixture with 11% oxygen are presented. The partial oxygen pressure in the alveolar space in all phases of the cycle would have been lower than 50 mm Hg, except the fourth phase where the parameter value was 50.9 mm Hg. In arterial blood the oxygen tension would have decreased much below the critical level.

A natural consequence of arterial hypoxemia is a decrease in the oxygen tension in studied tissues below the critical level.

We would like to note also that in the first phase of menstrual cycle, in normoxia conditions, the oxygen tension in studied tissues is higher than in the second,

Figure 4: Dynamics of Oxygen Tension in Tissues: 1-Heart, 2-Brain, 3-Skeletal Muscles, 4 - Other Tissues According to Phases of the Cycle with Compensation Only Due to the Respiratory System. MC - Menstrual Cycle



Decrease in the arterial blood of oxygen tension below the critical level can lead to the decrease in oxygen consumption velocity with the development of uncompensated hypoxia in tissues. Thus, our studies at model demonstrated that if the gas mixture was inhaled with 11% oxygen, the oxygen tension in brain tissues would decrease to 16.4 mm Hg, in the third and fifth phases it would be slightly higher than 20 mm Hg, and in the fourth phase only it would be 25.91 mm Hg, which is still below the physiological norm. It would also result in

third and fourth phases. At the same time, in the first phase during hypoxic hypoxia the tissues of other organs are even in more difficult conditions in terms of their oxygen supply.

Experiment 2

VBM was equal to normoxia conditions; the compensation is carried out only through the respiratory system. The partial oxygen pressure in alveolar air increases slightly, especially in the first, third and fifth phases of the cycle (Figure 4). The oxygen tension in mixed venous blood is below 30 mm Hg. This is especially visible in the second phase, and only in the fifth phase in mixed venous blood is somewhat higher in comparison with others.

decrease in skeletal muscles and in tissues of the rest of the organs, besides the heart muscle, in which in the first, third and fifth phases would increase, without achieving normoxia values, in the second and fourth it would be below 20 mm Hg.

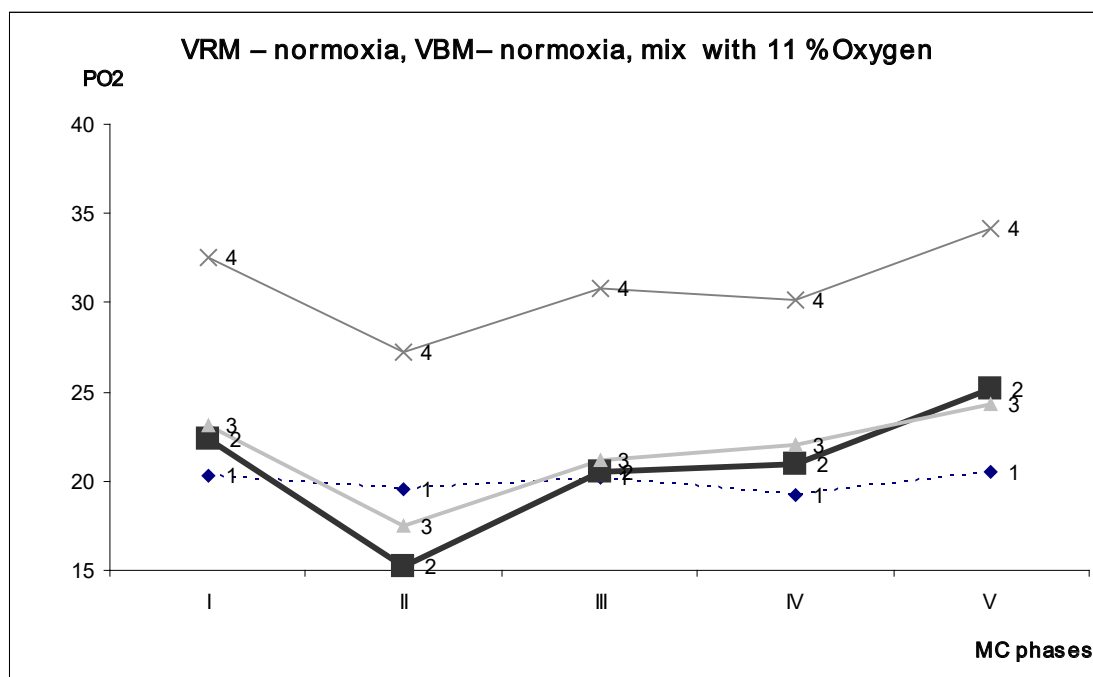
Thus, if there is no VBM increase during hypobaric hypoxia, it would lead to significant arterial and venous hypoxemia, especially in the second and fourth phases, and this, respectively, would lead to decrease in tissues of working organs.

Experiment 3

Values of VRM and VBM have not been changed in comparison with normoxia. Calculations demonstrated that in the second and fourth phases there is a decrease in oxygen tension below 50 mm Hg; in the third phase this value would be 50.23 mm Hg, in the fifth phase – it would be slightly higher. In Figure 5 one can see that oxygen

tension in arterial blood is between of values in case of absence of VBM compensation and VRM compensation. With regard to the degree of venous hypoxemia, the smallest values of this index were in the second phase, the values in the third and fourth phases would be somewhat larger, in the fifth phase in mixed venous blood would be 30 mm Hg.

Figure 5: Dynamics of Oxygen Tension in Tissues: 1-Heart, 2-Brain, 3-Skeletal Muscles, 4 - Other Tissues According to Phases of the Cycle in the Absence of Compensation Due to the Functioning of Respiratory and Blood Circulation System. MC - Menstrual Cycle.



With complete absence of compensation from the respiratory and blood circulation systems in brain tissues, a sharp decrease occurs in the second phase, in the third and fourth phases this index slightly increases to 20.77 and 20.86 mm Hg, in the fifth phase to 25.27 mm Hg, so, these values are even slightly higher than for compensation absence, either from VRM or from VBM. At full absence of compensatory reactions of respiratory and blood circulation systems, the values of index in heart muscle are approximately the same as in the absence of compensation from the VBM. When there is no pulmonary ventilation increase, this leads to the lowest values of the oxygen tension in heart tissues.

An analysis of imitation of compensation absence from the external respiration system revealed that and decreased reliably during all phases of the cycle. The partial pressure in alveoli and pressure in arterial blood were higher in the third and fifth phases of the cycle in

comparison with the second and fourth phases. In the absence of compensation only from the side of systemic blood flow during hypoxic hypoxia, the decrease of these parameters were less pronounced, but simultaneously decreases in mixed venous blood.

The next series of experiments made it possible to find the unequal values of VRM and VBM for providing the organism with oxygen in different phases of menstrual cycle.

Results of imitation modeling were presented in Table 2.

Values of VRM and VBM were not changed in comparison with normoxia. Calculations revealed that in the second and fourth phases there is a decrease in the oxygen tension below 50 mm Hg, in the third phase this value would be 50.23 mm Hg, in the fifth phase - slightly higher. In Figure 5 one could see that oxygen tension in arterial blood is between the values in cases of absence of

Table 2: Oxygen Pressures in Tissues for the Simulation of Inspiration of Gas Mixtures with 11 % Oxygen During the Third Phase of Menstrual Cycle (MC), Depending on Different Selection of VBM and VRM (in mm Hg)

| VBM | VRM | Ways of Air Transportation | Alveolar Air | Artery | Brain | Heart | Skelet. Muscle | Other Tiss. | Vein |
|-----------|-----------|----------------------------|--------------|--------|-------|-------|----------------|-------------|-------|
| III phase | II phase | 74,51 | 51, 17 | 42,32 | 23,27 | 18,9 | 23,38 | 32,25 | 28,94 |
| II phase | II phase | 74,59 | 51,43 | 42,93 | 23,01 | 18,9 | 23,02 | 32,18 | 28,81 |
| II phase | III phase | 57,79 | 53,95 | 45,48 | 23,78 | 19,05 | 23,1 | 32,6 | 29,12 |
| III phase | III phase | 63,31 | 60,8 | 56,53 | 41,72 | 29,08 | 23,81 | | |

compensation by VRM and VBM. Concerning the degree of venous hypoxemia, the smallest values of this index were in the second phase, the values in the third and fourth phases would be somewhat larger, and in the fifth phase in mixed venous blood would be 30 mm Hg.

In case of complete absence of compensation by respiratory and blood circulation systems in brain tissues, a sharp decrease occurs in the second phase, in the third and fourth phases this index slightly increases to 20.77 and 20.86 mm Hg, in the fifth phase to 25.27 mm Hg. So, these values are even slightly higher than in absence of compensation, either from VRM or from VBM. In case of full absence of compensatory reactions from respiratory and blood circulation systems, values in heart muscle were approximately the same as in the absence of compensation from the VBM. When there is no increase in pulmonary ventilation, this leads to the lowest values of tensions in heart tissues.

An analysis of imitation of compensation lack from external respiration system revealed that and decreases reliably in all phases of the cycle. Partial pressure in alveoli and tension in arterial blood were higher in the third and fifth phases of the cycle in comparison with the second and fourth phases of the cycle. In case of compensation absence only from the side of systemic blood flow during hypoxic hypoxia, the decrease of these parameters were less visible; but decreases in mixed venous blood.

The next series of experiments made it possible to reveal the values of the unequal values of VRM and VBM for providing of organism with oxygen in different phases of menstrual cycle. Results of imitation modeling are presented in Table 2.

Experiment 4

In all phases of the cycle at normoxia, the values VRM and VBM were selected according to the second phase of the cycle, when the values of this index are the smallest alternately or simultaneously. With reduced VBM, the oxygen partial pressure in alveolar space and oxygen tension in arterial blood were changed more than in the absence of compensation from VBM.

Simultaneous decrease of VBM and VRM in the phase of ovulation leads to even greater decrease in arterial blood. At the same time, venous hypoxemia was pronounced even better.

Experiment 5

In all phases of the cycle at hypoxic hypoxia, the values of VRM and VBM were selected alternately or simultaneously corresponding to the second phase of the cycle, when values of this indicator are the smallest ones. Registered dependence was the same as for normoxia. The gradients of and changes were larger in case when VBM compensation is absent, than in case of VRM compensation absence. With simultaneous absence of both these compensatory components, venous hypoxemia becomes even more pronounced than in the absence of one of these compensatory components, especially VRM.

These results indicated that when the external environment is disturbed in the form of hypobaric mixture with 11% oxygen without an increase of pulmonary ventilation and systemic blood flow, the oxygen tension in tissues may be below the critical level (Table 2)

Experimental series 4 and 5 demonstrated that under normoxia conditions the brain tissues react on

changes in blood flow. In conditions of hypoxic hypoxia the brain tissues were sensitive also to the absence of compensation from both VRM and VBM, especially when compensatory reactions were absent from both VRM and VBM together.

Cardiac tissues at normoxia react more to the absence of compensatory reaction from the external respiration system. At hypoxic hypoxia in the third phase, in cardiac muscle decreases in comparison with normoxia by 4.42 mm Hg when VRM is unchanged.

In the fourth and fifth phases of the cycle due to the increase of the tone in central nervous system sympathetic department [9] in conditions of normoxia and hypoxia, the VBM increased. Therefore, the sense of the next series of experiments was in imitating of the deficit from the systemic blood flow in the fourth and fifth phases of the cycle at normoxia and hypobaric hypoxia.

Experiment 6

At VRM value that corresponds to the studied phase of the cycle, we took VBM equal in value to the second phase of the cycle. Obtained results demonstrated that the absence of compensation from systemic blood flow under conditions of normoxia would lead to pronounced venous hypoxemia with a certain increase in the partial oxygen pressure in arterial blood and alveolar space. So, when VBM in the fourth phase was equal to the VBM of the second phase, it means that it would have decreased by 489 ml / min, then in mixed venous blood would have decreased by 3.25 mm Hg, and in arterial blood it increased by 2.22 mm Hg. When imitating the inhalation of gas mixture with 11% oxygen in arterial blood, where was reliably below the critical level, the decrease of systemic blood flow (up to the level of the second phase of the cycle) would increase by 0.34 mm Hg in mixed venous blood. In the fifth phase, when VBM value was substituted by the same VBM value for second phase (VBM decreased by 537 ml/min in normoxia conditions and 633 ml/min at hypobaric hypoxia), there would be less pronounced venous hypoxemia in normoxia conditions as well as in conditions of hypobaric hypoxia.

Discussion

Decrease of compensatory effect of systemic blood flow suggests the greater manifestation of venous hypoxemia in the fifth and especially the fourth phase of the cycle, thus emphasizing the importance of systemic blood flow in these phases of the cycle.

At normoxia conditions the decrease in systemic blood flow would lead to decrease in the brain by 5.04 mm Hg and in heart tissues by 2.91 mm Hg.

In studied tissues hypoxic hypoxia (inhalation of air with 11% oxygen) in brain tissues would be only 23.27 mm Hg (decrease of 16.86 mm Hg relatively to normoxia and 0.82 mm Hg relatively to hypoxic hypoxia) that is significantly lower than the critical level. In cardiac tissues the oxygen tension would decrease by 9.98 mm Hg in relation to normoxia conditions and 0.33 mm in relation to hypoxic hypoxia (18.9 mm Hg).

In the fifth phase during normoxia conditions' simulation, the calculations revealed that in the brain would decrease by 4.73 mm Hg, in the heart tissues by 3.07 mm Hg after the simulation of inhalation of gas mixture with 11% oxygen; in the brain tissues decreased at 13.91 mm Hg, and in the heart muscle by 7.56 mm Hg. Decrease of systemic blood flow value would reduce in brain tissues by 0.95 mm Hg, in the heart by 1.12 mm Hg, so, the reaction would be more pronounced than in the fourth phase.

Suggested results of imitating modeling clearly demonstrate some existing differences in oxygen regimes of organism tissues in different phases of women menstrual cycle and significant differences in the reactions of brain, heart, skeletal muscle tissues to hypoxic hypoxia when the hormonal status of athlete's organism changes.

The results of theoretical investigation on the mathematical model of respiratory gases mass transfer in organism evidences about the necessity to take into account phases of menstrual cycle in planning of athletes training process from one side, and from the other side to develop new methods that improve the athlete's organism functional state and promote the growth of sport results.

When planning the volume, intensity, orientation of training loads, taking into account the hormonal status of the women athlete's organism, it is necessary to take into account that the second and fourth phases of the cycle are characterized by economy and efficiency of respiratory and blood circulation system, organism oxygen modes, manifestation of speed- strength capabilities, proprioceptive sensitivity and movements coordination. Therefore, in these phases it would be more effective to develop the speed-strength qualities, special endurance, and technical skills.

In the third phase, due to biological characteristics of female organism, all kinds of activities that do not have direct relationship to the process of ovulation become

secondary. So, movements' accuracy and coordination become worth, lability of the nervous processes increases that leads to work capacity decrease. So, functional value of the work increases as well as its strength and speed capabilities.

Conclusion

On the mathematical model of functional respiratory system some parameters of functional self-organization of woman athlete's organism were calculated in response to inhalation of hypoxic mixtures. The adequacy of the model was confirmed by the fact that calculated values of minute volume of blood (VBM) simulated by the respiration of hypoxic gas mixture coincide with other values, obtained during instrumental examination. Calculated parameters of self-organization evidenced about the specificity of functional self-regulation and, consequently, about adaptive capabilities to hypoxia of female organism during cyclic changes in its hormonal status in different phases of menstrual cycle. Cyclic hormonal changes in woman's organism initiated significant changes in the reactions of functional respiratory system and in organism oxygen regimes as well as degree of tissue hypoxia expression in response on perturbations of organism's external environment. During this the significant differences in compensatory reactions of woman's organism on inhaling the hypoxic gas mixture were registered.

Described approach allows estimating the functional resource of woman's organism at secondary tissue hypoxia caused by inhalation of hypoxic mixtures and can be useful for planning of individual training loads for women athletes, because the training loads have to be chosen individually, taking into account cyclic changes in female organism resistance to hypoxia.

Experience of our work with imitation models described above would serve as a basis for setting of new research tasks that may appear in process of athletes' training and in process of formation of teams for competitions.

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