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ENHANCING AEROBIC TRAINING EFFICIENCY THROUGH ARTIFICIAL RESPIRATORY MEDIA

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Abstract. **Aim.** This study investigates the efficacy of artificial respiratory media in enhancing aerobic performance during physical endurance training. **Materials and methods.** Forty male participants were randomized into two groups. The training protocol consisted of 10 cycles, each involving a 4-hour session in the test facility, during which participants performed standardized physical exercises. The main group (n = 20) trained under the following breathing conditions: argon (30–35%), oxygen (4–13%), and nitrogen. After each session, participants in Subgroup A (n = 10) were exposed to hyperbaric conditions (0.05 MPa) for 60 minutes in a gas mixture of argon (35%), oxygen (25%), and nitrogen (40%). Participants from Subgroup B (n = 10) recovered under normobaric conditions. The Control group (n = 20) performed identical exercises in a normoxic-nitrogen environment with progressively reduced oxygen levels: 19% (cycles 1–2), 18% (cycles 3–4), and 17% (cycles 5–10). After each session, participants in Subgroup A (n = 10) were exposed to hyperbaric conditions (0.05 MPa) for 60 minutes in a gas mixture of oxygen (30%) and nitrogen. Participants from Subgroup B (n = 10) recovered under normobaric conditions. **Results.** Combined training in the main group elicited a significant improvement in maximal aerobic capacity across all 20 volunteers, with increases ranging from 5% to 9% relative to baseline levels. The mean improvement in subgroups A and B was approximately 8% and 5%, respectively (p = 0.045). In contrast, only 9 individuals (40%) in the control group exhibited an increase in aerobic performance, 8 of whom belonged to Subgroup A. The magnitude of improvement in the control group ranged from 0.5% to 5%, with mean increases of 2% in Subgroup A and 1% in Subgroup B. **Conclusion.** The innovative technology under development demonstrates efficacy in enhancing physical endurance training, attributable to the multimodal physiological effects of the applied barotherapeutic agents. This approach may serve as an effective strategy for optimizing training adaptations in individuals engaged in endurance training.

Keywords: physical endurance, argon-hypoxic training, hyperbaric effects

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ПРИМЕНЕНИЕ ИСКУССТВЕННЫХ ДЫХАТЕЛЬНЫХ СРЕД ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ АЭРОБНЫХ ТРЕНИРОВОК

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Аннотация. **Цель:** оценить эффективность различных искусственных дыхательных сред в сочетании с мышечными нагрузками для повышения физической выносливости человека. **Материалы и методы.** В исследовании приняли участие 40 мужчин, разделенных на 2 равные группы (основная и контрольная). Тренировка включала 10 циклов 4-часового пребывания в испытательной установке, где добровольцы выполняли физические нагрузки. В этот период испытуемые основной группы находились в газовой среде, состоящей из аргона – 30–35 %, кислорода – 14–13 % и азота. После каждой тренировки испытуемые основной группы А (10 человек) еще в течение 60 минут находились под избыточным давлением (0,05 МПа) при концентрации кислорода 25 %, аргона 35 % и азота 40 %. Остальные добровольцы этой группы (основная группа Б) находились в обычных условиях. Добровольцы контрольной группы выполняли аналогичные физические нагрузки в газовой среде с содержанием кислорода в азоте: 19 % – 1–2 цикла, 18 % – 3–4 цикла и 17 % – 5–10 циклов. После каждого цикла 10 тренирующихся из этой группы (контрольная группа А) находились под давлением 0,05 МПа в течение 60 минут при содержании кислорода в азоте 30 %. Остальные (контрольная группа Б, 10 человек) находились в обычных условиях. **Результаты.** Комбинированные тренировки в основной группе обеспечили прирост максимальной аэробной работоспособности в диапазоне от 5 до 9 % от исходного уровня у всех 20 добровольцев. Средний прирост показателя в подгруппах А и Б составил около 8 и 5 % соответственно (p = 0,045). В контрольной группе прирост данного показателя наблюдался только у 9 (40 %) человек, из них 8 человек – из подгруппы А. Прирост показателя составил от 0,5 до 5 %: в среднем в подгруппе А – 2 %, в подгруппе Б – 1 %. **Заключение.** Таким образом, разрабатываемая нами инновационная технология позволяет оптимизировать тренировочный процесс для людей, тренирующих физическую выносливость, за счет разнонаправленного воздействия на организм применяемых баротерапевтических средств.

Ключевые слова: физическая выносливость, аргоно-гипоксическая тренировка, гипербарические воздействия

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1. Introduction

Currently, specialists in occupational and sports physiology and medicine are actively searching for non-drug means and methods to enhance the effectiveness of physical training aimed at expanding the physiological functional capacities (PFC) and increasing aerobic endurance of persons with a predominantly motor profile of professional (sports) activity [8, 13, 14, 19]. A mandatory requirement for such means is their safety for the body (no doping effect). As additional requirements, convenience of use, the speed and persistence of positive changes in the body, affordability of the technology, the possibility of using it in "field" conditions, and other criteria are considered.

To date, the high efficiency and safety of such auxiliary non-drug methods as massage and vibromassage, electrical and electromagnetic stimulation, local and general thermal procedures, ultraviolet radiation, hydrotherapy, acupuncture, biofeedback-based bioacoustic correction, etc., have been proven [6, 14, 22, 23]. The mechanisms of action of these and similar methods on the body are synergistic with physical training, which determines the increase in the effectiveness of the latter in the case of their combined (parallel) use.

Non-specific, non-drug methods that help expand PFC also include pneumotherapy, including the use of artificial respiratory media (ARM) with high or low oxygen content at high, normal, or low total barometric pressure [3, 4, 11, 12].

At the same time, the use of hyperoxia in the form of oxygen therapy or hyperbaric oxygenation is, first of all, a way to restore the body after heavy physical exertion, auxiliary treatment of musculoskeletal injuries, and other concomitant pathologies [4, 11]. Hypoxic hypoxia is used as a training factor, the so-called hypoxic training – HT (normo-, hypo-, or hyperbaric training) [3, 12]. The main mechanism of HT is an increase in the resistance of tissues of vital organs to transient hypoxia, which is known to be a key link in the development of fatigue during prolonged and intense physical activity [1, 2, 21].

Physical training in mountainous (hypobaric-hypoxic) conditions has found wide application primarily in sports medicine [15, 16]. However, this method has many limitations and disadvantages associated with organizational difficulties, unpredictable weather conditions in mountainous areas, the risk of mountain sickness in trainees, possible adaptation and re-adaptation issues, etc. [12, 16, 21].

A more convenient and affordable option is normobaric hypoxic training (NHT). Unlike mountain-climatic therapy and pressure-chamber "high-altitude" hypoxia, this method has no negative effect of barometric pressure drops and provides strict dosing of the therapeutic factor and adequate direct control of the functional state of the trainee, economical efficiency, and ease of use.

An innovative technological solution that made it possible to significantly expand the NHT possibilities, solve the problems associated with the "mask" type of breathing by hypoxic ARM from gas-balloon inhalers or hypoxicators, was the development of hypoxic facilities that allow the formation of a hypoxic gaseous medium of a given and easily changeable composition in a sealed chamber. The most important advantage of this technological solution is the combined (simultaneous) use of NHT and physical training, which ensures their greatest synergy in solving the main task, i.e. increasing physical endurance, expanding PFC, and preventing overtraining [9, 10, 20].

In addition, the most technically equipped facilities can create conditions for high or low barometric pressure [18, 20] by adding other gases to the gas environment, of which the use of inert argon gas seems to be the most promising, which has proved its pronounced antihypoxic, cerebro-, cardioprotective and other effects in multiple reliable experimental studies [5, 7, 17]. At the cellular level, argon facilitates the transport of respiratory gases and cellular metabolites in the most intensively functioning organs, and thus accelerates metabolic processes. These and other effects of argon provide an increase in tissue tolerance to hypoxia and, therefore, make it possible to safely reduce the oxygen content in the training hypoxic gas environment to increase the effectiveness of combined training. At the same time, argon is not included in the official list of substances prohibited for use by elite athletes by the International Anti-Doping Committee.

However, despite the obvious promise, to date, the issues of differentiated combined use of innovative pneumotherapy (including the use of argon-containing AGE) and physical exercises to expand the PFC and increase human muscle endurance have not been sufficiently studied.

This determined the **objective** of this study, i.e. to conduct a comparative assessment of the effectiveness of the combined use of various artificial respiratory media, hyperbaric effects and muscle loads to increase physical endurance and expand the functional potential of a person.

As a result of this work, we considered the development of an optimal regimen for the use of AGE, which provides the most effective training for the formation of aerobic physical endurance.

2. Materials and Methods

The study involved 40 male volunteers (19–23 years old), divided into groups (MG, 20 people, and CG, 20 people), comparable in significant anamnestic, anthropometric and functional characteristics. All volunteers indicated the absence of bad habits (alcoholism, smoking), had a normosthenic body type (body mass index 22–26 kg/m^2), trained regularly (running, cycling, strength training, sports games), but were not elite athletes.

The training programs included 10 cycles (10 days) of 4-hour stay of volunteers in the test chamber (schematically shown in Fig. 1), where they performed physical exercises on an exercise bike and a treadmill. The specified power of physical work is 70–100 W (depending on the initial PFC of the volunteer), the duration is 120–140 minutes with several breaks.

Variants and regimens of pneumotherapeutic effects in the compared groups and subgroups are schematically shown in Fig. 2.

The subjects of the Main group performed the specified physical activities while staying inside the premises, where the normobaric argon-hypoxic respiratory medium (ArHRM) was maintained: argon – 30–35%, oxygen – 14–13%, nitrogen – the rest. After each training, the subjects of the Main group A (10 people) stayed in the premises for another 60 minutes (in a calm state,

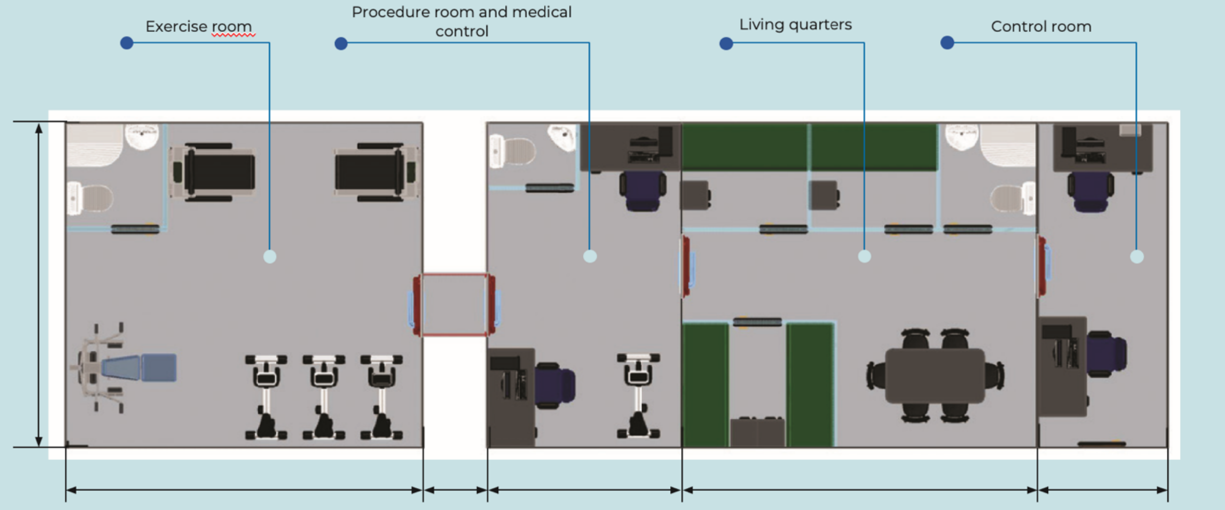

Fig. 1. Schematic representation of the complex/chamber

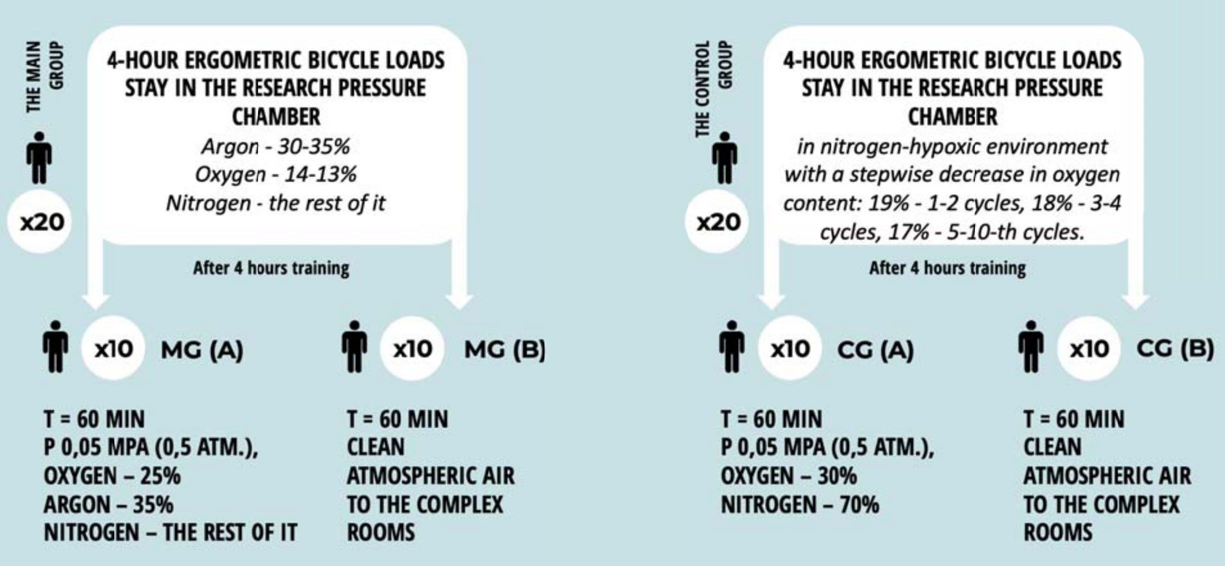

Fig. 2. Pneumotherapy training scheme

rested lying or sitting), where the following conditions were created: an overpressure of 0.05 MPa (0.5 atm.), oxygen 25%, argon 35%, nitrogen – the rest. The remaining volunteers from this group (Main group B, 10 people) remained under our supervision for 60 minutes, being under normal conditions (normal pressure, atmospheric air).

Volunteers of the control group (20 people) performed similar physical activities in the premises with normobaric HRM, in which oxygen was partially replaced by nitrogen. A standard stepwise reduction in the oxygen content in the HRM was applied, which is safe and recommended for persons not trained for hypoxia [**Ошибка! Источник ссылки не найден.**]: 19% – 1–2 cycles, 18% – 3–4 cycles, 17% – 5–10th cycles. After each cycle, 10 trainees from this group (Control group A) for 60 minutes (in a calm state, rested lying or sitting), stayed in the premises at a 30% oxygen content in nitrogen and an overpressure of 0.05 MPa. The remaining persons of this group (Control group B, 10 people) remained under our supervision for 60 minutes, being under normal conditions (normal pressure, atmospheric air).

Medical control of the functional state of volunteers during each training and recovery cycle included:

– visual observation;

– recording of complaints;

– periodic control of heart rate, blood pressure and oxygen saturation of capillary blood using Microlux automated diagnostic system (Russia);

– sampling of capillary blood: before and after each training cycle and then after another 60 minutes (in subgroups A – after HBT). Blood samples were used to measure hemoglobin, pH and lactate using Gem-Premier*3000 automated gas analyzer (USA).

The physical performance of the subjects was assessed based on standardized functional tests:

– Maximum aerobic performance. The test was performed on a Schiller Cardiovit CS-200 bicycle ergometer (Switzerland) until the anaerobic threshold (AnT, W) was reached according to the protocol: the power of the first “stage” was 50 W, the increment of the “stage” was 25 W, the duration of each “step” was 1 min, except for a step with a power of 100 W, the duration of which was 2 min.

– Ruffier squat test (30 squats for 45 seconds) with the calculation of the corresponding index (Rufier's index);

– Stange test to determine resistance to hypoxia.

All volunteers performed functional tests twice: before (Stage 1) and after (Stage 2) a course of combined training.

The results were processed using the methods of variational statistics and Excel and STATISTICA for Windows (v. 12). The mean values (M) and standard deviations (σ) of the evaluated criteria were calculated, which were presented in tables. The significance of differences in pairwise parameters in related and unrelated samples was determined using the Wilcoxon T-test and the Mann – Whitney U-test, respectively. Differences were considered significant at $p < 0.05$.

The studies were organized and conducted in accordance with the provisions and principles of current international legal acts, in particular the Declaration of Helsinki of 1975 and its revision in 2013. All examined persons signed a voluntary informed consent to participate in the studies. The legitimacy of the studies was confirmed by the conclusion of the independent ethical committee of the Northern State Medical University (protocol No. 5/10-15 dated 19.10.2015).

3. Results and Discussion

There were no significant differences between groups and subgroups at baseline; all subjects had a moderate or relatively high level of physical performance and resistance to hypoxia (Table 1).

Observation showed that physical training in a hypoxic environment places significant demands on the body, forcing it to perform activities with high stress on physiological supporting mechanisms. However, despite this, all volunteers successfully completed the training programs. It is important to note that there were no significant differences in the functional state of the volunteers of the main and control groups during physical exercises, despite significant differences in the oxygen content in the HRM and ArHRM at all stages of the study.

The repeated examination showed that combined training in the main group provided an increase in maximum aerobic performance **in all 20 volunteers**, which ranged from 5 to 9% of the initial level ($p = 0.008–0.027$). The average increase in the indicator in subgroups A and B was about 8% and 5% respectively ($pAB = = 0.045$).

Table 1

Functional stress test results in volunteers at different observation stages, M (σ)

Group	Subgroup (number of subjects)	Survey stage Indicator, unit rev. (σ)		
		AT, W	Ruffier Index (conventional units)	Breath-holding test, s
Stage 1				
MG	**A** (n = 10)	192 (5)	3.41 (0.17)	129 (7)
	B (n = 10)	190 (4)	3.50 (0.16)	127 (9)
CG	**A** (n = 10)	189 (5)	3.57 (0.15)	131 (5)
	B (n = 10)	192 (3)	3.61 (0.22)	131 (9)
Stage 2				
MG	**A** (n = 10)	207 (4) p = 0.008	2.97 (0.18) p = 0.004	149 (9) p = 0.003
	B (n = 10)	199 (3) p = 0.027 pAB = 0.045	3.14 (0.17) p = 0.028 pAB = 0.042	138 (8) p = 0.035 pAB = 0.047
CG	**A** (n = 10)	197 (4) p = 0.049 p1 = 0.035	3,46 (0,15) p = 0.049 p1 = 0.032	136 (5) p = 0.049 p1 = 0.030
	B (n = 10)	194 (3) p1 = 0.045	3,56 (0,12) p1 = 0.035 pAB = 0.049	132 (4) p1 = 0.040 pAB = 0.049

Note: level of significance: p – compared with stage 1 (Wilcoxon test); p1 – compared with the main group in the corresponding subgroup (Mann–Whitney test); pAB – between subgroups within the group (Mann–Whitney test).

In the control group, only 9 (40%) people had increase in this indicator, and 8 of them were from subgroup A. The increase in the indicator ranged from 0.5 to 5%: 2% in subgroup A, on average, and 1% in subgroup B. At the same time, at this stage of observation, significant intergroup differences were recorded between the corresponding subgroups of the main and control groups (p1 = 0.035–0.045).

Both the groups and subgroups had approximately similar trends in other criteria of stress tests that assess the level of PFC. So, in subgroups A and B of the main group, the decrease in the Ruffier index (and, consequently, the increase in physical endurance) averaged 13% (p = 0.004) and 10% (p = 0.028), respectively (pAB = 0.042). In the control group, this indicator decreased only by 3% (subgroup A) and 1.4% (subgroup B), with pAB = 0.049. Significant intergroup differences were also recorded, indicating the best effectiveness of the training and recovery program used in subgroup A of the main group.

The increase in the Stange test values, which characterizes the body's resistance to transient hypoxia, in subgroups A and B of the main group averaged 16% (p = 0.003) and 9% (p = 0.035), respectively, at pAB = 0.047. In the CG, the changes were significantly smaller: about 4% (subgroup A) and less than 1% (subgroup B), at pAB = 0.049.

The data showed that physical training in ArHRM with subsequent recovery using HBT in the tested version is the most effective of the tested means of emergency increase in aerobic performance and resistance to hypoxia. At the same time, physical activity in combination with the standard variant of hypoxic training without HBT cover showed the least effectiveness, apparently requiring a significantly larger number of procedures to achieve the desired results.

Table 2 shows fluctuations in the level of capillary blood lactate recorded in the groups and subgroups at the selected stages. The results obtained daily during the training period were averaged.

As the data shows, as a result of hyperbaric effects, subjects of subgroups A showed a more rapid leveling of lactatemia (as well as high blood acidity and other indicators associated with exposure to hypoxic and physical activity) than subgroups B. A greater increase in lactate found in the main group after training cycles was due to a significantly higher degree of hypoxia, in which the subjects of the main group performed physical activity. Despite this, as a result of the use of HBT, these differences were leveled.

As an illustration of one of the mechanisms of the influence of combined training on the maximum aerobic performance of a person, Fig. 3 shows the changes in blood hemoglobin in volunteers of the groups at the stages of observation.

Table 2

**Changes in blood lactate concentrations (mmol/l)
at different diagnostic stages among volunteer groups, M (σ)**

Stage of measurement	Group Subgroup (number of observations)			
	MG		CG	
	A (n = 10)	B (n = 10)	A (n = 10)	B (n = 10)
Baseline	1.7 (0.3)	2.7 (0.2) pAB = 0.027	2.0 (0.2)	2.4 (0.2) pAB = 0.042
Post-training	5.4 (0.4)	5.9 (0.4) pAB = 0.047	4.8 (0.2) p1 = 0.037	5.0 (0.4) p1 = 0.038
1-hour post-training	4.8 (0.3)	6.7 (0.2) pAB = 0.002	4.7 (0.3)	5.6 (0.3) p1 = 0.035 pAB = 0.022

Note: level of significance: p1 – compared with the main group in the corresponding subgroup; pAB – between subgroups within the group (Mann–Whitney test).

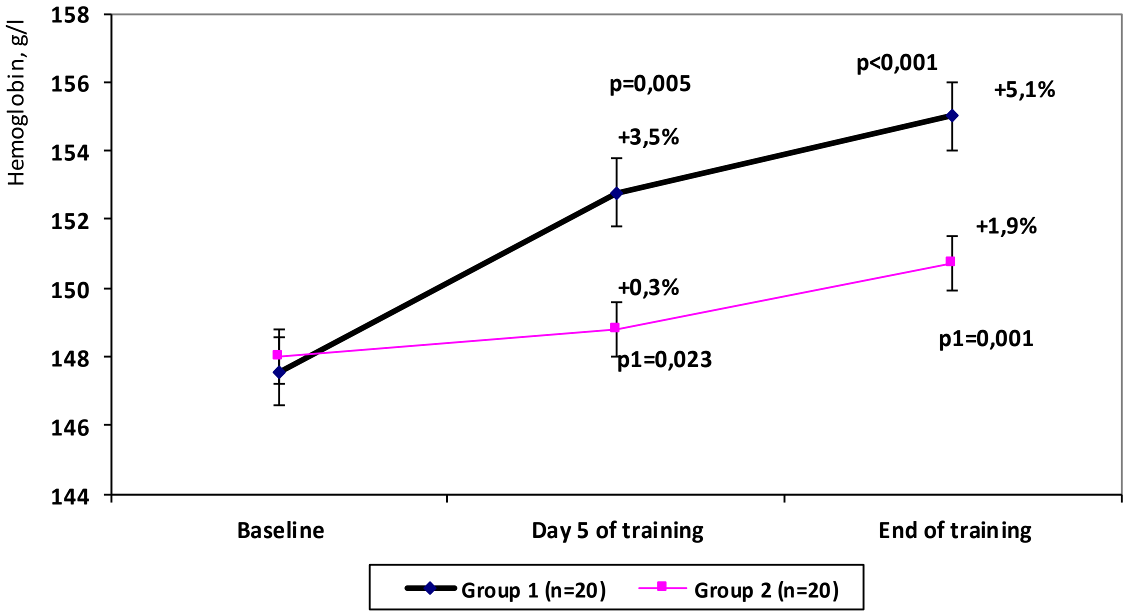

Fig. 3. Changes in capillary blood hemoglobin levels across observation stages in study groups, M ± σ
Note: level of significance: p – compared with the baseline (Wilcoxon test); p1 – compared with the main group (Mann – Whitney test)

As we can see, already by the 5th cycle of training, MG showed a significant increase in hemoglobin content, which averaged 3.5% of the baseline level and increased to 5.1% by the end of the training. CG tended only to increase in hemoglobin content by the end of training, which did not reach an average of less than 2% of the initial level. Thus, by the end of the training cycles, MG had a significantly greater increase in the oxygen capacity of the blood, which undoubtedly contributed to the above-mentioned increase in aerobic physical endurance and the expansion of PFC in the individuals of this group.

In our opinion and according to the data of other researchers [3, 12, 15, 21], the physiological basis of the revealed high efficiency of combined physical and normobaric hypoxic training is their synergistic effect on the body. The combined effect of hypoxic hypoxia and the so-called "load hypoxia" helps more quickly and safely expand the PFC of the athletes.

The following are considered as intimate mechanisms of the effects of hypoxic training [1, 2, 12, 15, 21]:

– adaptive restructuring of all components of the body's gas transport system,

– specific metabolic and regulatory changes;

– improvement of regional blood circulation and microcirculation;

– optimization of diastolic function of the heart;

– reduced hyperreactivity of the heart and resistive vessels to external effects.

The consequences of adaptation to hypoxia are [1, 3, 15, 21, 24]:

– increase in the proportion of perfused and ventilated alveoli;

– broncholytic and vasodilating action;

– increased erythropoietic activity of hematopoietic organs.

The addition of argon to hypoxic AGEs helps safely increase the intensity and effectiveness of physical training in a hypoxic environment. Argon is excreted from the body within a few minutes, without any cumulative effect. At the same time, in addition to increasing the body's resistance to hypoxia, argon, having a number of specific organ-protective effects [5, 7, 17], makes it possible to safely perform heavier loads under hypoxia, which will make it possible in the future to increase the effects of combined training.

4. Conclusion

Thus, a non-drug method based on a rational combination of physical and normobaric hypoxic training can be considered an effective means of increasing the physical performance of a person engaged in intense muscular activity. The main advantages are the controllability of the training process due to the individual selection of the intensity of the hypoxic stimulus, the nature and power of physical activity. By combining these factors, optimal training results are achieved. Special mention should be made of the safety of this method for the body and the absence of a doping effect, “rebound” or “addiction” syndromes.

Another advantage is the possibility of changing the composition of the artificial gaseous medium by including the inert gas argon. Our studies have shown the high efficiency of argon-hypoxic and physical training and confirmed the safety of this method for the body. In addition, staying in an ***argon-hyperoxic*** gas environment after the end of each training session (for up to 60 minutes) can significantly speed up the recovery processes in the body and ensure better readiness for the next cycle.

Summary. Considering the above facts, the innovative technology we are developing, due to the multidirectional effect on the body of the applied non-drug means, can significantly optimize the training process for various categories of people who train physical endurance, including elite athletes.

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